OCEAN
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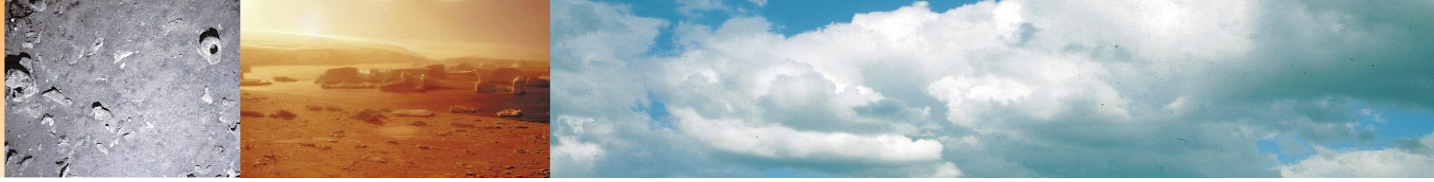

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JOIDES journal

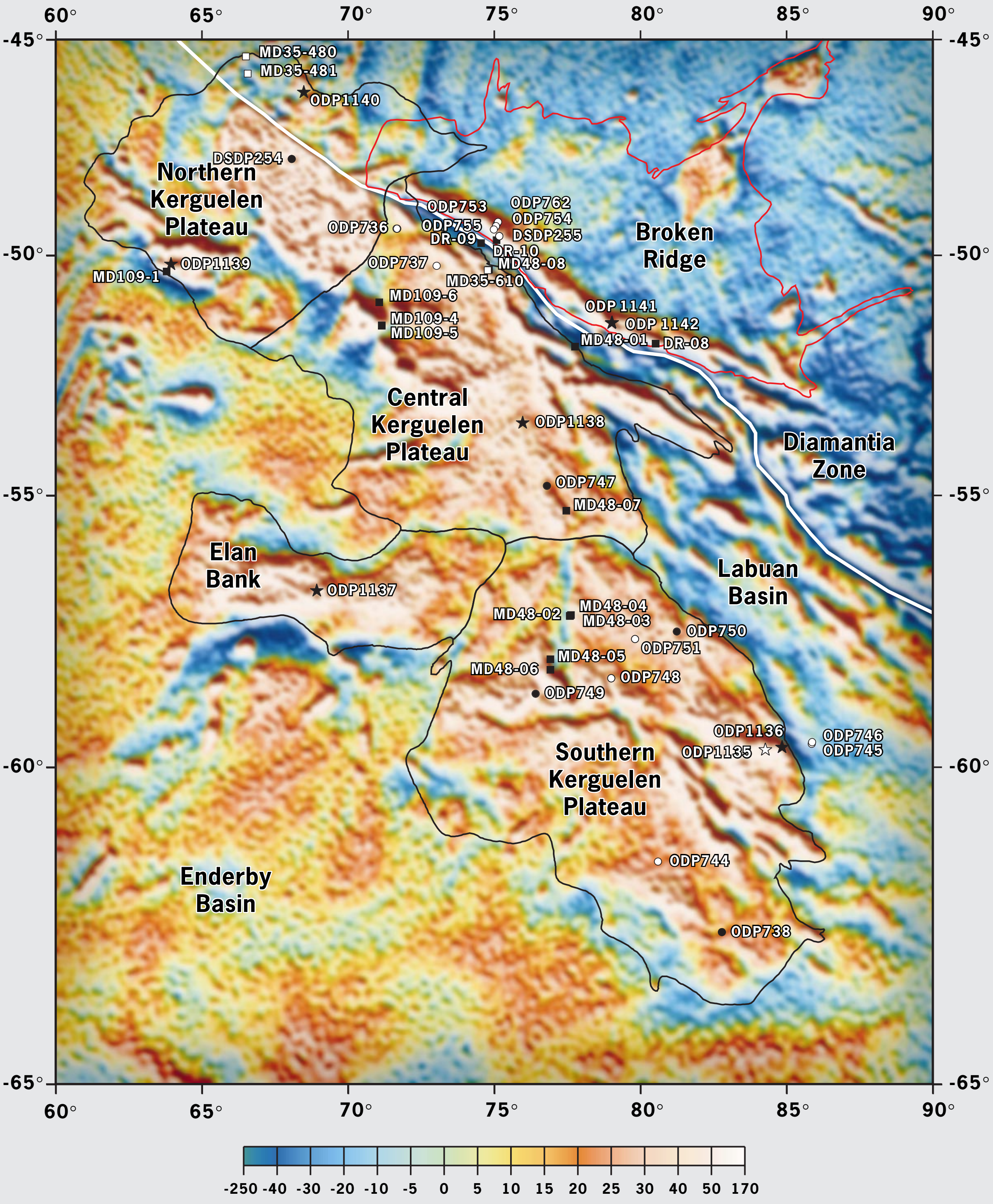
Joint Oceanographic Institutions for Deep Earth Sampling

Development of an Intra-oceanic Large Igneous Province: The Kerguelen Plateau and Broken Ridge, Southern Indian Ocean

Japan Trench Geophysical Observatories: ODP Leg 186

Excerpts from the Final Report of the JOIDES Extreme Climates Program Planning Group

The FY 2001 Drilling Program



Development of an Intraoceanic Large Igneous Province: The Kerguelen Plateau and Broken Ridge, Southern Indian Ocean.

FIGURE 1 *Plate reconstruction of the Kerguelen Plateau and Broken Ridge free-air gravity field at C18n.2no (40.1 Ma). Kerguelen Plateau sector boundaries are outlined in black. Leg 183 drill sites (stars), other DSDP/ODP drill sites (circles), and dredge or piston core locations (squares) where igneous basement was recovered are in black; where only sediment was penetrated, the symbols are white.*

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Leg Reports

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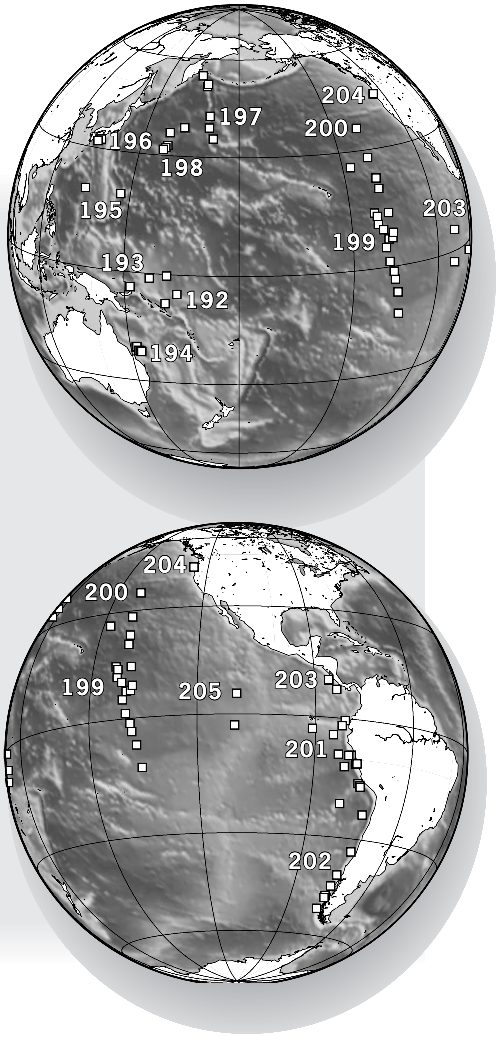
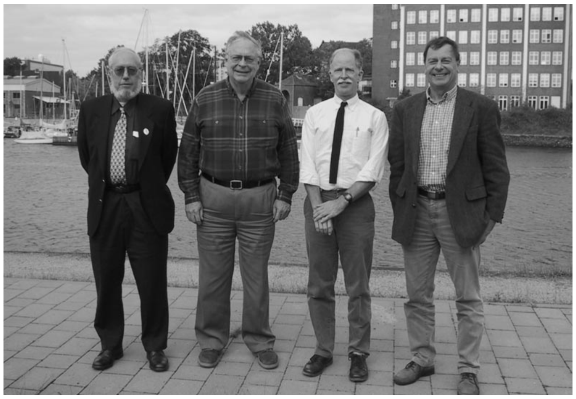
Planning

Scheduled Legs until November 2002

LEG	TITLE	DEPARTURE	DATES
192	Ongtong Java	Guam	09/10/00 – 11/09/00
193	Manus Basin	Guam	11/09/00 – 01/06/01
194	Marion Plateau	Townsville	01/06/01 – 03/04/01
195	Mariana/West Pacific Ion	Guam	03/04/01 – 05/02/01
196	Nankai II	Keelung	05/02/01 – 07/01/01
197	Hawaiian HS-Emperor Seamounts	Yokohama	07/01/01 – 08/27/01
198	Shatsky Rise	Yokohama	08/27/01 – 10/23/01
199	Paleogene Equatorial Pacific	Honolulu	10/23/01 – 12/16/01
200	H2O Ion Site	Honolulu	12/16/01 – 02/06/02
201	Peru Margin Microbiology	Panama City	02/06/02 – 04/07/02
202	SE Pacific Paleoceanography	Valparaiso	04/07/02 – 06/06/02
203	Costa Rica Subduction Factory	Panama City	06/06/02 – 08/05/02
204	Hydrate Ridge	San Francisco	08/05/02 – 10/03/02
205	Equatorial Pacific Ion	San Francisco	10/03/02 – 11/08/02



Looking to the Future



Present and future JOIDES EXCOM and SCICOM Chairs: from left to right - Chris Harrison, Bill Hay, Keir Becker, and Helmut Beiersdorf. Chris and Keir take over when the JOIDES office rotates to Miami on January 1, 2001 (see new address on the back cover).

The future IODP program is becoming more clearly defined since the meeting of the International Working Group (IWG) in Tokyo, August 30–31, 2000. The IWG agreed on the basic Implementation Principles for IODP identified below. Of most direct significance to JOIDES is the formation of an interim science advisory structure (ISAS) to continue the planning that IPSC has begun. This interim science advisory structure will be organized in June 2001 and will last until the beginning of IODP on October 1, 2003. ISAS is planned as a joint working group of JOIDES and OD21 scientists and engineers. ISAS will be responsible for informing the scientific community on the procedures for submitting drilling proposals to the IODP. The IWG has requested IPSC to provide recommendations on the required panel structure, terms of reference, and mandates. These recommendations will be considered at the next IWG meeting in the United Kingdom in January 2000.

IODP Implementation Principles

SCHEDULE

1. IODP will begin officially on 1 October 2003. Membership and implementing agreements will be effective from this date.
2. The first year of the program will be spent in detailed planning activities and preparing for drilling operations (engineering development, detailed site surveys, etc.) 2005 will begin operation of the non-riser vessel. 2006 will begin operation of the riser vessel.

INTERIM SCIENCE ADVISORY STRUCTURE (ISAS)

1. An Interim Science Advisory Structure (ISAS) for IODP will be organized beginning in June 2001 and will exist until 1 October 2003. ISAS will be a joint working group representing JOIDES and the OD21 Science Advisory Committee. The purpose of ISAS is to continue scientific planning for IODP.
2. Membership on ISAS committees will be nominated by JOIDES and the OD21 Science Advisory Committee. Representation on the committees and panels of ISAS is expected to be proportional to the optimal international participation in IODP (1/3 Japan, 1/3 United States, 1/3 other IWG members). It is expected that JOIDES and the OD21 Advisory Committee will confer and consider appropriate disciplinary balance and expertise in making their nominations.
3. An Interim Planning Committee (IPC) will serve as the highest level committee and management authority for the ISAS and is expected to oversee and implement ISAS activity. Representation on IPC will be restricted to IWG members seeking full IODP participation. The IPC will be responsible to the IWG for its guidance and direction and will report to the IWG. IPC will be co-chaired by the chairs of IPSC and the OD21 Science Advisory Committee.
4. IPC will encourage the international community to submit drilling proposals for IODP. The proposals will be examined and reviewed by ISAS, but final evaluation, ranking and scheduling will be conducted by the formal IODP Science Advisory Committee which will be established on 1 October 2003.
5. IWG will request IPSC to provide recommendations on the necessary committees and panels for ISAS, a schedule for their creation, and panel mandates by 1 January 2001.
6. ISAS committees are expected to meet in conjunction with their equivalent JOIDES committee.

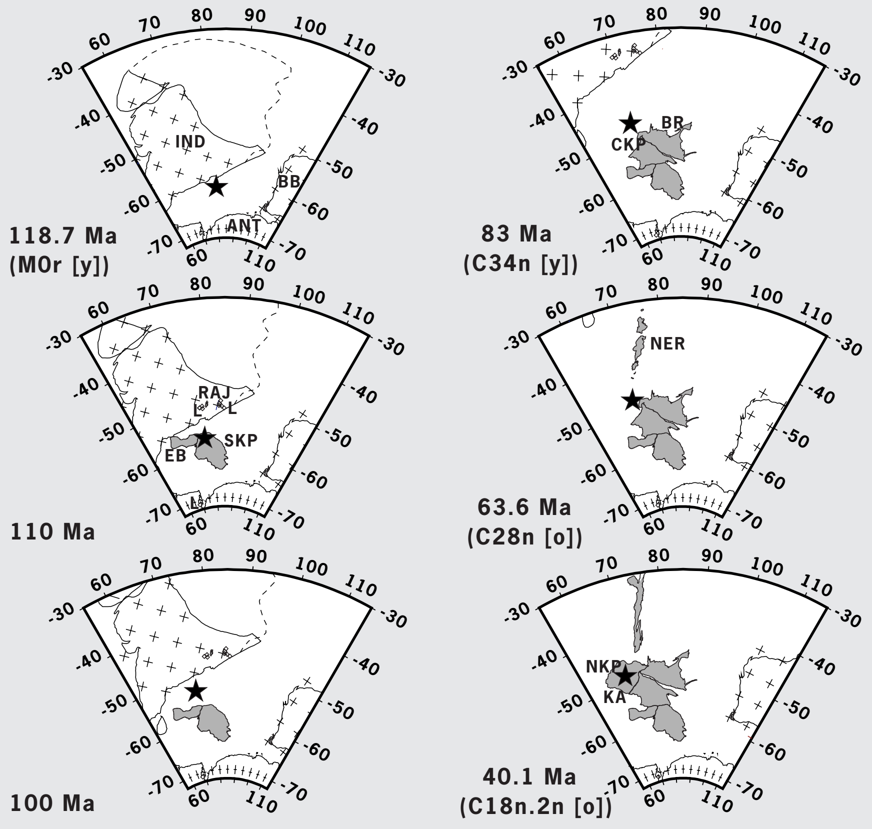
Development of an Intraoceanic Large Igneous Province: The Kerguelen Plateau and Broken Ridge, Southern Indian Ocean

Mike Coffin[1], Fred Frey[2], Paul Wallace[3] and the Leg 183 Scientific Party

Large igneous provinces (LIPs) form when copious amounts of mantle-derived magma enter regions of the earth's crust. This type of volcanism typically differs in process, style, tectonic setting, and geochemistry from volcanism at active divergent and convergent plate boundaries. Many LIPs formed during Cretaceous time; the two most voluminous LIPs are Cretaceous oceanic plateaus, Ontong Java in the Pacific Ocean and Kerguelen Plateau/Broken Ridge in the southern Indian Ocean (Figs. 1, see inside of front cover, 2). The intense igneous activity resulting in many Cretaceous LIPs perhaps reflects a more vigorous mode of whole mantle convection than the present, temporarily increasing the flux of mass and energy from the mantle to the crust, hydrosphere, biosphere, and atmosphere. Possible consequences are global environmental changes involving climate, sea level, oceanic anoxia, seawater composition, and biological radiations and extinctions. Despite the huge size of some LIPs and their potential role in contributing to our understanding of mantle circulation and environmental change, they are among the least understood features in the ocean basins.

Ocean Drilling Program Leg 183 focused on investigating the temporal and spatial development of a giant LIP by drilling and coring five holes into igneous crust of the Kerguelen Plateau and two into Broken Ridge (Figs. 1, 3). Results from the Leg 183 holes, combined with four others from Legs 119 and 120 (1987-88), show that the dominant rocks are basalts with geochemical characteristics distinct from those of mid-ocean ridge basalts. Moreover, physical characteristics of the lava flows and wood fragments, charcoal, pollen, spores and seeds in the shallow water sediments overlying igneous basement show that the growth rate of the plateau was sufficient to form subaerial landmasses. Much of the southern Kerguelen Plateau formed at ~110 Ma, but the uppermost submarine lavas in the northern Kerguelen Plateau erupted during Late Cretaceous and Cenozoic time. These

FIGURE 2 *Plate reconstructions of the southern Indian Ocean region using a hot spot reference frame; Antarctica is fixed. Reconstructed position of the Kerguelen hot spot is indicated by black stars. Volcanic rock associated with the Kerguelen hot spot is indicated in light stipple, and lamprophyres as diamonds, as they have appeared through geologic time. Dashed line indicates a possible northern boundary for Greater India. IND: India; ANT: Antarctica; AUS: Australia.*



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results are consistent with derivation of the plateau by partial melting of the Kerguelen plume. At several locations, volcanism ended with explosive eruptions of volatile-rich, felsic magmas. Although the total volume of felsic volcanic rocks is poorly constrained, the explosive nature of the eruptions may have resulted in globally significant effects on climate and atmospheric chemistry during the late-stage, subaerial growth of the Kerguelen Plateau. At one Leg 183 drill site, clasts of garnet-biotite gneiss, a continental rock, occur in a fluvial conglomerate intercalated within basaltic flows. The gneiss is the first unequivocal evidence of continental crust in this oceanic plateau. We propose that during the early opening of the Indian Ocean, the spreading center(s) between India and Antarctica jumped northwards, transferring slivers of the continental Indian plate to oceanic portions of the Antarctic plate.

BACKGROUND

The conjugate Kerguelen Plateau and Broken Ridge in the southern Indian Ocean (Figs. 1, 2) together cover a vast area (~2 x 10^6 km^2), stand 2 to 4 km above the surrounding ocean floor and have thick mafic crusts of 15 to 25 km compared to the typical oceanic crustal thickness of 7 km. The Kerguelen Plateau is divided into distinct domains: the southern (SKP), central (CKP), and northern Kerguelen Plateau (NKP); Elan Bank; and the Labuan Basin. Multichannel seismic reflection data show that numerous dipping intra-basement reflections interpreted as subaerial flood basalts form the uppermost igneous crust of the Kerguelen Plateau. The Cretaceous Kerguelen Plateau/Broken Ridge LIP is interpreted to represent voluminous volcanism associated with arrival of the Kerguelen plume head below young Indian Ocean lithosphere (Fig. 2). Subsequently, rapid northward movement of the Indian plate over the plume stem formed a 5000 km long, ~82 to 38 Ma, hot spot track, the Ninetyeast Ridge. At ~40 Ma the newly formed Southeast Indian Ridge (SEIR) intersected the plume's position. As the SEIR migrated northeast relative to the plume, hot spot magmatism became confined to the Antarctic plate. From ~40 Ma to the present, the Kerguelen Archipelago, Heard and McDonald Islands, and a northwest-southeast trending chain of submarine volcanoes between these islands were constructed on the northern and central sectors of the Kerguelen Plateau (Figs. 1, 2). Thus, a ~110 m.y. record of volcanism is attributed to the Kerguelen plume.

AGE AND ERUPTION ENVIRONMENT

Recovery of volcanic rocks, and interbedded and overlying sediment on ODP Legs 183, 120, and 119 (Figs. 1, 3) indicate that much of the SKP formed at ~110 Ma, but younger ages, ~85 Ma, have been reported for the CKP and Broken Ridge. In progress radiometric dating of lavas from Leg 183 Site 1137 will provide the first basement ages from Elan Bank, and radiometric dating of basement rock from Sites 1136, 1138, and 1141/1142 will more firmly establish the ages of the SKP, CKP, and Broken Ridge, respectively. After the SKP, Elan Bank, CKP and Broken Ridge formed, plate motions over the Kerguelen plume resulted in formation of Ninetyeast Ridge (~82-38 Ma) and the NKP. Radiometric dating of basalt from Leg 183 Sites 1139 and 1140 is underway and will provide the first ages for submarine portions of the NKP; these will complement recent radiometric dating results from the Kerguelen Archipelago. However, a Cenozoic age for the NKP is indicated by a biostratigraphic age of 35 Ma for sediment intercalated with pillow basalts at Site 1140 (Fig. 3).

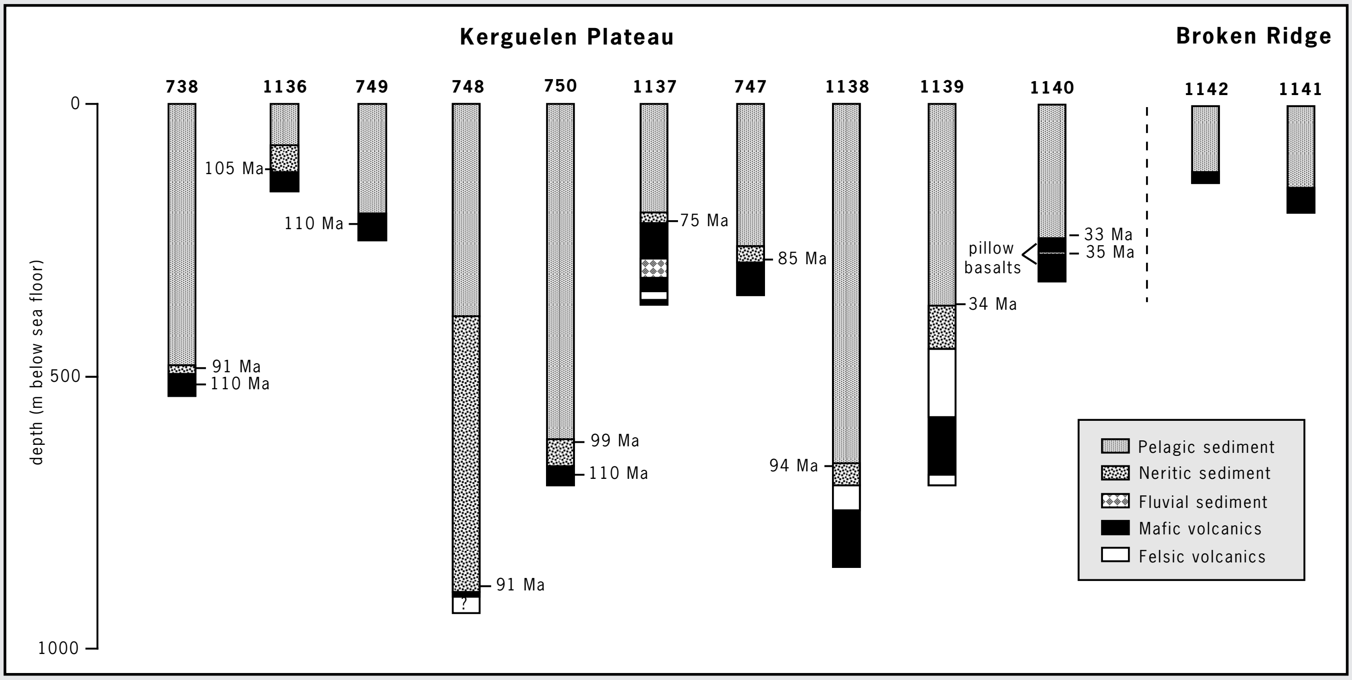
The growth rate of the Kerguelen Plateau and Broken Ridge at five of seven new drill sites (Figs. 1, 3) was sufficient to form subaerial landmasses. This was most spectacularly revealed at Site 1138 on the CKP by wood fragments, seeds, spores, and pollen in dark brown sediment overlying subaerial pyroclastic flow deposits, which in turn overlie subaerially erupted aa and pahoehoe lava flows. These results are consistent with charcoal and wood fragments previously found in sediment overlying igneous rock at ODP Site 750 in the SKP. On Broken Ridge, the vesicularity and oxidative alteration of basement basalts at Sites 1141 and 1142, which formed close to the CKP (Fig. 2), are also consistent with a subaerial environment. At SKP Site 1136, upper bathyal to neritic sediment overlies inflated pahoehoe lavas which lack features of submarine volcanism (e.g., pillows and quenched glassy margins) suggesting subaerial eruption. The igneous basement complex of Elan Bank (Site 1137) includes basaltic lava flows that were erupted subaerially, as indicated by oxidation zones and inflated pahoehoe flows. Some interbedded volcaniclastic rocks were deposited in a fluvial environment, consistent with subaerial eruption of the basalt. Gradual subsidence of Elan Bank is documented by the upward succession of intercalated subaerial basalt flows and fluvial sediment, neritic packstone, and pelagic ooze. The NKP (Site 1139) was also subaerial during its final stages of formation, as indicated by a succession of variably oxidized volcanic and volcaniclastic rock. After volcanism ceased, paleoenvironments changed from intertidal (beach deposits) to very high-energy, near-shore (grainstone and sandstone) to low-energy offshore (packstone) to bathyal pelagic ooze. In contrast, igneous basement at Site 1140 at the northernmost edge of the NKP consists entirely of pillow basalts and intercalated pelagic sediment.

COMPOSITIONS AND ENVIRONMENTAL EFFECTS

Tholeiitic basalt is the dominant rock forming the Cretaceous Kerguelen Plateau/Broken Ridge LIP (Fig. 4), the Ninetyeast Ridge, and the NKP; the volume and age progression and geochemical characteristics of these basalts are consistent with derivation from a long-lived Kerguelen plume. The uppermost tholeiitic basalts forming the Kerguelen Plateau, however, do not have compositions expected of primary melts derived from partial melting of peridotite; for example, basement basalts from Leg 183 drill sites range from 2.8 to 8.1% MgO, and Ni contents are <100 ppm at five of the seven basement sites. Such evolved compositions imply significant cooling, partial crystallization, and segregation of mafic phases (olivine and pyroxene) from mantle-derived primary magmas as they ascended through the lithosphere. In contrast to lavas from other Leg 183 drill sites, igneous basement at Skiff Bank (Site 1139) consists of an alkaline lava series ranging from trachybasalt to trachyte and rhyolite (Fig. 4). Ongoing geochemical studies will help determine the sources of both the tholeiitic and alkaline basalts.

An unexpected result of Leg 183 drilling was the discovery that highly evolved, felsic magma was erupted explosively during the final stages of volcanism over extensive regions of the Kerguelen Plateau (Figs. 3, 4). Previous drilling at four ODP sites had found no evidence for explosive felsic magmatism, but at three Leg 183 drill sites (1137, 1138, and 1139), we recovered both pyroclastic flow deposits and lavas of trachyte, dacite, and quartz-bearing rhyolite. At Site 1137 on Elan Bank, a 15 m thick sanidine-rich vitric tuff separates basaltic lava flows. Well-preserved bubble-wall glass shards in part of the tuff together with abundant broken sanidine crystals indicate an explosive volcanic eruption (fig. 5, see inside of back-cover). Higher in the stratigraphic sequence at Elan Bank, a fluvial conglomerate contains clasts of rhyolitic and trachytic lavas. At Site 1138 on the CKP, we recovered a 20 m thick volcaniclastic succession containing six trachytic pumice lithic breccias that were deposited by pyroclastic flows. This volcaniclastic sequence also includes highly

FIGURE 3 *Summary of ODP drill holes on the Kerguelen Plateau that recovered volcanic rocks. Data are shown for Leg 119 (Site 738), Leg 120 (Sites 747, 748, 749, and 750) and Leg 183 (Sites 1136, 1137, 1138, 1139, 1140, 1141, and 1142). Multichannel seismic reflection profiles indicate that the volcanic rocks at all sites except Site 748 were recovered from the uppermost basement of the plateau, which lies beneath younger sedimentary cover. Basalt at Site 748 was recovered ~200 m above acoustic basement and overlies a poorly recovered zone containing smectitic clay and highly altered basalt. Radiometric ages of basalt and biostratigraphic ages of sediments overlying basement are indicated.*



altered ash fall deposits that contain accretionary lapilli. Above this sequence, we recovered rounded cobbles of flow-banded dacite. At Site 1139 on Skiff Bank, which forms part of the NKP, the uppermost basement contains various felsic volcanic and volcaniclastic rocks. The section includes densely welded pyroclastic flow deposits of quartz-bearing rhyolite, in addition to lava flows and reworked cobbles of volcanic rock ranging from sanidine-rich trachyte to rhyolite.

The subaerial eruption of enormous volumes of basaltic magma during formation of the Kerguelen Plateau and Broken Ridge probably had significant environmental consequences due to subaerial release of volatiles such as CO_2, S, Cl, and F. The LIP formed at high latitudes (Fig. 2), which would have enhanced environmental effects because the relatively low tropopause would have allowed large mass flux, basaltic fissure eruption plumes to transport SO_2 and other volatiles into the stratosphere. Sulfuric acid aerosol particles that form in the stratosphere after such eruptions have a longer residence time and greater global dispersal than if the SO_2 remains in the troposphere; therefore they have greater effects on climate and atmospheric chemistry. The large volume and long duration of subaerial basaltic volcanism on the Kerguelen Plateau and Broken Ridge, combined with the high latitude of most of the plateau, would all have contributed to potential global environmental effects. During the final stages of plateau construction, highly explosive felsic eruptions, such as those that produced the pyroclastic deposits on Elan Bank, Skiff Bank and the CKP, likely injected both particulate material and volatiles (SO_2, CO_2) directly into the stratosphere. The previously unrecognized, significant volume of explosive felsic volcanism that occurred when the Kerguelen Plateau and Broken Ridge were subaerial would have further contributed to the effects of this plume volcanism on global environment.

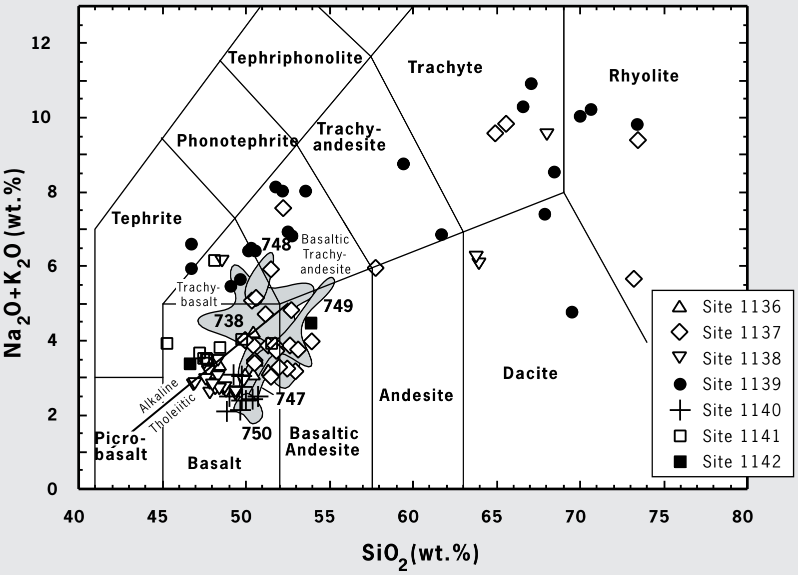


FIGURE 5 *Total alkalis (Na_2O + K_2O) versus SiO_2 classification plot for igneous rocks recovered by drilling on the Kerguelen Plateau and Broken Ridge. Although in detail this plot is affected by post-magmatic mobility of alkalis, the principal aspects of the data reflect magmatic characteristics. Important features are: (a) the dominance of basalt with subordinate trachyte, rhyolite and dacite at sites 1137, 1138 and 1139; and (b) lavas at some sites are dominantly tholeiitic basalt (sites 750 and 1140) whereas the low SiO_2 lavas at site 1139 are alkalic (trachybasalt and basaltic trachyandesite).*

CONTINENTAL ROCK

At Site 1137 on Elan Bank (Figs. 1-3), ~26 m of fluvial conglomerate is intercalated with basaltic flows; most notable are clasts of garnet-biotite gneiss (Fig. 6, see inside of back-cover), a continental crustal rock. This is the first unequivocal evidence of continental crust from the Kerguelen Plateau and Broken Ridge. Geochemical studies in progress will help determine the significance of continental components in Leg 183 basalts. Previous geochemical studies of basalt from the SKP and eastern Broken Ridge identified a component derived from continental crust. However, the mechanism for incorporation of a continental component into the oceanic plateau was unconstrained. Possible processes range from recycling of continental material into the Kerguelen mantle plume to mobilization and incorporation of delaminated Gondwana lithosphere into the basaltic magmas forming the Kerguelen Plateau to contamination of mantle-derived basaltic magma by fragments of continental crust isolated in the embryonic Indian Ocean crust. The last process is consistent with the finding of continental crustal rocks on Elan Bank. We speculate that a northwards spreading center jump transferred a fragment of the continental Indian plate, i.e., Elan Bank, to the oceanic part of the Antarctic plate.

For more detailed Leg 183 drilling results, including references, see

Coffin, M. F., Frey, F. A., Wallace, P. J., et al., 2000. Proceedings of the Ocean Drilling Program, Initial Reports, 183 [CD-ROM]. Available from: Ocean Drilling Program, Texas A & M University, College Station, TX 77845-9547, U.S.A.
Frey, F. A., et al., 2000. Origin and evolution of a submarine large igneous province: the Kerguelen Plateau and Broken Ridge, Southern Indian Ocean, Earth and Planetary Science Letters, 176: 73–89.

ACKNOWLEDGEMENTS

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LEG 183 SHIPBOARD SCIENTIFIC PARTY

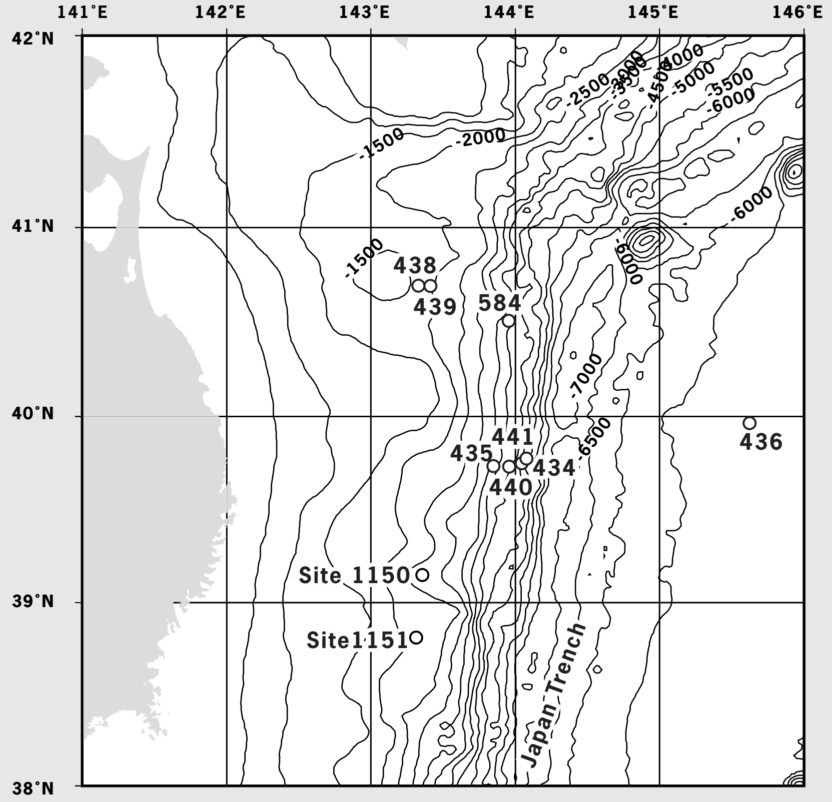
Millard F. Coffin and Frederick A. Frey, co-chief scientists; Paul J. Wallace, staff scientist; Dominique A. M. Weis, Xixi Zhao, Sherwood W. Wise, Jr., Veronika Wähnert, Damon A.H. Teagle, Peter J. Saccocia, Douglas N. Reusch, Malcolm S. Pringle, Kirsten E. Nicolaysen, Clive R. Neal, R. Dietmar Müller, C. Leah Moore, John J. Mahoney, Laszlo Keszthelyi, Hiroo Inokuchi, Robert A. Duncan, Heike Delius, John E. Damuth, Dimitri Damasceno, Helen K. Coxall, Mai K. Borre, Florian Boehm, Jane Barling, Nicholas T. Arndt, Maria J. Antretter.

Japan Trench Geophysical Observatories: ODP Leg 186

Kiyoshi Suyehiro[1], Selwyn Sacks[2], Gary Acton[3], and the Leg 186 Scientific Party

The Leg 186 Scientific Party sailed out to investigate the dynamic properties of one of the world's most active plate subduction zones, the Japan Trench. Here the Pacific plate (>100 Ma) is subducting at a high rate (~90 km/m.y.). Sites 1150 and 1151 at 2681- and 2182-m water depths, respectively, on the eastern edge of the forearc basin were drilled into the Neogene section of ~1.5 km thickness. These sites are separated about 50 km along arc strike with contrasting seismic activity (Fig. 1). Two geophysical observatories were successfully installed for monitoring strain, tilt, and seismic waves to understand how plate motion is accommodated across a subduction zone. The scientific importance of establishing long-term geophysical stations in deep oceans has been acknowledged by earth sciences and ODP communities (Montagner and Lancelot, 1995; Ocean Drilling Program, 1996). Previous drilling (Legs 56, 57, and 87) found the forearc area to be subsiding as a result of tectonic erosion with little accretionary prism development (e.g. von Huene et al., 1982; 1994). Coring and logging were aimed at learning more about past and present sedimentary and tectonic environments.

FIGURE 1 *Map of the Japan Trench area off northeast Japan showing ODP Leg 186 Sites 1150 and 1151; and previous drilling sites from DSDP Legs 56, 57, and 87.*



Until near the end of cruise, we were uncertain how many of the objectives we would accomplish due to a number of unexpected incidents. The Site 1150 installation was successfully completed on 28 July, 1999 with only 18 days left for operations at the second site. With improving sea conditions, we successfully completed the instrument installation at Site 1151 on 9 August, followed by double APC coring and logging to attain most of the goals for this Leg.

Each site was equipped with a reentry cone (Fig. 2) and was cased through unstable sections leaving a 50- to 100-m open-hole section to the bottom. Because the sensor package diameter cannot run through the drill string, it had to be connected at the bottom of the drill string. The drillship was cemented in the sensors, which is essential for the strain measurements.

DYNAMIC SLIDING OF THE SUBDUCTING PLATE AND EARTHQUAKE PROCESS

The plate boundary off northeast Japan fulfills three important conditions for a long-term geophysical observatory:

1. Dense geophysical networks already exist on land to optimally link to the offshore observatories.

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2. Moderately large (M>= ~7) seismic events occur frequently (7 occurred in the last 30 yr between 38 and 41 °N), and significant aseismic slips (slow earthquakes) are expected to occur even more frequently.

3. Crustal and uppermost mantle structures have been well studied by reflection-refraction seismic surveys (Suyehiro and Nishizawa, 1994; Tsuru et al., 2000).

Of the total Pacific plate motion expected off NE Japan, only about one-quarter is seen as stick-slip motion leading to thrust-type earthquakes. One possibility is that three-quarters of the motion is released as slow earthquakes, which are not recorded on normal seismographs. Any data leading to better understanding of the partitioning of strain release into damaging "fast" events and slower events will be extremely valuable and may lend further insight into the whole earthquake process.

FIGURE 2 *Two reentry cones, 2.44 m in diameter, were installed during Leg 186.*

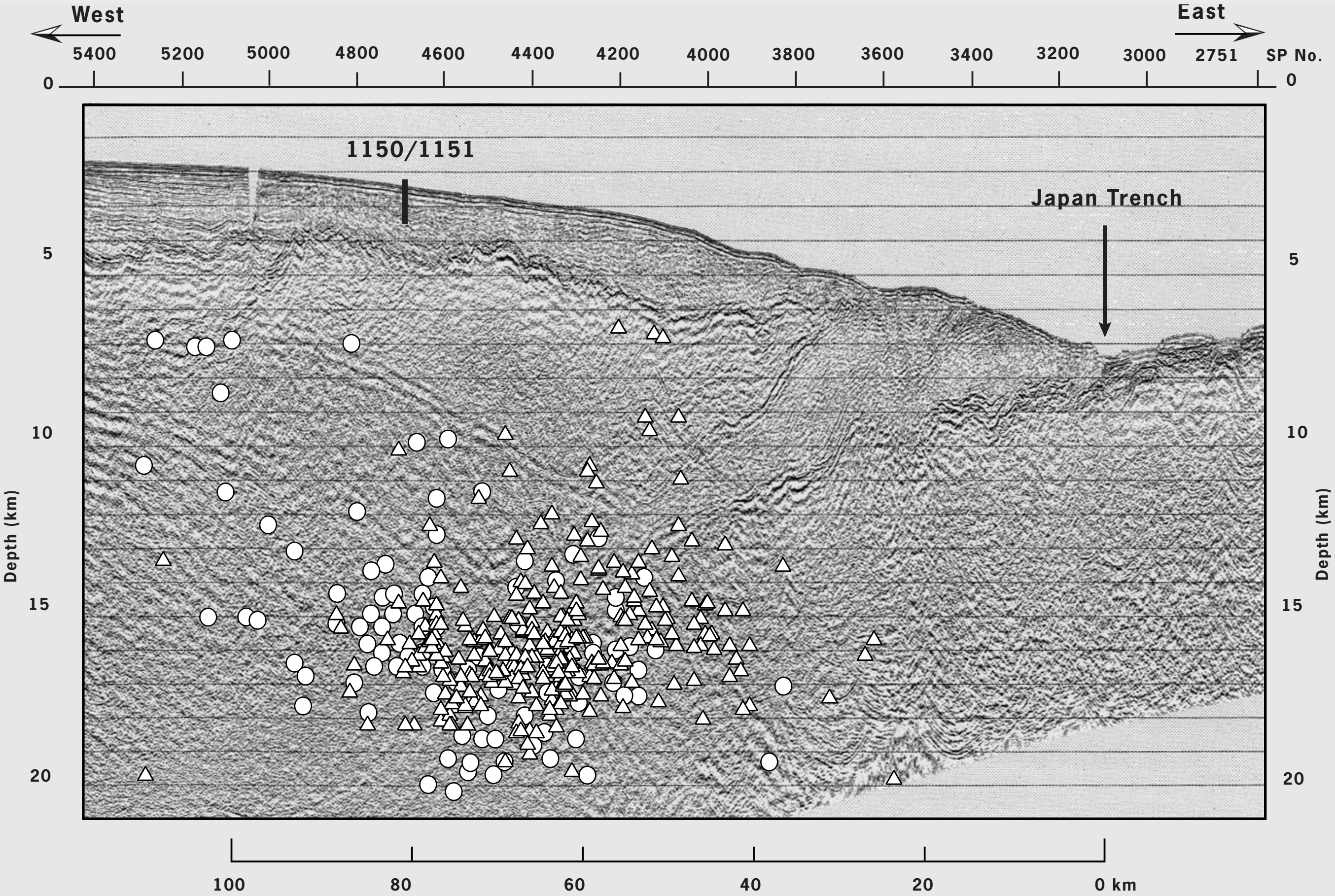


FIGURE 3 *Reflection seismic cross section across JapanTrench transecting near Site 1150 (~SP No 4900) (from Tsuru et al., 2000). Microearthquake depths from ocean bottom seismographs are also shown.*

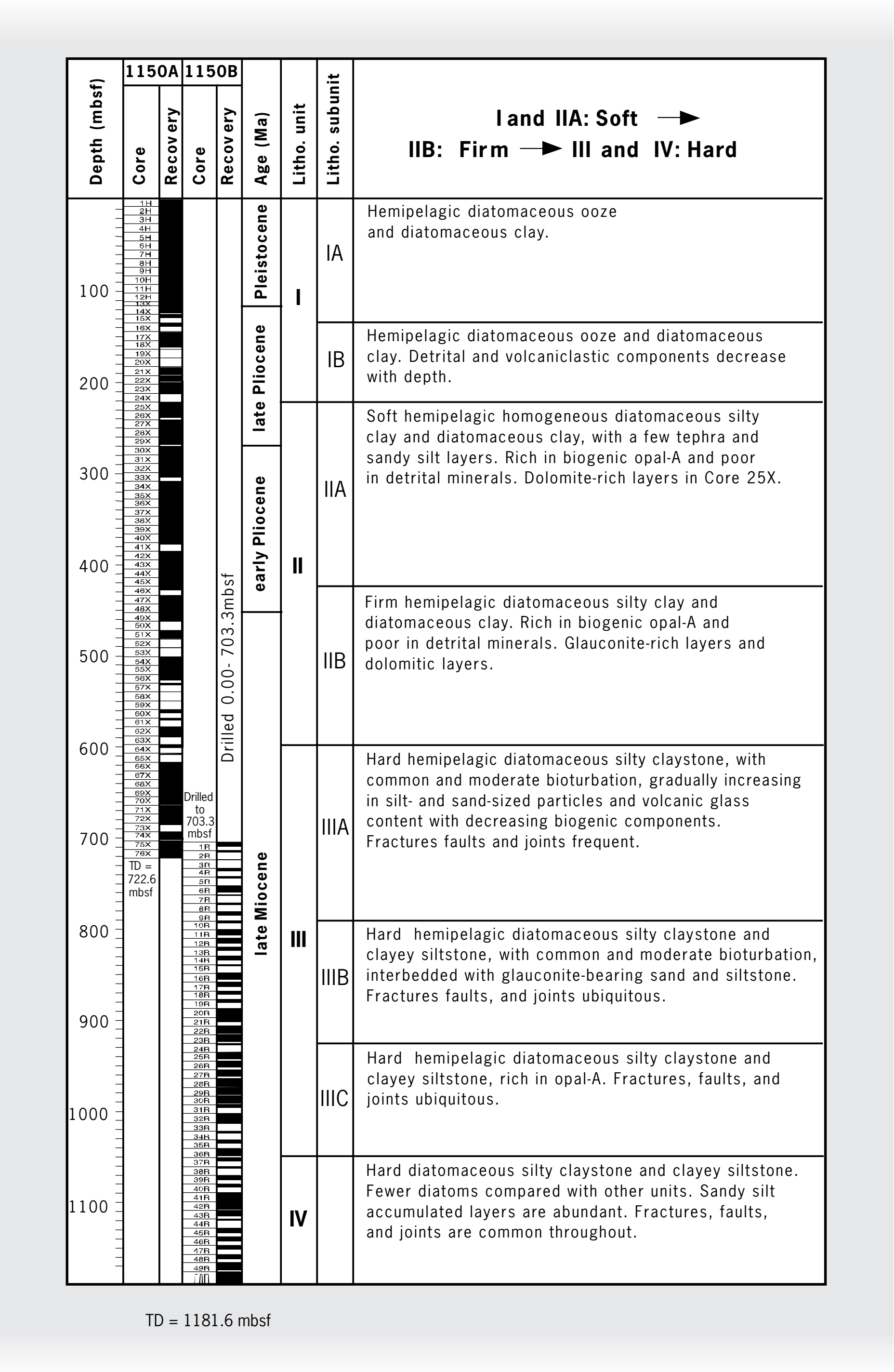


FIGURE 4a *Lithostratigraphic summary for Sites 1150.*

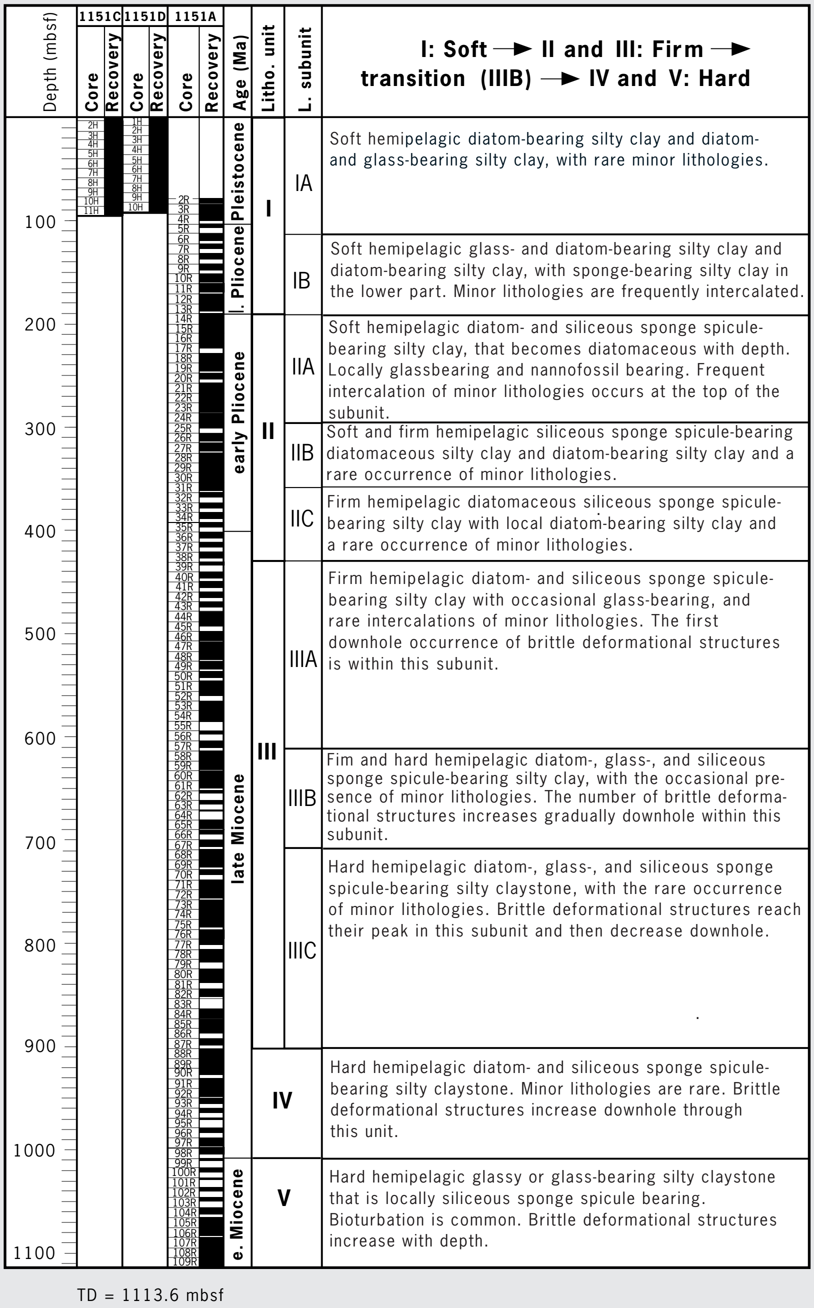
Generally, interplate thrust earthquakes occur within a zone termed the seismogenic zone. The candidates of controlling factors of this zone, such as temperature, material, or pore pressure that affect the frictional state of the fault are consequences of geological processes. We must know exactly where earthquakes of various sizes are occurring to relate fault slips to these factors. The borehole observatories will greatly improve earthquake location (particularly depth) and focal mechanism determinations near the Japan Trench (Suyehiro and Nishizawa, 1994; Hino et al., 1996).

OFFSHORE GEOLOGY

In the Japan Trench area, a forearc basin has developed in the deep-sea terrace and trench upper slope, which extends from the north-west coast of Hokkaido more than 600 km to the south and is filled with Neogene sediments as much as 5 km thick. In multichannel seismic profiles, the reflective sequence above a major horizon represents a seaward transgressive sequence across an extensive angular unconformity (Fig. 3). Below the unconformity is well-consolidated Upper Cretaceous drilled rock at Site 439. It was suggested that a pre-Oligocene forearc once extended at least to the present midslope terrace where Site 440 is located (Arthur et al., 1980). The Neogene sequence is cut by landward-dipping normal faults spaced ~10 to 15 km apart (Nasu et al., 1980). Site 584, at the outer slope, reached sediment of middle Miocene age, confirming persistent subsidence during the Miocene. It was suggested that extensional tectonics continued from the middle Miocene until the early Pliocene (Kagami et al., 1986). Numerous ash layers from all the sites suggest that onshore volcanic activity increased near the end of the late Miocene and continued through the early Pliocene.

SITE 1150

The first successful emplacement of a borehole geophysical observatory (NEREID-1) with a three-component strainmeter, a two-component tiltmeter, and three-component broadband seismometers was made above the active portion of the seismogenic zone. The sensing sections are <11 m in length bottoming at 1120 mbsf and were cemented in the 105-m-long open hole at Hole 1150D. In the interval where the borehole instruments were installed, the porosity, bulk density, and P-wave velocity are 55%, 1.65 g/cm3, and 2.0 km/s, respectively. Because the



I: Soft → II and III: Firm → transition (IIIB) → IV and V: Hard

Litho. unit	L. subunit	Description
I	IA	Soft hemipelagic diatom-bearing silty clay and diatom- and glass-bearing silty clay, with rare minor lithologies.
	IB	Soft hemipelagic glass- and diatom-bearing silty clay and diatom-bearing silty clay, with sponge-bearing silty clay in the lower part. Minor lithologies are frequently intercalated.
II	IIA	Soft hemipelagic diatom- and siliceous sponge spicule-bearing silty clay, that becomes diatomaceous with depth. Locally glassbearing and nannofossil bearing. Frequent intercalation of minor lithologies occurs at the top of the subunit.
	IIB	Soft and firm hemipelagic siliceous sponge spicule-bearing diatomaceous silty clay and diatom-bearing silty clay and a rare occurrence of minor lithologies.
	IIC	Firm hemipelagic diatomaceous siliceous sponge spicule-bearing silty clay with local diatom-bearing silty clay and a rare occurrence of minor lithologies.
III	IIIA	Firm hemipelagic diatom- and siliceous sponge spicule-bearing silty clay with occasional glass-bearing, and rare intercalations of minor lithologies. The first downhole occurrence of brittle deformational structures is within this subunit.
	IIIB	Fim and hard hemipelagic diatom-, glass-, and siliceous sponge spicule-bearing silty clay, with the occasional presence of minor lithologies. The number of brittle deformational structures increases gradually downhole within this subunit.
	IIIC	Hard hemipelagic diatom-, glass-, and siliceous sponge spicule-bearing silty claystone, with the rare occurrence of minor lithologies. Brittle deformational structures reach their peak in this subunit and then decrease downhole.
IV		Hard hemipelagic diatom- and siliceous sponge spicule-bearing silty claystone. Minor lithologies are rare. Brittle deformational structures increase downhole through this unit.
V		Hard hemipelagic glassy or glass-bearing silty claystone that is locally siliceous sponge spicule bearing. Bioturbation is common. Brittle deformational structures increase with depth.

FIGURE 4b *Lithostratigraphic summary for Sites 1151*

instrument string and battery frame could not be installed simultaneously, the electrical connection to the downhole instruments was made after Leg 186. The observatory sites were visited by the Dolphin 3K of the Japan Marine Science and Technology Center (JAMSTEC) in September 1999 to start the systems, check the status, and collect initial data. The initial broadband seismic data proved to be a significant improvement over ocean bottom data, especially at long periods in noise level.

All of the cores from 0 to 722.6 mbsf from Hole 1150A are dominated by diatomaceous silty clay (Fig. 4a). The age of the lowermost sediment is interpreted to be younger than 9.9 Ma. The average sedimentation rate is 119 m/m.y., with higher sedimentation rates (>200 m/m.y.) occurring between 6.7–3.7 Ma and between 0.3 and 0.0 Ma. The lowest sedimentation rate occurs between 2.0 and ~1.2 Ma (18 m/m.y.) (Fig. 5).

Chemical analyses of pore waters from Hole 1150A cores show that chlorinity gradually decreases with depth from ~550 mM at the top of the hole to 500 mM at ~200 mbsf. From ~550 mbsf, values abruptly decrease with depth to reach a minimum of 350 mM at ~700 mbsf. A similar trend is observed in the magnesium, potassium, and alkalinity profiles. Physical properties data show several systematic trends that correlate with downhole chemical and lithologic changes, appearing to indicate variations in hydrological and mechanical conditions. (Fig. 6a). The geothermal gradient is 28.9°C/km and the calculated heat flow is 20.1 mW/m2. The declinations from the Hole 1150B cores have proved useful for reconstructing structural orientations of the numerous microfaults and fractures observed in the core. For example, after reorienting fracture and fault planes into geographic coordinates, we find that most in the depth range from 703 to 940 mbsf have north-south strikes and dips of 45° to 80°, with a clear preference for eastward-dipping planes. Normal offset is observed on most of the fault planes, suggesting that an east-west extensional stress field is responsible for the deformation observed in this interval. The extensional stress direction changes downhole, so that below 1080 mbsf the dominant direction is west-northwest to east-southeast. The FMS data show borehole geometries to be oval below ~750 mbsf with east-west elongation.

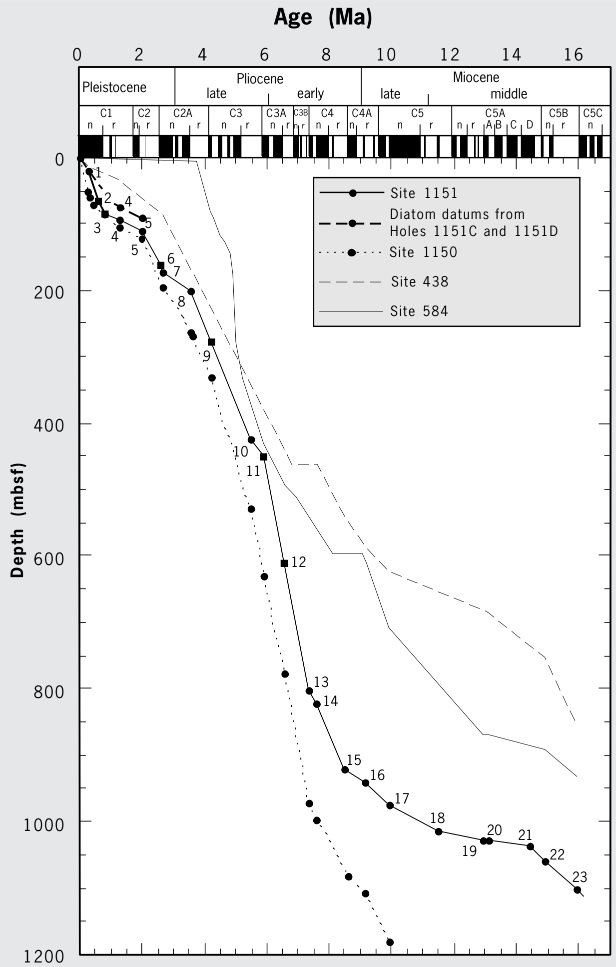


FIGURE 5 *Age-depth curves for Leg 186 sites and other Japan Trench sites. The geometric polarity time scale is also shown.*

SITE 1151

A key difference of this site from Site 1150 is that this area is above an aseismic portion of the seismogenic zone. The strainmeter at this site measures volumetric strain changes. The sensor string was set in a section with a density of ~1.9 g/cm3 and P-wave velocity of ~2 km/s. The target depth is at 1095 mbsf for the sensor string bottom, with a more competent rock environment than at Site 1150. The bottom of the open hole was filled with cement up to ~50 m into the cased hole section.

The recovered sequence ranges from Holocene to middle Miocene age. The common major lithology at this site is diatomaceous silty clay with intercalations of minor lithologies such as volcaniclastic ash, pumice, silt, and sand. Diatom assemblages from all samples consist almost entirely of oceanic species, mainly from the subarctic North Pacific Ocean. Calcareous nannofossils are generally barren to abundant, with variable preservation. The bottom diatom datum is in the middle Miocene (<16.3 Ma) (Fig 4b). Sedimentation rate in the upper 200 m has a relatively low rate (20 to 152 m/m.y.). It increases between 200 and 450 mbsf, reaching ~240 m/m.y., and remains at that level down to 800 mbsf, below which the rate gradually decreases. At 1027 mbsf, there is a hiatus of >0.2 m.y., and the rate then gradually increases downhole to 43 m/m.y. The intervals of low rate correspond to the early late Miocene (before 8.5 Ma) and the early to mid-Pleistocene (2.0–0.78 Ma) (Fig. 5).

Several geochemical parameters exhibit similar distributions with depth. Chlorinity, salinity, magnesium, and alkalinitiy show a characteristic decreasing trend with depth. Salinity gradually decreases with depth from a value of ~32 at the top of the borehole to a value of 18 at ~900 mbsf. Below this depth, salinity remains constant at 18 to the the bottom of the hole. Chlorinity concentrations remain constant at ~500 mM in the upper 200 m of the borehole and then steadily decrease to 320 mM at the bottom. The average thermal gradient is 35.9°C/km. In Hole 1151A, P-wave velocity (horizontal) ranges from 1540 to 5290 m/s, with most values being <2150 m/s. The highest velocities were measured in thin beds of carbonate-rich sediments (i.e., dolomite layers or dolomite concretions). The ranges of porosity, bulk density, and grain density in Hole 1151A are 10%–77%, 1.32 to 2.42 g/cm3 , and 2.09 to 3.91 g/cm3 , respectively. Three logging runs (one triple combo and two FMS/sonic runs down to 850 mbsf) were achieved in Hole 1151D by extending the second APC/XCB hole. The hole condition (caliper log) was much more stable at Site 1151, and logging was accomplished without difficulty (Fig. 6b).

Similar to Site 1150, the stable declinations from these cores have proved useful for reconstructing structural orientations of the microfractures and bedding planes. We have found that the orientation of fracture planes changes down-hole with dip azimuths dominantly to the west-northeast and east-southeast in the upper domain but dominantly east and west in the middle and lower domains. Below 900 mbsf, the dip angles of bedding planes are >10° and preferentially dip toward the east.

SUMMARY

The principal objective of Leg 186 was to install two permanent borehole observatories with several seismic and deformation-measuring sensors. A strainmeter, tiltmeter, and two broad-frequency range seismometers were grouted in at the bottom of boreholes drilled deep enough to penetrate higher velocity, indurated rock. This objective was successfully achieved. Both sites were cored to instrument depth. In all, we recovered 1742 m of

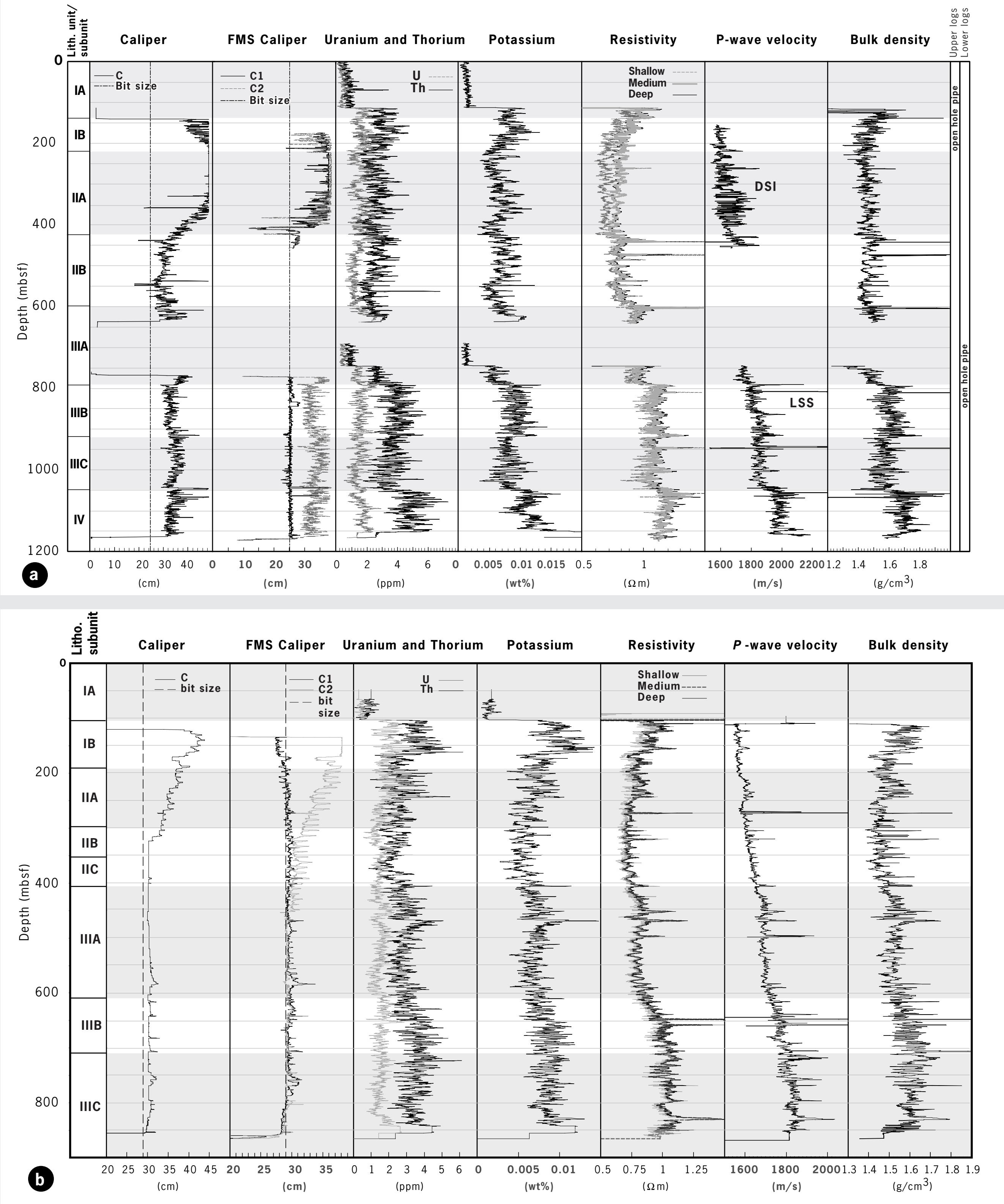


FIGURE 6 *Summary of logs a. Hole 1150B and b. 1151D.*

core from the two sites. The dominant lithology was diatomaceous silty clay or claystone with many ash and some dolomite layers. The salinity and chlorinity decrease with depth are probably the largest among other DSDP/ODP measurements made in the subduction regime. Until 14 m.y. ago, the islands were subjected to east-west tension, and the Sea of Japan was opening. Today, there is strong east-west compression. It is possible that some of the change in sediment flux as well as volcanic output is affected by the changes in the force system at the subduction interface. It is apparent that there was a major increase in volcanic deposits at Site 1150 at ~3 Ma and a decrease in the most recent half million years or so. At Site 1151, the increase starts at ~4 Ma. Further north (40.6°N) in Hole 438A, volcanism increased from ~5 Ma until ~2 Ma.

Overall, the long-term deformation, as determined by number, orientation, and offset of faults, indicates that the two sites are broadly comparable. Normal faulting dominates in both holes with the extension direction being west-northwest–east-southeast in both cases. Once an observatory is established, ways and means to recover the data and to keep the station running become necessary. A new fiber-optic cable owned by the University of Tokyo already exists and currently terminates near Site 1150. There is a plan to extend this cable to link the two borehole observatories for real-time and open access over the Internet.

For more information see: http://www-odp.tamu.edu/publications/186_IR/186ir.htm

LEG 186 SHIPBOARD SCIENTIFIC PARTY

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Excerpts from the Final Report of the JOIDES Extreme Climates Program Planning Group

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SUMMARY

The Extreme Climates PPG met three times, in Edinburgh, Scotland; Freiburg, Germany; and in Santa Cruz, California, USA. In addition to the regular members, Paul Wilson, University of Cambridge (UK), Lisa Sloan, University of California (USA), Mark Pagani, University of California (USA), Bridget Wade, University of Edinburgh (Scotland), Elisabetta Erba, University of Milan (Italy), and Bradley Opdyke, The Australian National University (Australia) participated in one or another of the meetings as visitors. Rainer Zahn and Ellen Thomas served as liaisons to the ESSEP.

The PPG discussed the overall scientific goals of “extreme” climate research and came to a consensus that drilling should recover sediments that would provide evidence of periods characterized by long-term (millions of years) intervals and transient (thousands of years) events of exceptional global warmth. The periods of exceptional warmth, particularly the transients, e. g. the Late Paleocene Thermal Maximum, and the Cenomanian-Turonian boundary and early Aptian oceanic anoxic events, most likely were forced by greenhouse gases. Both the LPTM and early Aptian events appear to be characterized by a large negative carbon isotope excursion indicating rapid gas release. The effects of increased greenhouse gases should be revealed in deep sea sediments, adding to the understanding of the response of the ocean-climate system to fossil fuel input such as today. We outline in this report drilling strategies and areas where sediments representing the target periods can be drilled. The PPG has been very active since its first meeting in September of 1998. The group was involved in running several of the sessions at the COMPLEX meeting and in developing the final report. Since the inception of the group, five new drilling proposals targeting extreme climate intervals have been submitted, three of which were prepared by working group members: 1) Walvis Ridge; 2) Demerara Rise and 3) J-Anomaly Ridge. Several other proposals are anticipated.

We submit the final report of the “Extreme Climate” PPG with a strong sense of new accomplishments spurred by Ocean Drilling. Recent advances in site selection, and innovations in sampling methods and techniques have brought paleoceanographers to a new position to identify, characterize, and model extreme climates of the past. Many of the phenomena now recognized have societal relevance; all test our ability to understand fundamental aspects of earth’s climate, the carbon cycle, and marine ecosystems. Paleoceanographers now recognize that it is possible to recover Cenozoic to Cretaceous age sediments with minimal burial alteration, and to study extreme climates at Milankovitch resolution. Signs of recent successes include high impact publications characterizing climatic and geochemical aspects of the Paleocene/Eocene boundary event and of greenhouse climates in general (e.g. Norris and Röhl, 1999; Katz et al., 1999; Pagani et al., 1999; Bains et al., 1999; Pearson and Palmer, 2000). These and other successes of the ODP were featured in a recent special session of the 1999 Fall AGU meeting, which examined extreme climate records from Cretaceous through Cenozoic age before a full auditorium.

RECOMMENDATIONS TO SCICOM

- To test the hypothesis that all transient extreme-warm periods were caused by rapid inputs of greenhouse gases, we recommend that scientific drilling target three key events or time intervals; Late Paleocene Thermal Maximum, Cenomanian-Turonian boundary and earliest Aptian oceanic anoxic events. A key component of this test will be to document the rate and duration of the restoration period after the initial massive input of gas.
- Multiple depth transects (minimum of one per basin) be drilled to understand how the ocean geochemical cycles responded and contributed to enhanced input and removal of greenhouse gases during these events.
- Latitudinal arrays spanning the equatorial and temperate to sub-polar regions (in the Atlantic and Pacific) be

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drilled to constrain and understand the global heat budget, oceanic and atmospheric dynamics on orbital time-scales under extreme greenhouse conditions, and subsequent "cool" periods.

- Multiple hole strategies should be implemented in drilling all extreme climate intervals to obtain continuous and expanded sections suitable for documenting the oceanic and climatic sensitivity to Milankovitch forcing during these events.
- High-resolution logging is required to provide critical information missing from core gaps where full recovery is not possible.
- A return to the Pacific is necessary as the largest basin has still not been drilled properly for investigating processes associated with mid-Cretaceous events.

INTRODUCTION

Cretaceous and Paleogene marine deposits provide accessible archives to document Earth system processes during partly to entirely deglaciated states. Although investigations of these ancient times have traditionally fallen into the category of basic academic research, recent results obtained through ocean drilling suggest that important and societally relevant issues can be addressed with Cretaceous and Paleogene sequences. These issues include the stability of tropical sea surface temperatures, the relationship between biodiversity and climate, and the global effects of carbon cycle perturbations. Ironically, the best examples of rapid, wholesale extinctions linked to climate change or massive input of carbon come from Paleogene and Cretaceous records rather than those from more recent times.

The Cretaceous and Paleogene portion of the geological record is punctuated by several transient intervals of extreme climate. These brief (103 – 106 yr) time intervals are characterized by profound fossil turnovers and major upheavals of the global carbon cycle. The combined rate and magnitude of observed biogeochemical change during these events is unparalleled in the Neogene except at present-day.

Certain key intervals of the Cretaceous and Paleogene are marked by rapid climate change and massive input of carbon. These intervals are the Late Paleocene Thermal Maximum (LPTM) and Oceanic Anoxic Events (OAEs) in the early Aptian and at the Cenomanian-Turonian Boundary. Although the PPG acknowledges the existence of other fascinating time intervals of the Cretaceous and Paleogene (e.g., Aptian-Albian boundary interval, the late Albian, the mid-Maastrichtian, the Cretaceous-Tertiary Boundary, the Eocene-Oligocene Boundary), the chosen three time intervals are particularly significant to current Earth science objectives because focused research has the potential to considerably improve our understanding of the general dynamics of the Earth during rapid perturbation of the carbon cycle. We stress that the LPTM and OAEs were also marked by prominent (but selective) turnovers in major fossil groups. A thorough knowledge of Earth system processes during these extreme climate intervals would significantly contribute to our understanding of biological evolution and the biological response to rapid perturbations of the carbon cycle.

Several important pieces of information are required to understand basic Earth processes and biological evolution during extreme climate intervals of the Cretaceous and Paleogene. This information includes critical components of the ocean system such as the mode and direction of thermohaline circulation, the amount and composition of carbon, oxygen and other dissolved species in various ocean reservoirs, and the temperature gradients of surface and deep water. Most importantly, the PPG recognizes the need for quantification of climate proxies before, during and after extreme climate intervals. We cannot address important global-scale issues on the thousand-year time scale without continuous, high-resolution depth transect records at multiple locations. Critical to this endeavor will be the development of an integrated astonomically-tuned Cretaceous and Paleogene time scale.

In this final report, we detail why knowledge of the LPTM and OAEs is important to Earth science, and highlight a general interest in studying biological turnovers during the Paleogene and Cretaceous. We then discuss how available ocean drilling and scientific approaches can be used to understand the selected extreme climate events. Greenhouse world drilling has attracted a lot of attention lately by excellent papers in journals such as Nature, Science and Geology as a direct result of drilling at Blake Nose in the North Atlantic (ODP Leg 171), which was only a half-Leg.

The PPG identified the Walvis Ridge, Demerara Rise and J-Anomaly Ridge as three locations where well-designed ODP drilling legs could significantly improve our knowledge of extreme climates of the Paleocene and Cretaceous. Members from the PPG have actively responded and written three proposals to drill in these areas, and have laid the groundwork for future proposals development in this area. We also endorse two proposals currently in the system for Pacific drilling (Paleogene Equatorial Pacific; Shatsky Rise, now scheduled for 7/2001) and southern latitudes (Weddell Sea).

MANDATE SET BY SCICOM 1997 AND RESPONSE OF PPG

- develop the drilling strategy to complete the defined goals.

  Action taken by the PPG: strategies should contain elements of drilling for complete sections and core recovery in high sedimentation areas to document Milankovitch cyclicity (see drilling strategy in this report).

- identify geographic areas appropriate to meeting the scientific objectives.

  Action taken by the PPG: current proposals in the system are highlighted in this report that foster 'extreme' climate drilling (see leg proposals in this report).

- organize the development of specific drilling proposals.

  Action taken by the PPG: three proposals have been submitted as a response to the activities of this PPG.

OVERALL GOALS SET BY SCICOM 1997 AND RESPONSE BY PPG

- Determine the frequency, amplitude, and forcing of global climate change, latitudinal thermal gradients, sources of deep water and vertical ocean structure, and changes in global sedimentary fluxes – Focus on major intervals of abrupt climate change (e.g., Barremian-Aptian, Cenomanian-Turonian, Cretaceous-Paleogene boundaries, Paleocene-Eocene, lower-middle Eocene and middle-upper Eocene boundaries).

  Action taken by the PPG: forcing of global climate towards brief episodes of extreme warmth can best be explained by increased gas input into the oceanic-climate system and therefore we have selected three prominent intervals as drilling targets: LPTM, Cenomanian-Turonian boundary and early Aptian oceanic anoxic events. High latitudinal drilling targets are highlighted in this report to gain insights in latitudinal thermal gradients and deep water sources. Sedimentary fluxes will follow on from the use of Milankovitch cycles.

- Investigate major aberrations in the global carbon budget (e.g., mid-Cretaceous black shale).

  Action taken by the PPG: we wished to highlight the Cenomanian-Turonian boundary and early Aptian oceanic anoxic events, as well as the Paleocene-Eocene transition. Members of the PPG panel have written proposals, and endorsed by the panel, to emphasize the importance of understanding both major inputs of the carbon cycle (such as the LPTM) and outputs (such as the Cretaceous OAEs). Of key importance is determining the rates of carbon cycling, where the carbon comes from, how it is removed, and the biological and climatological effects of large transient changes in carbon reservoirs.

- Develop a firm astronomical time scale for the Paleogene and a preliminary one for the Cretaceous and integrate this chronology with the magnetobiostratigraphy.

  Action taken by the PPG: Milankovitch cycles are at the heart of this exercise (see section on Milankovitch cycles in this report).

LATE PALEOCENE THERMAL MAXIMUM (LPTM)

Our society is concerned with the fate of fossil fuel carbon which we are presently adding to the atmosphere of the global carbon cycle at a rate of 5 x 10^{14} mol C/yr during an interglacial time interval that already is warm. Although we have a considerable understanding of how the global carbon cycle operates, we have limited knowledge on how a rapid and massive input of fossil fuel will perturb the global carbon cycle and related systems. Studies of the Neogene geological record provide boundary conditions for the global carbon cycle. However, these records provide no analogue for our current fossil fuel forcing function, or massive carbon input during a time interval that was already warm.

A brief time interval at (or near) the Paleocene-Eocene Boundary (ca. 55 Ma) is now known to have been characterized by a rapid 4 to 8 °C increase in deep ocean, high-latitude and continental temperatures as well as major turnovers in terrestrial and marine flora, fauna and microbiota (e.g., Kennett and Stott, 1991; Zachos et al., 1993; Thomas and Shackleton, 1996; Fricke et al., 1998). This time interval has been coined the "Late Paleocene Thermal Maximum" or LPTM (Zachos et al., 1993). The LPTM is notable for a prominent negative carbon isotope excursion of at least -2.5‰. This d^{13}C excursion has been documented in planktic and benthic foraminifera in sediment of all oceans, in fossil tooth enamel and carbonate concretions in terrestrial sequences of North America, and in terrestrial organic carbon in sediment from Europe and New Zealand (e.g., Kennett and Stott, 1991; Koch et al., 1995; Kaiho et al., 1996; Thomas and Shackleton, 1996; Bralower et al., 1997; Schmitz et al., 1997). The onset of the d^{13}C excursion occurred within 1000 yrs (Bains et al., 1999), and the entire excursion likely spanned about 200,000 yrs (Kennett and Stott, 1991; Bralower et al., 1997; Schmitz et al., 1997). Norris and Röhl provided the first astronomically-calibrated date for the LPTM (~54.98 Ma) and a chronology for the event itself using a cyclostratigraphy. The timing, magnitude and global nature of the d^{13}C excursion, although it may not have been an isolated event around the Paleocene-Eocene boundary (Thomas et al., 1999), may be unique in the Phanerozoic record.

The isotope excursion across the LPTM is especially intriguing from a mass balance perspective because it cannot be explained unless an immense quantity of CO_2 greatly enriched in ^{12}C was rapidly added to the ocean or atmosphere (Dickens et al., 1995; Thomas and Shackleton, 1996). This inference is consistent with pronounced dissolution of carbonate in deep sea sediment deposited during the LPTM (Thomas and Shackleton, 1996; Dickens et al., 1997; Bralower et al., 1997; Thomas, 1998).

One plausible explanation for the observed LPTM $d^{13}C$ excursion involves massive release of CH_4 from gas hydrates in the ocean (Dickens et al., 1995, 1997; Kaiho et al., 1996). This hypothesis suggests that a change in ocean circulation caused significant warming of intermediate to deep ocean water during the LPTM (Kennett and Stott, 1991). This warming resulted in steepened sediment geotherms on continental margins and thermal dissociation (melting) of gas hydrate. Methane released from gas hydrate and underlying free gas zones then escaped to the ocean or atmosphere where it was oxidized to CO_2. Simple models have demonstrated that release and oxidation of between 1 and 2 x 10^{18} g of CH^4 with a $d^{13}C$ of -60‰ into the present-day exogenic carbon cycle over 10,000 yrs results in geochemical perturbations similar to those observed across the LPTM (Dickens et al., 1997). No other reasonable explanation for the observed $d^{13}C$ excursion has been offered.

The importance of the observed carbon cycle perturbation at the LPTM is that it strongly suggests release of reduced carbon to the ocean and atmosphere at rates approaching those of present-day anthropogenic inputs of fossil fuel at a time of profound climatic, biological, and geochemical change. The LPTM is the only known analogue in the geological record for understanding how the global carbon cycle and other systems relate to a rapid and massive input of fossil fuel.

Outstanding issues surrounding the LPTM include the following:

- What was the cause of carbon input? Was it indeed CH_4 from the seafloor and did it lead or lag changes in the chemistry and temperature of the ocean and atmosphere?
- What was the cause of the apparently rapid thermohaline reversal and did it precede carbon input?
- Where was the carbon added? Was carbon added first to the atmosphere or ocean?
- What was the precise rate of carbon input and did it vary over time?
- What was the nature of climate variability across latitude before, during, and after the LPTM?
- How did the carbon input and temperature increase affect biological systems?
- Did tropical SST increase during the LPTM? If so, to what extent?

CRETACEOUS OCEANIC ANOXIC EVENTS (OAES)

Understanding the causes and effects of major disturbances in the steady-state carbon cycle is a primary objective currently facing the ocean sciences. Investigations of mid-Cretaceous Ocean Anoxic Events (OAEs) have become focal points in this endeavor because they represent major perturbations of the ocean system defined by massive deposition of organic matter in marine environments (Schlanger and Jenkyns, 1976; Jenkyns, 1980; de Graciansky et al., 1984; Arthur et al., 1990). Although similar events are known from earlier time intervals of the Mesozoic and Palaeozoic, they cannot be studied extensively because deep-ocean records are unavailable. OAEs did not occur during the Cenozoic.

There were arguably between two and five OAEs during the mid-Cretaceous. Each of these OAEs was different in geographic extent, but all record rapid changes in the carbon cycle, and all were associated with major changes in marine biota (following section). Two of these events, the late early Aptian Selli Event (=OAE1a; ~120 Ma) and the Cenomanian-Turonian Boundary Bonarelli Event (=OAE2; ~93.5 Ma) are particularly prominent, represented by sedimentary records in all ocean basins (Arthur et al., 1990; Bralower et al., 1993, 1994). Both events were likely associated with major steps in climate evolution since burial of excess organic carbon, by drawing down CO_2, apparently initiated global temperature decline from relative maxima (Jenkyns, 1999). The highest global temperatures of the last 115 Ma were likely obtained between Cenomanian-Turonian boundary time and the middle Turonian (Huber et al., 1995, 1999; Clarke and Jenkyns, 1999).

Recent high-resolution work indicates that OAE1a (“Selli Event”) was characterized by a complex sequence of apparently global biogeochemical variations. An interval of rapid radiation in calcareous nannoplankton was followed by a marked negative $d^{13}C$ excursion and loss of nannoconids (Erba, 1994). This negative $d^{13}C$ precursor has now been verified in Alpine sections of southern and northern Tethys (Weissert and Lini, 1991; Menegatti et al., 1998), in southern England (Gröcke et al., 1999), in Mexico (Bralower et. al., 1999) and at Resolution

Guyot in the Pacific (Jenkyns, 1995; Jenkyns and Wilson, 1999). This negative excursion is registered in both marine carbonate and organic matter and terrestrial higher-plant material and clearly influenced the whole of the ocean-atmosphere system. In all of these localities this negative d^{13}C excursion is superseded by an abrupt positive d^{13}C excursion. Black shales of the Selli Event occur exactly at the stratigraphic level where d^{13}C values rapidly increase from relatively low to relatively high values.

The series of events surrounding 120 Ma OAE1a has been linked to the Ontong Java-Pacific "superplume" event, whereby a profound increase in submarine volcanism may have forced global warming and increased marine productivity (Larson, 1991; Erba,1994; Follmi et al., 1994; Menegatti et al., 1998; Larson and Erba, 1999). Such a scenario is consistent with an observed decrease in the ^{87}Sr/^{86}Sr ratio of seawater (Ingram et al., 1994; Jones et al., 1994; Bralower et al., 1997). One hypothesis (Bralower et al., 1994) also relates the distinct negative d^{13}C perturbation to input of mantle-derived CO_2 associated with submarine volcanism, but it may also be related to release of gas hydrates (Opdyke, pers com; presentation AGU, 1999).

Sediments rich in marine organic matter of Cenomanian-Turonian boundary age have been recovered from all ocean basins (Arthur et al., 1990). As evidenced by widespread laminated sediment and a variety of geochemical indices (e.g., Dickens and Owen, 1995; Sinninghe et al., 1998), the response of the carbon cycle during OAE2 was somehow related to dysoxic to euxinic conditions in the water column, although the exact cause and dimensions of O_2-deficiency remain unclear and controversial.

The substantial positive d^{13}C excursion of sea water at the time of 93.5 Ma OAE2 (Scholle and Arthur, 1980; Schlanger et al., 1987; Jenkyns et al., 1994) has also been attributed to increased productivity and carbon burial. Here, however, it is unclear whether heightened productivity was stimulated by changes in circulation, water-mass sources (Arthur et al., 1987, 1990; Leckie et al., 1998), or submarine volcanism (Sinton and Duncan, 1997; Kerr, 1998) in terms of nutrient availability. A pronounced negative d^{13}C excursion precursor has not yet been identified for OAE2 in marine sections from Europe (Jenkyns et al., 1994), but some sections (e.g., Japan, Hasegawa, 1997) show a slight negative trend prior to the major positive excursion at the Cenomanian-Turonian boundary. Plateau volcanism at 93-88 Ma is recorded in the Pacific, Indian and Caribbean basins (Bercovici and Mahoney, 1995; Tarduno et al., 1998), and there is a decrease in the ^{87}Sr/^{86}Sr ratio of seawater (Ingram et al., 1994; Jones et al., 1994; Bralower et al., 1997).

Major issues surrounding extreme climate and the carbon cycle during OAEs include the following

- What were the specific triggers leading to abrupt perturbations of the carbon cycle? Was it submarine volcanism? Was it elevated nutrient concentrations?
- What was the ultimate cause of O_2 deficiency? Was it enhanced productivity, reduced circulation, or input of alternative oxidizing agents?
- What was the vertical extent of O_2 deficiency?
- Were all OAEs linked to greenhouse warming?
- What was the nature of climate variability across latitude before, during, and after OAEs? What is the relationship between climate change and OAEs?
- How did the carbon input and oceanographic changes affect biological systems?
- How did oceanic temperature structures change during different OAEs?
- What is the connection, if any, between putative release of gas hydates and OAEs?

BIOTIC RESPONSE DURING EXTREME CLIMATES

The modern pressure on marine and terrestrial ecosystems highlights our ignorance of the long-term consequences of rapid habitat changes on biotic evolution and the maintenance of biological diversity. Although we know a considerable amount about the causes of the modern crisis, it is far less clear how resilient the biosphere is to major climate events or how changes in nutrient cycling and thermal gradients influence evolutionary processes on long timescales. Just as the LPTM and OAEs provide analogs for modern rapid climatological changes, these events also offer the opportunity for analyzing the biological response to global perturbations.

The Cretaceous to Paleogene "extreme greenhouse" period was a time characterized by major marine and terrestrial biotic turnovers many of which fundamentally restructured biotic communities and established the 'modern' fauna and flora. Most of these events seem to be linked to major changes in climate and oceanography, and the mid-Cretaceous OAES and LPTM are excellent examples. Yet nearly all these events remain poorly understood, in large measure because previous deep sea drilling targeted relatively condensed sections or failed to recover the entire sedimentary column. We also are just beginning to establish direct correlations between marine and terrestrial sections which are invaluable for deducing the role of the atmosphere and climate in these turnover events.

The early Aptian OAE1a (Selli Event) was associated with a major turnover event for calcareous nannoplankton, radiolaria, planktic foraminifera, and benthic foraminifera (Coccioni et al., 1992; Erba, 1996; Erbacher and Thurow, 1997; Kaiho 1998; Premoli Silva and Sliter, 1999). The OAE2 (Bonarelli Event) was even more pronounced, with major extinctions in the above groups, ammonites, bivalves and even angiosperms (Jarvis et al., 1988; Leckie, 1989; O'Dogherty, 1994; Kaiho and Hasegawa, 1994; Kuhnt and Wiedmann, 1995; Coccioni et al., 1995; Erbacher and Thurow, 1997; Boulter et al., 1998; Kaiho, 1998; Premoli Silva and Sliter, 1999).

Current models for biotic turnover during the mid-Cretaceous OAEs largely invoke O_2 deficiency and eutrophication of the oceans. For example, an increase in oceanic productivity during OAE1a (Weissert et al., 1998; Grötsch et al., 1998) may have resulted in expanded oxygen minimum zones in several areas (Caron and Homewood, 1983; Erbacher et al., 1996) that, in conjunction with rapid eutrophication, could have caused extinctions and subsequent radiations in a variety of marine groups (Norris and Wilson, 1998). Leckie (1989) also stressed the importance of upper water column thermal gradients in influencing the nature of productivity and plankton evolution, and how these gradients may have changed with rising sea level and different modes of water mass production. However, these theories require testing with biotic, biogeographic, and isotopic data that establish the sequence of turnover in groups with different susceptibility to low oxygen conditions and nutrient cycling at orbital resolution. Correlations between marine and terrestrial ecosystems are particularly important as a means of determining whether a process like "anoxia" is a primary cause in extinction or merely a secondary result of some larger process.

The LPTM is associated with a suite of biological events that include extinction of about 50-55% of deep sea cosmopolitan benthic foraminifera (Thomas, 1998) and a major immigration event of mammals to North America and Europe (Koch et al., 1995). New mammals suddenly appearing in the fossil record include the first recorded ancestors of primates. Although it is unclear where the new mammals came from, it is likely that this major mammal dispersion event involved the opening of high-latitude gateways and elevated temperatures both of which may also have played important roles in the benthic foraminifer extinction (Meng and McKenna, 1998).

Notably, the warming at the LPTM is not associated with major turnovers in planktic foraminifera and nannoplankton (Kelly et al., 1996). These groups both experience more significant speciation and extinction several 100 ky after the $d^{13}C$ excursion (Pardo et al. 1997; Aubry, 1998). Indeed, the turnover in marine planktonic groups is approximately coeval with an interval of elevated extinction in mammal faunas from Wyoming and a jump in land plant diversity from the same area (Koch et al., 1992; Maas et al. 1995; Wing et al. 1995; Wing, 1998). Floral assemblages from the Bighorn Basin provide evidence for an approximately 5°C drop in temperature associated with the biotic changes immediately after the LPTM. The delay in biotic turnover suggests that the LPTM was part of a larger series of climatological events that had major biological effects, such as the ramp-up to the early Eocene Warm Period. Hence, it is critical to analyze not only the LPTM event itself, but also its larger context in the late Paleocene-early Eocene. It has also been speculated that there may be at least one additional late Paleocene to early Eocene carbon isotope event (Stott et al., 1996). Unfortunately, it has been extraordinarily difficult to construct a complete and unambiguous chronology of detailed events surrounding the Paleocene-Eocene boundary (Aubry and Berggren, 1999).

OUSTANDING ISSUES RELEVANT TO BIOLOGICAL CHANGE DURING EXTREME CLIMATES INCLUDE THE FOLLOWING:

- Are observed turnover events abrupt or do they occur over an extended period?
- How taxon-specific are the turnovers and are particular ecological groups more profoundly affected than others?
- Are turnover events associated with just the onset of warm periods and OAEs or do the terminations of these events also produce turnovers? That is, is the magnitude of forcing more important than its direction?
- How do turnover patterns compare between the marine and terrestrial realms?
- Was provincialism substantially different than at present-day?

MILANKOVITCH "REFERENCE SECTIONS"

Until recently, paleoceanographic studies of warm intervals of the Paleogene and Cretaceous carried the label "low resolution". While this description derived correctly from the typically low-resolution sampling intensity of most existing biostratigraphic, stable isotopic, or geochemical studies of these periods, it also reflected the view that warmer worlds were inherently less climatically variable than the late Neogene, and that in any case stratigraphers would never resolve time in older geological sections to better than perhaps 0.5 Myr intervals. Better sampling has brought to light brief, extreme excursions in the ocean-atmosphere system such as the Oligocene-Miocene (Shackleton et al., 2000) and Paleocene-Eocene events (LPTM), that challenge the “low resolution” paradigm. Recent recognition of another class of high frequency events, semi-periodic features in sedimentation and/or biotic composition that show statistical patterns and periods characteristic of variations in the Earth’s orbital elements (eccentricity, obliquity, and precession) open up the possibility of studying geologically warm periods at resolutions similar to those achieved in the Pleistocene (Park and Herbert, 1987; Gale, 1989; Herbert and D’Hondt, 1990; Huang et al., 1992).

Targetting orbital reference sections, with the requirements of continuous sedimentation, complete core recovery, and optimal integration of other stratigraphic tools (i.e. magnetostratigraphy, biostratigraphy, and chemostratigraphy), promises to advance our quantitative understanding of past climates in two major ways. First, we can view climatic variance in the “Milankovitch” band as a unique experiment in climate sensitivity. The forcing functions (variations in sunlight received at the top of the Earth’s atmosphere as a function of season, and latitude, and orbital parameters) that have driven the Plio-Pleistocene ice ages have continued from the remote past with very nearly their recent values. While celestial mechanics cannot provide complete solutions to the earth’s orbit much beyond 10 Myr, the statistical behavior of the orbital terms can be deduced (Berger et al., 1992). The Earth itself has evolved as part of this oscillating pattern of insolation anomalies, and, by working in the Milankovitch band, we have the chance to detect which aspects of climate sensitivity, and which geographic regions, maintain responses to orbital forcing, so many of which are well documented for the Pleistocene epoch.

Orbital cyclicity, as it does for Pleistocene paleoclimatology, also provides the best practical method for measuring elapsed time. It thus has the potential to greatly increase the temporal resolution of global correlations based on geomagnetic polarity time scales (e.g. Cande and Kent, 1992; 1995; Berggren et al., 1995; Shackleton et al., in press). For example, the well-known secular trend of increasing geomagnetic reversal frequency from the Cretaceous Long Normal Superchron to the Present results in a vernier that typically parses time to only 0.5–1 Myr resolution. Determining the duration of events within polarity chrons, and documenting their correlation between sites, relies, in the absence of orbital chronology, on the assumption of constant sedimentation rate. The ability of properly sampled cyclic sections to measure time in 20, 40, 100, and 400 kyr increments clearly adds to the study of any aspect of warm climates where determining rates is important. One example in which orbital dating has improved the resolution of a geologically important “event” comes from studies of the Cretaceous-Tertiary boundary, where cyclic sequences with reliable magnetostratigraphies and good core recoveries have increased constraints on the shortness of the K/T transition, and documented the slow recovery of the sedimentation and planktic foraminiferal diversity following the K/T event (Herbert and D’Hondt, 1990; Herbert et al., 1995, D’Hondt et al., 1996). The successful application of cyclostratigraphic techniques will be critical to our understanding of the LPTM which occurs with a 2.5 m.y. long polarity chron (C24R) and to the OAEs which generally occur within the 30 m.y. Cretaceous Long Normal, for example, the Bonarelli (OAE2) at the Cenomanian/ Turonian boundary.

Few Paleogene and Cretaceous sections have been sited or cored optimally to record orbital stratigraphies. The existing orbital template is patchy, with good coverage only in the earliest Paleocene through the Late Cretaceous (early Campanian). The encouraging observation is that so many sections, despite episodic core recovery, suggest a strong orbital influence. Simple, relatively easily measured properties of lithological variance (measuring % $CaCO_3$, % Corg, etc.) or indirect lithological proxies (reflectance spectroscopy or magnetic susceptibility) work well to produce time series with clear “Milankovitch” features. Downhole logs tied to analysis of cores may well play a role in the future (Kroon et al., 2000). Few high-resolution stable isotopic time series of Paleogene and Cretaceous age exist, but these may show patterns paced by orbital cycles as well. Focused efforts to drill sites with moderate Neogene cover, with a high likelihood of obtaining magnetostratigraphies, which must be the “backbone” of high-resolution studies, and with multiple-hole strategies should result in a near-continuous marine “Milankovitch” template into the middle Mesozoic.

DRILLING STRATEGIES

Many issues relevant to understanding the LPTM and OAEs can be addressed by the same drilling strategies that are currently and successfully employed for tackling Neogene paleoceanographic objectives. Drilling transects should be conducted at multiple locations where chosen drill sites have a number of criteria:

- a wide range of paleodepths;
- good preservation of primary carbonate;
- high sedimentation rates across time intervals of interest;
- good potential to preserve a paleomagnetic signal or contain sediments with strong magnetic susceptibility.

Complete core recovery through chosen intervals and wire-line logs

Issues of rate and magnitude during OAEs and the LPTM require continuous stratigraphic records. This can only be accomplished by complete core recovery through chosen intervals by taking multiple cores, and logging holes with the formation microscanner (FMS). Related to this is the need for an astronomically-tuned Paleogene and Cretaceous time-scale. Observed biogeochemical changes during extreme climate intervals of the Cretaceous and Paleogene occur significantly faster than the temporal resolution by conventional stratigraphic approaches. Key issues concerning timing, magnitude, and rate of change during the LPTM and OAEs will have to be pursued with the same rigor applied to Neogene sediment records. Earlier DSDP and ODP legs have provided reconnaissance data to indicate that astronomical approaches can be extended into Paleogene and mid-Cretaceous sequences.

The reason for the above criteria can be appreciated by considering logical objectives for understanding extreme climate during the LPTM. For example, rapid release of 1 x 10^{18} g of CH_4 with a $d^{13}C$ of -60‰ into the deep Atlantic Ocean over 10,000 yrs should result in an average annual removal of 4.5 x 10^{14} g of dissolved O_2, and substantial dissolution of $CaCO_3$ that would be represented by a burndown of previously deposited carbonate and a major shoaling of the CCD (Dickens et al., 1997). Moreover, such deep ocean carbon input would result in an intriguing temporal offset whereby the $d^{13}C$ shift in benthic foraminifera will precede the $d^{13}C$ shift in planktic foraminifera. A series of depth transects in each of the major ocean basins would allow for characterization of the $CaCO_3$ dissolution event as well as quantification of dissolved O_2 and $d^{13}C$ of different water masses. Ultimately, in order to model and understand basic biogeochemical perturbations during the LPTM, the Earth science community will need to know the rate, magnitude and relative timing of surface water warming, deep water warming, carbon input to the deep ocean, carbon input to the shallow ocean, carbon input to the atmosphere, O_2 deficiency in the deep ocean, carbonate dissolution on the seafloor, and biological turnovers in the deep ocean, shallow ocean, and on land. Such links can only be addressed by correlating numerous sites from different environments at the 100 to 1000 year time-scale.

New technology?

In Paleogene and Cretaceous sediments, lithological changes (e.g. chert bands) present challenges. We therefore highlight the need to develop the technology that would allow us to revert from rotary coring to hydraulic piston and/or extended barrel coring techniques, once resistant lithologies are known to have been penetrated, in second or third holes at any site.

Depth of burial of the mid Cretaceous sediments

A very important consideration is depth of burial of the mid-Cretaceous sections. Expanded mid-Cretaceous sections that have not been deeply buried are the highest priority targets of OAEs. Areas such as the J-Anomaly Ridge, Demerara Rise and Newfoundland Ridge in the Atlantic, Exmouth Plateau and Scott Plateau of the southeast Indian Ocean will provide complementary mid-latitude localities for comparison with the well-preserved tropical records of OAE1b, 1d, and 2 cored on Blake Nose during ODP Leg 171B.

Cretaceous Quiet Zone

Finally, there may be a connection between the OAEs, generation of oceanic lithosphere, mantle plume activity, sea level and continental weathering (e.g., Larson, 1991; see also Ingram and Richter, 1994; Heller et al., 1996; Larson and Erba, 1999). A key unknown is the rate of sea floor spreading during the Cretaceous Long Normal Superchron. Due to the lack of diagnostic magnetic anomalies in the Cretaceous Quiet Zone, the rate of lithospheric production can only be estimated as an average over about 30 Myr. of the mid-Cretaceous. At such coarse resolution, it is not possible to determine if there was a global increase in the rate of sea floor spreading that coincided with the pulse of Ontong-Java superplume activity toward the beginning of the Cretaceous Long Normal. This problem can only be addressed by drilling, i.e., direct sampling and dating of ocean floor within the Cretaceous Quiet Zone in different ridge systems. Sediment immediately overlying basement should have been deposited when the ridge was at its shallowest and thus should generally preserve an age-diagnostic calcareous fossil assemblage. An important constraint on any basement site used for this purpose is a known flow-line distance from the end(s) of the Cretaceous Quiet Zone; such sites can be considered holes of opportunity on different legs to build up an inventory of age information on the global ridge system in the mid-Cretaceous. Such opportunities should be sought in conjunction with planning for drilling in the Atlantic Ocean (e.g., Walvis Ridge and Newfoundland Ridge).

Opportunistic Sites

In Paleogene and Cretaceous drilling, results from earlier DSDP and ODP legs have provided vital reconnaissance information to guide our selection of new sites for scientifically focused dedicated transect drilling. However, these reconnaissance sites are a limited resource. We have discussed a number of potentially exciting target areas for transect drilling where we have no borehole control. Our discussion highlights the need to give increased priority to drilling 'sites of opportunity' in such areas.

Modeling

The combination of climate modeling and paleoceanographic data can help to define and understand the climate system. We can gauge our understanding of these past warm climate systems by predicting aspects of the paleoceanographic system with models, and then testing the hypotheses with strategic scientific drilling. For example, modeling results can be used to predict oceanic regions with high sensitivity to particular (or tectonic) forcing, for boundary conditions of a given time period. Drilling of sediments in these regions can support or refute such hypotheses, and analyses of sediments from these regions may provide more valuable information than sediment from other, less climatically sensitive, ocean regions. Certainly important as highlighted by the modeling are the implications of the low-high latitude temprature gradient as a function of CO_2 on the climate system. Drilling is essential to define the latitudinal gradients in the Paleogene and Cretaceous. Attempts have been made in the past, but these results are sporadic and highly expanded sections with well-preserved foraminifera are needed to document the gradients. Particularly the need to find high-resolution sites in the high latitudes becomes obvious.

DRILLING PROPOSALS IN THE SYSTEM THAT ADDRESS 'EXTREME CLIMATE' PPG OBJECTIVES

Relevant proposals that were already in the system included

- Shatsky Rise (534) (now schduled for drilling in 2001 as Leg 198);
- the Paleogene Equatorial Pacific Transect (486) (scheduled for drilling as Leg 199 in 2001);
- Weddell Sea (503); Scott Plateau (513); and
- Arctic drilling (533).

To supplement these, three new proposals were submitted by members of the PPG: Walvis Ridge (559); Newfoundland Ridge (562); and Demerara Rise (577).

Abstracts of all of these proposals are available at the JOIDES Office website (http://www.joides.geomar.de).

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Evolution of the FY 2001 Drilling Program

THE PROCEDURE

At its August 1999 meeting, SCICOM considered 21 externally reviewed proposals that had been carried forward from last year and those forwarded to it by the SSEPs. The proposals were considered in terms of their relation to the objectives and priorities of the Long Range Plan (LRP). The LRP identifies fundamental scientific problems under two major research themes: Dynamics of the Earth's Environment and Dynamics of the Earth's Interior. Before ranking the proposals, SCICOM discussed the status of investigations of the scientific topics under these two themes.

Two of the proposals 431-Rev (West Pacific ION Seismic Network) and 517-Full (Nankai II), had already been considered and highly ranked the previous year. They were forwarded to OPCOM for scheduling before ranking the remaining proposals.

The problem of repeated ranking of proposals that were far from the area foreseen for operations, was considered. SCICOM expressed concern about highly ranked proposals (those forwarded to OPCOM) that clearly lie outside the projected area of ship operations for several years yet receive a new global scientific ranking each year. Such proposals inevitably slip in rank because of the higher priority placed on those proposals with a geographic urgency to schedule. SCICOM therefore adopted the following procedure:

Every proposal, regardless of its geographic location, will receive a global scientific ranking when first reviewed by SCICOM.

If OPCOM does not schedule a highly ranked proposal primarily because it lies outside the projected area of ship operations, SCICOM will not automatically re-rank that proposal the following year. When the possibility arises to schedule such a proposal, SCICOM may request the proponents to submit an update, in the form of either an addendum or a revised proposal (not subjected to further external review), for consideration at the spring meeting of the SSEPs.

SCICOM members voted by closed ballot to establish a global scientific ranking of the 19 proposals remaining and then voted to forward the top 10 to OPCOM for possible scheduling:

Rank	Proposal	Title
1.	523-Full	Hawaiian-Emperor Seamounts
2.	465-SE	Pacific Paleoceanography
3.	486-Rev2	Paleogene Equatorial Pacific
4.	525-Full	Mid-Atlantic Ridge Peridotite
5.	500-Full2	H2O Long-Term Seafloor Observatory
6.	499-Rev	ION Equatorial Pacific
7.	546-Full	Hydrate Ridge
8.	505-Full3	Mariana Convergent Margin
9.	534-Full	Shatsky Rise
10.	510-Full3	Marion Plateau

After considering scheduling and operational matters, OPCOM returned three alternative plans to SCICOM for discussion. SCICOM considered these and approved a schedule for FY 2001 and early FY 2002. Legs 192 and 193 were carried over into FY 2001 from the planning for FY 2000. It was hence decided to drill the legs in the following sequence: Leg 192: Ontong-Java Plateau; Leg 193: Manus Basin; Leg 194, Marion Plateau; Leg 195: Western Pacific ION; Leg 196: Nankai II; Leg 197: Hawaiian-Emperor Seamounts; Leg 198:Hydrate Ridge; Leg 199: Equatorial Pacific Paleogene Transect; Leg 200: H2O; Leg 201: SE Pacific Paleoceanography. Legs 200 and 201 would fall into FY 2002.

Immediately prior to the JOIDES Executive Committee Meeting in Washington, D. C., Feb. 15-16, 2000, it became apparent that the schedule for FY 2001 that had been worked out by SCICOM in 1999 contained costs that would exceed the available budgeted funds. Accordingly, Legs 198 and 199, originally Hydrate Ridge and the Equatorial Pacific Paleogene Transect respectively, were swapped, moving Hydrate Ridge into the beginning of FY 2002. This revised schedule was presented to JOIDES EXCOM. At the same time, JOIDES OPCOM examined the revised schedule and expressed concern about the weather window for Hydrate Ridge.

At the February meeting EXCOM approved the following sequence of Legs for FY 2001 and the beginning of FY 2002:

- Leg 192: Ontong-Java Plateau;
- Leg 193: Manus Basin;
- Leg 194, Marion Plateau;
- Leg 195: Western Pacific ION;
- Leg 196: Nankai II;
- Leg 197: Hawaiian-Emperor Seamounts;
- Leg 198: Equatorial Pacific Paleogene Transect;
- Leg 199: Hydrate Ridge.

It subsequently became apparent that in order to assure optimum weather conditions, Hydrate Ridge drilling would need to be postponed until the summer or early fall of 2002.

Because of these changes, OPCOM and SCICOM, at their August 2000 meeting, reconsidered the order of all Legs after 197 (Hawaiian-Emperor Seamounts), taking into account the rankings of the 30 proposals considered at that meeting as well. This time 12 proposals were forwarded on to OPCOM for consideration:

Rank	Proposal	Title
1.	533-Full2	Arctic Ocean
2.	534-Full	Shatsky Rise
3.	525-Full	Mid-Atlantic Ridge Peridotite
4.	571-Full	Peru Margin Microbiology
5.	505-Full3	Mariana Convergent Margins
6.	455-Rev3	Laurentide Ice Sheet Outlets
7.	482-Full3	Wilkes Land Margin
8.	544-Full2	Costa Rica Subduction Factory
9.	559-Full	Walvis Ridge Transect
10.	564-Full	New Jersey Shelf
11.	539-Full2	Blake Gas Hydrates
12.	512-Full2	Mid Atlantic Ridge Core Complex

The highest ranked proposal, for drilling on the Lomonosov Ridge, could not be scheduled because it would require a drilling vessel other than the JOIDES Resolution and support from at least two icebreakers. This would have resulted in additional cost of $4–10 million, far exceeding funds available. Two of the proposals that had ranked highly in 1999 were again highly ranked: 534-Full: Extreme Warmth/Shatsky Rise, which became 2 of 30, and 505-Full3/Add, which was now 5 of 30. The result was a revision of the schedule that had been presented to EXCOM in February 2000, rearranging the order of Legs to be drilled in FY 2001 and setting a sequence for FY 2002, permitting more high-priority science to be accomplished with greater efficiency in transits and economies in port calls.

The new revised schedule for FY 2001, proposed by SCICOM, which has now been approved EXCOM is as follows:

- Leg 192: Ontong-Java Plateau;
- Leg 193: Manus Basin;
- Leg 194, Marion Plateau;
- Leg 195: South Chamorro Seamount (Marianas)/Western Pacific ION;
- Leg 196: Nankai II;
- Leg 197: Hawaiian-Emperor Seamounts;
- Leg 198: Shatsky Rise.

The tentative proposed schedule for FY 2002, which will be presented to JOIDES EXCOM for approval in January 2001 is as follows:

- Leg 199: Equatorial Pacific Paleogene Transect;
- Leg 200: H2O;
- Leg 201: Peru Microbiology;
- Leg 202: SE Pacific Paleoceanography;
- Leg 203: Costa Rica Subduction Factory;
- Leg 204: Hydrate Ridge;
- Leg 205: Equatorial Pacific ION.

This makes it possible for the JOIDES Resolution to return to the Atlantic before the end of 2002 as required by SCICOM Motion 99-2-23: SCICOM resolves that the JOIDES Resolution will operate in the Atlantic Ocean during at least part of 2002.

The relation of the FY 2001 drilling program to the major themes of the ODP Long-Range-Plan (LRP) is as follows:

DYNAMICS OF THE EARTH'S ENVIRONMENT

- The Marion Plateau program will make a major contribution toward understanding the effects of sea-level change on sedimentary systems by defining the absolute magnitude of the major Middle Miocene sea-level fall and the magnitude of younger sea-level changes. It will also contribute to understanding the effects of sea-level change on carbonate sedimentary systems.
- The Shatsky Rise drilling will provide a depth transect designed to characterize changes in the nature of surface and deep waters through the Cretaceous and Paleogene, including the frequency, amplitude, and forcing of warm climate intervals, documentation of latitudinal and vertical gradients of temperature, and changes in the sources of deep water, vertical ocean structure, oxygenation, and corrosiveness with respect to carbonate through time.
- Although the Hawaiian-Emperor Seamounts Leg is primarily directed toward understanding the nature of hotspots, it will contribute important information on the orientation of the Pacific plate during the Early Cenozoic, aiding in the interpretation of paleoenvironmental data.

DYNAMICS OF THE EARTH'S INTERIOR

- Manus Basin is unique as an oceanic hydrothermal system in that it is hosted in acidic rocks. It bears a much closer relation to many continental ore deposits than the basalt-hosted hydrothermal systems associated with the mid-ocean ridge.
- South Chamorro Seamount [Marianas] is directed toward understanding the processes of mass transport and geochemical cycling in the subduction zone and forearc of a non-accretionary convergent margin.
- The W-Pacific Network–WP-1 and H2O Observatory sites will fill major

gaps in the global seismic monitoring program.

- Nankai II will use Logging While Drilling (LWD) and advanced CORKs to develop a more quantitative understanding of hydrogeologic, geochemical and tectonic processes on a convergent margin.
- The study of the Hawaii Hot Spot Emperor Seamounts will explore an important aspect of mantle dynamics by providing a test of the hypothesis that deep-seated mantle hotspots are not fixed, but move with time.

LEG 192: ONTONG-JAVA PLATEAU
PROPOSAL NO: 448

Full Title: Assessing the Origins, Age, and Post-Emplacement History of the Ontong Java Plateau through Basement Drilling

Proponents: L. W. Kroenke, J. Mahoney, A. D. Saunders, G. Ito, P. Wessel, D. Bercovici, T .Gladczenko, O. Eldholm, L. Abrams, R. Larson, M. Coffin, and A. Taira.

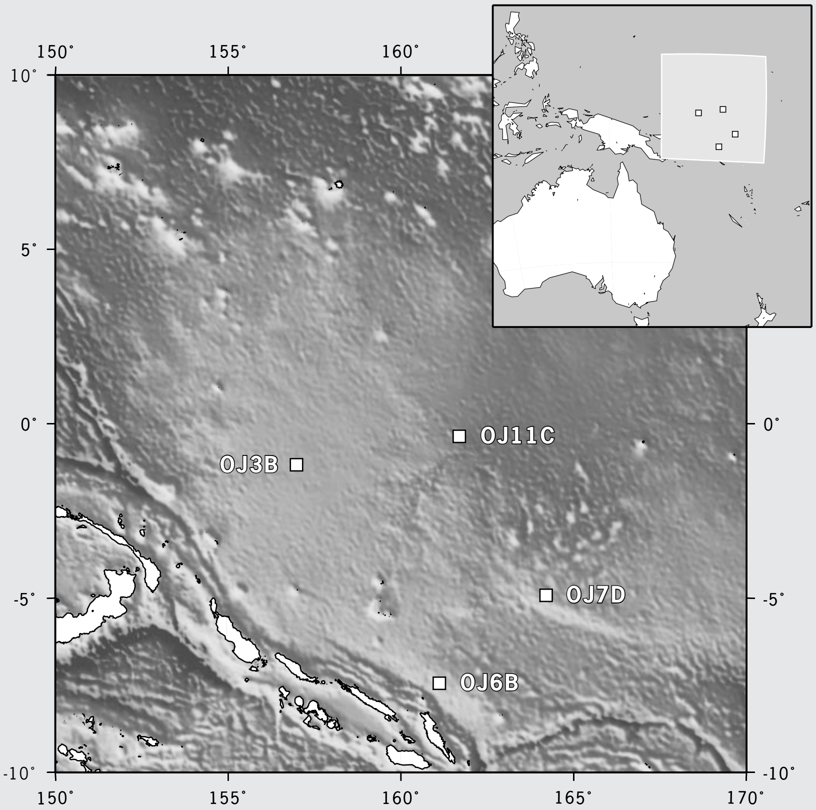


FIGURE 1 *Leg 192: Ontong-Java Plateau*

The importance of oceanic volcanic plateaus has become widely appreciated by the earth science community in the last several years. Many of these large igneous provinces (LIPs) represent immense volumes of magma erupted on the seafloor in fairly short time periods and emplacement rates of the largest ones may have approached the entire magma production rate of the global mid-ocean ridge system. In fact, the Alaska-sized Ontong-Java Plateau in the western Pacific may represent the largest igneous event of the last 200 my. The construction of LIPs and their effects on subduction patterns, continental growth and crust evolution, ocean circulation, and global climate are only beginning to be understood, but are clearly very significant in some cases.

Leg 193 is the first in a proposed two-leg program aimed at understanding the formation of the world's largest plateau. A transect of drill holes into basement across the Ontong Java Plateau will be drilled to determine its age and duration of emplacement, the range and diversity of magmatism, the environment of eruption, the post-emplacement vertical tectonic history of the plateau, the effects of rift-related tectonism, and the paleolatitude of the OJP at the time(s) of emplacement.

Drilling and Logging Plans

Four drilling sites are proposed in 1800-3915 m water depth. The holes will be RCB cored through 330-1200 m of sediment and 100-150 m into basement. Note that portions of the sediment column will be washed without core recovery to maximize the time available for basement penetration and recovery. Basalt recovery is the priority objective at all sites because samples are needed to address the primary question of the age of the plateau and the composition and temperature of the mantle source. These samples will also be used to determine the character and mode of emplacement of the lava flows and to address the question of whether volcanism was submarine or subaerial and how far from the eruption site the flows were emplaced. Basement logging will be completed at two sites, OJ-3B and one site to be named (Sites OJ-7, -11c or alternate 803).

LEG 193: MANUS BASIN
PROPOSAL NO: 479

Full Title: Anatomy of a Felsic Volcanic-Hosted Hydrothermal System: Eastern Manus Back-Arc Basin.

Proponents: R. A. Binns and S. D. Scott

One of the major goals of the Long Range Plan is to understand interactions between ocean water and hot crustal material in hydrothermal systems. Most hydrothermal systems are associated with the Mid-Ocean Ridge system and involve seawater-basalt interactions. Manus Basin provides a unique opportunity to investigate another class of hydrothermal system, one in which the reactions occur between seawater and acidic volcanic rocks.

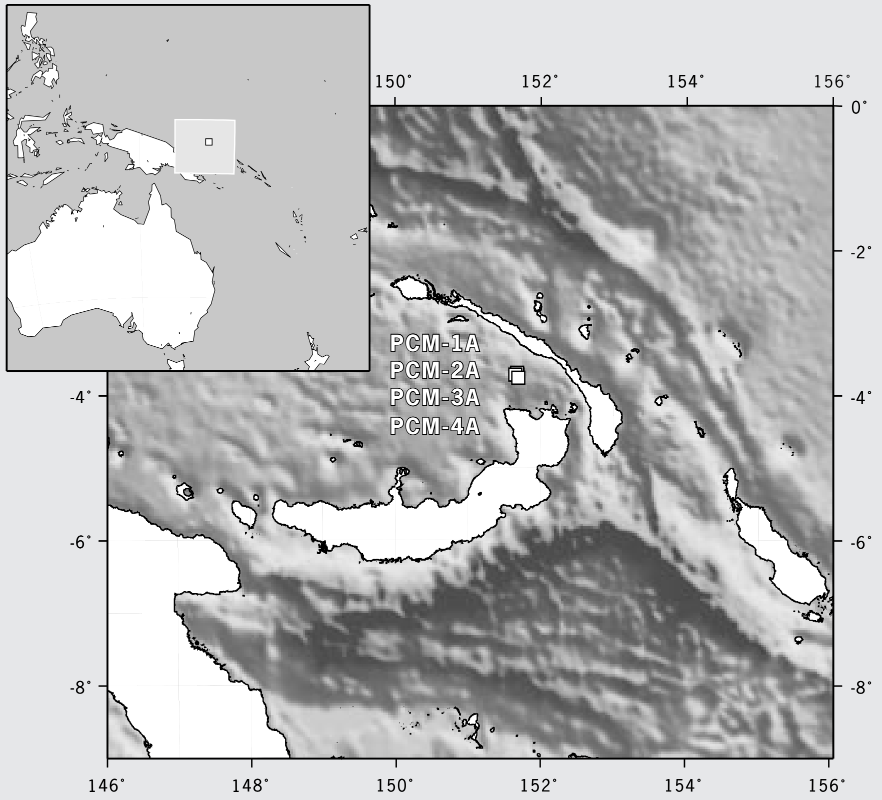
The objectives of Leg 193 are to study the magmatic-fluid interactions in a felsic volcanic-hosted hydrothermal system. This will be accomplished by

1. looking at mineralogical, geochemical, and isotopic analyses of mineralized veins and alteration intervals below outflow zones;
2. comparing investigations below shallow and deep inflow zones, particularly using isotopes for tracing the deposition of seawater-derived anhydrite;
3. performing quantitative modeling of the entire hydrological system using physical and chemical constraints derived from studies of core samples and wall structures of the boreholes.

Drilling and Logging Plans

The hydrothermal field will be cored at three sites in 1655-1720 m water depth. Two sites will be cored with the RCB/ADCB to 300 mbsf. One site will be cored with the RCB/ADCB to 500 mbsf. The holes are in a hot active hydrothermal system with possible H_2S safety concerns. The HRRS may be deployed for testing/operational use during this leg. Logging and downhole measurements will be critically important to the scientific objectives of Leg 193, particularly because previous core experiences in Middle Valley and TAG have been characterized by poor core recovery. The main objectives of the coring program will be to assess the changes in physical properties resulting from hydrothermal alteration and to determine how these changes relate to existing hydrological models. Hole stability and temperature conditions will determine the amount of wireline logging completed during this leg. Schlumberger tools rated to 175°C will be deployed when adequate hole cooling is achieved by circulating fluids prior to tool deployment. Overall, if temperature and borehole conditions are favorable (T <175°C, wireline logging operations will consist of two to three tool strings plus a fluid sampling probe. The strings will consist of the triple combo with the HNGS, the accelerator porosity sonde (APS), the HLDS, the dual induction tool [DIT]), a caliper tool, and cable head temperature measurement tool. Following deployment of the triple combo, the FMS/DSI combination will be deployed. There are two potential plans for LWD operations during Leg 193. At the present time the compensated dual resistivity tool is scheduled to be available for the duration of the cruise to provide gamma-ray and borehole compensation deep and shallow resistivity measurements that will allow direct correlation with core and wireline results in nearby holes. A resistivity-at-the-bit (RAB) tool may be used in lieu of the CDR. The RAB will be brought on board at the end of the cruise and three holes will be drilled near existing holes during a six day period.

FIGURE 2 *Leg 193: Manus Basin*



LEG 194: MARION PLATEAU
PROPOSAL NO: 510

Full Title: Sea-Level Magnitude and Variations Recorded by Continental Margin Sequences on the Marion Plateau, Northeast Australia

Proponents: A. R. Isern, C. J. Pigram, D. Müller and F. Anselmetti

Cretaceous rifting in the western Coral Sea formed a number of continental fragments, which are now capped by carbonate platforms. Leg 194 will drill a series of holes on one of these fragments, the Marion Plateau. The drilling will address the causes, magnitudes, and effects of sea-level change on continental margin sediments – a major objective of the ODP Long Range Plan. Specifically, the drilling transect on the Marion Plateau will investigate the Miocene sea-level variations and their influence on continental margin sediments. The Leg will build on the achievements of earlier ODP drilling in the region (Leg 133), targeting sequences with a high likelihood of successfully resolving major scientific problems. This program also builds on the results of previous sea-level legs in the Bahamas and on the New Jersey Margin.

It is widely accepted that sea-level fluctuations are fundamental in controlling the nature and geometry of continental margin deposition, but much of our knowledge is qualitative. The program on Marion Plateau is designed to provide quantitative information that can be used to calibrate the global sea-level curve. This region provides a unique opportunity to determine the absolute magnitude of one of the major Cenozoic sea-level falls.

The drilling strategy outlined for the Marion Plateau utilizes the stratigraphic relationship between an early to middle Miocene and late Miocene second-order highstand carbonate platform complexes to determine the absolute magnitude of the middle Miocene N12–N14 sea-level fall. The middle Miocene sea level fall caused a shift in the locus of carbonate platform deposition. The sites to be drilled lie along a single strike line on a single structural element. Thermal subsidence of the platform should have affected all sites equally, enabling an accurate measure of the amplitude of the sea-level fall.

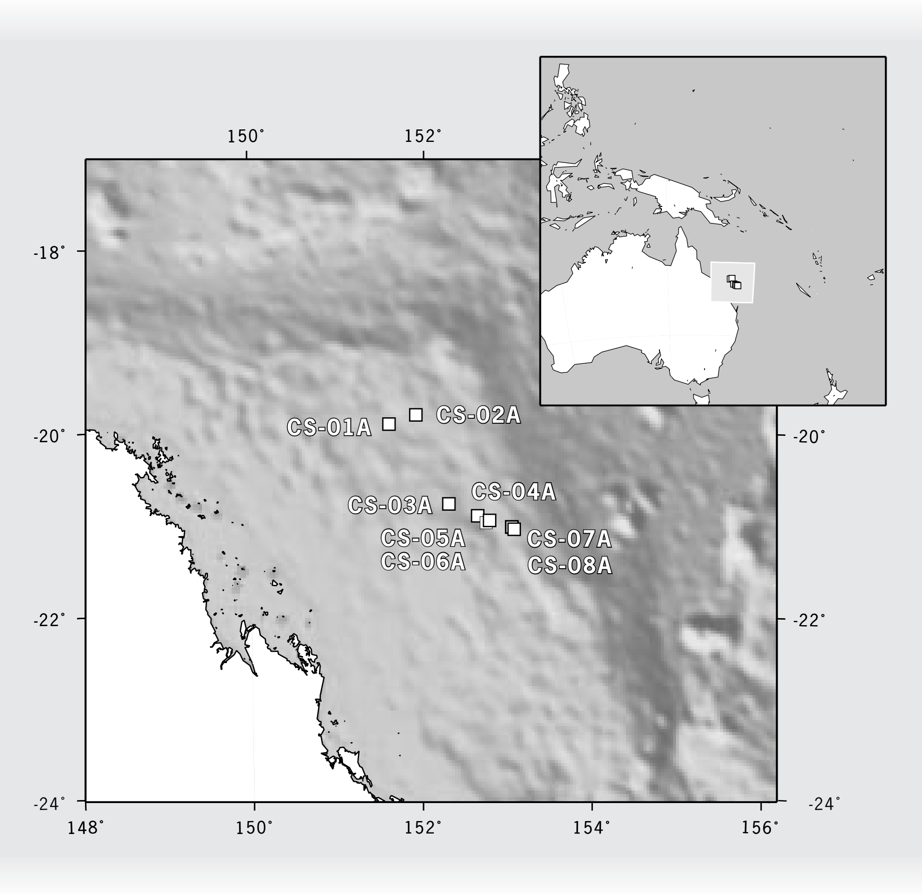
In addition to the N12–N14 sea-level fall, the Marion Plateau also has an excellent overall Miocene sea level record including a complete third order event stratigraphy between 30 and 4 Ma.

Drilling and Logging Plans

Water depths for the sites vary between 314 and 431 m, and penetrations to basement are 340–570 mbsf. All holes will be wireline-logged. Operations will be conducted under ODP's shallow water guidelines. The sites lie near the Great Barrier Reef in an environmentally sensitive area. Recovery of unconsolidated sand and reef debris may result in low core recovery.

The success of Leg 194 depends on the ability to correlate well between all of the sites and to map the facies into a common, well-dated stratigraphy integrated with the seismic data. To accomplish this, standard logs (gamma, density, resistivity, porosity) combined with detailed sonic and WST logs will be required. High-resolution log data, in particular FMS images and the third party high-resolution gamma tool (if available), will be useful for cyclo-stratigraphic analysis of the margin sequences.

FIGURE 3 *Leg 194: Marion Plateau*



LEG 195/1: SOUTH CHAMORRO SEAMOUNT

PROPOSAL NO: 505

Full Title: Mariana Convergent Margin: Geochemical, Tectonic, and Biological Processes in Intermediate Depths of an Active Subduction Factory

Proponents: P. Fryer, M. Mottl, G. Moore, C. Todd, L. Becker, G. Wheat, A. Fisher, R. Stern, J. Hawkins, K. Brown, J. Martin, S. Phipps, and C. Moyer

The original proposal 505 Full 3 was intended to drill three serpentine mud volcanoes on the forearc, the region between the trench and the volcanic arc, of the Mariana system, a non-accretionary convergent plate margin in the western Pacific. The purpose of the proposed drilling is

1. to develop an understanding of the processes of mass transporting subduction zones and forearcs of non-accretionary convergent margins with a view toward understanding geochemical cycling in these settings,
2. to ascertain variability of slab-related fluids within the forearc environment as a means of tracing dehydration , decarbonation and water/rock reactions in the subduction and supra-subduction zone environments,
3. to study the metamorphic and tectonic history of non-accretionary forearc regions,
4. to gain a better understanding of physical properties of the subduction zone as controls over dehydration reactions and seismicity and
5. to investigate biological activity associated with deep-derived subduction zone material.

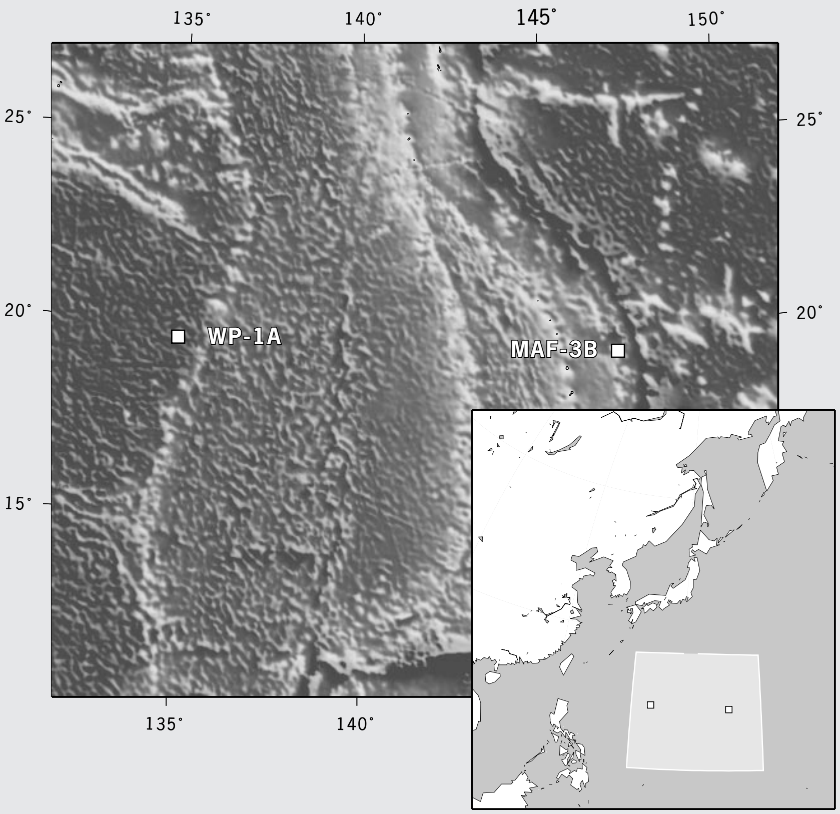
Although the science is regarded as excellent, addressing a new aspect of the ODP Long Range Plan concerning material fluxes into and from the interior of the earth, the full program was not scheduled because of a lack of site survey information that would ensure the most effective siting. The proponents then proposed drilling at South Chamorro Seamount, where adequate data, in the form of a side-scan sonar survey will exist in the near future.

Drilling this single hole will achieve all of the objectives of proposal 505 Full 3 with the exception of the investigation of variations in slab-derived fluids with depth to slab. This is because South Chamorro Seamount is in a position approximately equivalent, in terms of distance from the trench, as is Conical Seamount, which was drilled on Leg 125. South Chamorro Seamount has the advantage that it is the site from which we have the strongest indication of the presence of large volumes of blue sodic amphiboles that indicate the muds derive from a region of high-pressure low-temperature metamorphism. It also has the advantage that it is located in the southern, most seismically active, part of the Mariana Arc, and hence is well suited to gaining a better understanding of physical properties of the subduction zone related to dehydration reactions and seismicity. Finally, it is the only one of the originally proposed sites in which it is feasible to investigate biological activity associated with deep-derived subduction zone material.

Drilling and Logging Plans

See LEG 195/2

FIGURE 4 *Leg 195/1: South Camorro Seamount*



LEG 195/2: WP SEISMIC NETWORK
PROPOSAL NO: 431

Full Title: Western Pacific Seismic Network

Proponents: K. Suyehiro, H. Fujimoto, T. Kanazawa, J. Kasahara, Y. Fukao, H. Momma, K. Fujioka, T. Matsumoto, H. Kinoshita, S. Sacks and A. Linde

Plate consuming boundaries are concentrated in the Western Pacific area. It is the most suitable region to study the dynamics of plates undergoing subduction, formation and evolution of island arcs and marginal seas, and the relation of these processes to mantle convection. Over the past years a dense regional geophysical network has been established on the land areas. The network in Japan is one of the densest sets of seismic stations in the world, and good coverage extends throughout eastern Asia. However, the land network needs to be supplemented by stations that can provide data from the mid-ocean floor and from the plate subduction boundary. Development of the ocean seismic network is proceeding through ODP boreholes that are outfitted as long-term geophysical observatories. They provide unique seismic data hitherto unavailable. These data will help to quantify the dynamics of subducting plates from their entry into the mantle to their destruction in the deep mantle.

The proposal for the Western Pacific Geophysical Network called for two sites which had been endorsed by the International Ocean Network (ION). The long-term ocean seismic observatory network was included as an initiative in the ODP Long Range Plan (LRP) as a contribution to the Global Seismic Network. The GSN has been successful in resolving the earth's interior from land and island based seismic installations, but still lacks coverage in large areas of the oceans. Two Western Pacific sites are designed to aid study of earthquake dynamics, the dynamics of the subducting plates, the formation of island arcs, and the relation of these processes to mantle convection.

The first of the sites is scheduled for drilling during FY 00 (Leg) and the second (WP-IA) is scheduled here for drilling in 2001. Long-term seismic observatories will be installed at both sites. Both observatories are to be connected to nearby telecommunications cables in the future.

Drilling and Logging Plans

Leg 195 consists of two science programs: one devoted to coring and setting a long-term observatory at the summit of South Chamorro Seamount and the second to coring and casing a hole on the Philippine Sea abyssal seafloor coupled with installation of a broadband seismometer for a long-term borehole observatory.

The South Chamorro Seamount site is positioned in a water depth of 2930 m. A pilot hole will be XCB/MDCB cored to a maximum of 400 mbsf to characterize the composition of the fluids and metamorphosed rock material. A second hole will be equipped with a reentry cone, casing, and the CORK instrumentation to a maximum depth of 400 mbsf. The CORK instrumentation package will consist of a thermistor string and an osmotic sampler.

The ION site is located in a water depth of 5640 m. Two pilot holes will be completed to characterize the site prior to drilling a third hole for setting a reentry cone and casing string and installing the ION intrumentation string installed. The overall strategy is to penetrate 100 m into basalt basement. Actual penetration will be decided during operations, based on information provided by the cores and the wireline logs, drilling data, and time available. The instrument package for Leg 195 consists of two seismometers.

LEG 196: NANKAI TROUGH, LWD & A-CORKS
PROPOSAL: 517

Full Title: Nankai Trough LWD/Advanced CORK Experiments

Proponents: K. Becker, E. Davis, G. Moore, M. Kinoshita, T. Gamo, A. Taira, H. Tokuyama, K. Suyehiro, M. Yamano, E. Kikawa, T. Matsumoto, H. Kinoshita

This is the second leg of the Nankai Trough program designed to investigate hydrogeologic, diagenetic, and tectonic processes in an accretionary prism. Nankai Trough is a classic example of a convergent margin where a thick section of clastic sediment is being accreted. It is known for its structural simplicity, shown in excellent high-resolution seismic profiles. Leg 196 will be devoted principally to LWD (Logging-While-Drilling) and installation of Advanced CORK hydrologic observatories, at sites either scheduled to be cored during ODP Leg 190 in 2000 or cored previously during Leg 131. The observations resulting from this leg and later gleaned from the CORK observatories will help develop rigorous mechanical, geochemical and hydrologic models of fluid-related diagenetic and tectonic processes in rapidly deforming accretionary wedges.

New features of Advanced CORKs include a multi-level isolation/monitoring/testing capability essential to understanding the fluid flow regime at the Nankai accretionary prism. They also include provision for future deployment of instrument strings by wireline vehicle.

Drilling and Logging Plans

Three Sites, located along a transect in the eastern Nankai Trough will be studied and instrumented on Leg 196. The LWD program will determine the physical properties and structure at each site. The A-CORK seals are configured to determine elastic and hydrologic parame-

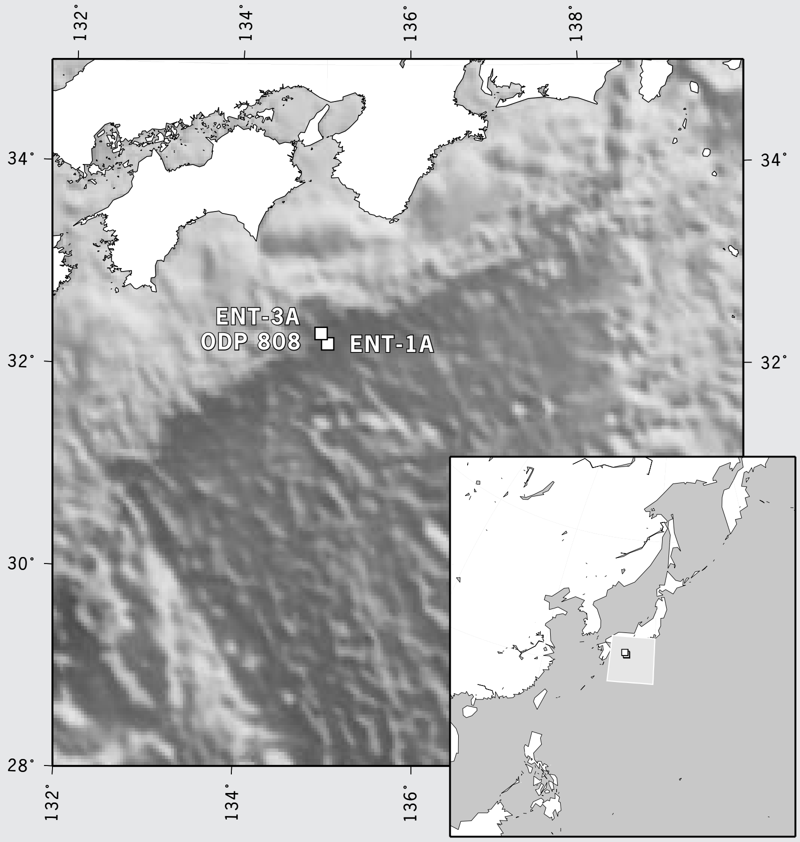


FIGURE 5 *Leg 196: Nankai Trough, LWD & A-Corks*

ters and to monitor fluid flow processes in the frontal and proto-thrust zones, the decollement and proto-decollment, the sediments above and below the decollement, and the upper oceanic basement of the downgoing plate. Leg 196 will also study a comparative site in the western proto-thrust region.

Following the Leg, a wireline reentry system will be used to download pressure data from the A-CORKs. The reentry system will then install thermistor-tiltmeter-seismometer instrument strings in the A-CORKs, geochemical monitoring systems on the fluid sampling ports, and set up coordinated seafloor monitoring systems. Ultimately, links to fiber-optic cables on the seafloor may extend the lifetimes of these experiments from several years to decades. With such long-term monitoring of multiple parameters at multiple sites, it will be possible to study strain and changes in the hydrology and mechanical properties of the Nankai accretionary prism through a significant part of the subduction thrust earthquake cycle.

State-of-the-art LWD tools are requested and should be used to measure high-quality porosity and density (ADN) logs from the seafloor to TD, to measure resistivity images, similar to FMS images, and gamma radiation at the bit (RAB). As demonstrated by the results from Leg 156, 170, and 171A, the information acquired from these LWD logs will also allow in-situ pore pressures within the accretionary prism to be inferred.

The Resistivity-at-the-bit tool will acquire azimuthal resistivity images of the borehole to detect resistivity heterogeneity and borehole structures (fractures and stratigraphic contacts - like FMS, but lower resolution), total gamma-ray measurements for lithology estimation, and four depths of investigation.

The Azimuthal Density Neutron (ADN) tool will provide borehole-compensated formation density, neutron porosity, and photoelectric factor measurements in four quadrants around the borehole.

LEG 197: HAWAIIAN HOTSPOT & EMPEROR SEAMOUNTS PROPOSAL NO: 523

Full Title: Motion of the Hawaiian Hotspot During Formation of the Emperor Seamounts: a Paleomagnetic Test

Proponents: J. A. Tarduno, R. D. Cottrell and B. Steinberger

Assuming a fixed-hotspot frame of reference, the bend in the Hawaiian-Emperor chain has often been cited as the best example of a change in plate motion. Alternatively, the bend might be a record of the motion of the Hawaiian hotspot relative to the Pacific lithosphere. Four lines of inquiry support the latter view:

1. global plate motions predicted using relative plate motion data;
2. spreading rate data from the North Pacific basin;
3. mantle flow modeling utilizing geoid and seismic tomographic constraints; and
4. new paleomagnetic data from the Emperor chain.

The best available paleomagnetic data suggest that Pacific hotspots may have moved at rates comparable to those of lithospheric plates in Late Cretaceous to early Tertiary times (81–43 Ma). If correct, this requires a major change in how we view mantle dynamics and the history of plate motions.

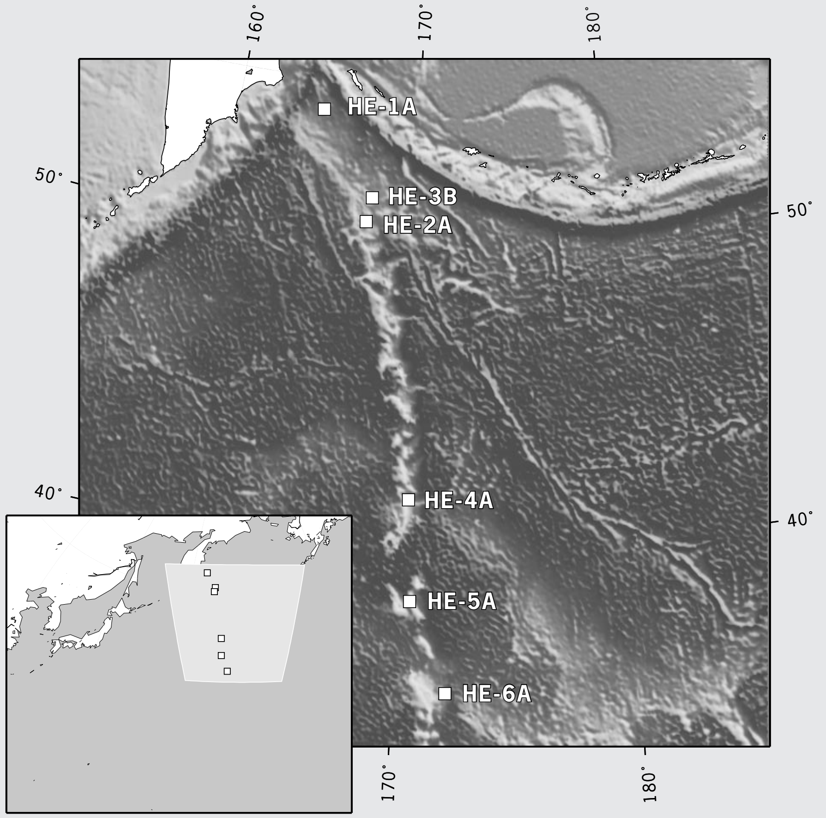
Leg 197 will test the hypothesis of southward motion of the Hawaiian hotspot by drilling 5 seamounts of the Emperor trend. The principal objectives are to obtain moderate penetrations of the basement (150-250 m) to obtain samples suitable for radiometric age and paleomagnetic paleolatitude determinations. A comparison of these dated paleolatitude values versus fixed- and moving-hotspot predictions form the basis of the proposed test.

This sampling strategy will also address important geomagnetic questions which require paleomagnetic data from the Pacific plate, including the history of the time-average field and its paleointensity. The data will place fundamental constraints on the Late Cretaceous to early Tertiary motion of the Pacific plate. An improved picture of this motion history is needed if proxy climatic data from previous and future drill sites are to be used to define past latitudinal gradients.

Drilling and Logging Plans

Leg 197 will drill five seamounts in the Emperor chain in 1300-3200 m water depth. No sediment cores are planned because of time limitations. All holes will be RCB cored 150 m into basement and use standard logs. The final drilling strategy has not yet been completed.

FIGURE 6 *Leg 197: Hawaiian Hotspots and Emperor Seamounts*



LEG 198: SHATSKY RISE
PROPOSAL NO: 534

Full Title: Exploring Extreme Warmth in the Cretaceous and Paleogene: A Depth Transect on Shatsky Rise, Central Pacific

Proponents: T. J. Bralower and J. C. Zachos

Shatsky Rise is a medium-sized Large Igneous Province in the west-central Pacific which was emplaced at the end of the Jurassic in the central Pacific in equatorial latitudes. Sediments on Shatsky Rise include a sequence of the Paleogene and Cretaceous at relatively shallow burial depths. The sediments of these ages can be reached readily through drilling, and the fossil faunal and floral assemblages are known to be sufficiently well-preserved to allow reliable stable isotope and trace element analyses. The mid Cretaceous (Barremian-Turonian) and early Paleogene were characterized by some of the most equable climates of the Phanerozoic, and are among the best-known ancient "greenhouse" climate intervals. In addition, these intervals contain some of the most abrupt and transient climatic changes in the geologic record, including the Late Paleocene Thermal Maximum (LPTM), the mid Maastrichtian event when the sources of deep water appear to have shifted from low to high latitudes, and the early Aptian Oceanic Anoxic Event. These transitions involved dramatic changes in oceanic circulation, geochemical cycling and marine biota. The proposed drilling plan is designed to address the long-term climatic transition into and out of "greenhouse" climate as well as the abrupt climatic events.

Combined with the results of previous and future legs the proposed drilling will help determine:

1. the frequency, amplitude, and forcing of warm climate intervals,

2. the latitudinal thermal gradients in discreet mid Cretaceous to Paleogene time slices, and
3. changes in the sources of deep water and vertical ocean structure through time.

Shatsky Rise has been the target of three Deep Sea Drilling Legs, but most sites were spot- cored or plagued by low recovery, especially in the Cretaceous where chert provided a significant problem. Previous drilling was centered on the southern part of Shatsky Rise. The proposed drilling leg includes sites in the central and northern part of Shatsky Rise, where the stratigraphy is less well known but where the reflectors are only poorly developed, indicating that chert layers are thinner or absent.

The major objectives are:

1. to test hypotheses proposed for the Late Paleocene Thermal Maximum: that it resulted either from massive outgassing associated with rifted margin volcanism or from sudden dissociation of methane clathrates on the continental shelves and slopes, or both;
2. to assess regional/global circulation changes during the late Paleocene-early Eocene;
3. to enhance knowledge of how global ocean chemistry or circulation evolved in response to high-latitude cooling and glaciation during the Eocene to Oligocene transition from a "greenhouse" to an "ice-house" world;
4. to better understand the long-term cooling history of the Cretaceous;
5. to investigate the "cool tropics paradox" to determine whether the apparent cool tropical temperatures of the Maastrichtian are real or the result of diagenetic alteration;
6. to correlate early and mid-Cretaceous faunal diversification events from the Atlantic with as yet undocumented events in the Pacific;
7. to document the subsidence history of Shatsky Rise;
8. to determine a maximum age for Shatsky Rise.

Drilling and Logging Plans

The drilling program involves a depth transect designed to characterize changes in the nature of surface and deep waters through time, including vertical gradients of temperature, oxygenation and corrosiveness with respect to carbonate. The proposed drilling program includes a total of five sites, SHAT-1, -2, -3, -4, and -5 in 2450–3900 m water with penetrations between 250-780 m of sediment. Sites will be cored with APC/XCB/RCB depending on the nature of the sediment and desired depth of penetration. Standard logging will occur as necessary. Note that the final drilling strategy has not yet been completed.

FIGURE 7 *Leg 198: Shatsky Rise*

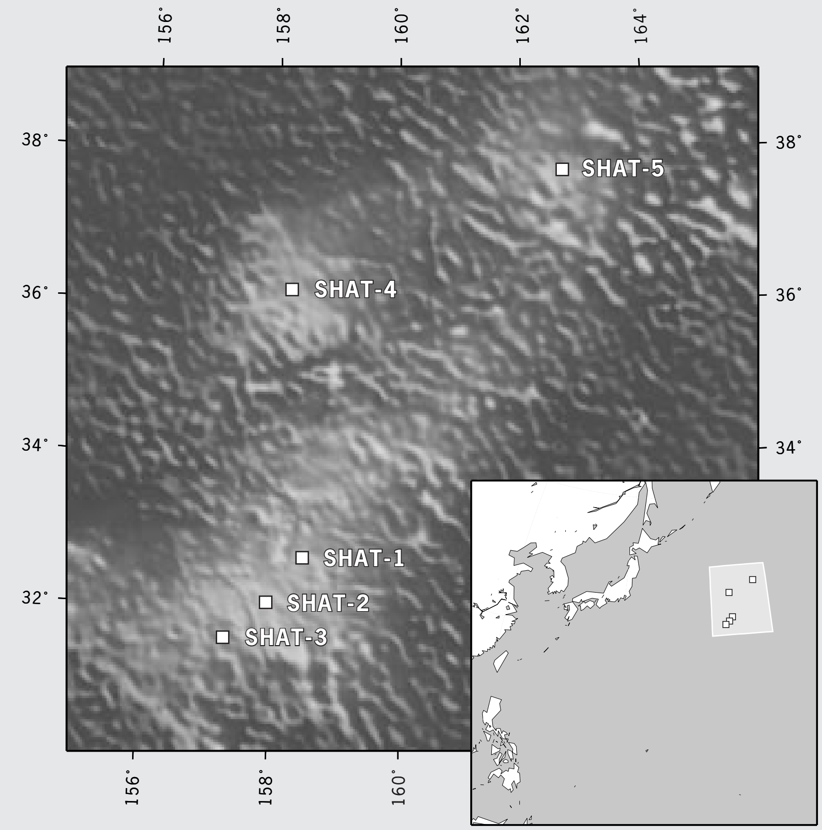
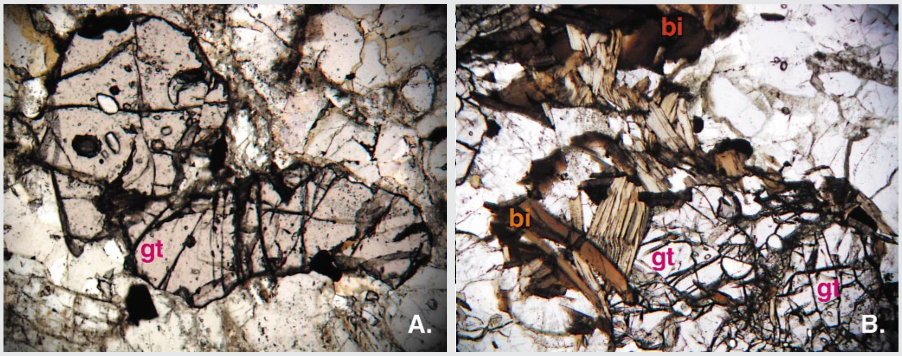
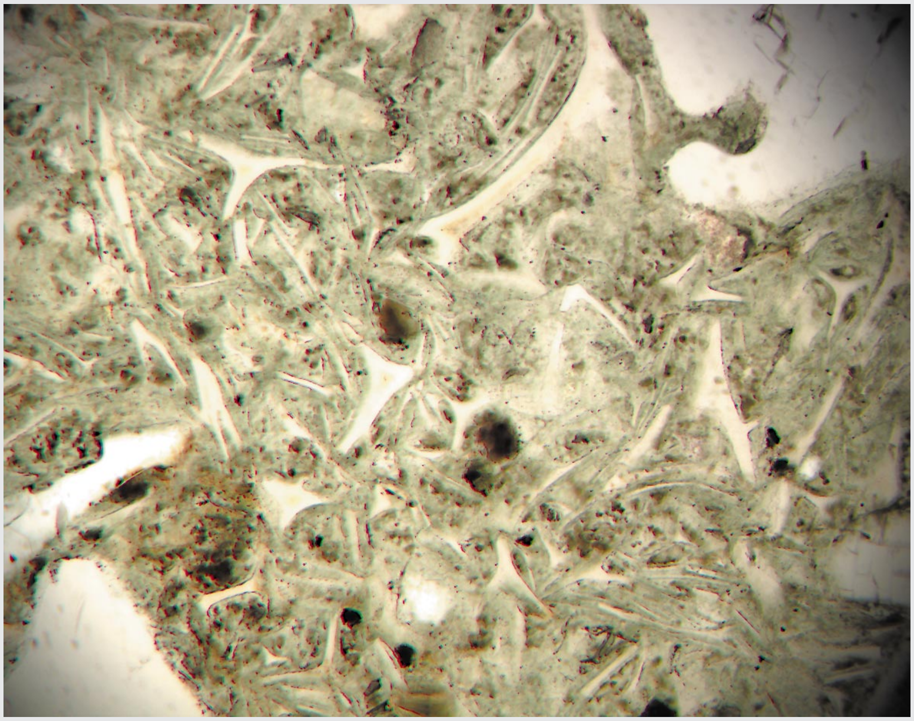


FIGURE 6 *Photomicrograph of garnet gneiss clasts in basement rocks at Site 1137 (Elan Bank).*
A. Poikiloblastic (gt) in a conglomerate clast. Field of view is 1.4 mm, plane-polarized light.
B. Porphyroblastic garnet (gt) and biotite (bi) in a clast contained in a crystal-vitric tuff. Field of view is 2.75 mm, plane-polarized light.



Development of an Intraoceanic Large Igneous Province: The Kerguelen Plateau and Broken Ridge, Southern Indian Ocean.

FIGURE 5 *Photomicrograph of crystal-vitric tuff at Site 1137 showing well-preserved cuspate and tricuspate glass shards, which form during explosive fragmentation of vesiculating magma. Field of view is 1.40 mm.*



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