OCEAN DRILLING PROGRAM

LEG 135 PRELIMINARY REPORT

LAU BASIN

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ABSTRACT

Leg 135 of the Ocean Drilling Program drilled and cored eight sites across the Lau Basin and adjacent Tonga Ridge to study the geological evolution of a backarc basin and adjacent oceanic arc and forearc. Six sites (Sites 834, 835, 836, 837, 838, and 839) were drilled within the Lau Basin, each within smaller and narrower (<10 km) north-south fault basins and collectively representing a broad east-west transect. Two other sites were drilled on the Tonga Ridge, in the forearc of the Tofua Arc. Site 840 lies on the crest of the Tonga Ridge, a shallow, uplifted carbonate platform overlying older volcanic basement, while Site 841 lies on the arc-trench slope in 4800 m of water. Results from this cruise will provide crucial data toward determining the geological history of the Lau Basin-Tofua/Tonga Arc oceanic-arc system as well as provide a heretofore uncollected observational base for the understanding of oceanic-arc and backarc spreading systems in general.

The principal results of Leg 135 were quite different than anticipated, with two results being of particular significance. First, the Lau Basin is much older than expected (>5.6 Ma instead of 2.5-3 Ma), with seafloor-type spreading having occurred in the backarc only in the last 1 to 2 Ma or so. Prior to this, extension occurred by a combination of repeated extensional rifting ("basin and range") with associated local volcanism, with new crust created, if at all, only within the north-trending fault basins. No consistent variations in the chemistry of the Lau Basin volcanic products were noted either within time or space; the igneous basement rocks collected represent basalts, basaltic andesites, and andesites with affinities to both oceanic-arc and mid-ocean-ridge lavas, and indicate complex heterogeneity of the mantle source. Volcaniclastic sediments collected in the cores also show that volcanism of arc affinity may have occurred throughout much of the Lau Basin during extension, rather than being confined to a narrowly defined arc.

The second principal result was the coring of dacitic tuffs, welded tuffs, and lavas of upper Eocene or older age at the base of Hole 841B. These are in fault contact with overlying upper Eocene to lower Oligocene carbonates and a thick sequence of Miocene proximal and distal volcaniclastic sediments. These subaerially erupted dacitic igneous rocks have subsided more than 6 km since their formation, representing profound tectonic foundering. Similar rhyolites of Late Cretaceous age were cored at DSDP Site 207 on the Lord Howe Rise to the west of the Lau Basin; reconstruction of pre-Eocene plate geometry allows speculation for a common source of the silicic volcanic rocks at both sites.

INTRODUCTION

The objective of Leg 135 was to deduce the geologic history of the Lau Basin and the adjoining Tofua/Tonga Arc in the context of a dynamic volcanic-arc system. The results are crucial for a thorough understanding of the evolution of this arc and backarc system, and are also important for gaining a better understanding of the geologic processes that form new oceanic crust at convergent plate margins. In addition to adding to our knowledge of Lau Basin-Tonga Arc and forearc geology, a major goal was to assess the links between backarc spreading, island-arc volcanism, and subduction. The leg addressed the temporal relationships between arc volcanism, subduction processes (e.g. accretion vs. non-accretion), and backarc extension and compression. The Lau Basin studies will complement parallel studies of the Mariana Arc-Trough, Bonin Arc, and New Hebrides

Arc areas (Ocean Drilling Program Legs 125, 126, and 134); collectively the results should help to improve our models for backarc-basin evolution.

The Lau Basin comprises the region of lithospheric extension between the Lau Ridge and the Tonga Trench. The rate of opening probably varies with latitude; near 18°S, where the magnetic data are better constrained, the spreading rate may be 5-6 cm/yr in an east-west direction. It is clear that crustal generation by seafloor spreading has operated in the basin only since the Pleistocene. It is also well established that the modern volcanic arc (Tofua Arc) has been active since at least early to mid-Pleistocene time (~1 Ma), and that parts of the forearc basement include pre-upper Eocene gabbro and basaltic rocks as well as younger arc-volcanic rocks. The age of initial volcanism of the Tofua Arc has not been determined, although some have proposed that it represents a direct continuation of Lau Ridge volcanism, which lasted until about 3 Ma. Alternatively, the data may be interpreted as indicating a hiatus in arc volcanism that resulted in the modern (Tofua Arc) volcanoes being new volcanic-plutonic systems imprinted on what was formerly the forearc region of the Lau Ridge.

The Lau Basin appears to be spreading actively and has a well-defined axial ridge system near 176°30'W between latitudes 17°S and 22°S (Figs. 1 and 2). The axial ridge is formed of relatively unfractionated olivine tholeiite basalt, but more fractionated and Fe-Ti-enriched lavas are found near a propagating rift tip at 19°30'S. The extreme southern end of this axial ridge (Valu Fa Ridge) differs markedly from the rest of the basin in being dominated by rocks of andesitic to dacitic composition. This part of the axial ridge has abundant hydrothermal vents, and seismic data have been interpreted as indicating the presence of a magma chamber. The basin is much more complex north of 17°S and east of 178°W: here there are abundant seamounts, including the volcanically active island Niua Fo'ou; a nascent triple junction having one limb that intersects the Tofua Arc and a western limb that projects toward Niua Fo'ou; and a well-defined ridge which presently marks the trend of a zone of right-lateral strike-slip as defined by first-motion studies of shallow seismic activity (Peggy Ridge).

The Lau Basin presents a number of important problems concerning the tectonic/petrologic evolution of the lithosphere above the plate-convergence system of the Tonga Trench subduction zone. In addition to giving insights into how backarc basins evolve, it also offers an opportunity to understand broader problems of crustal evolution that pertain to other intra-oceanic trench-forearc-backarc systems.

REGIONAL SETTING OF LAU BASIN

The Lau Basin separates the Lau Ridge (remnant arc) from the Tonga Ridge. The Tonga Ridge comprises two parallel chains of islands and shoals that cap the older seafloor on the inboard side of the Tonga Trench. The western chain includes active volcanic islands of the Tofua Arc which have erupted basaltic andesite to low-K rhyolitic magmas (Ewart and Bryan, 1972; Ewart et al., 1973). The eastern chain consists of tilted blocks formed of upper Eocene to Pleistocene limestone with interbedded tuffs and volcaniclastic beds which overlie an igneous basement comprising mafic plutonic rocks, basaltic to andesitic pillow lavas, dikes, and aa flows. Ewart and Bryan (1972) proposed that the rocks of 'Eua constitute the upper part of an ophiolite assemblage. The oldest rocks of the region are the Eocene (46 Ma) "crystalline basement" of 'Eua, known from boulders of gabbro, norite, basalt, andesite, dacite, and rhyolite (Cunningham and Anscome, 1985).

The chemistry of these rocks is typical of an island-arc volcanic-plutonic series (Ewart and Bryan, 1972; Cunningham and Anscome, 1985). The lowest outcrops exposed in the 'Eua section are basaltic to andesitic flows and dikes (Hawkins and Falvey, 1985). These are overlain by upper Eocene to lower Oligocene limestone (Cole, 1970), and in turn these are overlain by a series of Miocene to Pliocene volcaniclastic rocks that are interbedded with foraminiferal limestone (Cunningham and Anscome, 1985). Three distinct episodes of Tertiary volcanic activity are recognized on 'Eua by Duncan et al. (1985). The oldest, 40-46 Ma, is measured on the gabbro and basalt beach boulders; basaltic and andesitic flows give ages of 31-33 Ma, and andesitic dikes give 17-19 Ma ages. Paleontologic ages of tuffaceous sediments range from middle Miocene to early Pliocene, i.e., until 3-5 Ma.

The islands of the Lau Ridge display a more complete record of early Tertiary volcanism than is exposed on the uplifted blocks of the Tonga Ridge. The oldest rocks known are the middle to upper Miocene Lau Volcanic Group (6-14 Ma), which are mainly basalt and basaltic andesite but also include andesite, dacite, and rhyolite. This group consists mainly of low- to medium-K arc tholeiitic and calc-alkaline series lavas (Woodhall, 1985; Cole et al., 1985) and is interpreted as representing the early and mature stages of arc evolution. Some of the Oligocene and Miocene rocks of the Tonga Ridge probably are correlative with the Lau Ridge volcanism even though no Oligocene rocks are known from the Lau Ridge. It is likely that the Lau Ridge first became active in Eocene time, based on other occurrences of Eocene volcanic series in the broader Fiji-Tonga area.

Lau Ridge volcanism ended in the late Miocene and was followed by erosion, subsidence, and the growth of coral reefs. Renewed volcanism, forming the Korobasaga Volcanic Group (4-3 Ma), may have been in response to the initial phase of rifting that led to the opening of the Lau Basin (Cole et al., 1985). The Korobasaga Group is formed mainly of submarine tholeiitic basalt but also includes some hornblende andesite. The youngest Lau Ridge volcanism is represented by the Mago Volcanic Group (<2.5 Ma), which includes alkalic olivine basalt and hawaiite. The eruption of these lavas may have been coeval with, or slightly older than, the earliest phases of Lau Basin opening.

An early model (Karig, 1970) proposed that the Lau Ridge arc system split, with the Lau Basin subsequently forming in the rifted area. A consequence of this style of evolution would be that arc volcanism in the Tofua Arc is a direct continuation of Lau Ridge volcanism. The area encompassing the former forearc to the Lau Ridge (except what has been removed by tectonic erosion) has moved eastward relative to the Lau Ridge. A more recent model (Hawkins et al., 1984; Hawkins and Melchior, 1985) proposes that the rifting to form the Lau Basin was initiated in the forearc instead of within the Lau Ridge volcanic arc. In this case, the modern Tofua Arc is a new volcanic system built either on the Lau Ridge forearc or on an older part of the current backarc basin. This model suggests that some fragments of forearc crust may have been left under the western Lau Basin. The presence or extent of this forearc material would depend on how close the rifts formed to the Lau Ridge.

The crust of the Lau Basin is floored mainly by basalt, which has most of the mineralogic, chemical and isotopic characteristics of mid-ocean-ridge basalt (MORB) and includes varieties termed "normal" (N-MORB) and "enriched" (E-MORB). The least altered, least fractionated, basalt glasses of the neo-volcanic zones of the axial ridges generally have this N-MORB signature, with the notable exception that $^{87}Sr/^{86}Sr$ is more radiogenic than N-MORB (e.g., 0.7035 or higher), but otherwise element ratios and abundances are clearly MORB-like, rather than like arc lavas. Rocks and glasses collected from the outer (older) edges of the Lau Basin are variable in composition, and many show "arc-like" characteristics. This suggests that there is an age-dependent magmatic variation from initial arc-like or transitional to arc composition to more MORB-like compositions (Hawkins, 1976; Hawkins and Melchior, 1985; Sinton et al., 1985; Volpe et al., 1988).

The data are interpreted as indicating that the Lau Basin, as well as other backarc basins, have undergone a petrologic evolution from basaltic melts having a strong imprint, or memory, of an arc source (or arc-like melt component) to basalts that have a strong N-MORB signature. In the evolutionary process there are many petrological diversions that may be unique to certain basins, e.g., the formation of extensive eruptions of "high-silica" (56%-62% SiO_2) lavas such as those of the Valu Fa Ridge in the Lau Basin (von Stackelberg et al., 1985; Vallier et al., in press; Nautilau, 1990). A further complexity in the Lau Basin is the development of the northern seamount province, which has an E-MORB or "plume" signature (Poreda, 1985; Volpe et al., 1988). Our interpretation of Lau Basin history from the Leg 135 cores will be guided by these observations.

The Lau Basin and other backarc basins are important geologic features in their own right, but an understanding of their geology has two important implications for understanding crustal evolution. They may offer insight to the earliest stages of the tectonic/petrologic processes that form mid-ocean ridges; the evidence for these stages is usually long since buried by seafloor sediments. A second implication is related to the origin of ophiolites and the ophiolite model for the nature of oceanic lithosphere. There is a growing consensus that many, if not most, ophiolite suites originally formed in arc/backarc settings (e.g., Dewey and Bird, 1971; Hawkins, 1976; Hawkins et al., 1984). A proper understanding of the range in chemistry and petrology of backarc-basin lavas is necessary for evaluating the origin of ophiolite series and their relevance to models for ocean crust formed at mid-ocean-ridge settings.

LEG 135 SITE RESULTS

A total of eight sites were cored during Leg 135 (Fig.1), six in the Lau Basin back-arc region (Sites 834-839), one on the Tongan platform (Site 840), and one in the Tonga fore-arc region on the arc-trench slope (Site 841).

Site 834

Hole 834A: 18°34.058'S 177°51 735'W; water depth, 2692 m
Hole 834B: 18°34 052'S 177°51 737'W; water depth, 2688.6 m

Site 834 is located in the western Lau Basin about 100 km east of the Lau Ridge. The Lau Ridge is the remnant arc of the trench-arc-backarc system related to the convergent plate margin of the Tonga Trench. The site is in a small, north-south-trending basin of about 200 to 400 m relief. Single-channel seismic-reflection data indicate that the basin fill is about 0.17 two-way traveltime; drilling encountered basalt at a depth of 112.5 m.

The main scientific objectives for Site 834 were (1) to sample igneous rocks formed in the first 0.5 Ma of crustal extension of the Lau Basin; (2) to determine the age of the beginning of opening of the basin; and (3) to collect a sedimentary, paleontologic, and paleomagnetic record from the basin fill; and (4) to determine physical and chemical properties of the cores. The site was selected on the assumption that the small basin formed early in the history of crustal extension and that the drill cores would preserve a record of the early magmatic and sedimentary processes. Magnetic data are ambiguous in that various ages had been assigned to the anomaly at this site. The combination of accurate dates for the basal sediments with a detailed magnetic stratigraphy from the cores was expected to resolve this question. The chemistry and petrology of the igneous basement were required in order to understand magma evolution from the arc-like to MORB-like rocks that have been collected in the basin by dredging.

A continuous sediment sequence was recovered at Hole 834A down to 112.5 mbsf. Below this, sediments are intercalated with basaltic layers of varied thickness. These are sills or flows and it is likely that both forms are represented. The interlayered sediment and basalt continue down to 164 mbsf. The sedimentary assemblage consists of clayey nannofossil oozes, turbiditic foraminiferal sands and oozes, clayey nannofossil mixed sediments, and claystones. Many of these units are interbedded with epiclastic vitric ash or, more rarely, pyroclastic airfall tuff layers. The sequence can be divided into four lithologic units, primarily on differences in sediment composition, particularly on the occurrence of vitric ashes and the increasing clay content of the sediment downhole.

Unit I is 42 m thick and is composed predominantly of brown clayey nannofossil oozes with scattered interbeds of turbiditic calcareous sands and oozes. Although three vitric-ash layers are present in the upper 12 m , volcaniclastic material is generally rare in the rest of the unit. Based on paleomagnetic and biostratigraphic data, the age span of Unit I is late Pleistocene to 2.3 Ma.

Unit II extends from 42 to 78 mbsf and is composed of clayey nannofossil mixed sediment interbedded with vitric ash layers. Volcaniclastic sediments--either primary pyroclastic airfall ashes or, much more commonly, epiclastic clastic turbidites--make up 20% of the total bulk of Unit II. Individual ash layers range from 0.02 to 1.20 m in thickness. Paleomagnetic and biostratigraphic data suggest that the age span of Unit II is 2.3 to 3.8 Ma.

Unit III extends from 78 to 112.5 mbsf and is distinguished from Unit II by its increased vitric-ash content. Thick vitric ashes are the dominant lithology. These are interbedded with iron oxy-hydroxide-stained nannofossil clayey mixed sediments and nannofossil clays. The base of Unit III is, as yet, poorly constrained by paleomagnetic or biostratigraphic data, but it is interpreted as early Pliocene in age.

Unit IV is composed primarily of firm or indurated claystones, vitric tuffs, and calcarenites, which are found as thin bands of intercalated sediments within lava flows. These are generally shallow-water to neritic sediments probably deposited close to the time at which the basin first began to open.

Biostratigraphic studies of sediment cores show that sediment Unit I contains abundant well-preserved planktonic foraminifers and calcareous nannofossils ranging in age from middle Pleistocene (N22, Globorotalia crassaformis hessi Subzone; CN14a) to late Pliocene (top of N21; CN12a). Unit II is almost completely restricted to the late Pliocene (Zone N21 to N19/20; CN12a to CN11b), with only the top part of Core 135-834A-9H ranging into early Pliocene sediments; planktonic foraminiferal assemblages are less diverse and not as well preserved as in Unit I. In Unit III preservation continues to deteriorate and assemblages are of low diversity. The age of Unit III is entirely early Pliocene (CN11b to CN11a), being based mainly on calcareous nannofossils due to the poor and patchy distribution of foraminifers. Two zones contained good planktonic foraminiferal faunas indicating Zones 19/20. Within the basalt units were ash beds containing N19/20 planktonic foraminifers and CN11a calcareous nannofossils.

Sedimentation rates show fairly low accumulation rates for the sequence above the basalts, averaging 20 m/m.y. The basalts were accumulated over at least a 2-million-year interval, with accumulation rates of around 110 m/m.y.

Interstitial waters from the sediments showed little variation in composition throughout the sampled section and suggested that the interstitial fluids behaved as an open system. Hydrocarbon analyses of the fluids showed only background levels .

A well-behaved, detailed magnetic polarity record was obtained from the sediments of Hole 834A down to 75 mbsf, revealing all polarity chrons and major subchrons back to about 4.0 Ma. The approximately 320 m of volcanic rocks in Hole 834B, which extend the polarity record further back in time, show a major normal polarity between 165 and 435 mbsf. This is interpreted as the upper normal polarity part of Chron 5 (marine magnetic anomaly 3A), implying a magnetic age of about 5.5 Ma for the bottom of the hole. Cyclical variations in the modified Q-ratio (the ratio of AF - cleaned remanent magnetization to susceptibility) with a period of about 41 Ka in the sediment magnetic record suggest that climatic Milankovitch cycles are present in the sediments.

One of the major objectives for Site 834 was to recover samples of the igneous basement in order to compare its petrology with rocks from the Lau Ridge (arc) and the basaltic rocks exposed on the active ridge axes of the backarc basin. The igneous rocks drilled at Site 834 are from sills or flows intercalated with sediments and a thick section that probably constitutes the igneous "basement." Petrographic information from visual core descriptions and thin-section study were used to define 13 units at the site. Interpretation of major-element data collected by XRF demonstrates similarity to Lau Basin backarc crust rather than to Lau Ridge arc samples. The first igneous rocks were recovered at about 112 mbsf. The samples (Unit 1) are sparsely phyric plagioclase olivine basalt. Aphyric basalt (Unit 2) was recovered at Hole 834B at about 112.5 mbsf. A series of thin flows (Units 3 and 4) was cored in Hole 834A but not at Hole 834B; these are underlain by a distinctive poikilitic textured diabase (Unit 5) also found in both holes and extending from 136 down to about 162 mbsf in Hole 834B. A sedimentary interbed, found at 162 mbsf in Core 135-834B-13R, separates Unit 5 from Unit 6. Unit 5 is highly altered in its upper part and appears to be a single thick cooling unit, possibly a shallow sill. Units 6 through 13 alternate between aphyric, olivine-phyric, plagioclase-phyric,and plagioclase-olivine-phyric. A common and relatively distinctive feature of many of these basalt units is their tendency to have a microvesicular texture, which gives them a noticeable porosity and a "pumiceous" surface appearance under high magnification. In many, several size ranges of vesicles are noted. The abundance of vesicles seems to be consistent with the recognition of shallow-water to neritic faunal assemblages in the sedimentary interbeds. Highly vesicular basalts are common in other parts of the Lau Basin, even on the axial ridges at depths of 2500 m, as well as in other backarc basins. This may be attributed to the high volatile content, mainly water, but also CO_2, that has been measured in these rocks.

However, with a few exceptions, there is little evidence for extensive post-magmatic hydrothermal alteration or mineralization in these or in most backarc-basin basalts. Sulfides appear to be primary and are limited to globules of copper-iron sulfides, some with pyrrhotite intergrowths, in the groundmass. Some vesicles also have copper-iron sulfide encrustations. Rock alteration appears to be either deuteric or normal low-temperature seafloor alteration, and leads to oxidation of the sulfides and palagonitization of the glass.

The age of Units 1 to 9 is well constrained by paleontologic dating of thin sedimentary interbeds. The youngest basalt layers are early Pliocene; the oldest ones for which we have paleontologic dating are late Miocene.

Physical properties of the sediments sampled in Hole 834A generally show little change with depth, with the bulk density averaging 1.53 g/cm^3 and the sonic velocity averaging 1.51 km/s. However, thin turbidite flows show marked increases in both velocity and density, and a slight decrease in bulk density accompanies increased vitric ash content below about 78 mbsf. The basalts sampled in Holes 834A and 834B show marked changes in the bulk density and velocity. Basalts between 112 and 215 mbsf have an average bulk density of 2.7 g/cm^3 and an average velocity of 4.23 km/s. Below 286 mbsf, these values decrease to 2.5 g/cm^3 and 3.92 km/s. The changes in bulk density and velocity are apparently related to the degree of vesicularity, and hence the effective porosity within the basalts.

Site 835
Hole 835A: 18°30.061'S, 177°18.162'W; water depth, 2916.5 m
Hole 835B: 18°30.050'S, 177°18.192'W; water depth, 2916.5 m

Site 835 is located in the west-central Lau Basin, approximately 200 km eastward from the foot of the paleovolcanic arc of the Lau Ridge and about 80 km west of the propagating ridge of the Central Lau spreading center. The site overlies crust of about 3 Ma, according to the most consistent interpretations of magnetic-anomaly patterns. Its regional setting is on the eastern flank of the broad, north-south bathymetric high centered on 18°35'S 177°25'W, which rises from a water depth of around 2700 m in the vicinity of Site 834 to about 1650 m at its summit. The rocks forming the bathymetric high are of unknown composition, but the high may represent the location of an extinct spreading ridge, abandoned after arcward migration or jump of the backarc spreading axis. The principal objectives of the site were to assess the age and the chemistry of the basement rocks and to determine their petrogenetic relationship to those recovered at Site 834; to sample the overlying sedimentary sequence to review variations in carbonate, clay and volcaniclastic components and their stratigraphic relationships to marker units identified at Site 834; and to identify the tectonic setting of the site in terms of models of backarc ridge relocation by ridge jump, ridge migration, or asymmetric spreading.

The sedimentary sequence recovered at Site 835 consists of 155 m of clayey nannofossil oozes, mud-clast conglomerates, turbiditic foraminiferal sands and oozes, and clayey nannofossil mixed sediments. Many of these units are interbedded with epiclastic and volcanic silt layers. These epiclastic layers are much more common below 130 mbsf. The sediments of Site 835 are divided lithologically into clayey nannofossil ooze (Unit I) and volcanic sand and silt (Unit II). Calcareous nannofossils are abundant and well preserved throughout sediments of all cores, but planktonic foraminiferal assemblages are less diverse and poorly preserved in Cores 135-835A-3H and -4H of Unit I and the lower part of Unit II. The sediments of this site range from middle Pleistocene to late Pliocene in age. The middle Pleistocene fauna occurs between Cores 135-835A-1H and 135-835A-3H, and the boundary of the middle /lower Pleistocene is thought to be at the base of Core 135-835A-3H. The Pleistocene/Pliocene boundary (base of nannofossil Zone CN14a of Okada and Bukry, 1980) is within Core 135-835A-9H. However, upper Pliocene calcareous nannofossils, ranging from Zones CN12a to CN13a, were found from the lower part of Core 135-835A-6H to the upper part of Core 135-835A-8H. This section is interpreted as being allochthonous, emplaced as a slump block or series of slump blocks into the basin during the early Pleistocene. The sediments just above the basaltic basement contain late Pliocene fauna and flora, indicating Zone CN12a of Okada and Bukry (1980) and Zone N21 of Blow (1969).

We believe that the lithostratigraphy of Site 835 can be correlated on sedimentological criteria with that of Site 834, with 130 mbsf marking the boundary between Units I and II, also described at Site 834. However, Unit I at Site 835 is much thicker than at Site 834. At Site 835, it contains a significant proportion of resedimented material, including mud-clast conglomerates several meters thick that may possibly be debris-flow deposits. These are commonly overlain by thick turbidite deposits. Unit I at Site 835 also contains several more ashy horizons than the corresponding unit at Site 834.

The magnetostratigraphic record of the sediments of Hole 835A shows a complicated pattern of reversals which cannot be interpreted as a simple time sequence. Parts of the sequence appear to carry magnetic overprints, are tectonically or sedimentologically disturbed, and give scattered or abnormal remnant directions. Combining biostratigraphic information with the polarity record, it is possible to obtain a coherent stratigraphic interpretation, which suggests that the topmost 55 m of Hole 835A reaches back into the Jaramillo Subchron (ca. 0.95 Ma), overlying at least two major slumps or allochthonous units showing truncated reversal sequences of parts of the Matuyama and Gauss polarity chrons. These allochthonous sequences in turn discordantly overlie the lowermost 84 m (64-153 mbsf) of the sequence, which covers the interval between the Jaramillo and Gauss polarity chrons, including the Mammoth Subchron (ca. 3.2 Ma).

Inorganic-chemistry data from Site 835 were remarkably similar to those for Site 834, in that there was little change in the interstitial-water chemistry throughout the section. This observation suggests that rapid seawater circulation in the sedimentary column is occurring here. Only background levels of hydrocarbons wre detected throughout the section. A positive gas pressure was observed in Sections 135-835A-9H-5 and -6 at the surface, but was not caused by hydrocarbons. The identity of the gas is unknown\ but is likely carbon dioxide or air.

Sparsely to highly phyric, fresh to moderately altered olivine-clinopyroxene-plagioclase basalts were recovered from below 154.5 mbsf at Site 835. The basalts are highly variable with respect to grain size, degree of vesicularity, and overall texture, but there are enough mineralogical similarities to warrant the classification as a single unit. Porphyritic glassy pillow margins and diabasic fragments were recovered, with no clear relationship to depth in the core. Changes between these textural types are often gradational. The relative proportions of the silicate phases vary throughout the unit, but plagioclase and clinopyroxene dominate. The rocks are generally highly vesicular, except for the 2-3 cm adjacent to glassy margins. Many parts of the unit appear to have a fine-scale, high porosity due to the abundance of microvesicles in the groundmass. Large (several cm), dark, globular regions are filled with very highly vesicular (70%-80%), quenched-textured basalt. These features are similar to those seen in many of the units at Site 834 and in rocks dredged elsewhere in the Lau Basin, suggesting that they may be a common feature in Lau Basin basalts.

The physical properties of the sediments drilled at Site 835 show little change with depth or lithology, although slight changes in velocity and shear strength appear to be correlated with the base and top of the slumped Pliocene section. *P*-wave shear velocities within the basalts average 4.6 km/s, which is slightly higher than the uppermost basalts sampled at Site 834. The geothermal gradient, established by five temperature measurements in the sediments, is extremely low for young crust (about 15°C/km), as compared to the 50°C/km gradient measured at Site 834. The low geothermal gradient and the minor change in physical properties with depth indicate that rapid fluid circulation through the sedimentary section may be dissipating heat derived from the young backarc crust.

Downhole-logging measurements using the induction, sonic, and density tools at Site 835 readily distinguished sediments from igneous basement. Sedimentary interbeds between flows showed low resistivity, bulk density and sonic velocity, and corresponding high-porosity signatures. Logs provided strong evidence for the presence of sediment interbeds in areas of low recovery, particularly unit boundaries. The boundary between lithological Units II and III was also tentatively recognized using a combination of chemical parameters on the unprocessed geochemical data. FMS records processed on board ship supported identification of variations in volcaniclastic input in the sediment units, and aided structural interpretations for the basement section.

Site 836

Hole 836A: 20°08.494'S, 176°30.008'W; water depth, 2455.4 m
Hole 836B: 20°08.505'S, 176°30.011'W; water depth, 2457.7 m

Site 836 is located in the western Lau Basin about 220 km east of the Lau Ridge and about 48 km west of the East Lau spreading center. The Lau Ridge is the remnant arc of the trench-arc-backarc system related to the convergent plate margin of the Tonga Trench. The East Lau spreading center is the present locus of crustal generation due to seafloor-spreading processes in the Lau Basin. Site 836 is in a small, elongated, oval-shaped basin for which we use the informal name Basin 836 in this discussion. The basin trends north-northeast (020°) and is about 20 km long and about 5 km wide in a north-northwest direction at the 2400 m isobath. Basin 836 is one of a number of linear depressions bounded on the west and east by discontinuous ridges that we interpret as horsts separating grabens and half-grabens, although we lack data to delineate faults that may control their form. The ridge on the west side of Basin 836 has an irregular crest line with several small peaks rising to less than 1900 m. The ridge on the east side rises to less than 1500 m. It has a northwesterly trend and appears to be part of an en-echelon ridge system. The maximum depth of Basin 836 is in a narrow elongated area near the center that is greater than 2500 m.

Site surveys provided seismic and bathymetric data to help select the drill site, but the seismic reflection data proved difficult to interpret. Our interpretation of these records is that the data may show a thin sediment cover or indicate scatter from an exposed or scoured basement. Unlike the other sites in the western Lau Basin, Site 836 showed little or no seismic layering that could be assigned to either seismic units A or B. Magnetic anomaly data in the area have also proved difficult to interpret, and ages ranging from about 2 to about 1 Ma have been inferred for the area near Basin 836. Site 836 was selected as a likely place to sample crust that had formed shortly after a postulated ridge jump or initiation of a new ridge at the present location of the East Lau spreading center.

The sedimentary sequence at Site 836 was sampled only through the mid-Pleistocene to 20.8 mbsf. The sequence is distinguished by the abundance of volcaniclastic material at all depths but in particular in the deeper levels of the core from about 12 mbsf downward. The uppermost 12 m comprises hemipelagic deposits, mostly dark brown to brown clayey nannofossil ooze interbedded with volcaniclastic sediments. They may contain up to 25% (volume) interspersed glass shards and are commonly mottled by bioturbation. Rapid deposition of volcaniclastics that make up as much as 50% of the lower half of the hole, with individual layers as thick as 1 m, started soon after the end of volcanism that formed the igneous basement, at perhaps 50 Ka. The volcanic-derived sediments came from a basaltic andesite source (55% to 56% SiO_2) as shown by shipboard chemical analyses by X-ray fluorescence and refractive index studies. Many of the glass shards are medium brown with blocky to angular shapes and low to intermediate vesicularity. They are interpreted as indicating derivation from spalling of glassy rinds of active pillowed flows or sheet flows or both to form hyaloclastites. It is likely that the source of the volcanic detritus was less than 10 km from the site of deposition. There was negligible input of turbidites carrying silicic shards.

The biostratigraphic data and paleomagnetic data indicate that only the middle and late parts of the Pleistocene, all within the Brunhes normal polarity chron (0.73 Ma), are present in the Site 836 sediments. The calcareous nannofossil flora indicate zones CN15 (e.g., *Emiliania huxleyi*), CN14a (e.g., *Gephyrocapsa oceanica*), and CN14b (e.g., *Emiliania ovata*). The planktonic foraminifers are abundant and well preserved; zones N23 (e.g., *Pulleniatina finalis*) and N22 (e.g., *Bolliella praeadamsi*) and *Globorotalia* (*Truncorotalia*) *crassaformis hessi*) are present. The sediment sequence consists of calcareous oozes with interbedded coarse volcanic-ash beds; the amount of volcanic material greatly increases downcore, beginning with Core 135-836A-3H. The calcareous planktonic assemblages in the Pleistocene oozes and volcanic ash sands are very well preserved, but diversity and preservation deteriorates in sediments associated with the igneous rocks. The sediment accumulation rates determined for Site 836 may be separated into two parts, which reflect the differences in the volcaniclastic component. The sediments that accumulated before 0.5 Ma have a thick volcaniclastic component and represent that part of the section overlying and including the mafic igneous rocks. A rate of 75 mm/k.y. is indicated. The younger part of the sediment column, less than 0.5 Ma, has a lesser volcanic component with an estimated sediment-accumulation rate of around 25 mm/k.y..

Sediments recovered in Cores 135-836A-1H through -3H, as well as basaltic and basaltic andesite rocks from Cores 135-836A-7X through -9X, were all normally polarized and evidently formed during the Brunhes normal polarity chron (i.e., in the last 0.73 Ma). Magnetic susceptibility in the sediment column of Hole 836A displayed small oscillations that may be related to Milankovitch climate cycles. Susceptibility in the basalts recovered in Holes 836A and 836B is about 50% higher in Units 3 and 4 than in Unit 5; this implies a slight compositional difference and that the former contain more magnetic minerals.

The shipboard analyses for hydrocarbons in the sediments of Site 836 indicated methane concentrations on the order of 2-3 ppm which was considered the background level. No ethane or propane was detected. The extremely low concentration of methane indicated that methanogenesis was not occurring in these sediments. This would be expected because of the shallow sediment depths penetrated and because it is extremely unlikely that the bottom waters were anoxic in an open-ocean setting. The percentage of $CaCO_3$ was calculated from a determination of inorganic carbon measured on selected samples and gave values ranging from 15.7% to 56.3%. Total organic carbon was calculated from the difference between total carbon and the amount of inorganic carbon giving values ranging from 0.07% to 0.53%. Sulfur ranged from 0.01% to 0.07%.

Five igneous-rock units were identified on the basis of mineralogy, mineral proportions and texture. The two uppermost units are glassy, sparsely phyric, andesitic hyaloclastites. Underlying these andesitic rocks are three basalt units: moderately phyric olivine-plagioclase basalt; sparsely phyric plagioclase basalt; and moderately phyric olivine-clinopyroxene-plagioclase basalt. All of the units are highly vesicular, with up to 40% vesicles in some samples, indicating a high volatile content of the parental magmas. Trace- and minor-element data suggest that the samples all have an "arc-like" geochemical signature and are distinct from lavas erupted at the nearby East Lau spreading center. In spite of the "arc-like" signature, they also are distinctly different from the modern lavas of the Tofua Arc.

The GRAPE and *P*-wave logger data show a good correlation of the hyaloclastite layers to measured values of high density and high velocity in the sediment section. Marked variations in basalt *P*-wave velocities could be due to alteration or instead msy represent the variable vesicularity of the samples.

<u>Site 837</u>
Hole 837A: 20°13.307'S, 176°49.360'W; water depth, 2752.5 m
Hole 837B: 20°13.319'S, 176°49.362'W; water depth, 2753.0 m

Site 837 is located in the central Lau Basin about 200 km east of the Lau Ridge (remnant arc) and approximately 69 km west of the axial rift zone of the East Lau spreading center. The East Lau spreading center (ELSC) is the present site of seafloor spreading and the generation of new backarc-basin crust at the latitude of the drill site. Site 837 is located in a region of north-south-striking ridges and deeps interpreted as horsts and grabens or half-grabens. The bathymetric relief in the area is about 400 m at ridges, shoaling to about 2300 m, rising above basins some of which exceed 2700 m in depth. In this discussion we will use the term Basin 837 for the irregular diamond shaped, narrow, linear, sedimented trough in which the site is located. Basin 837 is about 10 km long on its major axis, about 2.5 km wide in the north, and narrows toward the south-southwest to about 1 km wide at 20°15'S. The seismic character of the sedimentary section is dominated by planar parallel reflectors, which overlie an irregular hummocky surface comprising a complex series of discontinuous low-frequency reflectors which are assigned as acoustic basement. The upper seismic unit reaches a maximum thickness of 0.15 s, two-way traveltime (TWT). The site was selected to give data for a part of the Lau Basin crust that had been estimated to be intermediate in age between the oldest backarc crust (e.g., Site 834) and young crust formed at the axial rift of the East Lau spreading center.

The sedimentary sequence recovered at Site 837 is 84 m thick and ranges in age from latest Pliocene to Holocene. The sequence is subdivided into two lithological units. Unit I comprises the sediments from the seafloor down to 13.5 mbsf, and consists of clayey nannofossil oozes with thin calcareous and volcaniclastic turbidites. Unit II extends from 13.5 to 84.0 mbsf and is subdivided into five subunits on the basis of grain size, sedimentary structures and composition. Each subunit defines a sedimentary cycle, starting at the base with thick volcaniclastic turbidites. Upward there is a thinning and fining of individual turbidites and a gradual transition into clayey nannofossil oozes. The thickest turbidite, measuring 17.1 m, occurs in Subunit IIC. The volcaniclastics at Site 837 consist of clear, angular, and platy glass shards of rhyodacitic composition, but there is also a minor component of basaltic andesite composition. Below 22 mbsf the sedimentation rate is 39 mm/k.y., and decreases to 28 mm/k.y. for the nannofossil oozes in the upper part of the section.

The sediments from Site 837 range in age from middle Pleistocene (N14b, *Globorotalia (Truncorotalia) crassaformis hessi* Subzone of N22) to the upper Pliocene (CN12d, *Globigerinoides quadrilobatus fistulosus* Subzone of N22). The Pleistocene/ Pliocene boundary (based on the top of Zone CN13b) is placed within Core 135-837A-8H. Diversity and preservation decrease within the ash and pumiceous beds.

Magnetic-polarity-reversal results show the base of the Brunhes normal polarity chron (0.73 Ma) at 13.6 mbsf, and the Jaramillo (0.91-0.98 Ma) and Cobb Mountain (1.11-1.13 Ma) polarity subchrons at 21.4-22.7 mbsf and 24.3-24.7 mbsf, respectively. For the deeper parts of Hole 837A two polarity models are suggested. Model A interprets a normal polarity sequence at 69.6 to 79.0 mbsf as between the top of the Gauss polarity chron (2.48 Ma) and the top of the reversed Kaena polarity subchron (1.88 Ma), whereas Model B interprets these depths as the Olduvai Subchron (1.66-1.88 Ma). The sedimentation rate calculated from the magnetic-polarity-reversal data is similar to that calculated from the paleontologic data within 5 mm/k.y. Furthermore, the short length of the Brunhes recovered in Hole 837A may indicate that up to 55% if this polarity chron is missing. In the sediment section, cyclic variations in the modified Q-ratio (ratio between remanent magnetization intensity and susceptibility) at periods of 37 Ka can probably be correlated to Milankovitch cycles.

Results of the shipboard organic-geochemical analyses indicated only background levels of methane in the cores at Site 837. These low methane levels indicated that methanogenesis was not occurring in the sediments either because sulfate levels were too high or because there was insufficient organic carbon to maintain microbial activity. Trace levels of organic carbon (0.01% - 0.27%) were found. A sample of volcanic sand (13.31 mbsf) was analyzed for total carbon, but none was detected. Carbonate values range from 1.9%-66.1%; the lowest values are from the intervals having volcanic sand and silt. Sulfur was looked for but not detected.

A single igneous lithologic unit was recognized in Hole 837B. It consists of approximately 4 m of very fresh, vesicular, sparsely phyric orthopyroxene-clinopyroxene-plagioclase basaltic andesite, underlying upper Pliocene sediments. The rocks have seriate porphyritic texture with phenocrysts of plagioclase, clinopyroxene, partially resorbed olivine, and rare orthopyroxene. Some of the plagioclase phenocrysts have resorbed cores and irregular scalloped edges. Many have sodic rims. Some of the euhedral orthopyroxene phenocrysts have rims of clinopyroxene. Two samples, analyzed by shipboard x-ray fluorescence, are low-K basaltic andesites and have 3.5% MgO, very low Ni and Cr and low Ti, Zr, and Y. Some of the incompatible trace-element characteristics are intermediate between MORB values and rocks from the Tonga and Kermadec volcanic arcs. The Site 837 basaltic andesites are also similar to Units 1 and 2 from Site 838.

The physical-property data, particularly the GRAPE density and *P*-wave logger compressional wave-velocity, correlate well with the lithological units identified in the core. The density of the nannofossil ooze in Unit I is relatively constant around 1.49 g/cm^3. An increase in the proportion of volcanic sands and silts (30-35 mbsf) and an increase in consolidation of the sediment (70-80 mbsf) are reflected in increased density values. Compressional-wave velocity reflects the changes in sediment grain size downhole. The velocity of the nannofossil ooze is about 1490 m/s throughout, and values higher than this reflect increases in grain size as seen in the 30-37-m interval. In the interval between 37 and 53 mbsf, the grain size of the sediments increases from clay to silt with fine vitric ash. Because the density remains constant throughout this interval, the increased velocity is related to the increase in grain size. The heat flow measured at Site 837 is 24.4 mW/m^2 which is low if compared to theroetical heat-flow values of 175 to 200 mW/m^2, predicted for young ocean crust. Although Site 837 is undoubtedly not located within the same heat and fluid circulation cell as Sites 834 and 835, similar conclusions can be drawn: (1) the sediments are not thick or diagenetically altered enough to act as an impermeable cap to impede fluid exchange between the sediments and seawater, and (2) the basins are zones of recharge for fluid circulation that serves to dissipate large amounts of heat.

Structural data for the cores at Site 837 are limited, and there are no logging data to support interpretations made from them. The turbidite flows in the upper part of the section (0-20 mbsf) show a general dip of up to 18°C in the eastern hemisphere (when plotted on the lower hemisphere of a stereographic projection net), i.e., dips to the north, east, or south. Slightly steeper easterly dips in the lower part of the section (50-80 mbsf) may indicate tilting of the sediments a few degrees to the east during sedimentation. The intermediate stratigraphic levels, in which no bedding planes were measurable, are dominated by a remarkable volcaniclastic turbidite deposit 17 m thick. Although its upper part is fine grained, its thickness indicates very rapid deposition, and close proximity to its source may be inferred. It may be an indication of local tectonic activity. Part of the wide dispersion of the dip data may be due to depositional processes in addition to tectonic processes. At 16 mbsf, gently dipping hyaloclastite turbidites are cut by a number of planar features lying at a steep angle to the bedding. They are infilled by poorly lithified fossil ooze, and definitely cut but do not offset banding in the turbidite. Although the volcaniclastic layer is unconsolidated, it appears that it was nevertheless competent enough to fracture prior to injection of the ooze. The strike of the features is to the north-northeast, parallel to the elongation of the basin; they may represent fractures due to extension. Steeply dipping joint planes cut the igneous rocks, but they were not oriented, and no interpretation of them is possible.

<u>Site 838</u>
Hole 838A: 20°49.618'S, 176°53.402'W; water depth, 2322.8 m
Hole 838B: 20°49.629'S, 176°53.402'W; water depth, 2322.7 m

Site 838 is located in the central Lau Basin, approximately 55 km west of the active backarc axis of the East Lau spreading center and about 200 km east of the axis of the Lau

Ridge. The regional topography at the site is dominated by broad, north-south-striking linear basins and highs, ranging in water depths between less than 1500 m and greater than 2900 m. Approximately 50 km to the west of the site, a tectonically (and probably volcanically) active rift structure has been identified on long-range sidescan data, and one suggestion is that it may represent a site of off-axis magmatism along an extinct ridge, the Western Lau spreading center. The site is close to an arbitrary north-south line separating Lau Basin floor characterized by rifting and amagmatic(?) extension from seafloor generated at the East Lau spreading center. Interpretations of the magnetic anomaly fabrics, however, suggest a simple seafloor-spreading mechanism, with an age for the crust beneath the site of 2 Ma. The principal objectives of the site were (1) to assess the age and the chemistry of the basement rocks, and to determine their petrogenetic relationship to those recovered at other sites throughout the basin; (2) to sample the overlying sedimentary sequence to review variations in carbonate, clay, and volcaniclastic components, and to determine their likely source and stratigraphic relationships to other marker units identified during Leg 135, but especially at Sites 836 and 837; and (3) to identify the tectonic setting of the site in terms of models of backarc ridge relocation by ridge jump, ridge migration or asymmetric spreading.

The sedimentary sequence recovered at Site 838 is 103.2 m thick and ranges in age from Holocene to the late Pliocene. The sequence is subdivided lithologically into three units. Unit I comprises clayey nannofossil oozes with thin volcaniclastic turbidite interbeds and extends down to 23.04 mbsf. Unit II, which is subdivided into five subunits, comprises volcanic gravel (pumice and glass), vitric sands, vitric silts and clayey nannofossil ooze, and is characterized by an overall upward-fining sequence. The entire Unit I, and the upper sequences of Unit II, carry abundant well-preserved fauna and flora, and the Pleistocene/Pliocene boundary at the base of nannofossil Subzone CN14a is identified within Subunit IIC. The sediments of Unit II were deposited by mass-flow processes, probably derived from a source toward the south or southwest, based on regional bathymetric trends. The rapid deposition locally resulted in poor biostratigraphic control, and the thick tubiditic sections resulted in a number of barren intervals.

Such fauna and flora that are present are wellpreserved and moderately abundant throughout the lower part of Unit II and Unit III. The deepest sedimentary unit, Unit III, extends through 98.7-259.2 mbsf, but the detailed lithostratigraphy is poorly constrained due to the low recovery. The sediments recovered consist of pumiceous volcanic gravel, conglomerate, vitric sandstone, and vitric clayey siltstone. The sediment-accumulation rates for Site 838 vary between 177 mm/k.y. for 55.0-94.0 mbsf through 47 mm/Ka for the 18.0 -55.0 mbsf interval to 21 mm/k.y. for the most recent section above 18.0 mbsf. Compositionally, the volcaniclastics at Site 838 are dominated throughout by pumiceous material of rhyodacite composition, but there is also a minor component of basaltic andesite glass and lithic fragments. Basement was not reached at Site 838, but igneous-rock fragments recovered from the breccias and very coarse sand layers comprised plagioclase-pyroxene phyric andesites (54%-57% SiO_2) and plagioclase-amphibole-quartz phyric pumices with 70%-72% SiO_2. Quartz and cryptocrystalline silica occur as secondary phases.

The unstable sediments hampered the identification of a smooth magnetic stratigraphy. The Brunhes-Matuyama (0.73 Ma), Jaramillo (0.98 Ma), and Cobb Mountain

(1.13 Ma) magnetic events were distinguished, but the shortness of the sedimentary column in the Brunhes Chron suggested that part of it is missing at this site.

Only background levels of hydrocarbons were detected at Site 838. Low methane concentrations indicate that methanogenesis was not occurring, probably due to levels of organic carbon being too low to sustain microbial activity. A low gradient in dissolved calcium and magnesium concentration-depth profiles calculated from interstitial-water samples suggests a diffuse exchange with the underlying igneous basement. The limited pore-water data confirm the downwelling of seawater through the stratigraphic section as found at previous sites, but with more basement exchange at Site 838 than at the earlier sites.

Physical-property measurements for Site 838 show a wide scatter, caused by the variations in interbedded lithologies. Bulk density, porosity, water content and void ratio decrease with depth in the section down to 200 mbsf. Below this point, however, all three index properties increase significantly, indicating that the deeper part of the section is probably underconsolidated with high pore pressures preventing continued consolidation of the sediments at the base of the hole. The temperature gradient at the site is 8.7° C/100 m, the highest recorded at any of the sites to date.

<u>Site 839</u>

Hole 839A: 20°42.531'S, 176°46.492'W; water depth, 2617.4 m
Hole 839B: 20°42.539'S, 176°46.501'W; water depth, 2617.3 m

Site 839 is situated in the central Lau Basin about 225 km east of the axis of the Lau Ridge (the remnant arc) and approximately 55 km west of the East Lau spreading center. The site is located in an irregular elongated basin that trends northeasterly and is about 11 km wide at the 2500-m isobath. The basin extends to the northeast beyond the area for which we have bathymetric data but is at least 15 km long. The basin is segmented into a western part with maximum depths of about 2600 m and an eastern part with depths down to nearly 2800 m. The age of the crust at Site 839 was estimated to be about 2 Ma on the basis of regional patterns of magnetic anomalies. The scientific objectives for the site were to core the sediment column and to sample the igneous basement with the goal of interpreting the geologic history of this part of the Lau Basin.

The sedimentary sequence at Site 839 consists of clayey nannofossil ooze, turbiditic glass-rich sands and silts, pumiceous volcaniclastic gravels, and rare pyroclastic airfall ashes. Three major units were recognized on the basis of changes in lithology, in particular on the presence or absence of volcaniclastic sands and silts. Unit I (middle Pleistocene) comprises 17.85 m of iron oxide-hydroxidestained clayey nannofossil ooze with sporadic layers of vitric sand and silt. Unit II (late Pliocene) is 81.65 m thick and is distinguished from Unit I by its very high content of volcaniclastic material. It comprises thick to thick-bedded vitric sands and silts (turbidites) with some interbeds of clayey nannofossil ooze. The unit is subdivided into six subunits with upward-fining sedimentary cycles. Unit III groups all sediments below 99.5 mbsf. It comprises nannofossil clays, clays, vitric silts and sands, and volcanic gravel. Poor core recovery did not allow further separation of the unit. It too is late Pliocene.

The biostratigraphic and paleomagnetic studies were key factors in interpreting the history of the Lau Basin as recorded at Site 839. The calcareous nannofossils and planktonic foraminifers range in age from middle Pleistocene to late Pliocene (CN14b-CN12d). The Pliocene/Pleistocene boundary occurs in Core 135-839A-7H. The remainder of the sedimentary sequence at the site is late Pliocene in age. Microfossils from the sediment in Section 135-839B-10R, CC, 6 m above igneous Unit 2 in Hole A, are latest Pliocene (CN13b) in age. Sample 135-839B-17R, CC immediately overlies basalts of Unit 2 in Core 135-839B-18R and is late Pliocene in age (CN12d). Sediments younger than middle Pleistocene were not recovered in the drilling operation.

The sedimentary accumulation rates at Site 839 ranged widely and show a correlation to the abundance of ash beds. In the lower part of the sequence (213.5 to 56 mbsf) where the main ash beds are found, the rate is 882 mm/k.y. Between 56 and 25 mbsf, the rate decreases to about 51 mm/k.y. In this range the ash beds are thinner. Above 25 mbsf, where ash beds are rare, the rate is 9 mm/k.y.

Magnetic-polarity measurements of sediments show normal polarity intervals (at 0-16 mbsf, 35.2-38.3 mbsf, and 40.9-41.4 mbsf) corresponding to the Brunhes Chron (0-0.73 Ma), the Jaramillo Subchron (0.91-0.98 Ma), and the Cobb Mountain event (1.12 Ma). Lower in the core, another normal polarity interval was found and is interpreted to be either the Olduvai Subchron (1.66-1.88 Ma) or the Réunion Subchron (2.01-2.14 Ma). The paleomagnetic studies of basalt and basaltic andesite recovered from between 256 and 213 mbsf yielded anomalously low inclinations (between -5° and 15°) suggesting that the rock cooled during a magnetic-polarity transition. A sediment layer beneath these lavas at about 257 mbsf has reversed polarity, while lavas from still deeper levels have normal polarity. Biostratigraphic data constrain the reversely polarized sediments to the Matuyama Chron between the Olduvai and Réunion Subchrons. Thus, the deepest level, normally polarized basaltic andesites are likely to represent either the Réunion Subchron (2.01-2.14 Ma) or the Gauss Chron (2.48-2.92 Ma). The magnetic-susceptibility record appears to be a good indicator of major ash layers. As at previous sites, cyclic variations in the modified Q-ratio (1mmT AF cleaned remanent intensity/susceptibility) may indicate a Milankovitch climatic cyclicity present in the nannofossil-ooze sediments.

Hydrocarbon analyses of the core showed only background levels as at the other sites. Analyses of the pore-water fluids showed that, except for dissolved Mn, they were indistinguishable from average seawater and are like the values for the other sites. The Mn concentrations showed an initial downcore increase, reaching a maximum value at 48.5 mbsf, before decreasing downcore again toward the base of the sediment.

Igneous rocks that form the basement to the sedimentary section were recovered between 205.85 and 497.26 mbsf. The hole was terminated because of drilling difficulties at 497.26 mbsf. Chilled margins and quenched mineral textures suggest that many of the cooling units recovered were parts of extrusive flows and pillow complexes. All of the rocks recovered are highly vesicular (10% - 25%) attesting to their high volatile content at the time of eruption. Two main petrologic varieties are present: olivine and clinopyroxene phyric basalt and orthopyroxene-clinopyroxene-plagioclase phyric basaltic andesite. The latter type has not been encountered at any of the other sites. Nine units were recognized on the basis of texture, mineralogy, and mineral proportions. The lowermost part of the section recovered comprises a series of flows of moderately to highly phyric clinopyroxene-orthopyroxene-plagioclase basalts having high ratios of plagioclase to pyroxene. They resemble many of the rocks of the Tofua Arc. These are overlain by three major eruptive units comprising numerous flows of very Mg-rich, aphyric to highly phyric clinopyroxene-olivine basalts with minor interbeds of basaltic andesite and rare sediment layers. The overall geochemical signature of the entire mafic-rock series at Site 839 has many similarities to island-arc tholeiite magmas. Some of the basalts have high concentrations of Mg, Cr, and Ni and are the most primitive igneous rocks encountered in the Leg 135 cores. They may represent near-parental magmas for some of the volcanic units in the Lau Basin that have an arc-like geochemical signature.

Physical properties of the sediments show a good correlation with lithologic types. The cyclic change in grain size results in cycles of increasing density and decreasing water content, porosity, and void ratio. The *P*-wave logger compressional-wave-velocity data vary with the alternation of silts and sands interbedded with the dominant nannofossil ooze. There is also an excellent correlation between grain density and velocity in the basalt samples, but the correlation between bulk density and velocity is poor. This may be due to the random distribution of vesicles. The temperature gradient of 7.1°C/km, and the derived heat-flow value of 9.3 W/m^2, are the lowest values measured in the Lau Basin during Leg 135.

Bathymetric profiles show that Site 839 is situated in a basin that is bounded on the northwest by a 200-300-m-high northeast-southwest trending scarp. This feature is clearly visible on GLORIA side-scan sonar records. Seismic reflection profiles suggest that the scarp is coincident with a fault zone, and the profiles clearly show an angular unconformity within the sedimentary fill of the basin. The lowermost identifiable reflectors dip at about 4° toward the northwest and are onlapped from the west by a second seismic unit. The whole section is then truncated by a shallower "drape" of reflectors that extends up to the sediment/water interface and which are themselves apparently inclined at about 1° toward the northwest.

Bedding orientations were measured in cores from both holes in the interval between 0 and 250 mbsf. Dips were recorded mainly from bases of individual volcaniclastic turbidites; many of these have erosive bases, and some component of depositional dip may be included in the dip measurements. The sediments between 30 and 50 mbsf have an average southeasterly dip of about 7.4°. Between 90 and 100 mbsf, the average dip is about 9.6° to the west or west-northwest. This change in dip direction may correspond to the unconformity observed in the seismic data. A possible candidate for the sedimentary horizon marking the base of the unconformity is a 5-m-thick zone of poorly sorted volcanic gravel at 82-87 mbsf. The gravel deposit and oozes beneath it are all of latest Pliocene age (nannofossil Zone CN13b).

Site 840

Hole 840A: 22°13.249'S, 175°44.916'W; water depth 743.3 m
Hole 840B: 22°13.259'S, 175°44.918'W; water depth 743.3 m
Hole 840C: 22°13.234'S, 175°44.925'W; water depth 743.3 m

Site 840 is located on the south-central Tonga platform, which forms the crest of the Tonga Ridge, south of latitude 21°S. The site is in 754.4 m of water, approximately 45 km east-northeast of Ata island and about 130 km south-southwest from the islands of Tongatapu and 'Eua. The site is on the west flank of the platform which at this latitude is about 60 km wide at the 1000-m isobath. The Tonga Ridge has been in existence in some form at least since the Eocene, when it was a component of an ancestral Melanesian megaarc comprising the elements of Fiji, Lau, Tonga, and New Hebrides arcs. This protoarc was building during the time of the early history of the South Fiji Basin (magnetic anomalies 12-7, 33-26 Ma) as the ancestral Tonga Trench represented the site of a west-dipping subduction zone. The cessation of backarc spreading in the South Fiji Basin, the rifting off of the New Hebrides Arc at around 10 Ma(?), the initiation of the Lau Basin rifting (around 5-6 Ma), and the subsequent onset of backarc spreading have all been major tectonic events involving profound thermal upwelling (disturbance) in the arc and backarc region. These would have affected the uplift, subsidence, and sedimentological and volcanic history of the arc and its environs. It was intended that Site 840 would address the sedimentological and tectonic history of the arc throughout the middle and late Cenozoic, in particular to understand the nature and age of regional seismostratigraphic hiatuses which are suggested to relate directly to these regional events. Specific objectives of the site were 1) the identification of the age of the angular unconformity referred to as Horizon "A," thought to be late Miocene/early Pliocene, and reasoned to be the event coinciding with the initiation of rifting and opening of the Lau Basin; (2) the identification and timing of the onset of the volcaniclastic deposits associated with the early Tofua Arc, the assessment of their composition and temporal variations in composition, and their interrelationship with other source areas such as the Lau Ridge; and (3) the identification of the rocks presumed to be volcaniclastics below Horizon "A," and their regional relationships with potential source areas in the Lau Basin area, such as the Lau Ridge.

The sedimentary sequence recovered at Site 840 is 597.3 m thick and ranges in age from Holocene to late Miocene. The sequence is subdivided into three units. Unit I comprises the sediments from the seafloor down to 109.98 mbsf and consists of nannofossil oozes, vitric silts, vitric sands, and pumiceous gravels. Unit II extends from 109.98 to 260.5 mbsf and is dominated by nannofossil chalks and pumiceous gravels, but vitric siltstones and vitric sandstones are also common. Three depositional cycles can be distinguished, fining upward from predominantly pumiceous gravel into predominantly nannofossil chalk. Unit III extends from 260.5 to 597.3 mbsf and consists of a sequence of volcaniclastic turbidites of vitric sandstone, and vitric siltstone, interbedded with nannofossil chalks. Near the base of the sequence there are also beds of volcaniclastic breccia and conglomerate. Upward through the unit there is a fining and thinning of individual turbidites, indicating a change from proximal to more distal deposition. Volcanic glasses are basaltic to rhyodacitic, as estimated from their refractive indices, and are strongly focused around intermediate compositions. Alteration of vitric shards is low but has locally resulted in complete replacement of volcanic glass by smectite, celadonite, and zeolites. Structures in the core appear to be related to soft-sediment deformation. Dewatering structures are common in the silty upper portions of volcaniclastic turbidite flows, above planar laminated bases, and some microfaults are visible in clay-rich zones. In most cases the sense of motion indicated on these microfaults seems to be the same as the paleocurrent direction of coarser material deposited directly on top of them. Middle Pleistocene (Subzone CN14b) to late Miocene (Zone CN9) planktonic foraminifers and calcareous nannofossils were recovered at Site 840 from strata consisting mainly of vitric volcaniclastics with interbedded calcareous oozes and chalk zones. A probable hiatus of approximately 1 Ma lies between 95 and 101 mbsf, between Samples 135-840B-10X, CC (late Pliocene nannofossil Subzone CN12a) and 135-840B-11X, CC (early Pliocene nannofossil Subzone CN10b). The seismic-reflector Horizon "A," thought to be a regional unconformity, was not identified biostratigraphically.

For Site 840 the sediment-accumulation curve can be divided into five sections, illustrating changes in the rates of accumulation. The lowermost part, between 570 and 320 mbsf, shows rapid sedimentation rates of about 357 mm/k.y. Between 320 and 265 mbsf, the sedimentation rate decreases to about 110 mm/k.y., followed by a return to a very high sedimentation rate of 820 mm/k.y. over the interval from 265 to 101 mbsf. These high rates of sedimentation coincide with a period of deposition of numerous pumiceous gravel and sand beds. Between 101 and 95 mbsf, immediately prior to the mid-Pliocene hiatus, sediment-accumulation rates drop to 10 mm/k.y.; above the hiatus, from 95 to 24 mbsf, these rates increase to 50 mm/k.y., and between 24 mbsf to the seafloor, rates drop to 14 mm/k.y.

Paleomagnetic measurements on samples from Holes 840B and 840C showed numerous intervals of reversed and normal polarity. Samples between 40 and 71 mbsf were all normally polarized and probably represent the Gauss Chron (2.47-3.40 Ma); however, no polarity boundaries were found in this part of the hole because of the unsuitability of much of the sediments to preserve good magnetic signatures, so the exact part of the Gauss Chron is uncertain. Beneath the mid-Pliocene hiatus at about 95 mbsf, the observed polarities agree reasonably well with the geomagnetic polarity-reversal time scale from the Thvera Subchron (4.57-4.77 Ma, 121.8-190.8 mbsf) of the Gilbert Chron down to the top of Chron 4 (6.7 Ma, 521.7 mbsf). The magnetic stratigraphy indicates rapid sedimentation in the late Miocene, ranging from 148 to 213 m/m.y. Palaeomagnetic measurements were obtained from eight oriented APC cores of lower to mid-Pliocene sediments from the upper part of Hole 840C. Despite scatter caused by drilling disturbance in unconsolidated sediments, a preliminary analysis of the data indicates a 21°± 11° clockwise rotation of the Tonga Arc with respect to oriented sections in the western Lau Basin.

Although there were some safety concerns prior to the drilling of this site because of known hydrocarbon occurrences within 100 km, these concerns proved groundless. Methane concentrations remained at background laboratory level, and no other volatile hydrocarbon gases were detected. The organic-carbon content of these sediments is very low. Rock-Eval analysis indicates that the organic matter has no hydrocarbon potential and is presumably inertinite. The organic-carbon and the carbonate contents both decrease with depth below Unit I. This is because of the increasing volcaniclastic contribution to the sediments in Units II and III. At Site 840, it would appear that alteration of volcanic material in the sediments is the major factor causing variations in the calcium, magnesium, and potassium gradients in the pore waters. Concentrations of sulfate and ammonia do not vary much, indicating that the bacterial activity in these sediments is minimal. This is further substantiated by the low level of dissolved manganese. In the most enriched carbonate layer, the observed decrease in alkalinity is probably caused by the precipitation of calcium carbonate in response to an increase in calcium from the alteration of the volcanogenic material.

Physical property and downhole-logging measurements correlate well with lithology. The contact between lithostratigraphic Units I and II is marked by decreases in density and velocity, while that between Units II and III is marked by increases. Within Unit III, a marked increase in the average velocity at about 383 mbsf correlates with a drop in total carbonate percentage from around 30% to 40% to almost zero. Velocities in Unit II average about 2100 m/s, and in Unit III they average about 2300 m/s, close to values measured with refraction sonobuoys prior to Leg 135. However, the velocity and all index-property measurements show large variations within short depth intervals, reflecting the widely varying lithologies of the turbidite sequences which comprise much of the sampled section. Measurements of individual units commonly show decreasing velocity and density values from top to base of individual turbidite units; the variation can be as much as 0.4 g/cm^3 and 300 m/s within a 2-m-thick turbidite. Only one valid temperature measurement was obtained from Site 840; the temperature gradient derived from that point and the seafloor temperature is 29.3°C/km, a value similar to that recorded in wells on Tongatapu.

Downhole logs were acquired from 141 to 553 mbsf. The logs also show wide variations in measured values, again reflecting the dominant turbidite lithology. High-quality formation microscanner (FMS) images were acquired between 250 and 505 mbsf, and these accurately image the turbidite units showing a continuous cyclicity of light to dark bands indicative of the changing lithology within each turbidite unit. Automatic processing of the dip data from the data identifies the bedding orientations as showing a progressive increase in dip from an average of 2° at 250 mbsf to 4° at 500 mbsf. Dip direction is consistent toward the north below 250 mbsf; between 100 and 200 mbsf, the magnitude of dip is approximately 2°, but its direction is random.

Site 841
Hole 841A: 23°20.746'S, 175°17.871'W; water depth, 4809.8 m
Hole 841B: 23°20.741'S, 175°17.872'W; water depth, 4809.8 m
Hole 841C: 23°20.720'S, 175°17.879'W; water depth, 4809.8 m

Site 841 was planned to recover an estimated 500 m of sediment and to core 50 m into basement. The intent was to characterize both the sedimentary section and the basement for comparison with forearc sites drilled in the Mariana and Bonin arc systems. In addition to information gained from petrologic studies of the rocks and sediments, another objective was to gain provide information about differential uplift and subsidence of the forearc. Other objectives included the acquisition of data for paleomagnetic measurements, physical properties of the rocks and sediments, and fluid geochemistry. Drilling went faster than expected, and coring at this site was extended to 834.2 mbsf. We had anticipated the possibility of drilling into serpentinite masses but did not expect to drill into the remnants of a silicic volcanic arc, as we did.

The core recovered at Site 841 gives a record ranging from middle Pleistocene to late Eocene or older. A barren interval separating the middle Pleistocene from the upper Miocene may be due to dissolution because of deposition below the carbonate compensation depth (CCD). Sedimentation began in late Eocene to early Oligocene time with the accumulation of carbonates in a shallow-water environment on an igneous substrate formed of rhyolitic volcanic rocks. Carbonate sedimentation was disturbed by occasional influxes of volcanic debris from a nearby rhyolitic source. From early Oligocene to early middle Miocene time there was a hiatus in sedimentation followed by a phase of relative subsidence. This resulted in deposition of volcaniclastic conglomerates, sandstones, and siltstones mostly by gravity mass flows and turbidity currents. The sequence fines and thins upward but younger cores show that in late Miocene time a fresh influx of volcaniclastic conglomerates reflected rejuvenation of the volcanic source. Volcanic debris in the Miocene section ranges from basaltic to dacitic. Subsidence continued until middle Pleistocene or possibly Pliocene time, when Site 841 subsided below the CCD. Epiclastic volcanic turbidites were reduced to very thin, rare intervals within the pelagic clayey background sedimentation. Minor thin pyroclastic airfall deposits have also been accumulating from the middle Pleistocene to the present time. Nannofossil oozes are present in minor amounts in middle Pleistocene (to Pliocene?) sediments. The sediment accumulation rates vary widely with time and appear to be controlled largely by the input of volcaniclastic material. The interval from 604 to 549 mbsf, which includes an Eocene limestone with large foraminifers, accumulated at 14 mm/Ka. Both the biostratigraphic and paleomagnetic values give similar rates. Between 549 and 458 mbsf (lower middle Miocene volcaniclastic sediments) the rate increases from 35 mm/Ka in the lower part to 160 mm/Ka in the upper part. The base of the upper Miocene to Pleistocene section (458 to 203 mbsf), an interval of volcanic sandstones and conglomerate, accumulated at 142 mm/Ka. The rate falls to 53 mm/Ka between 203 and 60 mbsf and to 11 mm/ka above 60 mbsf.

Two major igneous-rock sequences were recovered. There are nine separate small bodies (dikes, sills, or flows) of basaltic andesite and andesite in the upper Miocene to lower middle Miocene volcaniclastic series. These are dominantly plagioclase phyric with lesser amounts of orthopyroxene and clinopyroxene. The other major unit comprises a series of dacitic rocks including lapilli tuff, welded tuff, tuff breccias, and massive dacitic. Visible amounts (0.5% -1%) of fine-grained disseminated pyrite are common in most of the samples. This high-silica, low-potassium (presumably island arc) volcanic complex, of pre-Eocene age, was totally unexpected. Similar rocks are rare in other intraoceanic island arcs, especially in their earliest stages of development. The closest known occurence of similar rocks in a submarine oceanic area is on Lord Howe Rise, where Upper Cretaceous rhyolitic flows and tuffs are found. At this time there is nothing to suggest a geologic tie to that area other than their similar petrologic features and broadly similar ages.

Paleomagnetic studies of the APC core from Hole 841A show that there is a relatively continuous sedimentary sequence from the Brunhes to the Gilbert Chron. The Brunhes Chron, Brunhes/Matuyama boundary, and Jaramillo Subchron all are clearly seen.

The pore-water chemistry is extensively modified from standard seawater values, consisting of Ca- and Cl-rich brines below 200 mbsf. Large variations were noted in Ca, Mg, K, Na, and Cl concentrations in pore waters from the uppermost 200 m of sediments. These variations are abnormal for marine sediments and are probably caused by the combined effect of abundant volcanogenic material and high rates of sedimentation that have led toward very low pore-water diffusivity. Sulfate and phosphate sharply decrease, and ammonia sharply increases downcore to 200 mbsf, changes that are likely related to decomposition of organic matter by sulfate-reducing bacteria. Si, Sr, and Mn substantially decrease in concentration with depth, changes probably controlled by diagenetic alteration of volcanogenic sediments.

The highest methane values recorded on Leg 135 were found in the lower part of Hole 841B but were only 15 ppm. Neither ethane nor propane was detected. The methane is associated only with the rhyolitic rocks at this level and it is possibly derived from an unspecified nonbiologic process.

PRINCIPAL CONCLUSIONS

Site 834

The prime objectives for Site 834 were successfully achieved in that (1) a sufficient thickness of igneous rock was recovered to confirm that basement had been penetrated; (2) the age of the oldest sediments recovered determined a minimum age for the basement emplacement; (3) the sedimentary section involving oozes, sands and claystones interbedded with vitric ash was used to define precisely the history of basin fill; and (4) the integration of the biostratigraphic and paleomagnetic data provided the age of rift initiation in this supposedly oldest part of the Lau Basin.

The igneous basement is basalt having LIL and HFS element abundances and element ratios that resemble values for N-MORB. In spite of proximity to the Miocene-Pliocene Lau Ridge volcanic arc, rocks at Site 834 were more like rocks from the modern axial ridges of the Lau Basin than were rocks at other Leg 135 sites closer to those spreading centers.

The uppermost flows/sills are interleaved with sediments of late Miocene age (5-6 Ma), an age which corresponds to previous estimates for the beginning of Lau Basin opening. The occurrence of MORB-like basement at this site, however, and the identification of the restricted areal extent and poorlydeveloped interconnectivity of the sub-basins characterizing the western Lau Basin, point to a style of crustal formation different from seafloor spreading but more like brittle extensional rifting. We thus speculate that almost half of the central and southern Lau Basin has formed by crustal extension and localized magmatism without the formation of a mid-ocean-ridge-type backarc spreading axis.

Site 835

The objectives for Site 835 were addressed in two holes which collectively penetrated a total of 183.20 mbsf, with a recovery of 155.2 m of sediment and 28.0 m of volcanic rock. The drilling program successfully identified the age and composition of the basement rocks; assessed the composition, age, and environment of deposition of the sedimentary cover sequence; and used biostratigraphic and paleomagnetic data to define a 15-m-thick allochthonous raft of Pliocene sediments which had slumped into the lower Pleistocene section.

The sediment section comprises two lithologic units. Unit I extends down to 130 mbsf and comprises clayey nannofossil ooze. Unit 2, 130-154.5 mbsf, contains mixed sediment with volcanic silts and epiclastic ash beds of andesitic composition. Laminated mudstones and oozes indicate gentle, low-energy deposition of this pelagic sequence, although rare crossbeds support some suggestion of increased transport energy. The lower Pleistocene Unit I sequence is interrupted between 55 and 70 mbsf by a raft of Pliocene nannofossil ooze, which appears to have slumped from the eastern inward-facing scarp bounding the basin. In the section both below and above this allochthonous block, mud-clast conglomerates occur at several levels, indicating a prolonged period of slope instability. The shallow dips of the bedding planes toward the north confirm the north-to-south sediment transport direction surmised from the regional bathymetric compilation.

The igneous basement rocks recovered comprise a single plagioclase olivine clinopyroxene phyric basalt unit, the chemistry of which is clearly more arc-like than that of any of the units sampled at Site 834. The presence of lithologies with arc signatures, both in the basement and in the overlying volcaniclastic deposits, confirms the importance of this type of volcanism in the generation of the floor of the western Lau Basin. The age of the basement at Site 835 is 3.4 Ma, corresponding to the earliest part of the 2' seafloor spreading magnetic anomaly. This is younger than most predictions of basin age at this longitude, with the consequence that, should normal spreading have created the remaining floor to the east, the spreading rate must be significantly higher than previous models predicted. An approximate half-spreading rate would have to be at least 48 mm/yr compared to the present-day rate of less than 30 mm/yr. Nevertheless, it is unlikely that the western Lau Basin formed by "normal" seafloor spreading or, indeed, formed entirely of MORB-like basaltic crust. The youthful Site 835 basement, the discontinuity of the magnetic "striping" in the Lau Basin, the mantle source for the Site 835 basalts being different from a MORB source, and the proximally deposited epiclastics cored shed further doubt on this scenario. The source for the volcaniclastics could have been the Tofua/Tonga Arc, the Lau Ridge, or sites within the developing basin. Although andesitic basalt volcanism of the Lau Ridge Korobasaga Group (5-3.5 Ma, Cole et. al., 1985) was in decline at the time of formation of the Site 835 basement, this still represents a possible candidate as a source for the clastic sediment. However, the distance between the axis of the Lau Ridge and Site 835 is now approximately 160 km, and contrasts with that between Site 835 and the restored 2' (3.4 Ma) position of the proto-Tofua/Tonga Arc (about 60 km). This may preclude the Lau Ridge contribution, or suggest that intrabasin arc volcanism is a more plausible source for the volcanic sediments.

Site 836

The principal objective of Site 836 was to determine of the nature of the basement rock and to deduce its mantle-source characteristics and petrogenetic history. In addition, we hoped that the dating of the sedimentary cover and the assessment of evolutionary trends using biostratigraphic data would pinpoint a minimum age of basement formation. This age would be crucial for the testing of models of crustal formation in the central Lau Basin.

Site 836, located in Basin 836, was selected on the basis of inconclusive seismic reflection profiles, although support for suggestions of a significant sediment thickness came from 3.5 kHz seismic profiles. Coring success at Site 836 was limited due to (1) a restricted sedimentary sequence only 20 m thick, and (2) operational difficulties involving the drilling of fractured and relatively unaltered young basalt. After only 58 m of total penetration, it was decided to stop coring at the site and that efforts should be diverted to obtain the site objectives at one of the alternate locations. Trace-and minor-element chemistry of the igneous rocks indicates that they consisted of basalts and andesitic hyaloclastite, the andesitic hyaloclastite being more evolved than the igneous lithologies cored at Sites 834 and 835. The rapidly deposited volcaniclastic sediments immediately overlying the "basement" have similar relatively SiO_2-rich compositions, and these are overlain by hemipelagic deposits with subordinate interspersed volcanic glass. The middle Pleistocene age for foraminifers and calcareous nannofossils contained in the lowermost sediments is consistent with the paleomagnetic determination that the cored sediments lie entirely within the Brunhes Chron; provisionally, the site may mark the oldest crust generated at the Eastern Lau spreading center. The thin (20 m) sediment cover at the site suggests that scour and sediment removal associated with bottom-water currents may have occurred, situated as it is in a narrow north-northeast-south-southwest basinal trough.

Site 837

The principal objectives for Site 837 were similar to those for Site 836, since we had limited success at that site. Regrettably, at Site 837, we were again unable to successfully core a thick (>200 m) basement section. We were successful, however, in the dating of the basement by the microfossil assemblage of the overlying sediment, and thus provided information crucial for timing of backarc spreading models. The integration of these data with those from Sites 836, 838 and 839 provides a powerful closely spaced dataset with which to test proposals regarding ridge jumps, ridge migration, and the initiation of the Eastern Lau spreading center.

Deep penetration into basement was not possible at Site 837 due to unstable hole conditions. The basement rock cored at this site consists of basaltic andesites, approximately straddling the compositional fields of N-MORB and those analyses available for Tonga-Kermadec Arc volcanics. The upper sedimentary unit of nannofossil oozes overlies a sequence of thick, locally derived vitric turbidites. Rhyodacitic shards in the sediments are abundant but are from an unknown source. The age of the lowermost sediments is late Pliocene, and these immediately overlie the basaltic andesite. The combination of paleomagnetics and biostratigraphy provides an age estimate of between 2 and 1.8 Ma for the basement. Sites 836 and 837 are separated across strike by a distance of around 20-25 km, and have youngest basement ages of 0.7 and 2.1 Ma respectively. If the basin floor has formed by a process of "normal" seafloor crustal accretion, an average half-spreading rate of 14 mm/yr has prevailed--not dissimilar to the rates recognized at the Eastern Lau spreading center.

Site 838

The principal objectives for Site 838 were a repeat of those for Sites 836 and 837. In particular, a deep penetration (>200 m) of the volcanic basement section was the intended goal. A thicker than anticipated sedimentary section was encountered, the base of which was not reached. A number of small andesitic clasts were recovered from breccias and very coarse clastic layers in the overlying sediment section. They have compositional affinities to lavas erupted from the active Tonga and Kermadec arcs. A late Pliocene age was determined for the deepest sediments sampled, which comprise extensive mass-flow deposits consisting of gravels, mixed andesitic and pumiceous conglomerates, vitric sandstones, and siltstones. These sediments suggest a proximal source. Turbidites overlain by nannofossil ooze in the upper units indicate a restoration of a more stable depositional system by theearly Pleistocene. As was also demonstrated at Site 839, the transition from high-energy sedimentation conditions (as shown by the coarse clastic sediments) to pelagic-dominated sedimentation during the early Pleistocene may coincide with the establishment of true seafloor spreading conditions to the east at the Eastern Lau spreading center. The northward-dipping floor of the linear, north-northeast-south-southwest basin where Site 838 is located indicates a sediment-transport direction toward Site 839 (north-northeast).

Site 839

The prime objectives for Site 839 remained the same as for tprevious Sites 836, 837, and 838: to obtain a deep penetration of the basement section, to identify the composition and affinities of the volcanics both in the basement and in the volcaniclastics, to determine the age of the initial formation of the basin, and to assess the history of basin fill and its correlation with that of adjacent sites.

All of the objectives outstanding from Sites 836, 837, and 838 in the central Lau Basin were successfully attained at Site 839. Basement age was determined, and the recovery of 283.11 m of basaltic basement revealed a magma lineage having the strongest affinities to the island-arc tholeiitic series of any of the Leg 135 backarc sites. Olivine-phyric basalts, interleaved with two-pyroxene andesitic flows, make up the lower volcanic section. Some units have very primitive characteristics, and may represent near parental magmas for some of the arc-like volcanics sampled from other Leg 135 sites. The volcanic basement is overlain by 214.15 m of oozes, vitric turbidites, and volcanic gravels. The oldest sediments recovered are of late Pliocene age (1.9-2.2 Ma), comparable with the oldest sediments at Site 837. Site 837, however, lies 20 km west of the position of Site 839 if projected along strike, and would thus have a predicted age up to 1 Ma older than that at Site 839 if the crust at both sites had formed by seafloor spreading from the same spreading center. Sediments at Site 839 are predominantly oozes in the uppermost unit, but the central section is dominated by volcaniclastics composed of basaltic andesite and andesite fragments, as well as siliceous pumice.

During late Pliocene extensional deformation, basement block faulting resulted in the development of a northwest-tilted half-graben, which was subsequently buried with onlapping mixed volcanic gravels, vitric sands, and silts with nannofossil clays. These rapidly deposited units were eventually overlain by latest Pliocene and Pleistocene clayey nannofossil oozes and silts in pelagic- and hemipelagic-dominated sequences. The present northwest dip of the seafloor and uppermost units suggests that recent extensional deformation has affected the basin.

Site 840

The objectives at Site 840 were addressed in three holes which collectively penetrated a total of 597.2 mbsf, with a recovery of 176.17 m, (29.5%). One of the principal objectives for this site was to be able to identify the regional seismostratigraphic unconformity (Horizon "A") recorded on seismic data throughout the Tonga platform. This we successfully achieved, not as we expected on biostratigraphic, lithostratigraphic, or structural criteria, but on variations in physical properties and downhole-logging measurements. A marked increase in the average velocity at about 383 mbsf correlates with a drop in total carbonate percentage from about 30% to 40% to almost zero, and a discrete zone of significant smectitic alteration of the vitric sandstones and siltstones. We believe that this corresponds to the 400-420-mbsf level of Horizon "A" on seismic reflection profiles as predicted using sonobuoy velocities.

It had been expected that the main sediment types to be cored at Site 840 would be a platform carbonate section with lesser amounts of volcaniclastic material. We cored mainly Miocene turbidites with a very large contribution of volcaniclastic sediments. The sediment textures, and the numerous relatively thin turbidites, suggested that the site was located on the distal end of sediment deposits derived from some former volcanic edifice on the Lau Ridge. The lowermost sediments comprise volcaniclastic breccia and conglomerate which fine upward to turbiditic vitric sandstones, interpreted as indicating the transition from a proximal to a more distal source. This downward coarsening of the sediment suggests either that volcanic activity at the source had diminished with time and the supply of sediments was decreased or that the locus of volcanism had retreated westward thereby diminishing the gradient to the depocenters.

The Miocene sediment-accumulation rate varied from an average of 357 mm/k.y. in the depth range 320 to 570 mbsf to an average rate of 820 mm/k.y. in the depth range 101 to 265 mbsf. These high rates reflect the large volumes of volcaniclastic sediments being supplied and must reflect the high rate of volcanic eruptive activity.

A probable biostratigraphic hiatus of approximately 1 Ma lies between 95 and 101 mbsf, and the decrease in sedimentation rates reflects this in a sharp precursor decrease in sediment accumulation. The Pliocene and younger sedimentation rate is markedly decreased relative to the Miocene; between 95 and 101 mbsf it is 10 mm/k.y. The rate increases to 50 mm/k.y. between 24 and 95 mbsf and then decrease again, above 24 mbsf to 14 mm/k.y. The sharp decrease in sedimentation rate for the early Pliocene is not surprising, as the present evidence indicates that the first stages of breakup of the crust to form the Lau Basin must have been at about 5.6 Ma. It is speculative to suggest that the hiatus observed has any bearing on this timing of the beginning of rifting, but it could reflect thermally driven uparching at the onset of crustal rifting.

Paleomagnetic data below this hiatus show a well-behaved agreement with the late Miocene geomagnetic reversal history down to the top of Chron 4 (6.7 Ma, 521.7 mbsf), and the magnetic stratigraphy confirms the rapid volcaniclastic sedimentation in the late Miocene, ranging from 148 to 213 m/Ma. Paleomagnetic data recovered from oriented APC cores in the upper part of the Site 840 section indicated a $21° \pm 11°$ clockwise rotation of the Tonga Arc with respect to oriented sections in the western Lau Basin.

Site 841

The objectives for Site 841 were addressed by three holes that penetetrated to 834.2 mbsf (mbsf). The drilling program met the objectives for the site, which were to identify the basement material and its age, to determine the stratigraphy and lithologies of the sedimentary sequence, to investigate the structures of the forearc slope, and to sample and analyze fluids in the crust.

The major discovery was that the basement rocks under this part of the forearc comprise a dacitic volcanic complex of uncertain age but are overlain, on a fault contact, by upper Eocene shallow-water carbonates. The dacitic assemblage is characterized by a very high silica content (76%-80%) but very low potassium content (0.4%-1.6% K_2O) for that level of silica. This is a common feature of silicic rocks of intra-oceanic-arc systems. The volcanic-rock series includes dacitic, dacitic tuffs, lapilli tuffs, flow breccias, and welded tuffs. The best estimate is that these rocks formed subaerially or in a very shallow- water environment. A consideration of plate-tectonic evolution of the southwestern Pacific since the late Mesozoic offers the interesting, but highly speculative, possibility that these rocks may have some petrologic relationship to rhyolitic rocks drilled on the Lord Howe Rise at

DSDP Site 207. Apart from the great distance of present separation, which is minimalized once post-Eocene crust is accounted for, there is an apparent age gap. The Lord Howe Rise rocks have been radiometrically dated as 93.7 ± 1.2 Ma and are overlain by Maestrichtian sediments. There is no reliable age for the Site 841 dacites other than that a major low-angle fault zone separates them from upper Eocene rocks.

The dacitic complex was drilled into at a depth of about 5400 mbsf. Inasmuch as all indications are that it formed very near or above sea level, there has been a remarkable foundering of the crust at this site since the beginning of Cenozoic time. If this dacitic material initially formed as part of the present Tonga Ridge system, then there has been considerable tectonic erosion of the deep levels of the forearc crust during Cenozoic plate subduction into the Tonga Trench. If it is a far-traveled exotic terrane, then some of this subsidence may have been due to dismembering by other geometric configurations of tectonic stresses.

The presence of intrusive material in forearc sedimentary accumulations is very unusual, although not without precedent, having been found in the Mariana forearc on ODP Leg 125, Site 781, where a Pliocene or younger basalt flow or sill was encountered. Site 841 cored nine separate basaltic andesite to andesite units in the Miocene sediments. An intrusive relationship was indicated by chilled margins and by hyaloclastite breccias on the igneous rocks and indurated sediments at the contact. These intrusive layers may have given rise to steepened thermal gradients that are expressed as a downward increase in low-grade metamorphic mineral assemblages from clays to zeolites to prehnite followed downward by a sharp inversion to unmetamorphosed sediments.

Interstitial waters from the forearc sediments proved unusual in that, beginning with the upper Miocene sediments at 171.3 mbsf, there is an increase in calcium and chloride that is associated with a decrease in magnesium, potassium, and sodium. These unusual waters are attributed to a zone of reaction between 250 and 640 mbsf, below which these relative concentrations are reversed. These trends are opposite to what is usually observed in seawater/basalt interaction. In this reaction zone, the pore-water chemistry is some of the most intensively modified pore water of seawater origin yet sampled by DSDP/ODP drilling. Only three other sites with similar fluid chemistry have been found: Sites 792 and 793 in the Izu-Bonin forearc, and Site 802 in the deep-sea Central Mariana Basin. At Site 841, the $CaCl_2$ brine probably is due to the combined effects of high rates of sedimentation that causes diminished diffusive exchange with the overlying ocean water, and the chemical exchange with the abundant supply of volcanogenic material.

There was only minor evidence for sulfide mineralization at the other drill sites, but Site 841 was distinctive in having several zones of sulfide minerals, mainly fine-grained pyrite but also minor pyrrhotite, chalcopyrite, and marcasite. These were commonly dispersed in zones of kaolinitic clay typically associated with brecciated rhyolitic rocks.

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FIGURE CAPTIONS

Figure 1. Regional setting for Leg 135 drill sites showing the major geologic features of the Tonga Trench and Lau Basin system. Site 203, drilled during the Deep Sea Drilling Project, is also shown. Z is Zephyr Shoal. Islands shown are as follows: T = Tongatapu, E = 'Eua, V = Vavau, NF = Niua Fo'ou, and U = Upolu. Locations of the Central Lau and Eastern Lau spreading centres, Valu Fa Ridge, and Mangatolu Triple Junction are shown as CLSC, ELSC, VF, and MTJ, respectively. Depths are in kilometres.

Figure 2. Schematic west-east cross-section across the Lau Ridge,Lau Basin, Tofua Arc, and Tonga Ridge. Depth and vertical dimension are not to scale, but horizontal dimension is to scale.

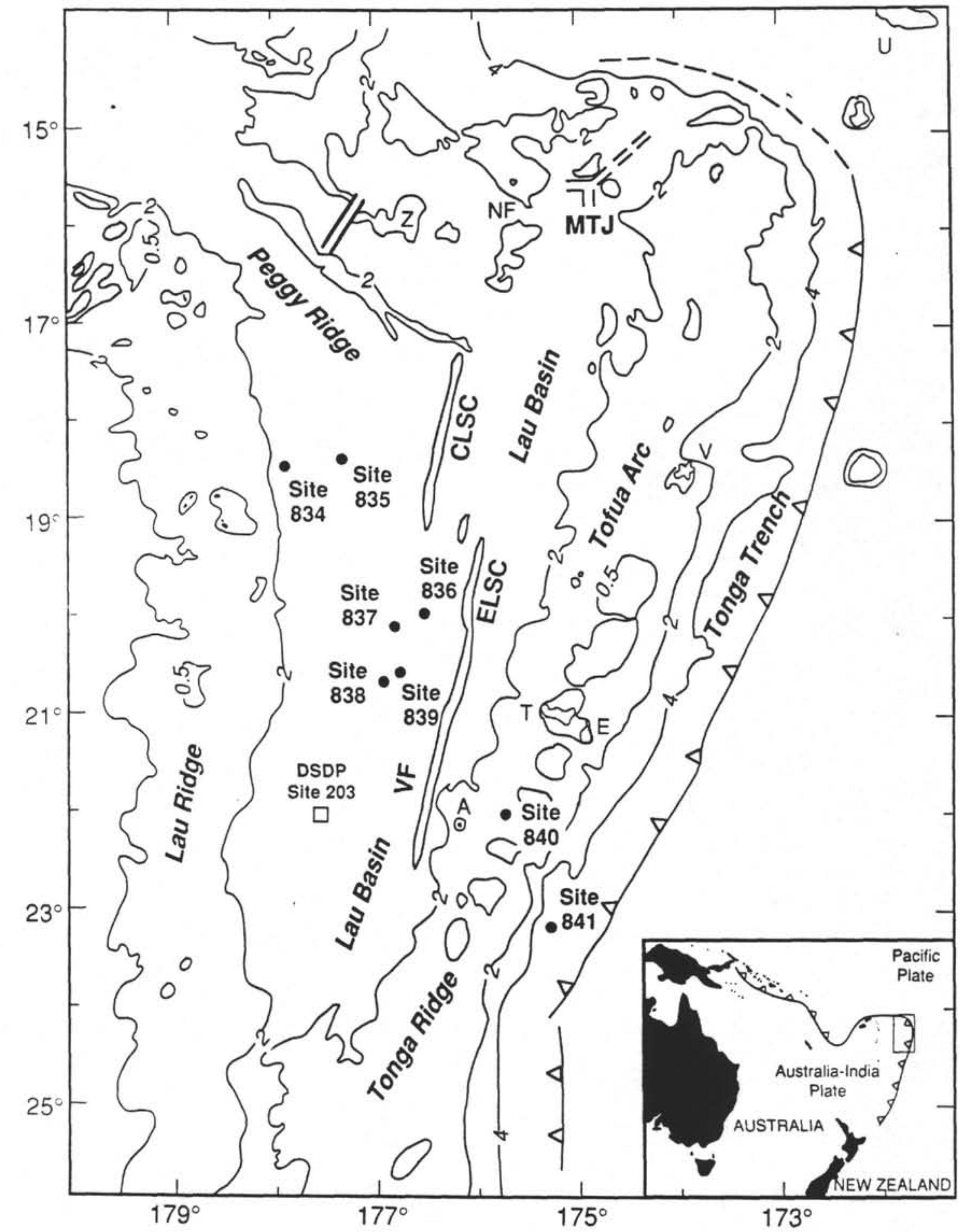

15°
17°
19°
21°
23°
25°
179°
177°
175°
173°
U
Z
NF
MTJ
Peggy Ridge
CLSC
Lau Basin
Tofua Arc
V
Tonga Trench
Site 834
Site 835
Site 836
Site 837
Site 838
Site 839
ELSC
T
E
Lau Ridge
DSDP Site 203
VF
A
Site 840
Site 841
Lau Basin
Tonga Ridge
Pacific Plate
Australia-India Plate
AUSTRALIA
NEW ZEALAND

Figure 1.

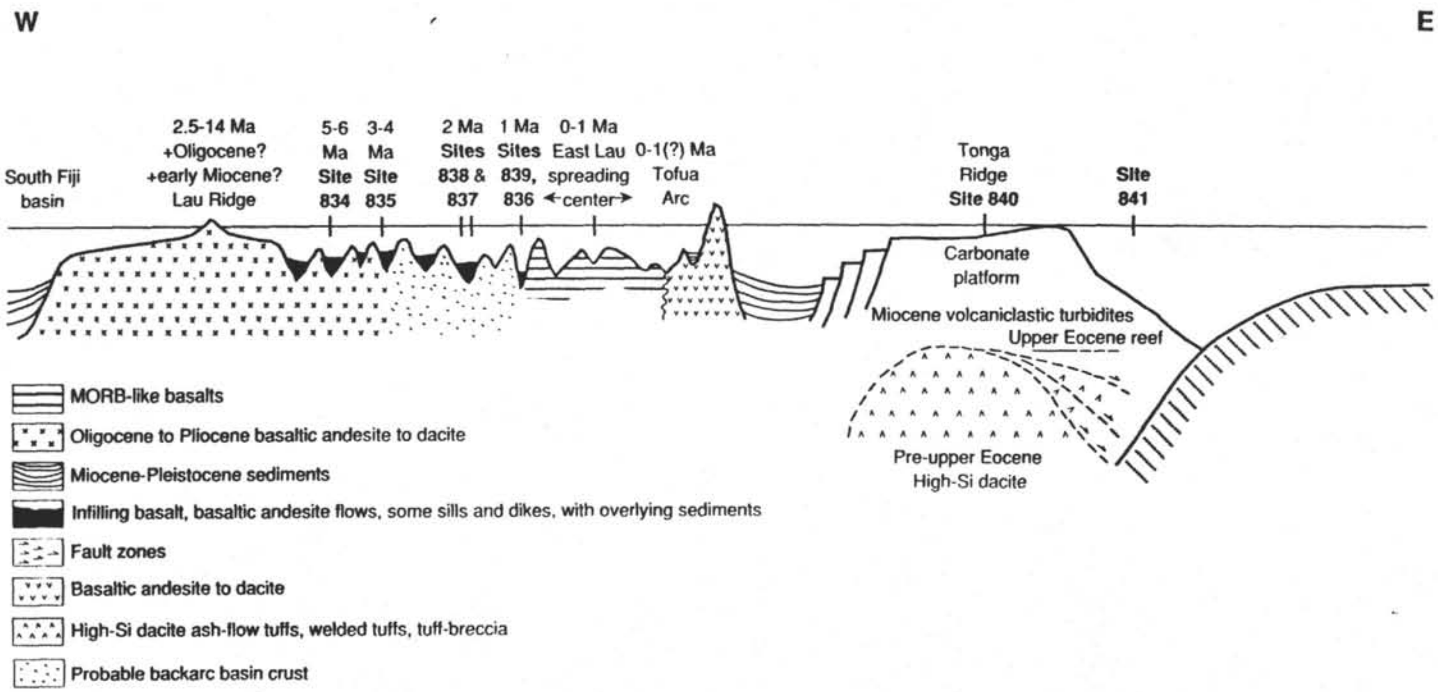

W
E
South Fiji basin
2.5-14 Ma +Oligocene? +early Miocene? Lau Ridge
5-6 Ma Site 834
3-4 Ma Site 835
2 Ma Sites 838 & 837
1 Ma Sites 839, 836
0-1 Ma East Lau spreading center
0-1(?) Ma Tofua Arc
Tonga Ridge Site 840
Site 841
Carbonate platform
Miocene volcaniclastic turbidites
Upper Eocene reef
Pre-upper Eocene High-Si dacite
MORB-like basalts
Oligocene to Pliocene basaltic andesite to dacite
Miocene-Pleistocene sediments
Infilling basalt, basaltic andesite flows, some sills and dikes, with overlying sediments
Fault zones
Basaltic andesite to dacite
High-Si dacite ash-flow tuffs, welded tuffs, tuff-breccia
Probable backarc basin crust

Figure 2.

OPERATIONS SUMMARY

The ODP Operations and Engineering personnel aboard *JOIDES Resolution* for Leg 135 were:

Operations Superintendent: Gene Pollard

OVERVIEW

Leg 135 of the Ocean Drilling Program investigated eight sites in a northwest to southeast transect across the Lau Basin and Tonga Trench, in an area south and west of the Tonga Island chain. The objective was to understand the evolution of the Lau Basin by sampling the oldest backarc-basin crust in the west, younger crust near the presently active axial ridge and the arc-forearc area of the Tonga Ridge. During the course of the leg, 18 holes were spudded at 8 sites, and 3356.0 m of sediment and basement was cored with 1248.50 m recovered. Sites 834 (LG-2) and 835 (LG-7) were in Fijian territorial waters, and Sites 836 (LG-10), 837 (LG-9), 838 (LG-9A), 839 (LG-10A), 840 (LG-3) and 841 (LG-6A) were in Tongan waters.

Site 834 (LG-2) (Holes 834A/B) is located in the oldest known backarc basin crust on the west side of the Lau Basin close to the Lau Ridge. The objective was to determine the temporal and compositional variation of arc volcanism; document the uplift and subsidence history of the forearc; identify the age, composition, physical properties, and fluid geochemistry of the outer forearc basement; and conduct paleomagnetic studies of the forearc basement. A total of 59.8 m was drilled and 525.0 m was cored with the APC/XCB/MDCB and RCB coring systems in 2 holes, with 218.64 m of core recovered for 41.65% recovery.

Site 835 (LG-7) (Holes 835A/B) is located about 60 km east of LG-2 in an intermediate-age backarc site and had similar objectives, with the specific goals of assessing the nature and extent of hydrothermal activity, and the metallogenesis and igneous-basement-rock chemistry in the neovolcanic zone. A total of 133.2 m was drilled and 209.3 m was cored with the APC/XCB and RCB coring systems in 2 holes, with 168.74 m of core recovered for 80.62% recovery.

Site 836 (LG-10) (Holes 836A/B) is located in the central Lau Basin on relatively young crust that formed from a different magma system/spreading center at a propagating rift about 10 km east of the site. LG-10 had similar objectives to LG-2 and -7. A total of 13.5 m was drilled and 83.0 m was cored with the APC/XCB and RCB coring systems in 2 holes, with 41.46 m of core recovered for 49.95% recovery.

Site 837 (LG-9) (Holes 837A/B) is located about 5 km southwest of LG-10 in an intermediate-age backarc site and had similar objectives to LG-2 and -7, with the specific goal of testing the hypothesis that there has been a ridge jump with different magma cells/spreading centers involved in the generation of the adjacent ridge segments. A total of 65.0 m was drilled and 118.6 m was cored with the APC/XCB and RCB coring systems in 2 holes, with 92.97 m of core recovered for 78.39% recovery.

Site 838 (LG-9A) (Holes 838A/B) is located about 60 km south of LG-9 in an intermediate-age backarc site and had similar objectives to LG-2, -7, -10, and -9, with the specific goal of testing the hypothesis that there has been a ridge jump with different magma cells/spreading centers involved in the generation of the adjacent ridge segments. A total of 144.0 m was drilled and 269.0 m was cored with the APC/XCB and RCB coring systems in 2 holes, with 100.17 m of core recovered for 37.24% recovery.

Site 839 (LG-10A) (Holes 839A/B) is located about 60 km south of LG-10 in an intermediate-age backarc site and had similar objectives to LG-2, -7, -10, and -9, with the specific goal of testing the hypothesis that there has been a ridge jump with different magma cells/spreading centers involved in the generation of the adjacent ridge segments. A total of

160.6 m was drilled and 574.8 m was cored with the APC/XCB and RCB coring systems in 2 holes with 123.21 m of core recovered for 21.44% recovery.

Site 840 (LG-3) (Holes 840A/B/C) had the objective of penetrating the shallow platformal sequence of the Tonga Ridge to permit sampling a regional seismic unconformity (the "A" horizon), enable an accurate assessment of uplift and subsidence history, and correlate basin and regional tectonics. In the interest of safety, an additional seismic profile was taken prior to operations to evaluate possible structural closures in the shallow seismic stratigraphy. A total of 136.0 m was drilled and 725.3 m was cored with the APC/XCB coring system in 3 holes, with 247.78 m of core recovered for 34.16% recovery.

Site 841 (LG-6A) (Holes 841A/B/C) lies at the trench-slope break where the distal forearc basin sediments thin significantly. LG-6A had the objective of recovering sediment overlying in-situ forearc basement and to characterize and determine the age of the basement, estimate uplift/subsidence history of the forearc and understand the volcanic history of the Tonga Ridge. A total of 944.8 m was drilled and 851.0 m was cored with the APC/XCB and RCB coring systems in 3 holes with 255.50 m of core recovered for 30.02% recovery.

Accomplishments

1. Used the APC to successfully spot core XCB sections with poor recovery, and the APC had no equipment failures with up to 150,000 lb overpull and several drillovers. The missing sections proved to be unconsolidated volcanic silt, sand, gravel, and ash.

2. The XCB six-tooth diamond impregnated bits were used to core up to 35 m into basalt, providing a time-saving alternative to using another RCB hole to obtain basement samples.

3. Tested the motor-driven core barrel (MDCB-134) in Holes 834A and 839A. Bad hole conditions prevented further testing, but both sediment and basalt were cored.

4. Three rewelded 9-7/8-in. RBI four-cone insert bits were run in hard basalt drilling, with no failures noted.

5. Tested a kevlar/aramid fiber core-catcher sock designed to recover soft formations cored with the XCB. The sock proved moderately successful in recovering unconsolidated sand and gravel with the XCB and RCB.

6. Despite sloughing unconsolidated volcanic material (especially in formations younger than 2 m.y.), no bottom-hole assemblies were lost in four severe stuck-pipe incidents. The hydrolex jars were lost in four severe stuck-pipe incidents. The hydrolex jars were used to free two stuck BHAs; one MBR failed, and one MBR was released intentionally to free the BHA. Frequent use of mud sweeps and high circulating rates were required to keep most holes open.

7. Fabricated the reentry cone to be run on the drill-in casing (DIC-135), but no holes were cased.

OPERATIONS REPORT

Leg 135 of the Ocean Drilling Program was dedicated to understanding the evolution of the Lau Basin-Tonga Arc and forearc and gaining a better understanding of backarc spreading, island-arc volcanism, accretion/subduction processes and backarc extension/ compression. Sites 834, 835, and 836 addressed backarc-basin targets and Sites 840 and 841 addressed arc-platform and forearc sites. Specific objectives were to determine the temporal and compositional variation of arc volcanism; document the uplift and subsidence history of the forearc; identify the age, composition, physical properties, and fluid geochemistry of the outer forearc basement; and conduct paleomagnetic studies of the forearc basement.

The approved coring plan in general was to APC core to refusal, XCB core to basement (or the approved depth), and then RCB core to the approved depth and log. Logs were scheduled for all the sites and consisted of the sonic/induction/density/gamma ray, geochemical, formation micro-scanner and German digital borehole televiewer. The magnetometer/ susceptibility/tool could not be run as planned because the tool was sent to Singapore. A bridal was not available for the Dual LaterLog (in the event high resistances were noted on the Dual Induction Log), but a bridle was made just in case. A reentry cone/casing site and a drill-in casing (DIC) site was planned. A drill-string packer was planned forSite 836.

Port Call

LEG 135 began officially when the *JOIDES Resolution* dropped anchor in Suva Harbor anchorage, Fiji, at 0700L 17 Dec. 1990, because dock space was not available. Fijian Health, Customs, and Immigration authorities cleared the ship at 1100L, and the crew change was done by tug at 1130L. The hoisting equipment inspection was started by UDI. The ship was moved to the King's Wharf dock at 1900L, with the first line ashore at 2000L. Loading and offloading ocean and air freight and normal port-call activities started 18 Dec. The lab and quarters air conditioning was shut down for 11 hr 19 Dec. to reroute the piping over the Cyberex power unit, and the high heat and humidity are blamed for numerous subsequent computer problems. A DEC computer engineer replaced the disc controller to the JAXVAX. Eng/Ops computer upgrading was completed. Fueling started at 0215L 20 Dec. and 1421.41 metric tons of fuel was loaded in 14 hr. Ship tours were conducted. Health officials refused to allow discharge of two boxes of scrap plastic core liner, so the scrap was kept on board. The last line was in at 2000L 20 Dec. and the sea voyage began at 2048L.

A decision was made to maintain Fijian time and date as ship (local "L") time for the leg until the sea voyage into Samoa, when the international date/time line was actually crossed. All depths refer to "meters below rig floor" ("mbrf" or "m") unless specifically identified as "meters below sea floor" (mbsf).

Sea Voyage from Suva, Fiji, to Site 834 (LG-2)

The sea voyage from Suva, Fiji, to Site 834 (LG-2) covered 210 nmi in 18.5 hr at 11.4 kt average. A seismic survey was run over the LG-2 site, covering 33 nmi in 5.8 hr at 5.7 kt average. A Benthos model 210 beacon, 15.0 kHz, S/N 43469, was dropped at 2035L 21 Dec.

Hole 834A

An APC/XCB bottom hole assembly (BHA) was made-up consisting of an 11-7/16-in. Security C-3 four-cone tungsten carbide (TnC) core bit, seal bore drill collar (SBDC), motor driven core barrel (MDCB) subs, monel drill collar (MDC), 6 ea. 8-1/4-in. drill collars (DC), Hydrolex jars, and 1 ea. 7-1/4-in. DC. The BHA was inspected while RIH, and tubulars were strapped and drifted. Hole 834A (Site LG-2) was spudded at 0805L 22 Dec. 1990, at lat. 18°34.058'S and long. 177°51.735'W. The estimated water depth from the precision depth recorder (PDR) was 2705.4 mbrf. Spud Core 135-834A-1H was shot at 2701 mbrf and recovered 7.64 m; therefore, the seafloor (mud line) was at 2702.9 mbrf by drill-pipe measurement (DPM). Continuous APC Cores 135-834A-1H to 9H were taken from 2702.9 to 2786.5 mbrf (0.0-83.6 mbsf), with 83.6 m cored and 86.02 m recovered for 102.89% recovery. The formation was brown nannofossil ooze and vitric ash. Cores 4H to 9H were oriented, and a WSTP heat flow measurement was taken after core 5H. APC coring was terminated when overpull increased from 10,000 lb on Core 6-8H to 150,000 lb on Core 9H. The fact that the APC-129 coring equipment was not damaged is a tribute to a continuing program of component improvements.

Continuous XCB Cores 135-834A-10X to 18X and 20X were taken from 2786.5 to 2852.4 mbrf (83.6-149.5 mbsf), with 65.9 m cored and 27.15 m recovered for 41.20% recovery. The formation was brown nannofossil ooze and vitric ash to 112 mbsf (Core 12X). Basalt was encountered at 112 mbsf; however, XCB coring was continued because recovery was good, and the basalt was believed to be a thin sill overlying another 190 m of soft sediment. The first of two-hard formation XCB six-tooth TnC core bits was destroyed by overheating in the basalt, but the second bit cut 37 m of mostly basalt by increasing the pump rate from 225 to 350 gpm. Coring parameters were 175-475 gpm at 250-2000 psi, 10-15,000 lbs WOB and 60-70 RPM at 200 amps.

The MDCB was tested on Core 19N at 144.6 mbsf, but it failed to turn during a 20-min. test run. It is theorized that the thruster section jumped the collet while free falling to bottom, and the core barrel scoped out before reaching bottom; therefore, the seal section did not pack-off below the motor. Rig pump pressure eventually forced the thruster section down until the motor seals engaged the landing saver sub, resulting in a pressure increase from 2150 to 3000 psi. However, the bit was buried (with the hydraulic force of high pump pressure on it) and could not overcome the resistance required to start rotation. The test was terminated when the mud-pump safety valve started leaking-off. Paint marks showed that the bit and motor had not turned.

A new Rochester coax cable for the Colmec TV and Mesotech sonar had been installed on Leg 134, but it had not been detorqued. While POOH with the APC BHA, the new coax was run in 2704-m water depth with a 1250-lb load to detorque it and a 440 V test load to detect any faults. The cable ran smoothly and was detorqued without any problems.

Hole 834B

A 9-7/8-in. RBI C-4 four-cone bit (with legs rewelded by RBI), RCB BHA and Hydrolex jars were run to the sea floor, and Hole 834B (LG-2) was spudded at 0345L 24 Dec. 1990. Punch Core 135-834B-1R was taken to confirm the water depth, which was 2699 mbrf DPM-DES. The 9-7/8-in. hole was washed from 2699.1 to 2767.3 (0.0-68.2 mbsf) with WSTP heat flows at 30.1, 48.9, and 68.2 mbsf. RCB Cores 2R to 34R were taken from 2767.3 to 2989.9

mbrf (68.2-290.8 mbsf), with 222.6 m cored and 71.67 m recovered. Coring parameters were 325-500 gpm at 400-1200 psi, 15-25K WOB, and 50-80 rpm at 250-400 amps torque. Basalt was encountered at 112 mbsf, and high torque and drag from ledges of fractured glassy basalt and boulders required reaming and rereaming each connection and pumping a mud sweep. Small basalt cobbles and fracture wedges jammed the hard-rock core catcher, often reducing recovery, and half cores were cut through most of the section to improve recovery. A 250-m basement penetration (362 mbsf) was the goal; therefore, the 39-1/4 hr on the bit precluded completing the hole with that bit at 3.0 m/hr. Coring was terminated (due to bit hours) to make a bit change.

A free fall funnel (FFF) was dropped at 1135L 27 Dec. nit no. 2 cleared the rotary at 1710L and was graded: teeth 2, bearings 6, 1/16-in. out of gage, one cone seal had failed, and 1/8-in. gage wear on the skirt. Gage wear was tolerated well with no gage buttons lost. This 9-7/8-in. RBI C-4 bit (S/N BA311) had been rewelded by RBI in the cone center, and visual examination revealed no cracks.

The search for the FFF required 4:04 hr using only the Colmec TV camera. The Mesotech sonar was not run because one of the two sonar tools had galled threads on the pressure case and some telemetry problems. A new backup telemetry pod was uncalibrated (precluding use with the other TV); therefore, the sonar was the only backup system working at the time. The new Rochester coax cable performed well on this hole with no problems noted.

RCB coring continued with Cores 35R to 59R from 2989.9 to 3134.4 mbrf (290.8-435.3 mbsf), with 144.5 m cored and 24.56 m recovered (17.00% recovery). The formation was altered basalt with vitric ash and siltstone. The basement-penetration target was exceeded, and coring was terminated to save time for additional sites. Coring parameters were 500 gpm at 1000 psi, 15-20K WOB, and 55-70 rpm at 3-500 amps torque. Ledges, boulders, and loose vitric sand caused erratic torque going down, with reaming and rereaming required for each core. Half cores were cut to improve recovery, and mud sweeps were circulated as required. Coring techniques and hole conditions were the same as on the initial bit run. The total for Hole 834B was 59.8 m washed, 375.5 m, cored and 105.47 m recovered (28.09% recovery). After conditioning the hole for logs with a short trip, the bit (a 9-7/8-in. RBI C-4 S/N BA246 with 12 rotating hr) was dropped with the hydraulic bit release (HBR). The bit was set on bottom with 10K WOB, and the pressure was increased to 2800 psi, before picking up the BHA and instantly releasing the bit.

The open end pipe was pulled to 74.6 mbsf, and logs were run as follows:

Run No. 1: "Quad Combo" Induction/Density/Sonic/Caliper/Gamma Ray (DITE/HLDT/SDT/MCDG/NGTC). The log found bottom 3.5 m above the driller's TD and required 3-1/4 hr to run.

Run No. 2: Geochemical/Aluminum Clay Tool/Gamma Ray (GSTA/HLDT/ACTC/CNTG/NGTC). The log found bottom 1.0 m above the driller's TD and required 6-1/2 hr to run.

Run No. 3: Formation Microscanner/Gamma Ray (FMS/NGTC). The log found bottom 0.6 m above the driller's TD and required 4-1/4 hr to run.

Run No. 4: German Digital Borehole Televiewer (BHTV). The initial attempt to run the digital BHTV was aborted due to a power-supply failure and required 2:45 hr. The older analog BHTV was run and found bottom 170 m off bottom (hung-up on a ledge). The log required 3:50 hr to run.

Log quality was hampered by numerous ledges and cavities in the basalt. The hole was left full of seawater, and the BHA cleared the sea-floor at 0425L 31 Dec., and cleared the rotary at 0840L.

Site 835 (LG-7)

The transit from Site 834 (LG-2) to Site (LG-7) started at 0900L 31 Dec., with a 2.2-nmi post site seismic survey west of Site LG-2, which required 1.0 hr at 2.2 kt average. The 24-nmi transit to Site 835 (LG-7) required 2.3 hr at an average speed of 10.4 kt. A 33-nmi pre-site seismic survey was run over the site in 5.7 hr at an average speed of 5.8 kt. A Datasonics model 354B commandable recall beacon, 14.0 kHz, S/N 611, was dropped at 1716L 31 Dec., 1990. A beacon motor housing (machined on the ship out of shipboard aluminum stock), a salvaged release motor assembly and a spare electronics section were combined to make the recall beacon. The two recall beacons on the ship at the end of Leg 134 were sent in for repairs. Benthos non-recallable beacons were available as a backup.

Hole 835A

An 11-7/16-in. Security C-3 four-cone TnC insert bit (bit no. 1RR) was run with an SBDC, monel DC, 5 ea. 8-1/4-in. DC, Hydrolex jars, and 1 ea. 7-1/4-in. DC. Hole 835A (LG-7) was spudded at 0013L 1 Jan. 1991 at lat. 18°30.061'S and long. 177°18.162'W. The estimated water depth from the PDR was 2922.4 mbrf. Spud Core 135-835A-1H was shot at 2916.5 m, recovered 9.59 m, and was accepted as a mud line core; therefore, the mud line was at 2916.5 mbrf by DPM. Continuous APC Cores 135-835A-1H to 17H were taken from 2916.5 to 3071.0 mbrf (0.0-154.5 mbsf), with 154.5 m cored and 159.38 m recovered (103.16% recovery). The formation was nannofossil ooze and clay with volcanic sand and silt. Orientation surveys were taken from Cores 3H to 17H, and heat flows were taken with the WSTP at 38.0, 57.0, 76.0, 95.0, 114.0, 133.0, and 154.5 mbsf. A 2.5-m partial stroke at Core 17H ended APC coring.

XCB Core 18X was taken from 3071.0 to 3076.0 mbrf (154.5-159.5 mbsf), with 5.0 m cored and 0.69 m recovered (13.8% recovery, of which 0.2 m was in basalt). Coring was terminated due to low ROP.

The paleomagnetists detected a 30° offset in the orientation of the APC cores in Hole 834A; therefore, the mechanical orientation of the directional-survey equipment was checked. A piston-rod lock pin (ODP P/N OP4810) was found to have been deformed because the inner shear pin sub/landing sub (where the survey instrument aligns with the core) was made up too far (possibly torque from drilling-over operations on Leg 134). The inner-shear-pin sub holes were not lining up with the antispiral groove on the piston rod; therefore, the orientation of the cores had been rotated about 30° from the start of Leg 135 (affecting Cores 135-834A-4H through 9H).

Hole 835B

The ship was repositioned 20 m north of Hole 835A, and Hole 835B was spudded at 1706L 2 Jan. 1991 at lat. 18°30.050'S and long. 177°18.192'W. The PDR indicated the same water depth as at Hole 835A (2916.5 mbrf DPM), and a punch core was taken at 2910.5 to 2920.0 for verification. The first punch core was a water core; therefore, a second punch core was taken from 2920 to 2928 mbrf (Core 135-835B-1R), but only 0.19 m was recovered. The mud-line depth at Hole 835A (2916.5 mbrf DPM) was accepted. A 9-7/8-in. hole was drilled from 2928.0 to 3061.2 mbrf (144.7 mbsf). RCB cores 135-835B-2R to 7R were taken from 2916.5 to 3099.5 mbrf (144.7-183.0 mbsf) with 38.3 m cored and 8.48 m recovered (22.14% recovery). Coring parameters were 100-600 gpm at 50-1200 psi, 15-20K lb. WOB, and 60 rpm at 2-400 amps.

Pillow basalt was encountered at 142 mbsf and hard basalt at 154 mbsf. The objective was to penetrate 50 m into the basalt; however, the relatively young basalt proved to be highly unstable causing high infill rates, high torque that stalled the rotary at 500 amps, and high overpull to 70K lb Core barrel 8R was dropped; however, the hole could not be cleaned out below 3086 m (13 m off bottom) despite repeated reaming and mud sweeps. Coring was terminated, with 41 m of basalt penetration.

After conditioning the hole for logs with a short trip, the bit (a 9-7/8-in. RBI C-4 S/N BA311 with 43 rotating hr) was dropped with the hydraulic bit release (HBR). The bit was held off-bottom and released with 2800 psi. The open end pipe was pulled to 82.6 mbsf, and logs were run as follows:

Run No. 1: Formation Microscanner/Gamma Ray (FMS/NGTC). The FMS failed the surface calibration, and a backup tool was used, losing 1-1/4 hr. The log found bottom 15.0 m above the driller's TD and required 2:35 hr to run.

Run No. 2: Induction/Sonic (DITE/SDT). The log found bottom 15.0 m above the driller's TD and required 2:40 hr to run.

Run No. 3: Density/Neutron (HLDT/NGT). The log found bottom 11.5 m above the driller's TD and required 2:40 hr to run.

Log quality was hampered by numerous ledges and cavities in the basalt below 154 mbsf. The hole was left full of seawater, and the HBR cleared the seafloor at 0405L 4 Jan. and cleared the rotary at 0815L. The rebuilt Datasonics 354B beacon was turned off/on and recalled, but it did not release. The ship was maneuvered across the location confirming that the beacon would not release. The rebuilt motor housing had apparently flooded.

Site 836 (LG-10)

The track from Site 835 (LG-7) included a sea voyage to Site 836 (LG-10) for a survey, a sea voyage to Site 840 (LG-3) for a survey, and finally a transit back to Site 836. The sea voyage started at 0918L 4 Jan. with a 98.0-nmi sea voyage from Site 835 to Site 836 that required 11.8 hr at 8.3 kt average. The propulsion system was run with three skids on line producing 120 shaft rpm to reduce fuel consumption; however, the speed was reduced further by fronting seas, a wind to 24 kt and a strong fronting current.

The survey over Site 836 (LG-10) covered 19 nmi in 2.9 hr at 6.6 kt average and was run to provide better seismic definition of the proposed site. The sea voyage continued from Site 836 to Site 840 (LG-3), covering 115 nmi in 10.7 hr at 10.7 kt average. The survey over Site 840 covered 94 nmi in 14.6 hr at 6.4 kt average and was run at the request of the PPSP to provide better seismic definition of the proposed site. The sea voyage from Site 840 back to 836 covered 113 nmi in 11.7 hr at 9.7 kt average. The resurvey over Site 836 covered 32 nmi in 5.2 hr at 6.2 kt average. A Benthos model 210 beacon, 15.0 kHz, S/N 434393, was dropped at 1558L 6 Jan. 1991, initiating Hole 836A.

Hole 836A

An 11-7/16-in. Security C-3 four-cone tungsten carbide insert bit S/N 479067 (bit no. 1RR) was run with a SBDC assembly, monel DC, 5 ea. 8-1/4-in. DC, Hydrolex jars and 1 ea. 7-1/4-in. DC. Hole 836A (LG-10) was spudded at 2312L 6 Jan. 1991 at lat. 20°08.494'S and long. 176°30.008'W. The estimated water depth from the PDR was 2452.4 mbrf. The first core was a water core shot at 2450 mbrf. Spud Core 135-836A-1H was shot at 2458 m, recovered 1.24 m, and was accepted as a mu-line core; therefore, the mud-line was established at 2466.3 mbrf by DPM. Continuous APC cores 135-836A-1H to 4H were taken from 2466.3 to 2487.5 mbrf (0.0-21.2 mbsf), with 21.2 m cored and 20.71 m recovered (97.69% recovery). The formation was brown clay with loose basalt at 20.2 mbsf. APC refusal was at 21.2 mbsf. Orientation surveys were taken from cores 3H to 4H, but no heat flows could be taken with the WSTP. Coring parameters were 250 gpm at 100 psi, 5K WOB, and 35 rpm at 150-200 amps.

XCB Cores 5X to 9X were taken from 2487.5 to 2504.5 mbrf (21.2-38.2 mbsf), with 17.0 m cored and 3.65 m recovered (21.47% recovery) in basalt. Coring was terminated due to low ROP (2 m/hr), wear to a hard-formation XCB bit, and erratic torque and overpull to 30K lb. Coring parameters were 300 gpm at 1000 psi, 5-8K WOB, and 60 rpm at 150-250 amps. The bit cleared the rotary table at 1940L 7 Jan.

Hole 836B

The ship was moved 20 m south. Hole 836B (LG-10) was spudded at 0010L 8 Jan. Punch core 135-836B-1R was from 2468.5 to 2473.0 mbrf (0.0-4.5 mbsf) and recovered 4.34 m; therefore, the seafloor was estimated at 2468.5 mbrf. The 9-7/8-in. hole was washed from 2468.5 to 2526.9 mbrf (4.5-18.0 mbsf). RCB cores 135-836B-2R to 8R were taken from 2486.5 to 2526.9 mbrf (18.0-58.4 mbsf), with 44.8 m cored and 17.00 m recovered (37.95% recovery). Coring parameters were 150-375 gpm at 100-600 psi, 5-10K lb WOB, and 35-40 rpm at 150-400 amps. Unstable sloughing basalt was encountered from 2517 to 2526 mbrf, with the rotary stalling at 550 amps and overpull to 90K lb. The hole filled back in instantly despite reaming and rereaming the section and circulating mud sweeps 12 times in 4-1/2 hr. The pipe could not be worked back to TD, and hole conditions were deteriorating; therefore, coring was terminated due to bad hole conditions. RCB Core 9R was recovered with no advance (after reaming infill) and had basalt from the bottom basalt unit. Although young-basement-penetration objectives had not been met at LG-10, it was not considered prudent (with the unstable basalt section only 30 m below the top of basement) to use 4 days to set the reentry cone/casing or use the one DIC system at that point in the leg. The bit cleared the rotary at 0250L 9 Jan.

Site 837 (LG-9)

The transit from Site 836 to Site 837 (LG-9) started at 0254L 9 Jan. The 13-nmi transit to the site required 1.2 hr at an average speed of 10.8 kt. A 290-nmi pre-site seismic survey was run over the site in 5.4 hr at an average speed of 5.4 kt. A Benthos model 210 beacon, 15.0 kHz, S/N 43637, was dropped at 0850L 9 Jan. 1991.

Hole 837A

An 11-7/16-in. Security C-3 four-cone tungsten carbide insert bit, S/N 479067 (bit no. 1RR), was run with an SBDC & MDCB assembly, monel DC, 5 ea. 8-1/4-in. DC, Hydrolex jars, and 1 ea. 7-1/4-in. DC. Hole 837A (LG-9) was spudded at 1505L 9 Jan. 1991 at lat. 20°13.307'S and long. 176°49.360'W. The estimated water depth from the PDR was 2765.4 mbrf. Spud core 135-837A-1H was shot at 2762 m and recovered 7.96 m; therefore, the mud-line was established at 2763.9 mbrf by DPM. Continuous APC cores 135-837A-1H to 9H were taken from 2763.5 to 2838.5 mbrf (0.0-84.0 mbsf), with 84.0 m cored and 83.57 m recovered (99.49% recovery). The formation was brown clayey ooze, gray sandy clay, and ash.

APC refusal was at 84.0 mbsf on Core 9H. The core barrel was stuck after a partial stroke (pressure had to be bled-off) and could not be retrieved with the overshot. The overshot was sheared-off, and the pipe was POOH, ending Hole 837A. The core barrel was stuck in the SBDC and covered with loose sand. A worn shear-pin stub was also recovered. There was no apparent damage to the equipment; therefore, the core barrel apparently was stuck by the loose sand flowing up into the SBDC (and possibly also stuck by the shear pin). The loose sand also apparently prevented shearing-off the overshot. A wireline cable clamp (used while unseating the oil saver) was also dropped in the pipe after it stuck, which complicated recovery. Orientation surveys were taken from Cores 3H to 9H. WSTP heat flows were taken at 36.5, 55.5, and 74.5 mbsf. Coring parameters were 300 gpm at 200 psi, 5K WOB, and 40 rpm at 150 amps. The bit cleared the seafloor at 0455L 10 Jan. and cleared the rotary at 1110L.

Hole 837B

The ship was moved 20 m south. Hole 837B (LG-9) was spudded at 1752L 10 Jan. Punch Core 135-837B-1R was from 2760.0 to 2769.5 mbrf (0.0-5.5 mbsf) and recovered 5.34 m; therefore, the seafloor was estimated at 2764.0 mbrf. The 9-7/8-in. hole was washed from 2769.5 to 2834.5 mbrf (5.5-70.5 mbsf). RCB Cores 135-837B-2R to 7R were taken from 2834.5 to 2868.6 mbrf (70.5-104.6 mbsf), with 34.1 m and cored 3.73 m recovered (10.94% recovery). Coring parameters were 300-400 gpm at 500-2100 psi, 5-15K lb WOB, and 50 rpm at 175-300 amps. High pump pressures were noted on Cores 5R and 6R because of plugged bit nozzles. Basalt was encountered at 2834.7 m (70.7 mbsf). Unstable sloughing basalt and sand were encountered from 2848 m (84 mbsf), with the rotary stalling at 550 amps. The pipe stuck, and overpull was gradually increased, while attempting to operate the jars. At 270,000 lb overpull (650,000 lb hook load) the pipe started moving and then came free. The pipe was POOH, and the lower MBR section was found to have failed by shearing-off the dogs, which freed the pipe. The 9-7/8-in. bit, flapper valve, MBR disconnect and core barrel 8R were lost in the hole. The MBR cleared the seafloor at 0940L 11 Jan. and cleared the rotary at 1355L.

A kevlar sock core catcher, which was originally designed for the APC/XCB to improve recovery in loose sand and gravel, was tested for the first time in Cores 135-837B-1R and 2R. Core 1R, a 5.5-m punch core, recovered 5.48 m of nannofossil ooze. Core 2R, a 9.7-m core, recovered 0.95 m of basalt and clayey foraminifer chalk. The 0.3 m sock was cut and pushed 0.7 m up the core-liner tube by the 0.26 m of basalt inside the sock, but the sock trapped 0.04 m of clay inside and 0.08 m of clay above.

Site 838 (LG-9A)

The transit from Site 837 (LG-9) to Site (LG-9A) started at 1700L 11 Jan. The 28-nmi transit to Site LG-9A required 2.8 hr at an average speed of 10.0 kt. A 79-nmi pre-site seismic survey was run over Site LG-9A in 13.8 hr at an average speed of 5.7 kt. A Benthos model 210 beacon, 15.0 kHz, S/N 43678, was dropped at 0614L 12 Jan. 1991. One motor on the port shaft and two motors on the starboard shaft went down during the transit and survey, requiring a reduction in shaft speed. The ship was stopped finally from 1700-1735L to shut down the starboard shaft for repairs just prior to the survey; furthermore, the ship's speed was reduced about 0.5 kt as a result of the motor problems resulting in about 1 hr total lost time. One motor had a bad brush holder, one motor had a flashover and one motor had a short to ground in the field coils.

Hole 838A

An 11-7/16-in. Security C-3 four-cone tungsten carbide insert bit S/N 479067 (bit No. 1RR) was run with an SBDC & MDCB assembly, monel DC, 5 ea. 8-1/4-in. DC, Hydrolex jars and 1 ea. 7-1/4-in. DC. Hole 838A (LG-9A) was spudded at 1235L 12 Jan. 1991 at lat. 20°49.618'S and long. 176°53.402'W. The estimated water depth from the PDR was 2332.4 mbrf. Spud Core 135-838A-1H was shot at 2328 m and recovered 3.76 m; therefore, the mud-line was established at 2333.8 mbrf by DPM. Continuous APC Cores 135-838A-1H to 11H were taken from 2333.8 to 2432.5 mbrf (0.0-98.7 mbsf), with 98.7 m cored and 95.52 m recovered (96.78% recovery). The formation was nannofossil ooze and clay with interbedded unstable gravel and sand breccia. Frequent mud sweeps were required to keep the hole clean. Cores 4H to 6H were oriented, and WSTP heat flows were taken at 32.2 and 51.2 mbsf. Orientation and heat flows were terminated after Core 6H because of unstable sloughing hole. Core 10H had 50K overpull, and Core 11H was a partial stroke; therefore, APC coring was terminated.

XCB Cores 12X to 19X were taken from 2432.5 to 2485.9 mbrf (98.7-152.1 mbsf) with 53.4 m cored and 1.46 m recovered (2.73% recovery) in unstable volcaniclastic sands and gravels with basalt fragments and pumice. Coring parameters were 125-550 gpm at 150-2500 psi, 5-12K WOB, and 50-70 rpm at 150-225 amps. A hard-formation diamond-impregnated 6-cutter bit was destroyed when 4 cutters fell out and were drilled on by the bit. The last two XCB cores had no recovery; therefore, a final APC run was made in an effort to obtain some of the loose unconsolidated material in the hole.

APC Core 20H was taken from 2485.9 to 2487.6 mbrf (152.1-153.8 mbsf), with 1.7 m cored and 1.68 m recovered. Core 20H was a partial stroke, and the plastic core-liner tube was collapsed at the top.Basalt fragments were recovered in the shoe; therefore, coring was terminated in favor of the RCB system.

Hole 838B

The ship was moved 20 m south. A new 9-7/8-in. RBI C-4 bit (bit no. 5) was run with an MBR, OCB assembly, 10 ea. 8-1/4-in. DC, Hydrolex jars, and 1 ea. 7-1/4-in. DC. Hole 838B (LG-9A) was spudded at 2210L 13 Jan. A punch core was not required; therefore, the seafloor was estimated at 2333.8 mbrf. The 9-7/8-in. hole was washed from 2333.8 to 2477.8 mbrf (0.0-144.0 mbsf). RCB cores 135-838B-1R to 13R were taken from 2477.8 to 2593.0 mbrf (144.0-259.2 mbsf), with 115.2 m cored and 1.51 m recovered (1.31% recovery). Coring parameters were 75-250 gpm at 50-300 psi, 10K lb WOB, and 60-70 rpm at 175-200 amps. Coring was terminated due to very poor recovery in a thicker than anticipated young sediment section.

A hard clay and ash zone (evident in samples from Cores 14X and 15X at 114-123 mbsf) was coincident with a sharply reduced ROP. The hard clay may have acted as a seal that resulted in abnormal compaction below (evident in sharply increased ROP and log-trend reversals). The abnormally compacted material appeared to be a loose sloughing ash and silt (recovery was poor). The abnormal compaction is confirmed by trend reversals on the density log at 187 m, the SP log at 183 m and the induction log at 73 m. The temperature data from the LDGO tool indicates a stable 3.5°C in the hole, which probably indicates a flow of cold seawater into the hole.

After conditioning the hole for logs with a short trip, the bit (a 9-7/8-in. RBI C-4, S/N BA314 with 3-1/2 rotating hours) was dropped with the mechanical bit release (MBR). The open end pipe was pulled to 73.0 mbsf, and logs were run as follows:

Run No. 1: Induction/Sonic (DITE/SDT). The log found bottom 20.0 m above the driller's TD (24.6 m on second pass) and required 2.33 hr to run.

Run No. 2: Formation Microscanner/Gamma Ray (FMS/NGTC). The log found bottom 32.6 m above the driller's TD and required 2.33 hr to run.

Run No. 3: Density/Neutron (HLDT/CNTG/NGT/TCC). The log found bottom 35.7 m above the driller's TD and required 2.25 hr to run.

Run No. 4: Geo-Chemical (GST/ACT/NGT/CNT/TCC). The log found bottom 35.7 above the driller's TD and required 4.17 hr to run.

Log quality was hampered by hole enlargement to 15 in. in unstable sloughing volcaniclastic silt, sand and gravel. The hole was left full of seawater, and the MBR cleared the seafloor at 1440L 15 Jan. and cleared the rotary at 1800L. The MBR was found to have lost the retainer nut and shifting sleeve. An inspection of the tool showed that the lock screw did not fully engage the shifting sleeve shoulder; therefore, the lock-screw nose diameter was reduced so it would engage properly.

Site 839 (LG-10A)

The transit from Site 838 (LG-9A) to Site (LG-10A) started at 1815L 15 Jan. A 24-nmi survey was run to Site LG-10A, requiring 4.3 hr at an average speed of 5.6 kt. The location was moved to 10 nmi northeast of LG-9A and 7 nmi west-northwest of LG-10A (as originally proposed). A Benthos model 210 beacon, 14.0 kHz, S/N 43680, was dropped at 2145L 15 Jan. 1991.

Hole 839A

An 11-7/16-in. Security C-3 four-cone TnC insert bit, S/N 479067 (bit no. 1RR), was run with an SBDC & MDCB assembly, monel DC, 5 ea. 8-1/4-in. DC, Hydrolex jars and 1 ea. 7-1/4-in. DC. Hole 839A (LG-10A) was spudded at 0423L 16 Jan. 1991 at lat. 20°42.531'S and long. 176°46.492'W. The estimated water depth from the PDR was 2627.4 mbrf. Spud Core 135-839A-1H was shot at 2623.5 m and recovered 4.53 m; therefore, the mud-line was established at 2628.5 mbrf by DPM. Continuous APC cores 135-839A-1H to 11H were taken from 2628.5 to 2728.0 mbrf (0.0-99.5 mbsf), with 99.5 m cored and 94.40 m recovered (94.87% recovery). The formation was nannofossil ooze and clay with volcaniclastic silts and sands. Cores 4H to 11H were oriented, and WSTP heat flows were taken at 33.0, 52.0, 71.0 and 90.0 mbsf. APC coring was terminated when Core 11H had a partial stroke and 100,000 lb overpull.

XCB cores 12X to 24X were taken from 2728.0 to 2846.2 mbrf (99.5-217.7 mbsf) with 53.4 m cored and 1.46 m recovered (2.73% recovery) in interbedded clay and volcaniclastic sands and gravels. Coring parameters were 75-400 gpm at 100-1150 psi, 10-12K WOB, and 35-70 rpm at 200 amps.

MDCB Core 25N was taken from 2846.2 to 2846.7 mbrf (217.7-218.2 mbsf), with 0.5 m cored and 0.45 m recovered (90.00% recovery) in vesicular basalt. Coring parameters were 210 gpm at 2300-3000 psi, with the 11-7/16-in. bit sitting on bottom with 15K WOB and the drill string rotating at 5 rpm. The MDCB had 3/4 and 11/11 nozzles in place. The MDCB was pumped 2846 m to bottom at 250 gpm (decreased to 100 gpm after 9 min) in 17 min. The MDCB was landed while pumping at 100 gpm at 35 psi. Immediately after the MDCB landed, the pump rate was increased to 210 gpm at 2600 psi. The pump rate ranged from 2200 to 2965 psi at 36-43 gpm, and coring proceeded for 46 min. The 3-3/4-in. Christensen diamond-impregnated "regular green" MDCB core bit was missing when the MDCB-134 was recovered. The bit sub had a rounded shoulder and pin end with some thread galling; therefore, it is assumed that the MDCB was over torqued or overloaded with weight applied by piston effect at the high circulating pressures. It appeared that the MDCB nozzles need to be enlarged to reduce bit hydraulic loading.

The MBR cleared the seafloor at 1113L 17 Jan. and cleared the rotary at 1540L. A 2 inch horizontal crack was found in the box of the 7-1/4-in. X 8-1/4-in. DC crossover, and a crack was found in the RS overshot body.

Hole 839B

The ship was moved 20 m southwest. A new 9-7/8-in. Smith F94CK bit (S/N AN7225, bit no. 6) was run with an MBR, OCB assembly, 10 ea. 8-1/4-in. DC, Hydrolex jars and 1 ea. 7-1/4-in. DC. Hole 838B (LG-9A) was spudded at 2055L 17 Jan. A punch core was not required; therefore, the seafloor was estimated at 2628.5 mbrf. RCB wash Core 135-838B-1W was taken from 2628.5 to 2718.5 mbrf (0.0-90.0 mbsf), with 90.0 m washed and 0.57 m recovered. RCB wash Core 2W was taken from 2718.5 to 2738.5 mbrf (90.0-110.0 mbsf), with 20.0 m washed and 1.30 m recovered. Wash parameters were 75 gpm at 100 psi, 10K lb

WOB, and 60 rpm at 150 amps. RCB Cores 135-838B-3R to 4R were taken from 2738.5-2757.9 mbrf (110.0-129.4 mbsf), with 19.4 m washed and 0.49 m recovered (2.53% recovery). RCB wash core 5W was taken from 2757.9 to 2808.5 mbrf (129.4-180.0 mbsf), with 50.6 m washed and 1.78 m recovered. The RCB spot coring was an attempt to get some recovery in hole sections that had very poor recovery in Hole 839A.

RCB Cores 6R to 28R were taken from 2808.5 to 3001.1 mbrf (180.0-372.6 mbsf), with 192.6 m cored and 21.19 m recovered (11.00% recovery). Coring parameters were 100-450 gpm at 100-750 psi, 10-20K lb WOB, and60-70 rpm at 175-350 amps. Torque increased to 4-500 amps after Cores 26R (353.3 mbsf) and 28R (372.6 mbsf), and two mud sweeps were circulated in an effort to clean the hole. While retrieving Core 28R, the rotary stalled at 600 amps, and the pipe was stuck with 100K lb overpull (500K total hook load). The Hydrolex jars hit one blow, and the pipe came free. Core 29R, 3001.1-3010.7 mbrf (372.6-382.2 mbsf), cored 9.6 m and recovered 1.06 m. Torque increased to 5-600 amps with 40K overpull. Hole conditions were steadily deteriorating; therefore, a wiper trip was made to 2831.0 mbrf (202.5 mbsf) to condition the hole and found 6 m of fill, which was cleaned out. The cause of the hole problems is thought to be unstable pillow basalt cobbles and silt falling into the hole.

Approval was received to deepen Hole 839B to bit destruction beyond the originally approved 400 mbsf. RCB coring continued, with Cores 30R to 45R taken from 3010.7 to 3145.7 mbrf (382.2-517.2 mbsf), with 135.0 m cored and 1.86 m recovered (1.38% recovery). Coring parameters were 450 gpm at 750 psi, 15-20K lb WOB, and 40-80 rpm at 200-350 amps. Mud sweeps were circulated for each core to reduce torque. The torque increased to 4-500 amps at 497.2 mbsf, the pipe was worked, and another mud sweep was circulated. From 400 mbsf to TD (517.2 mbsf), recovery was very poor to none (1.75 m or 1.49%) in unstable vesicular pillow basalts.

After conditioning the hole for logs with a short trip, the bit (a 9-7/8-in. Smith F94CK, S/N AN7225 with 19.25 rotating hours) was dropped with the mechanical bit release (MBR). The open end pipe was pulled to 90.0 mbsf, and logs were run as follows:

Run No. 1: Induction/Sonic (DITE/SDT). The log found bottom 44.3 m above the driller's TD and required 3.50 hr to run.

Run No. 2: Density/Neutron (HLDT/CNTG/NGT/TCC). The log found bottom 46.6 m above the driller's TD and required 3.75 hr to run.

Run No. 3: Geo-Chemical (GST/ACT/NGT/CNT/TCC). The log found bottom 47.9 m above the driller's TD and required 4.90 hr to run.

Run No. 4: Formation Microscanner/Gamma Ray (FMS/NGTC). The log found bottom 51.3 m above the driller's TD and required 4.23 hr to run.

The logs were reviewed to determine if a suitable packer seat or seats could be found for a packer test. A proposal for a packer test was reviewed, and three potential packer-setting depths were identified and approved. The free fall funnel was dropped at 0750L 22 Jan. while the logging wireline was reheaded. Logging proceeded with the BHTV, and preparations were made for a packer test.

Run No. 5: Analog Bore Hole Televiewer (BHTV). The log found bottom 56.5 m above the driller's TD and required 5.83 hr to run.

Log quality was hampered by hole enlargement to 14 in. in sediments and unstable basalts. The hole was left full of seawater, and the MBR cleared the seafloor at 1508L 22 Jan. and cleared the rotary at 1925L.

Prior to the test, a meeting was held to review the test procedure and packer-setting depths. The object of the packer test was to determine the permeability and transmissivity of the basalt. The rock samples recovered were highly porous, vesicular basalt and pillow basalts, which exhibited good vertical and horizontal permeability. Three packer setting depths were selected in fairly smooth 11- to 13-in. hole sections in the basalt.

The entire circulating system from the mud pumps through the rig-floor manifold, was pressure tested for 5 min at 300 psi and 10 min at 3000 psi. An electronic pressure recorder was installed in the flow line at the manifold, which read-out and printed-out on the downhole-measurements plotter. The internal packer parts were inspected and reconditioned, the packer element was pressure tested for 7 hr at 1500 psi, and the Kuster pressure recorders were tested. A Lo-Torq valve was installed on the manifold to isolate any leakage through the mud-pump line and pump valves from the manifold.

A packer assembly was made-up consisting of a reentry bit, single-element non-rotating TAM packer, 9 ea. 8-1/4-in. DC, Hydrolex jar, 3 ea. 8-1/4-in. DC, 1 ea. 7-1/4-in. DC and 5 ea. 5-1/2-in. DP. The search for the FFF and reentry required 11 min. The coax cable wrapped around the DP several times; therefore, the coax cable was detorqued again at Hole 841A in 4821 m water depth (the deepest water depth on Leg 135) with a 1250-lb load, and no problems were noted. The Mesotech sonar system was run with the Colmec TV this time, but the sonar flooded at 45 m water depth, ruining the sonar components. The problem was traced to a damaged O-ring seal on the penetrator cover plate, which was installed at the Mesotech factory. A warranty claim will be made.

The packer was run in to 3026.7 mbrf (398.2 mbsf) for Test No. 1. The DP volume was circulated at 65 spm at 500 psi to clear the DP and annulus. A go-devil was dropped with 2 ea. Kuster pressure gages with 10,000-psi elements and 6-hr clocks. The gages were in a 12-ft core barrel for protection. A first attempt to set the packer with 1200 psi pressure (15 strokes = 75 gal) was not successful. A second attempt to set the packer with 1500 psi was successful, and 10K lb drag was evident on the heave compensator. The packer was set with 15K lb weight using the heave compensator. A 20-min hydrostatic-pressure reading was taken.

Pressure Pulse Test No. 1 was run at 500 psi (pumped 470 gal in 2 min and SI 13 min), and the pressure bled from 500 to 0 psi immediately. Pressure Pulse Test No. 2 was run at 1000 psi (pumped 710 gal in 3 min and SI 12 min), and the pressure again bled from 1000 to 0 psi immediately. A packer leak was suspected, but two constant flow tests were run in the event that highly permeable basalt was taking the flow. Constant Flow Test No. 1 was at 50 spm (250 gpm), and 10,170 gal was pumped in 43 min at 350 to 380 psi. The pressure bled off from 375 to 0 psi immediately, and a 20-min SI was taken. Constant Flow Test No. 2 was at 100 spm (500 gpm), and 16,000 gal were pumped in 53 min at 1360 to 1380 psi. The pressure bled off from 1355 to 0 psi immediately, and a 20-min SI was taken. The packer was unseated, and 30 min was allowed for it to deflate.

The packer was pulled up to 2955.4 mbrf (326.9 mbsf) without any apparent drag for Test No. 2. A go-devil was dropped with 2 ea. Kuster pressure gages with 10,000-psi elements and 1 ea. 6-hr and 1 ea. 12-hr clocks. The gages were in a 12-ft core barrel for protection. The packer was set with 1500 psi (22 strokes = 110 gal) and had 5K lb drag down on the heave compensator. The packer was set with 15K lb weight using the heave compensator. A 20-min hydrostatic-pressure reading was taken. Pressure Pulse Test No. 3 was run at 500 psi (pumped 265 gal in 1 min and SI 10 min). The pressure bled from 500 to 0 psi in one min. Pressure Pulse Test No. 4 was run at 1000 psi (pumped 205 gal in 1 min and SI 12 min), but the pressure bled in 1 min from 1000 to 0 psi. A packer leak was suspected again, but three constant flow tests were run in the event that highly permeable basalt was taking the flow. Constant Flow Test No. 3 was at 52 spm (260 gpm), and 1555 gal was pumped in 6 min at 1000 to 2530 psi. The pressure bled-off from 2360 to 0 psi in one min, and a 20-min SI was taken. Constant Flow Test No. 4 was at 35 spm (175 gpm), and 3510 galwere pumped in 21 min at 1220 to 1350 psi. The pressure bled off from 1210 to 0 psi in one min, and an 18-min SI was taken. Constant Flow Test No. 5 was at the maximum allowable pump pressure of 3000 psi and 59 spm (295 gpm), and 18,340 gal was pumped in 63 min at 2990 to 2930 psi. The pressure bled off from 2950 to 0 psi in one min, and a 20-min SI was taken. The packer was unseated, and 30 min was allowed for it to deflate.

The Kuster pressure recorders from Test No. 2 were left in the packer to speed-up pulling the packer out of the hole. The packer was pulled without overpull to 2958-2902 m, where 50K lb overpull was required to continue POOH. Another overpull of 40K lb was encountered at 2721 m. The Kuster pressure gages were recovered when the packer cleared the seafloor. When the packer cleared the rotary at 0130L 24 Jan. the packer rubber was found to have been pulled inside-out over itself, and several steel cables had been broken. The packer damage almost certainly was caused when going through tight spots while POOH, and a well bore restriction (ledge) was noted at 2715 m on the caliper log. The pressure gages from Test No. 2 indicated that the formation below the packer had been exposed only to hydrostatic pressure, and there was no damage to the tool or packer rubber; moreover, if the shifting sleeve was not completely closed, pressure-drop calculations indicate that the pumping pressures could be explained by circulation through the 4 X 1/4-in. DP to annulus equalization ports. On inspection, the seal spacer ring in the go-devil was found to be rotated 45°, which could cause a flow restriction with a pressure drop of about 1600 psi.

Site 840 (LG-3)

Site LG-3 had been approved by the Pollution Prevention and Safety Panel following a review of additional surveying done on the transit to Site 836 (LG-10). The transit from Site 839 (LG-10A) to LG-3 started at 0100L 24 Jan. The 102-nmi transit to Site LG-3 required 12.5 hr at an average speed of 8.2 kt. A 19-nmi pre-site seismic survey was run over Site LG-3 in 3.8 hr at an average speed of 5.0 kt. A Benthos model 210 beacon, 15.0 kHz, S/N 44622, was run on the taut wire at 1725L 24 Jan. 1991.

Hole 840A

An 11-7/16-in. Security C-3 four-cone tungsten carbide insert bit, S/N 479067 (bit no. 1RR) was run with an SBDC & MDCB assembly, monel DC, 5 ea. 8-1/4-in. DC, Hydrolex, jars and 1 ea. 7-1/4-in. DC. Hole 840A (LG-3) was spudded at 2302L 24 Jan. 1991 at lat. 22°13.249'S and long. 175°44.916'W. The estimated water depth from the PDR was initially read as 737.4 mbrf on two separate readings. The first two APC shots at 733.0 and 741.0 m were water cores; therefore, the PDR equipment was rechecked. The 12.0-kHz PDR was found to have a 0.025-ms delay with the correlator turned off; therefore, the correct PDR was 754.4 mbrf. The spud Core 135-840A-1H was shot at 749.0 m and recovered 4.11 m; therefore, the mud-line was established at 754.5 mbrf by DPM. Continuous APC Cores 135-840A-1H were taken from 754.5 to 758.5 mbrf (0.0-4.0 mbsf), with 4.0 m cored and 4.11 m recovered (102.75% recovery). The seafloor was firm pumice fragments and clayey gravel. APC Core 2H was a partial stroke. The core barrel was stuck and could not be retrieved by CWL. The BHA was POOH, clearing the rotary table at 0253L 25 Jan. The APC core barrel was bent in an "S" shape, and the bottom section was brokenoff and lost in the hole. The APC CB was cut out of the bit.

Hole 840B

The ship was moved 20 m south, and the same APC/XCB BHA used in Hole 840A was rerun. The mud-line was found at 754.5 mbrf. Hole 840B (LG-3) was spudded at 0653L 25 Jan. 1991 at lat. 22-13.259'S and long. 175°44.918'W. Continuous XCB Cores 135-840B-1X to 63X were taken from 754.5 to 1351.8 mbrf (0.0-597.3 mbsf),with 597.3 m cored and 176.16 m recovered (29.49% recovery). The formation consisted of pumice, volcaniclastic sand, silt and claystone interbedded with vitric nannofossil ooze. The hole was amazingly stable in spite of the unconsolidated formation, and only occasional mud sweeps were required.

After conditioning the hole for logs with a short trip (10-m fill), an aluminum go-devil was dropped to lock open the LFV, which had a broken flapper spring already. The open end pipe was pulled to 94.8 mbsf, and logs were run as follows:

Run No. 1: "Quad/Combo" Induction/Density/Sonic/Caliper/Gamma Ray (DITE/HLDT/SDT/MCDG/NGTC). The log found bottom 25.7 m above the driller's TD and required 4.08 hr to run.

Run No. 2: Geochemical (GST/ACT/NGT/CNT/TCC). The log found bottom 45.7 m above the driller's TD. The tool failed on the first run due to a high-voltage instability problem in the NGT and required 2.37 hr. Run No. 2RR found bottom 55.8 m above the driller's TD and required 4.00 hr to run.

Run No. 3: Formation Microscanner/Gamma Ray (FMS/NGTC). The log found bottom 67.7 m above the driller's TD and required 2.72 hr to run.

Log quality was good with hole enlargement to 12.5-in. in vitric nannofossil ooze and unstable volcanic silt, sand and gravels. The hole was left full of seawater, and the bit cleared the seafloor at 1210L 29 Jan.

Hole 840C

Hole 840C was spot cored with the APC in a very successful attempt to improve recovery in loose volcaniclastic sections of the geological record, which were missed with the XCB in Hole 840B. The ship was moved 40 m north, and the same APC/XCB BHA used in Hole 840B was rerun. The mud-line was found at 754.5 mbrf. Hole 840C (LG-3) was spudded at 1309L 29 Jan. 1991 at lat. 22°13.238'S and long. 175°44.925'W. A 9-7/8-in. hole was drilled with a center bit from 754.5 to 792.5 mbrf (0.0-38.0 mbsf). APC Cores 135-840C-1H to 4H were taken from 792.5-821.0 mbrf (38.0-66.5 mbsf), with 28.5 m cored and 20.63 m recovered (72.39% recovery). Drilling parameters were 350 gpm at 350 psi, 10K WOB, and 50 rpm at 125 amps. The center bit was run, and a 9-7/8-in. hole was drilled from 830.5 to 878.5 mbrf (76.0-124.0 mbsf).

APC cores 5H to 12H were taken from 878.5 to 954.5 mbrf (124.0-200.0 mbsf), with 76.0 m cored and 44.46 m recovered (58.50% recovery). Cores 5H to 12H were oriented, and a heat flow measurement was taken at 171.5 mbsf. The center bit was run, and a 9-7/8-in. hole was drilled from 954.5 to 1004.5 mbrf (200.0-250.0 mbsf). APC Core 13H was taken from 1004.5-1014.0 mbrf (250.0-259.5 mbsf), with 9.5 m cored and 7.36 m recovered (77.47% recovery). The formation in Cores 1H to 13H consisted of pumice, volcaniclastic sand, silt, and claystone interbedded with vitric nannofossil ooze. The hole was amazingly stable considering the unconsolidated nature of the formation, and only periodic mud sweeps were circulated as a preventive measure.

Altogether, APC coring in Hole 840C recovered 67.50 m (54.66%) of the 136.0 m of loose volcaniclastic material cored, whereas, only 0.40 m (0.29%) was recovered with the XCB in Hole 840B. The MDCB could not be run as scheduled because the hole bottomed in loose volcanic sand and gravel. The bit cleared the seafloor at 1100L 30 Jan. and cleared the rotary at 1310L. The jars were found to be full of sand and could not be operated at the surface, but they were rerun because no other jars were available; moreover, jars frequently free up in the hole.

Site 841 (LG-6A)

The transit from Site 840 (LG-3) to Sites 841 (LG-6A) started at 1324L 30 Jan. and covered 62 nmi in 6.6 hr at 9.4 kt average speed. A 44-nmi survey was run over Site LG-6A, requiring 7.5 hr at an average speed of 5.9 kt. A Datasonics model 354A nonretrievable beacon, 14.0 Khz, S/N 611, 214dB, was dropped at 0243L 31 Jan. 1991, but the beacon signal was lost while positioning. A backup beacon, Benthos model 210, 15.0 kHz, S/N 43587, 211dB, was dropped at 0405L 31 Jan. 1991. The first beacon signal was acquired again after launching the backup beacon and was used on Hole 841C because the backup beacon failed.

Hole 841A

An 11-7/16-in. Security C-3 four-cone tungsten carbide insert bit (S/N 479067, bit no. 1RR) was run with an SBDC & MDCB assembly, monel DC, 5 ea. 8-1/4-in. DC, Hydrolex jars, and 1 ea. 7-1/4-in. DC. Hole 841A (LG-6A) was spudded at 1300L 31 Jan. 1991 at lat. 23°20.746'S and long. 175°17.871'W. The estimated water depth from the PDR was 4825.9 mbrf. Spud Core 135-839A-1H was shot at 4820.0 m and recovered 8.57 m; therefore, the mud-line was established at 4821.0 mbrf by DPM. Continuous APC Cores 135-841A-1H to 8H were taken from 4821.0 to 4892.7 mbrf (0.0-71.7 mbsf), with 71.7 m cored and 61.80 m recovered (86.19% recovery). The formation was unusually hard and dry tan to gray clay with ash. Cores 4H to 8H were oriented, and WSTP heat flows were taken at 27.5, 46.5, and 65.5 mbsf. Cores 4H to 8H were partial strokes. APC coring was terminated when Core 8H had 130,000 lb overpull, and the core barrel had to be drilled over.

Continuous XCB Cores 135-841A-9X to 21X were taken from 4892.7 to 5007.6 mbrf (71.7-186.6 mbsf), with 114.9 m cored and 8.45 m recovered (7.35% recovery). The formation consisted of hard gray silt, sand, claystone, and ash. The hole condition was very stable. A soft-formation three-bladed bit twisted apart on Core 14X. Coring was terminated due to a hard formation that was burning even hard formation six-bladed diamond-impregnated XCB bits with a 550-gpm circulating rate. The bit was POOH, clearing the seafloor at 0830L Feb. 2 and clearing the rotary at 1540L.

Hole 841B

The ship was moved 20 m north. A new 9-7/8-in. Smith F94CK bit (bit no. 7) was run with an MBR, OCB assembly, 10 ea. 8-1/4-in. DC, Hydrolex jars ,and 1 ea. 7-1/4-in. DC. Hole 841B (LG-6A) was spudded at 2240L Feb. 2. The seafloor was estimated at 4821.0 mbrf. RCB wash core 135-841B-1W was taken from 4821.0 to 4991.0 mbrf (0.0-170.0 mbsf) with 170.0 m washed and 2.84 m recovered. RCB cores 135-841B-2R to 70R were taken from 5090.8 to 5655.2 mbrf (169.8-834.2 mbsf), with 664.4 m cored and 181.4 m recovered (27.30% recovery). Coring parameters were 75-250 gpm at 100-300 psi, 10-20K lb WOB, 70-75 rpm at 175-200 amps in firm black to gray claystone to 265 mbsf. Below 265 mbsf, the formation was more indurated, and coring parameters were 250-550 gpm at 300-1600 psi, 20K WOB, and 70 rpm at 200-325 amps in hard volcanic siltstone, sandstone, claystone, and conglomerate, clay with hard cobbles and limestone, fault gouge, and highly altered loose pillow basalts and intrusive dike basalts. Recovery was fair to good in general, with poor recovery in clays and flowing sands(?) from 612-641 and 689-834 mbsf.

Circulating pressure increased by 400 psi; therefore, the bit deplugger was run twice after Core 14R to remove clay plugs in the core barrel. Mud sweeps were circulated every third or fourth core as required down to 700 mbsf, where clay and hard cobbles caused hole problems requiring a 30-bbl mud sweep for each core. Hole fill of 5 m was noted from 776 mbsf, and tight hole was noted at 815 mbsf. Two more cores were taken to 5655.2 m (834.2 mbsf), but hole conditions became too bad to continue coring. A 40-bbl mud sweep was circulated prior to the conditioning trip to log.

While retrieving RCB 71R (no advance but recovery was volcanic sand and gravel), the rotary stalled at 6-700 amps. The pipe was stuck with 70K lb overpull and could not be circulated at 3100 psi. Rotation was regained while attempting to cock the jars, and the pipe could be circulated (although it was partially plugged). Two 40-bbl mud sweeps were circulated, but the pipe stuck again as soon as pumping stopped. The pipe could not be circulated, rotated, or moved. The Hydrolex jars were cocked, and one 70K blow was hit, which regained rotation and circulation. A 40-bbl mud sweep was circulated again, and the pipe was pulled with 30K overpull to 224 mbsf, where the pipe was stuck again. The pipe could be circulated but could not be rotated at 650 amps or moved with 210K overpull (750K total). Attempts to engage the jars were unsuccessful; therefore, the string appeared to be stuck above the jars. As a last effort before backing-off, the bit was released with the MBR. The string could be moved, although the drag remained at 40K overpull. The pipe had to be back-reamed up the hole to 50 mbsf, where it came free. Bad and deteriorating hole conditions precluded a suitable logging run in Hole 841B, and a successful cleanout would have been doubtful because the bit and MBR metal were dropped with the MBR at 224 mbsf. The intense scientific interest in logging the hole led to a decision to drill a new hole (841C) to ± 650 mbsf specially for logging.

The ship had been positioning on the backup Benthos model 210 211 dB beacon, but ther beacon failed at 0900L 10 Feb. Positioning was maintained without interruption by switching back to the original Datasonics model 354A 214 dB beacon, which had been re-acquired after launching the backup Benthos beacon. The MBR cleared the seafloor at 1105L 10 Feb. and cleared the rotary at 2020L.

Hole 841C

The ship was moved 20 m north. A new 9-7/8-in. Smith F4 tri-cone drill bit (S/N CK5967, bit no. 8) was run with an MBR, OCB assembly, 10 ea. 8-1/4-in. DC, Hydrolex jars, and 1 7-1/4-in. DC. Hole 841C (LG-6A) was spudded at 0325L 11 Feb. The seafloor was estimated at 4821.0 mbrf. A 9-7/8-in. hole was drilled from 4821.0 to 5596.0 mbrf (0.0-775.0 mbsf). Mud sweeps were circulated about every fourth connection or as required to maintain hole cleaning. Some increase in torque was noted below 650 mbsf in areas of poor core recovery (probably sloughing sands and unstable rhyolites).

The wiper trip encountered 10K overpull while pulling off-bottom, and running-in had 40K drag at 5454 m and a bridge at 5478 m. While attempting to ream through the bridge at 5478 m (657 mbsf), the rotary stalled twice at 650 amps and had 70K overpull. The hole was sloughing-in (unstable rhyolite and sloughing sand), and hole conditions were deteriorating. Several attempts to release the bit with the MBR were unsuccessful; therefore, a free fall funnel was dropped, and the drill string was pulled out of the hole to remove the bit. The hole was filled with seawater treated with 2-1/2% KCl to stabilize any swelling clays. Two clay samples from Core 135-841B-61R (747 mbsf) had shown minor swelling tendencies (90 s) in dispersion tests with distilled water, but the progressive hole instability and crucial scientific requirement for logs in this special logging hole required that all precautions be exercised. The MBR which failed to operate was jammed in tension and rotation, possibly while stuck when attempting to ream through a bridge at 657 mbsf.

A reentry/logging bit was run, and the FFF was reentered after a 1.70-hr search. In the interest of preserving the remaining logging time, the bit was positioned at 78.1 mbsf without a trip to bottom.

Logs were run as follows:

Run No. 1: Formation Microscanner/Gamma Ray (FMS/NGTC). The Schlumberger logging computer crashed twice after calibrating the FMS; therefore, a third calibration was required. The tool was run in, but a short was noted. The tool was pulled out after 0.95 hr. The logging head was replaced, and the tool was run again. On Run No. 1RR, the FMS log found bottom 166.2 m above the driller's TD and required 6.92 hr to run.

Run No. 2: "Quad/Combo" Induction/Density/Sonic/Caliper/Gamma Ray (DITE/HLDT/SDT/MCDG/NGTC). A Schlumberger computer problem required 1.75 hr to correct. The log found bottom 213.5 m above the driller's TD and required 5.53 hrs to run.

The Quad/Combo was out of the hole at 0202L 15 Feb. The logging window extended to 0500L ± a few hours, but the Geochemical log was expected to take about 9 hr; therefore, logging was terminated. The logs could be run down only to the first zone of instability (found on the logging wiper trip at 657 mbsf) because sufficient time did not exist to trip in and clean out the bridge. The hole was left full of seawater with 2-1/2% KCl. The bit cleared the seafloor at 0350L 15 Feb. and cleared the rotary at 1400L. The drill string was coated with inhibitor, and the BHA was inspected on pulling out of the hole.

Sea Voyage from Site 841 to Pago Pago, Samoa

The sea voyage from Site LG-6A to Pago Pago, Samoa, started at 1415L 15 Feb. and covered 626 nmi in 66.9 hrs at 9.4 kt average speed. Ship time was changed from Fijian time (2400L 15 Feb.) to Samoan time (0100S 15 Feb.) upon crossing the international date line. A magnetometer survey was run during the sea voyage over the Capricorn Seamount east of Tonga and an unnamed seamount adjacent to and south of Samoa.

The *JOIDES Resolution* dropped anchor in Pago Pago harbor at American Samoa, 1015S 17 Feb. The scientists and some ODP staff disembarked in Pago Pago, and some fresh vegetables were taken on. The P18B propulsion motor was disconnected from the starboard shaft. The ship picked-up anchor at 1430S and departed Pago Pago harbor for Hawaii.

Sea Voyage from Pago Pago, Samoa, to Honolulu, Hawaii

The sea voyage from Pago Pago, Samoa, to Honolulu, Hawaii, covered 2266 nmi in 255.5 hrs at 8.9 kt average speed . Cracks in the welds on the derrick guiderails were repaired, and a fuel economy test was run during the transit on 12 Feb. for 9 hr. The ship was stopped to lock out the port shaft (to replace the armature in propulsion motor P18B) and proceeded with one shaft from 1652 24 Feb. to 1745 25 Feb. (24.9 hr). Ship time was changed from Samoan time to Hawaii time at 2400 27 Feb. Leg 135 ended with the first line ashore in Honolulu, Hawaii, at 0700 28 Feb. ending Leg 135.

OCEAN DRILLING PROGRAM
SITE SUMMARY REPORT
LEG 135

HOLE	LATITUDE	LONGITUDE	SEA FLOOR DEPTH (M)	NUMBER OF CORES	INTERVAL CORED (M)	RECOVERED CORE (M)	PERCENT RECOVERED	INTERVAL DRILLED (M)	TOTAL PENETRATION (M)	TIME (HRS)
834A	18-34.06S	177-51.74W	2852.4	20	149.5	113.2	75.7	.0	149.5	48.07
834B	18-34.05S	177-51.74W	3134.4	59	375.5	105.5	28.1	59.8	435.3	180.02
	SITE TOTALS:			79	525.0	218.7	41.7	59.8	584.8	228.09
835A	18-30.06S	177-18.16W	3076.0	18	159.5	160.1	100.4	.0	159.5	39.23
835B	18-30.05S	177-18.19W	3099.5	7	49.8	8.7	17.5	133.2	183.0	47.75
	SITE TOTALS:			25	209.3	168.8	80.6	133.2	342.5	86.98
836A	20-08.49S	176-30.01W	2504.5	9	38.2	24.5	64.1	.0	38.2	27.70
836B	20-08.51S	176-30.01W	2526.8	8	44.8	17.0	37.9	13.5	58.3	30.50
	SITE TOTALS:			17	83.0	41.5	50.0	13.5	96.5	58.20
837A	20-13.31S	176-49.36W	2847.5	9	84.0	83.9	99.9	.0	84.0	26.33
837B	20-13.32S	176-49.36W	2868.6	7	34.6	9.1	26.3	65.0	99.6	26.42
	SITE TOTALS:			16	118.6	93.0	78.4	65.0	183.6	52.75
838A	20-49.62S	176-53.40W	2487.6	20	153.8	98.7	64.2	.0	153.8	34.18

OCEAN DRILLING PROGRAM
SITE SUMMARY REPORT
LEG 135

HOLE	LATITUDE	LONGITUDE	SEA FLOOR DEPTH (M)	NUMBER OF CORES	INTERVAL CORED (M)	RECOVERED CORE (M)	PERCENT RECOVERED	INTERVAL DRILLED (M)	TOTAL PENETRATION (M)	TIME (HRS)
838B	20-49.63S	176-53.40W	2593.0	13	115.2	1.5	1.3	144.0	259.2	73.58
	SITE TOTALS:			33	269.0	100.2	37.2	144.0	413.0	107.76
839A	20-42.53S	176-46.49W	2846.7	25	218.2	98.1	45.0	.0	218.2	41.92
839B	20-42.54S	176-46.50W	3145.7	45	356.6	25.2	7.1	160.6	517.2	153.00
	SITE TOTALS:			70	574.8	123.3	21.5	160.6	735.4	194.92
840A	22-13.25S	175-44.92W	758.5	1	4.5	4.1	91.1	.0	4.5	9.47
840B	22-13.26S	175-44.92W	1351.8	63	597.3	176.2	29.5	.0	597.3	105.28
840C	22-13.24S	175-44.93W	1014.0	13	123.5	67.5	54.7	136.0	259.5	24.00
	SITE TOTALS:			77	725.3	247.8	34.2	136.0	861.3	138.75
841A	23-20.75S	175-17.87W	5007.6	21	186.6	70.3	37.7	.0	186.6	59.58
841B	23-20.74S	175-17.87W	5655.2	71	664.4	185.3	27.9	169.8	834.2	256.25
841C	23-20.72S	175-17.88W	5596.0	0	.0	.0	.0	775.0	775.0	113.76
	SITE TOTALS:			92	851.0	255.6	30.0	944.8	1795.8	429.59
	LEG TOTALS:			409	3356.0	1248.9	37.2	1656.9	5012.9	1297.04

OCEAN DRILLING PROGRAM
OPERATIONS RESUME
LEG 135

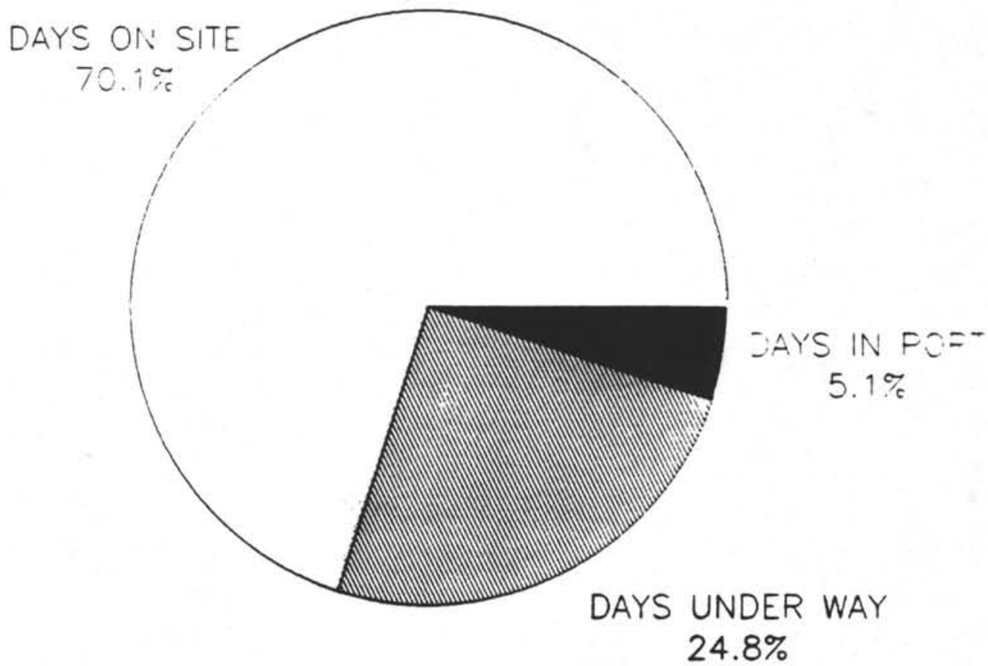
Total Days (12/17/90 - 2/28/91)	73.0
Total Days in Port	3.7
Total Days Under Way	18.1
Total Days on Site	51.2

Trip Time	10.4
Coring Time	26.9
Drilling Time	2.8
Logging/Downhole Science Time	7.1
Repair Time (Contractor)	0.1
Downhole Trouble Time	0.8
Survey Time	0.5
Development Engineering Time	0.1
Other	2.5

Total Distance Traveled (nautical miles)	4065.2
Average Speed (knots)	8.6
Number of Sites	8
Number of Holes	18
Number of Reentries	3
Total Interval Cored (m)	3356.0
Total Core Recovery (m)	1248.5
Percent Core Recovered	37.2
Total Interval Drilled (m)	1656.9
Total Penetration (m)	5015.7
Maximum Penetration (m)	834.2
Maximum Water Depth (m from drilling datum)	4814.4
Minimum Water Depth (m from drilling datum)	743.1

LEG 135

TOTAL TIME DISTRIBUTION



TOTAL DAYS OF LEG = 73

TECHNICAL REPORT

The ODP Technical and Logistics personnel aboard *JOIDES Resolution* for Leg 135 of the Ocean Drilling Program were:

Senior Laboratory Officer:	Dennis Graham
Laboratory Officer	Brad Julson
Yeoperson	Jo Claesgens
Curatorial Representative	Gretchen Hampt
Computer Systems Manager	John Eastlund
Electronics Technician	Roger Ball
Electronics Technician	Jim Briggs
Electronics Technician	Eric Meissner
Photographer	Roy Davis
Chemistry Technician	Scott Chaffey
Chemistry Technician	Joe Powers
Storekeeper	Jon Lloyd
X-ray Technician	Donald Sims
Paleomagnetics/ Formation MicroScanner Technician	Daniel Bontempo
Physical Properties Technician	Brad Cook
Marine Geophysics/ Thin Section Technician	"Kuro" Kuroki
Marine Technician	Norman Haywood

TECHNICAL OBJECTIVES

The primary goal of the technical staff during Leg 135 was to support the scientific staff while maintaining ODP policies and procedures. Other technical objectives included electronics support for the Totco drilling-parameters logging system, improvements to the shipboard balance system, improvements to the multi sensor track data-processing software, installation of VAX version 5.3 operating system, and laboratory technician cross-training during the Pago Pago - Honolulu transit at the end of the leg.

PORT CALL: SUVA, FIJI

On 17 December 1990 the *Resolution* docked in Suva, Fiji, ending Leg 134. During a 4-day port call we discharged all of Leg 134's cores and freight and loaded new supplies. In addition to normal port-call duties, technicians conducted tours for approximately 100 local residents, including the U.S. Ambassador to Fiji.

LABORATORY OPERATIONS

Underway Operations

We collected geophysical data on eight transit lines. Bathymetry and magnetic data were acquired at all times, while seismic data were collected during site approaches. We used two 80-$in.^3$ water guns for site surveys. During the transit line from Site 835 to Site 836, Site 840 was surveyed in advance. The Co-Chief Scientists faxed the seismic record to ODP to receive safety approval for the proposed site.

Continued deployment of the global positioning system (GPS) constellation has greatly improved coverage time and data quality. GPS coverage was nearly 90% and was used to navigate all geophysical lines.

On-Site Lab Operations

There were no special core lab experiments conducted on this leg. The following table summarizes the amount of lab analyses for this leg.

LABORATORY MEASUREMENT SUMMARY

General:	Sites:	8
	Holes:	18
	Meters cored:	3356
	Meters of core recovered:	1248.5
	Total number of samples:	6317

Analysis:

Physical Properties	Density:	738
	Velocity:	2282
	Thermal conductivity:	1004
	Vane shear:	181
	P-wave (MST):	33019
	G.R.A.P.E.(MST):	48628
Paleomagnetics:	Susceptibility (MST):	38558
	Cryogenic Magnetometer:	35455
	Spin Magnetometer:	444
Chemistry:	Inorganic carbon:	494
	Organic carbon:	132
	Total carbon:	132
	Gas/GC:	123
	Alkalinity:	57
	pH:	57
	Salinity:	61
	Sulfate:	63
	Chlorinity:	63
	Magnesium:	58
	Calcium:	63
	Phosphate:	53
	Potassium:	63
	Ammonium:	53
	Silica:	62
	Manganese:	62
	Sodium:	54
	Strontium:	62
X-ray:	Fluorescence - major & trace:	91
	Diffraction:	47
Petrographic:	Thin sections:	185

Underway Geophysics: (approximate)

	Bathymetry:	3374 nmi
	Magnetics:	3374 nmi
	Seismics:	362.4 nmi

Downhole Tools:

	Heat flow:	26
	Magnetic orientation:	55

New Projects

This was the second leg where an ODP Technician worked 50% of his time processing FMS data and managing the LDGO Borehole Research Group's MicroVax. The place and potential for FMS processing on board is significant. FMS data often fill in the picture in intervals where there is no core recovery. FMS data can also be processed with Schlumberger's dipmeter software to obtain structural and bedding information.