Collot, J.-Y., Greene, H. G., Stokking, L. B., et al., 1992
Proceedings of the Ocean Drilling Program, Initial Reports, Vol. 134

14. SUMMARY AND CONCLUSIONS[1]

Shipboard Scientific Party[2]

ABSTRACT

Leg 134 of the Ocean Drilling Program investigated the influence of ridge collision and subduction on the structural evolution of island arcs by drilling at a series of sites in the collision zone between the d'Entrecasteaux Zone and the central New Hebrides Island Arc. The d'Entrecasteaux Zone is an arcuate Eocene to Oligocene submarine chain of ridges and basins extending from the northern New Caledonia ridge to the New Hebrides Trench. Near the New Hebrides Trench, the zone comprises two parallel, east-west-trending morphologic highs: the fairly continuous North d'Entrecasteaux Ridge and the South d'Entrecasteaux Chain, composed of seamounts and guyots whose easternmost member is the Bougainville Guyot. The impingement of the d'Entrecasteaux Zone upon the central New Hebrides Island Arc has greatly disrupted and tectonically modified the forearc and arc morphology and structure. Holes at Sites 827 and 829 were drilled to penetrate the lowermost accretionary wedge and the interplate thrust fault (décollement). The primary objective of drilling at Site 828 was to obtain a critical reference section of the north ridge rocks. Sites 830 and 831 are located where the Bougainville Guyot has collided with the arc. At Site 830 we aimed to penetrate imbricated arc rocks, and at Site 831 we sought to determine the lithology, age, paleobathymetry, and mechanical properties of the guyot. Sites 832 and 833 are located in North Aoba Basin, an intra-arc basin that is considerably deeper than any other basin along the arc summit and that occurs directly east of the collision. This basin contains several unconformities that appear to document the structural evolution of the central New Hebrides Island Arc.

Preliminary interpretations of the results of Leg 134 suggest that each ridge of the twin-ridge d'Entrecasteaux Zone causes different forearc deformation. The sedimentary and surficial basement rocks of the North d'Entrecasteaux Ridge, whose basement rocks (MORB) are denser than those of the Bougainville Guyot, appear to have been scraped off and accreted to the forearc during subduction. This accretion has formed the Wousi Bank, which consists of uplifted forearc rocks and stacked thrust sheets. The South d'Entrecasteaux Chain impacts the forearc in a different manner: a narrower, less distinct form of deformation has occurred compared to the North d'Entrecasteaux Ridge collision zone, although the chain is converging at the same rate and at the same angle as the north ridge. Major compositional changes of pore fluids in the collision zone result from diagenetic alteration of volcanic sediment and are manifested as chloride and calcium concentrations greater than seawater values and sodium, potassium, and magnesium concentrations lower than seawater values. Variations in these solute concentrations correspond to structural features, particularly across thrust faults at Site 829 and in a fractured zone at Site 830. More fluid is present below thrust faults penetrated at Site 829, which implies that the faults may channelize fluid flow similar to the Barbados accretionary wedge. Low chloride and high methane concentrations characterize fluids from deep levels at Site 829, a covariance that also characterizes the pore-fluid chemistry within the décollement at the Barbados accretionary wedge. Thus, the fluid near the deep thrust fault at Site 829 may have been derived from the décollement and subduction-related processes.

Middle Miocene to Pleistocene sedimentary and volcaniclastic rocks were recovered from two holes drilled to a depth of more than 1 km in the North Aoba Basin. Drilling at Site 832 penetrated over 1106 m of basin-fill deposits and at Site 833 cored 1001 m of basin material. A strong reflector observed in the seismic reflection data around 700 meters below seafloor correlates with an apparent upper Pliocene or lower Pleistocene unconformity in the sediment record. This suggests a change in the basin's base and may indicate that uplift of Espiritu Santo Island in response to the collision of the d'Entrecasteaux Zone occurred at that time. Over 600 m of Pleistocene sediments were found at Site 832, with the upper 400 m apparently being the contribution of active Central Chain volcanism. At Site 833 a basaltic sill, tentatively dated using potassium-argon method as 3.30 ± 0.3 Ma, intrudes lower Pliocene sedimentary rocks at 840 mbsf, demonstrating that volcanism was active along the Eastern Belt during the Pliocene. Volcanic sediment within the North Aoba Basin has been diagenetically altered, producing some of the most altered and concentrated fluids yet drilled on an Ocean Drilling Program or a Deep Sea Drilling Project leg. The concentrations of calcium, chloride, potassium, sodium, and magnesium are most affected by this alteration.

INTRODUCTION

The New Hebrides Island Arc system extends for a distance of 1700 km from the Santa Cruz Islands in the north to Matthew and Hunter islands in the south (Fig. 1). This arc lies in the middle of a complex system of active volcanic arcs that extends from Papua New Guinea southward through the Solomon Islands to Vanuatu, where the New Hebrides Island Arc is displaced eastward along the Hunter Fracture Zone to Tonga (Fig. 1). From Tonga the arc system continues southward through the Kermadec Islands to New Zealand. Along most of the arc system, the Pacific plate is being subducted under the Australia-India plate. From Papua New Guinea to Vanuatu, however, the arc system defines a major plate boundary where the Australia-India plate is being subducted beneath the Pacific plate and the North Fiji Basin. The New Hebrides Island Arc is the product of intra-oceanic subduction, possible subduction polarity reversal, and ridge-arc

[1] Collot, J.-Y., Greene, H. G., Stokking, L. B., et al., 1992. *Proc. ODP, Init. Repts.*, 134: College Station, TX (Ocean Drilling Program).

[2] Shipboard Scientific Party is as given in the list of participants preceding the contents.

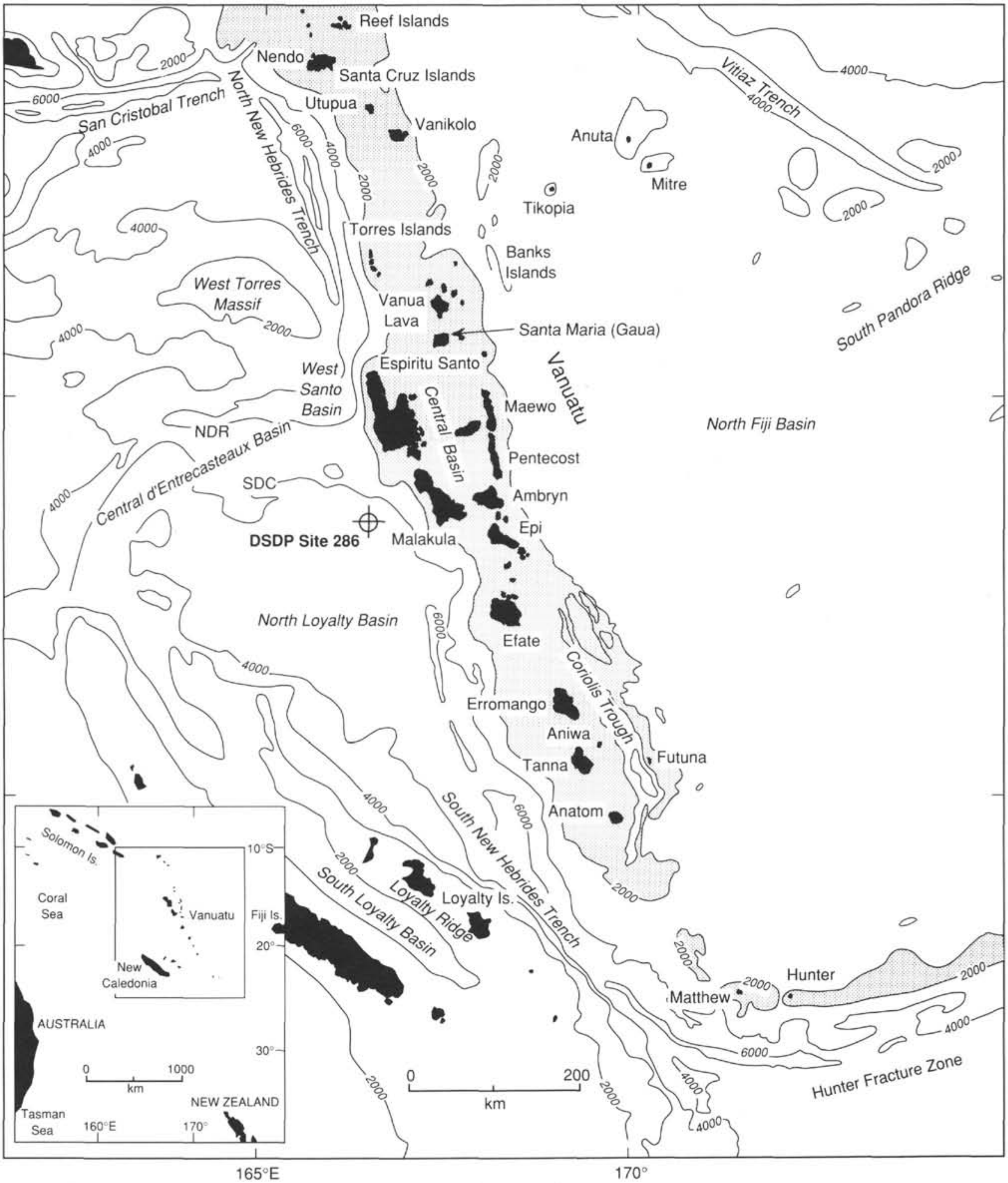

Figure 1. Regional bathymetry (in meters) of the southwest Pacific (after Kroenke et al., 1983). NDR = North d'Entrecasteaux Ridge; SDC = South d'Entrecasteaux Chain.

collision that has taken place during the Cenozoic. Leg 134 focused on three important and poorly understood aspects of this arc system:

1. The style of deformation occurring in the region of the collision between the d'Entrecasteaux Zone (DEZ) and the New Hebrides Island Arc and comparison of the deformation in two different types of ridges (the North d'Entrecasteaux Ridge, NDR, and the South d'Entrecasteaux Chain, SDC, of seamounts) that are impinging upon the arc (Fig. 2). Impingement of the DEZ against the arc has greatly altered the arc's morphology and structure. To determine the recycling of

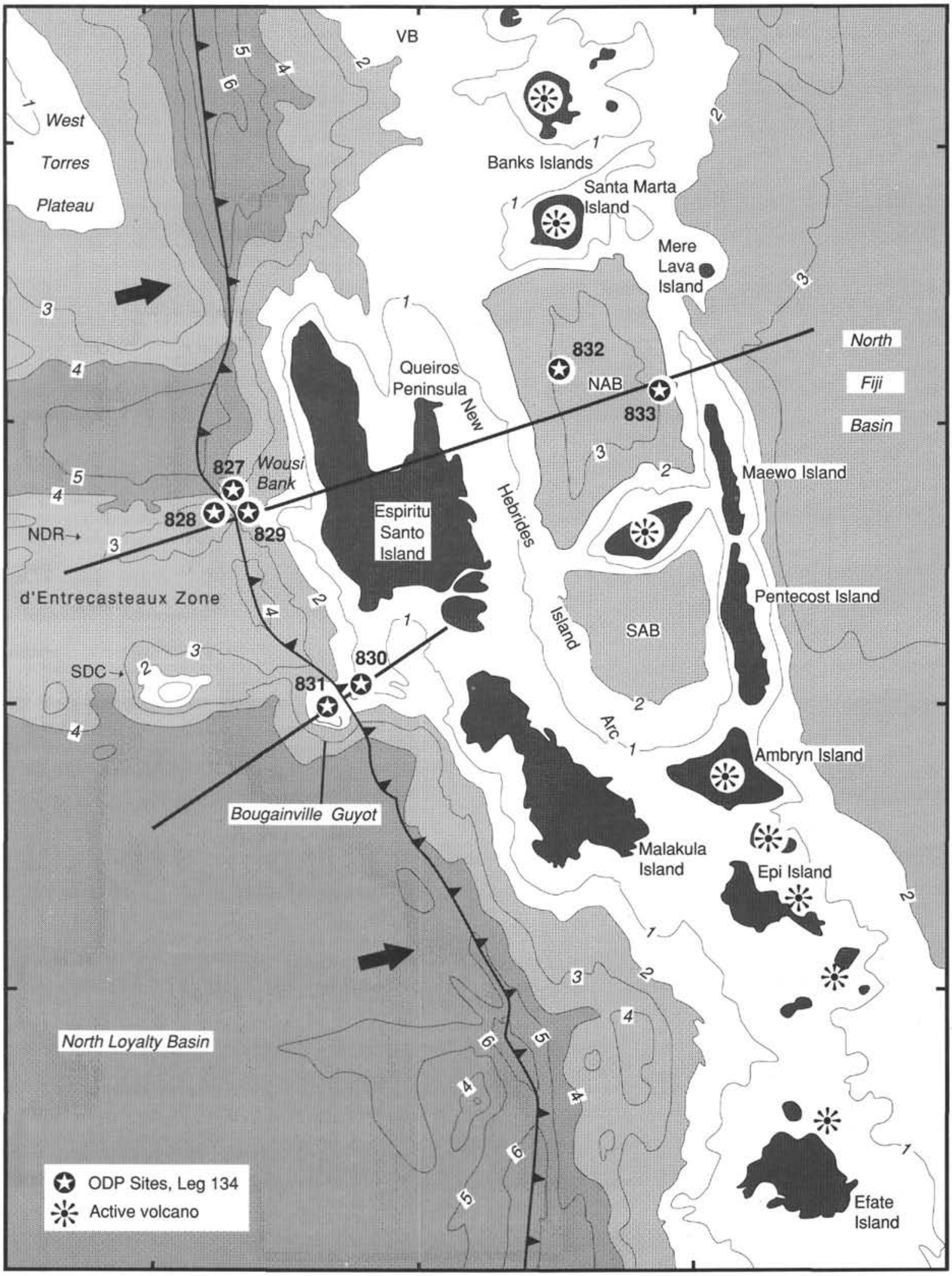

Figure 2. Locations of sites drilled during Leg 134. Bold lines indicate location of cross sections shown in Figure 3. NDR = North d'Entrecasteaux Ridge; SDC = South d'Entrecasteaux Chain; NAB = North Aoba Basin; SAB = South Aoba Basin; and VB = Vanikolo Basin. Bold line with teeth indicates approximate position of subduction zone; teeth are on upper plate. Arrows indicate direction of plate convergence. Bathymetry in kilometers.

lithosphere, or the transfer of material from one plate to another, a series of holes (Fig. 2) was drilled through the sediments and carbonate rocks of the forearc (Sites 827, 829, and 830) of the NDR on the Australia-India plate (Site 828) and the Bougainville Guyot of the SDC (Site 831).

2. The evolution of the magmatic arc in relation to a possible reversal of subduction during the Neogene. To investigate the evolution of intra-arc basins and to determine whether or not subduction polarity reversed, two sites (Sites 832 and 833; Fig. 2) were drilled in the summit basin of the arc, the intra-arc North Aoba Basin (NAB). The age of a major discordance in the basin fill may be contemporaneous with the beginning of collision of the DEZ with the arc, providing one of the best estimates of the age of subduction polarity reversal and initiation of collision. The holes drilled in the North Aoba Basin show the provenance, age, paleobathymetry, and lithology of basin fill, from which the rate and timing of basin subsidence can be derived.

3. Dewatering of the forearc and subducted lithosphere, which is to be investigated indirectly from the composition of the forearc crust and directly from the analyses of fluids and chemical precipitates from the forearc.

DRILLING OBJECTIVES

Arc-Ridge Collision Sites

Sites within the collision zone were designed to determine the influence that ridge composition and structure exert on the style of accretion and type of arc structures produced during collision. Sites 827 and 829 are located where the north ridge of the DEZ and the arc collide (Fig. 2). At Site 828 we sought to obtain a critical reference section of north ridge rocks to enable recognition of these rocks in other drill holes (Fig. 2). At Sites 827 and 829 we sought to penetrate the lowermost accretionary wedge, the interplate thrust fault (décollement), and the north ridge itself. We hoped that this site would show whether north ridge rocks have been accreted onto the arc, as well as reveal the age and mechanical properties of rocks where, despite the great relief of the subducted ridge, the collision has caused little indentation and shortening in the forearc.

Sites 830 and 831 are located where the Bougainville Guyot has collided with the arc, causing considerable indentation and shortening in the forearc (Fig. 2). At Site 830 we sought to penetrate imbricated arc rocks to test whether these rocks are part of an uplifted old accretionary wedge, recently accreted guyot rocks, or island-arc basement. At Site 831 we sought to determine the lithology, age, paleobathymetry, and mechanical properties of the guyot. Results obtained from drilling near the guyot were contrasted with those obtained near the north ridge to determine why arc structures induced by the collision are so different. The rate of uplift of the accretionary wedge was determined and compared to the rate at which onshore areas have emerged. This emergence occurred synchronously with collision, and onshore areas rose at rates exceeding 5 mm/yr during the Holocene.

Intra-Arc Basins

At Sites 832 and 833 in the North Aoba Basin (Fig. 2), we sought to investigate how arc-ridge collision has affected the development of the intra-arc basins and the evolution of the magmatic arc. In addition, we aimed to determine if volcanic ash within basin rocks contains a record of the hypothesized reversal in subduction polarity.

Site 832 is located within the center of the Aoba Basin (Fig. 2), which lies beneath significantly deeper water than does any other basin near the summit of this arc. We aimed to obtain the age of a major unconformity that likely correlates with the onset of arc-ridge collision and should provide one of the better estimates of when this onset occurred. The chemistry of Quaternary volcanic ashes will be used to show if the magmatic arc has been affected by subduction of the DEZ.

Site 833 is located along the eastern flank of the Aoba Basin (Fig. 2), where basin rocks include two unconformities. The shallower one provided temporal constraints on backarc deformation, possibly as a direct result of the collision. The deeper unconformity lies along the top of the oldest basin rocks, and drilling was aimed at helping understand the late Cenozoic evolution of the magmatic arc. The chemistry of volcanic ash should show whether the magmatic arc was affected by the subduction polarity change.

SITE 827

Site 827 (proposed site DEZ-2) is located within the deformation front of the DEZ, along the forearc slope of the New Hebrides Island Arc, 35 km west of the western shore of Espiritu Santo Island (Fig. 2). A short geophysical survey was undertaken to locate a flat, sedimented area suitable for spudding; the site was selected within a fairly small, flat yet hummocky-surfaced plateau 4 km east of the trace of the subduction zone, an area that appeared to have dammed and ponded sediment being transported downslope from the island. Here the NDR impinges upon the arc slope and has formed a tectonic front of lobate morphology that is composed of sheared and fractured accreted(?) and arc-derived material. This collision has produced an unstable slope prone to mass wasting and shearing from arcward-dipping thrust faults. Site 827 is located upon a thrust sheet or slump block that has been severely deformed by the active convergent tectonic processes. The site was chosen to penetrate the lower forearc slope, where rocks of the overriding plate are thin, in anticipation of drilling through the décollement and rock units of the underlying NDR. Our intent was to define the lithology, composition, age, and mechanical properties of rocks drilled to determine the degree and rate of material transfer from one plate to another, the timing of collision, the present-day stress field, and the composition and role of fluid circulation in the collision process.

We cored 110.6 m and recovered 100.8 m of sediment in Hole 827A for a 91.1% core recovery, and cored 400.4 m to recover 119.0 m of sediment and rock in Hole 827B for a 41.4% core recovery (Table 1).

Four lithostratigraphic units have been described (Fig. 3). Lithostratigraphic Unit I (0–86 meters below seafloor, or mbsf) consists of Pleistocene volcanic silt interbedded with normally graded, sandy volcanic silt beds (turbidites). This unit is subdivided into three subunits based on the concentrations of turbidite layers. Subunit IA (0–40 mbsf) is a volcanic siltstone with a few distinct turbidite layers, whereas Subunit IB (40–66 mbsf) is a volcanic siltstone with many turbidite layers and Subunit IC (66–86 mbsf) is a volcanic siltstone with fewer concentrated turbidite layers than are found in Subunit IB.

Lithostratigraphic Unit II (86–141 mbsf) is a sequence of upper Pliocene to Pleistocene volcanic silt and siltstones with varying components of clay and sand. This unit is differentiated from Unit I by the absence of graded beds.

Lithostratigraphic Unit III (141–252.6 mbsf) contains upper Pliocene to middle Pleistocene(?) highly bioturbated, partially lithified calcareous volcanic siltstone with intervals of sedlithic conglomerate. Unit III can be divided into three subunits consisting of an upper 59 m of tectonically disturbed, highly bioturbated, sandy to clayey volcanic siltstone (Subunit IIIA,

Table 1. Coring statistics, Leg 134.

Hole	Latitude (S)	Longitude (E)	Water depth (mbsl)	Number of cores	Length cored (m)	Length recovered (m)	Recovery (%)	Total penetration (m)
827A	15°17.74′	166°21.11′	2803.4	15	110.6	100.76	91.1	110.6
827B	15°17.75′	166°21.11′	2803.4	31	289.8	119.04	41.4	400.4
828A	15°17.34′	166°17.04′	3086.7	15	111.4	101.34	91.0	111.4
828B	15°17.26′	166°16.96′	3082.0	4	39.0	7.92	20.3	129.0
829A	15°18.96′	166°20.70′	2905.2	64	590.3	197.44	33.4	590.3
829B	15°18.97′	166°20.70′	2909.0	3	19.5	15.59	80.0	19.5
829C	15°18.96′	166°20.70′	2910.7	11	58.4	52.67	90.2	58.4
830A	15°57.00′	166°46.79′	1018.4	11	96.9	53.77	55.5	96.9
830B	15°57.00′	166°46.78′	1018.4	24	233.2	48.77	20.9	281.7
830C	15°57.00′	166°46.71′	1008.9	12	115.6	19.40	16.8	350.6
831A	16°00.56′	166°40.34′	1066.4	15	115.5	25.85	22.4	115.5
831B	16°00.56′	166°40.36′	1066.4	84	749.6	87.25	11.6	852.0
832A	14°47.78′	167°34.35′	3089.3	27	215.9	146.26	67.8	215.9
832B	14°47.77′	167°34.35′	3089.3	100	962.3	450.95	46.9	1106.7
833A	14°52.57′	167°52.78′	2628.5	26	199.5	97.75	49.0	199.5
833B	14°52.56′	167°52.78′	2629.0	99	923.7	519.54	56.2	1001.1

Note: Water depths are in meters below sea level.

141–200 mbsf), an intermediate 18 m of sed-lithic conglomerate/breccia (Subunit IIIB, 200–218 mbsf), and a lower 34 m of volcanic siltstone and foraminiferal and nannofossil ooze interbedded with ash and a highly sheared, variegated lustrous zone that appears rich in chlorite or some other micaceous mineral (Subunit IIIC, 218–252.6 mbsf).

Lithostratigraphic Unit IV (252.6–400.4 mbsf) comprises only clasts ranging in size from pebbles to the maximum diameter that can fit into the core barrel. These clasts consist of very well-lithified volcanic siltstone and sandstone, lithified breccias, and coarse sandstone containing a preponderance of igneous rock fragments and crystals. These clasts are mixed into a highly sheared and fractured matrix; the rock as a whole is called a partially lithified, matrix-supported sed-lithic conglomerate.

Initial interpretations of the core suggest that lithostratigraphic Unit I, which consists almost entirely of graded beds of volcanic silt and sandy silt containing both Pleistocene microfossils and reworked Miocene microfossils, was most likely derived from Espiritu Santo Island and transported to the site by turbidity currents. This unit contains plant debris fragments and coincides with a stratigraphic interval where benthic foraminifers suggest low-oxygen conditions, as would be expected in an environment where rapid burial by turbidity currents suppresses burrowing organisms that would otherwise consume and oxidize the organic matter. Lithostratigraphic Unit II is similar in lithology but is of late Pliocene to Pleistocene(?) age and devoid of graded bedding and is interpreted as a hemipelagic deposit. The coarse-grained and debris-like sediments of lithostratigraphic Unit III probably were deposited in a high-energy, deep-water (middle bathyal zone) environment close to a volcanic island source; this unit was then severely sheared and fractured by the collision of the NDR. Lithostratigraphic Unit IV is difficult to interpret because of the poor recovery; however, the depositional environment for such material must be proximal to the source because the material is very poorly sorted and the clasts are angular to subrounded.

Foraminifers and nannofossils provided the best source of age information. The sedimentary samples recovered were predominantly of Pleistocene to late Pliocene age, with reworked late Miocene fauna. Paleomagnetic results from Hole 827A indicate that the cored samples were well within the Brunhes Chron; cores from Hole 827B were too disturbed for paleomagnetic analysis.

Analyses of fluids from whole-round samples of the core indicate that chlorinity and salinity increase with depth to values 10%–15% higher than seawater concentrations at 250 mbsf. Both potassium and sodium decrease to 40%–50% of seawater values at 250 mbsf. Calcium concentrations increase strongly with depth to 250 mbsf but display a very slight minimum at about 75 mbsf. Overall concentrations of nutrients are low and silica concentrations are variable. Sulfate reduction is complete by 50 mbsf, but sulfate concentrations subsequently increase with depth to values equal to about 30% of seawater. Methane concentrations are near zero except for a strong, sharp maximum at about 75 mbsf. A significant finding is that the methane peak is probably not a result of organic matter diagenesis because (1) it appears too large relative to increases in the nutrients and (2) it is located below the maxima in nutrient concentrations. This peak suggests that there may be "exotic" fluids in that zone. This fluid appears to have lower chlorinity, lower salinity, higher sodium and potassium concentrations, and lower magnesium concentrations. The calcium concentrations in this zone are controlled more by the steep depth gradients and thus exhibit no maxima or minima. This level also marks the first appearance of sulfate below the sulfate-reduction zones. Low chlorinity concentrations, high methane concentrations, and sulfate below the zone of complete sulfate reduction are attributes of fluids in the Barbados and Nankai décollement zones (Mascle, Moore, et al., 1988; Taira, Hill, Firth, et al., 1991).

Physical properties correlate well with the lithostratigraphic units. In lithostratigraphic Unit I, the water content and porosity of the sediments decrease rapidly from a water content of 55% a few meters below the seafloor to below 40% at 40 mbsf. Bulk densities and velocities also agree, showing lithostratigraphic Unit II to be denser and less porous; sonic velocities increase significantly to more than 1920 meters per second (m/s) before dropping rapidly in the third unit as water content and porosity increase to 60% or more. Sonic velocities decrease further in the hard-rock breccia of lithostratigraphic Unit IV. Because of hole collapse, logging was not undertaken.

SITE 828

Site 828 (proposed site DEZ-1) is located at 15°17.34′S, 166°17.04′E, on the Australia-India plate, along the northeastern flank of the NDR about 2 km west of the active convergent margin that separates the Australia-India plate from the Pacific plate (New Hebrides microplate). The site lies 150 km

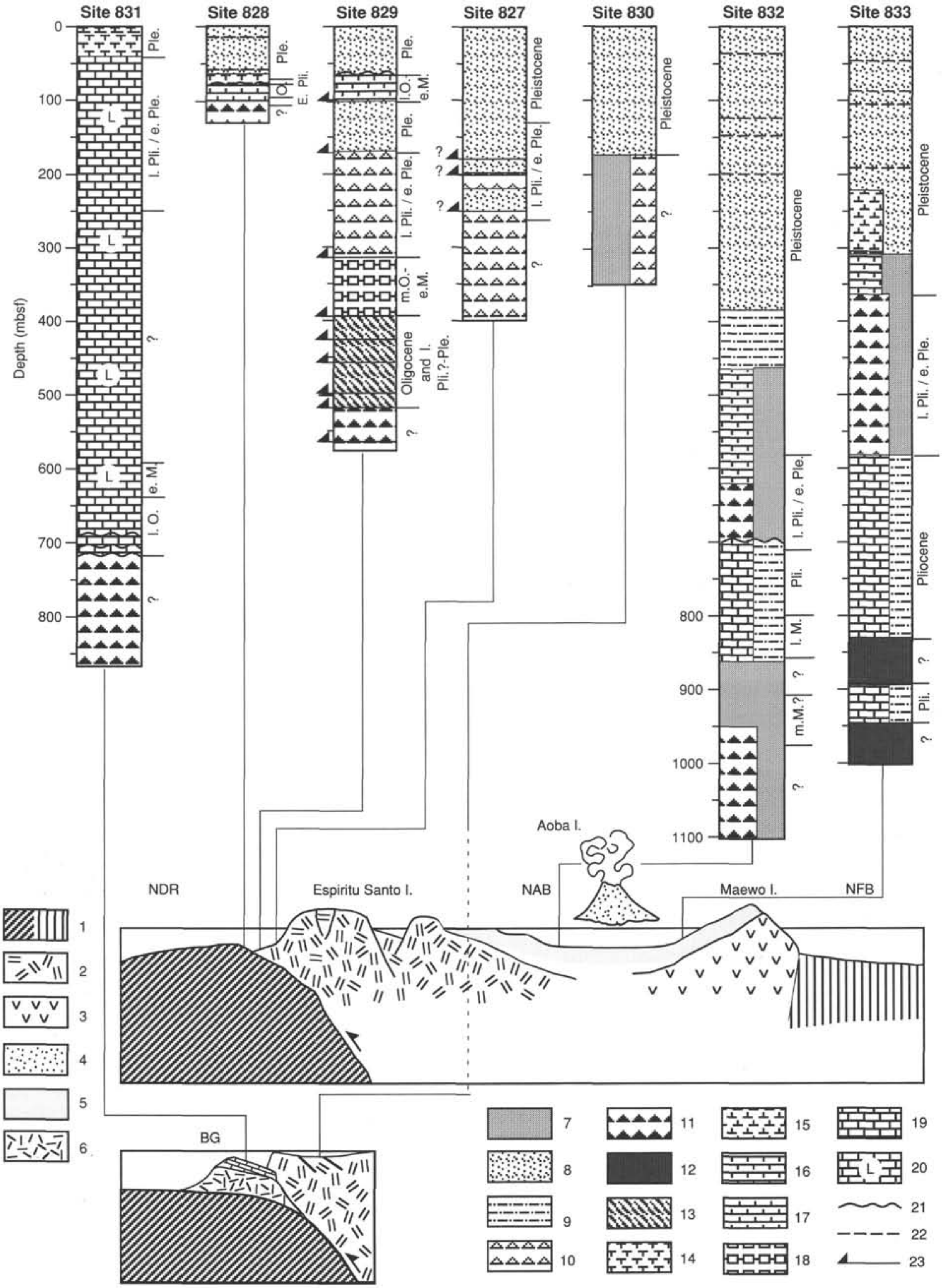

Figure 3. Geologic columns and cross sections, Leg 134. Location of cross sections is indicated in Figure 2. 1 = oceanic crust; 2 = Western Belt volcanic rocks; 3 = Eastern Belt volcanic rocks; 4 = Central Chain volcanic rocks; 5 = basin fill; 6 = guyot volcanic rocks; 7 = volcanic sand/sandstone; 8 = volcanic silt/siltstone; 9 = volcanic sandstone/siltstone/claystone; 10 = sed-lithic breccia; 11 = volcanic breccia; 12 = basalt chalk; 13 = multiple slivers of siltstone and chalk; 14 = foraminiferal ooze; 15 = nannofossil ooze; 16 = foraminiferal chalk; 17 = nannofossil chalk; 18 = calcareous chalk; 19 = pelagic limestone; 20 = lagoonal limestone; 21 = unconformity; 22 = ash; 23 = thrust fault. NDR = North d'Entrecasteaux Ridge; BG = Bougainville Guyot; NAB = North Aoba Basin; NFB = North Fiji Basin.

west of the active volcanic chain of the central New Hebrides Island Arc (Vanuatu) and about 40 km west of the western coast of Espiritu Santo Island, one of several islands associated with the lower Miocene Western Belt of islands (Fig. 2). Site 828 is located on a flat, terrace-like feature that projects out from the otherwise steeply dipping slope in a water depth of 3086.7 m. It lies near the collision zone of the NDR with the arc, an area where seafloor of the Australia-India plate is bending down into the eastward-dipping subduction zone. In response to this curvature, the terrace-like feature on which Site 828 lies has been faulted, and may be part of a series of structural features oriented northwest-southeast that step down to the east. Site 827 is 4 km east of Site 828, across the convergence boundary where the forearc is deformed from the collision of the NDR and subduction.

Two holes were drilled at Site 828. Hole 828A was cored with the advanced piston corer (APC) and extended core barrel (XCB) to 111.4 mbsf, with 101.3 m of core obtained for a recovery of 91%. Hole 828B, offset approximately 214 m to the northwest of Hole 828A, was drilled using the rotary core barrel (RCB) to a depth of 129 mbsf, coring 39 m, with 7.92 m of core obtained for a recovery of 20.3% (Table 1).

Four lithostratigraphic units were defined and described for this site (Fig. 3). Lithostratigraphic Unit I (0–58.7 mbsf) is a 58.7-m-thick, Pleistocene, dark greenish gray volcanic silt with foraminiferal sand interbeds. The contact with underlying Unit II is marked by a dark brown bioturbated ash bed.

Lithostratigraphic Unit II (58.7–69.3 mbsf) is a 10.6-m-thick, lower Pliocene to Pleistocene foraminiferal ooze divided into two subunits. Subunit IIA (58.7–61.9 mbsf) is a 3.2-m-thick, Pleistocene, light brownish gray to very pale brown foraminiferal ooze with nannofossils and alternating layers of silt and ash with firm-to-soupy foraminiferal sands. Subunit IIB (61.9–69.3 mbsf) is a 7.4-m-thick, lower Pliocene to upper Miocene, very pale brown to white unconsolidated foraminiferal ooze separated from Subunit IIA by a sharp color change, marking the end of the volcanic components of the overlying sediment.

Lithostratigraphic Unit III (69.3–90.8 mbsf) is a 21.5-m-thick, lower to middle Oligocene, highly bioturbated light yellowish brown nannofossil chalk that unconformably underlies Subunit IIB. This unit contains small (~5 cm in diameter) manganese nodules and the lower part has abundant dewatering structures.

Unit IV (90.8–111.4 mbsf) is at least 20.6 m thick and consists of upper Eocene to lower Oligocene igneous breccia that contains clasts of aphyric basalt and diabase. The clasts and matrix range in color from light greenish gray to dusky red.

Drilling at Site 828 revealed a 91-m-thick, lower Oligocene to Pleistocene marine sedimentary sequence unconformably(?) overlying a brecciated lava flow and an ig-lithic breccia that may have been subaerially altered. Hole collapse prevented penetration of basement rocks of the NDR, although the igneous rocks recovered are believed to be the eroded and weathered detritus of a volcanic basement complex. The rocks exhibit a blotchy red and greenish color that suggests extensive oxidation and alteration. The upper part of lithostratigraphic Unit IV included weathered clasts of apparently more differentiated volcanic rocks within a coarse-grained breccia. Beneath the breccia, rubbly, weathered, aphyric, fine-grained, vesicular basalts and basaltic andesites were encountered. One piece of olivine dolerite was found in Hole 828B. In contrast to the volcanic rocks recovered at Site 827, igneous rocks at Site 828 appear more mafic and lack phenocryst-sized orthopyroxene and hornblende. Initial geochemical analyses indicate that the basaltic rocks share a magmatic affinity intermediate between mid-ocean ridge basalt (MORB) and island-arc tholeiite (IAT), suggesting that an oceanic island-arc is their most probable origin.

At least three unconformities (61.9, 69.3, and 90.8 mbsf), two of which are questionable (61.9 and 90.8 mbsf), interrupt the marine sedimentary sequence above the igneous rocks of lithostratigraphic Unit IV. These unconformities bound lithologic units that vary considerably in lithology and give clues about the tectonic development of the region. All of the unconformities are restricted to the lower part of the sedimentary sequence, beneath 58 mbsf.

Nannofossil chalk of lithostratigraphic Unit III appears to be in unconformable contact with volcanic breccia of lithostratigraphic Unit IV. This contact may be a subaerially eroded surface. The chalk is of early to late Oligocene age compared to the late Eocene to early Oligocene age of Unit IV. Sediments of Unit III exhibit bioturbation and abundant dewatering structures.

Unconformably overlying lithostratigraphic Unit III is the upper Miocene to lower Pliocene foraminiferal ooze of Subunit IIB. The unconformity represents a major hiatus (~69 mbsf) of about 18 m.y., extending from the upper Oligocene (~24 Ma) to the lower Pliocene (~6 Ma); missing are deposits of the uppermost Oligocene and almost the entire Miocene epochs. At Deep Sea Drilling Project (DSDP) Site 286 (Fig. 1), located in the North Loyalty Basin approximately 120 km south of Site 828, the absence of Miocene strata indicates an important hiatus between 13 and 5 Ma (Andrews, Packham, et al., 1975), suggesting a regional elevation of the seafloor to a level where erosion occurred or deposition was curtailed. Subunit IIB is a very soupy foraminiferal ooze of late Miocene to early Pliocene age (6–4 Ma) that is unconformably(?) overlain by foraminiferal ooze of Subunit IIA, which is late Pleistocene (<1 Ma) in age. A hiatus of 3 to 5 m.y. may exist at 62 mbsf where sediments of middle Pliocene to middle Pleistocene age are missing. Lithostratigraphic Units II through III were deposited in a lower bathyal environment during a time of low sedimentation rates, between 2 and 7 m/m.y., as calculated from the microfossil analyses. Above Subunit IIA a major lithologic change occurs from the foraminiferal ooze and nannofossil chalks of Units II and III to the volcanic siltstones of Unit I, although the depositional environment remains lower bathyal. Unit I was deposited during the Brunhes Chron (within the last 700,000 yr) at a time of very high sedimentation rate (~60 m/m.y.). It consists primarily of Pleistocene volcanic silt interlayered with ash. Many interbeds occur, some with scoured bases of normally graded, sandy volcanic silt with foraminifers, indicating sedimentation on a slope with possible turbidity transport. A greater influence of volcanic sedimentation, as indicated by ash layers, appears to have occurred at Site 828 during the Pleistocene, indicating proximity to a volcanic source.

Although logging was not done at Site 828 because of hole problems, physical properties measurements and fluid chemistry assisted in the definition of the lithostratigraphic units. Magnetic susceptibility and porosity curves correlate well with the four lithostratigraphic units. Distinct "kicks" are given on both curves, and magnetic susceptibility remains high throughout lithostratigraphic Unit I, reaching zero at Unit II, increasing slightly through Unit III, and becoming high again in Unit IV. Porosity increases slightly in Unit I from about 61% to 63% with an anomalous low peak at about 18 mbsf, varying considerably from 50% to 93% in the soupy foraminiferal ooze of Unit II, remaining fairly constant between 62% to 64% in the nannofossil chert of Unit III, and exhibiting a sharp divergence of 66% to about 36% in volcanic breccia of Unit IV.

Interstitial fluids of Hole 828A have chloride concentrations that reach values at 50 mbsf of 570 mM, approximately 2% higher than seawater, which may result from local ash alteration or perhaps mixing with chloride-rich fluids from the accretionary wedge. Potassium, sodium, and magnesium decrease with depth, whereas calcium concentrations increase. This may result from diagenetic exchange reactions with the volcanic-ash-rich sediments and basement igneous rocks.

Initial examination of the cores from Site 828 suggests that the eastern terminus of the NDR formed in close association with a volcanic island arc. Igneous rocks recovered in both Holes 828A and 828B support the view that the ridge may have originated along a subduction zone as proposed by Daniel et al. (1977) and Maillet et al. (1983). From the late Eocene to early Oligocene, volcanic breccia and lava flows built up the flank of the ridge of Site 828 where the highly oxidized volcanic rubble was drilled. Subsidence of the ridge then occurred, followed by the deposition of over 21 m of pelagic nannofossil ooze during the early to late Oligocene (~7–12 Ma.). This was a time of low deposition rates as indicated by the ~5 m/yr average sediment accumulation rate and the presence of small manganese nodules found in lithostratigraphic Unit III. At some point between the late Oligocene and late Miocene, probable elevation, and perhaps emergence, of the NDR took place, causing complete removal or nondeposition of sediment, thus producing the 18-m.y. hiatus.

Subsidence recurred with slow deposition of the pelagic foraminiferal ooze during the late Miocene to early Pliocene. This unconsolidated, highly permeable unit is an aquifer that may facilitate transport of fluids away from the subduction zone. Sometime during the Pliocene, sea level fell or elevation may have once again occurred, perhaps in association with the arrival of the present eastern terminus of the NDR, including the location of Site 828, at the outer bulge, causing erosion or preventing deposition to produce the hiatus of 3–5 m.y.

The sedimentation rate during the Pleistocene increased considerably to ~60 m/m.y. with the influx of volcanic silts and ash. This was most likely in response to the convergence of the NDR, including Site 828, with the New Hebrides Island Arc. Sedimentation was influenced both by ash fall and hemipelagic contribution from the active volcanoes of the arc. Geochemical analyses of some of the Pleistocene ashes indicate that they originated from events associated with the volcanically active Central Chain, some 150 km to the southeast. Site 828 is currently about to be subducted beneath the forearc of the central New Hebrides Island Arc and appears to be undergoing initial tensional faulting in response to the bending of the lithosphere in this area.

SITE 829

We arrived at Site 829 (proposed site DEZ-2) on 27 October 1990 at 1930 Universal Time Coordinated (UTC). After 10 days and 1.5 hr on site drilling three holes (Holes 829A, 829B, and 829C), we departed Site 829 at 1230 UTC on 5 November 1990. We were forced to abandon Hole 829A because of hole collapse and filling problems at a depth of 590.3 mbsf. Hole 829B was aborted because a core barrel bent on the steeply sloping seafloor. Hole 829C was completed in a hard zone (58.4 mbsf) where the APC could not penetrate further.

Site 829 is located within the collision zone of the DEZ along the forearc slope of the New Hebrides Island Arc where the NDR impinges upon the arc-slope, approximately 3 km south of Site 827 and about 35 km west of Espiritu Santo Island, Vanuatu (Fig. 2). This site was located very close to the original proposed site (DEZ-2) along a single-channel seismic reflection line surveyed by the *JOIDES Resolution* prior to spudding in at Site 827. The site selected lies on a very narrow (~200-m-wide) shelf protruding out from a 10° slope. We were able to spud in without difficulty on our first try, and cored to 590.3 mbsf, recovering 197.4 m of core for a recovery rate of 33.4%. Hole 829B was drilled and cored to 19.5 mbsf, recovering 15.6 m for an 80% recovery rate; Hole 829C was cored to 58.4 mbsf, recovering 52.7 m of core for a 90.2% recovery rate (Table 1). The intent of drilling a second and third hole at this site was to recover cores with the APC in the upper 100 m of section that was poorly recovered during the RCB-drilling of Hole 829A. Oriented cores for paleomagnetic analyses and structural examinations were taken, and whole-round core samples for both fluid analyses and physical properties measurements were obtained. This was our second attempt to drill to the décollement in the DEZ–New Hebrides Island Arc collision zone. Although hole collapse prevented the penetration of the décollement, we successfully cored the overlying thrust sheets and accretionary prism and may have entered the upper reaches of the décollement zone.

Lithostratigraphic examination of the sedimentary and igneous rocks recovered at Site 829 indicate that the sequence can be divided into 21 lithostratigraphic units (Units I–XXI) that are repeated throughout the core. Because of these repetitions, the lithostratigraphic units can be divided into four composite units (Bigwan Wan, Bigwan Tu, Bigwan Tri, and Bigwan Fo, named in Bislama, the official language of Vanuatu). These composite units are defined on the basis of age and lithologies. Bigwan Wan is a Pleistocene volcanic silt, sandstone, and gray silty chalk. Bigwan Tu is an upper Oligocene to lower Miocene foraminiferal and calcareous chalk. Bigwan Tri is an upper Pliocene or Pleistocene chalk breccia with upper Oligocene to lower Miocene clasts. Bigwan Fo is an igneous breccia of unknown age with clasts of basaltic rock fragments, microgabbros, and gabbros with rare pyroxenite and serpentinite fragments. At least five major thrust faults and seven minor thrust faults separate the lithostratigraphic units within the sequence and bound seven tectonic units (A–G); tectonic Unit E is subdivided into two subunits (Subunits E_1 and E_2) based on the presence of major thrust faults (Fig. 3). These tectonic units are progressively more deformed downhole.

The lithologic units are defined on the basis of lithology, carbonate vs. volcanic composition, and structural relationships. Lithostratigraphic units are numbered consecutively starting with Hole 829A and ending with Hole 829C. In Hole 829A, lithostratigraphic Unit I (0–60.5 mbsf; Bigwan Wan, tectonic Unit A) is composed of Pleistocene clayey volcanic silt, siltstone, and sandstone. Lithostratigraphic Unit II (60.5–99.4 mbsf; Bigwan Tu, tectonic Unit A), based on fragments recovered from a poorly recovered zone, is an upper Oligocene to lower Miocene foraminiferal chalk. Lithostratigraphic Unit III (99.4–171.9 mbsf; Bigwan Wan, tectonic Unit B) is a Pleistocene clayey volcanic silt and sandstone that is separated from overlying Unit III by a 50-cm-thick layer of brown clay and by a thrust fault. Lithostratigraphic Unit IV (171.9–205.2 mbsf; Bigwan Tri, tectonic Unit C) is a siltstone chalk breccia composed of angular clasts of calcareous volcanic sandy siltstone and calcareous chalk that is separated from overlying lithostratigraphic Unit III by a minor thrust-faulted contact.

Lithostratigraphic Unit V (205.2–311.3 mbsf; Bigwan Tri, tectonic Unit C) consists of upper Pliocene or Pleistocene breccia with upper Oligocene to lower Miocene clasts. Lithostratigraphic Unit VI (311.3–398.9 mbsf; Bigwan Tu, tectonic Unit D) consists of middle Oligocene to lower Miocene calcareous chalk that is separated from underlying Unit VII by brown clay laminae.

Lithostratigraphic Unit VII (398.9–407.4 mbsf; Bigwan Fo, tectonic Unit D), a volcanic breccia of unknown age, is composed of igneous rock clasts in a matrix of calcareous silty clay with sedimentary fragments. The igneous clasts include aphyric to sparsely phyric basalts, pyroxenite, and serpentinite. It is a poorly recovered zone that appears to be highly sheared and fractured, exhibiting microfolds and reverse faults with a major thrust located near the base of the unit.

Lithostratigraphic Unit VIII (407.4–407.8 mbsf; Bigwan Tri?, tectonic Unit E_1) is a small (0.4-m-thick) sliver of lower Pliocene chalk. Lithostratigraphic Unit IX (407.8–421.6 mbsf; Bigwan Tu, tectonic Unit E_1) is a Pleistocene calcareous silty mixed sediment. Lithostratigraphic Unit X (421.6–427.3 mbsf; Bigwan Tu, tectonic Unit E_1) is a highly tectonized pale brown Oligocene chalk with a 14-cm-thick brown clay layer that marks a major thrust fault at the base of the unit.

Lithostratigraphic Unit XI (427.3–445.9 mbsf; Bigwan Wan, tectonic Unit E_2) is a Pliocene or Pleistocene dark gray silty chalk. Lithostratigraphic Unit XII (445.9–462.9 mbsf; Bigwan Tu, Tectonic Unit E_2) is an Oligocene pale brown chalk with brown clay laminae at its base and lies within a major northeast-dipping thrust-fault zone. Beneath this thrust contact lies lithostratigraphic Unit XIII (462.9–484.5 mbsf; Bigwan Wan, tectonic Unit F), a Pliocene or Pleistocene calcareous volcanic sandstone with sand-sized clasts of pumice, wood, and chalk, some of Oligocene age. Lithostratigraphic Unit XIV (484.5–495.6 mbsf; Bigwan Tu, tectonic Unit F) is an Oligocene brown, white, and pale brown chalk and brown mixed sediment with a major thrust fault at its base that separates this unit from underlying Unit XV. Lithostratigraphic Unit XV (495.6–517.2 mbsf Bigwan Wan, tectonic Unit G) is a sandy volcanic siltstone of Pliocene or Pleistocene age and is separated from underlying Unit XVI by an interval of sandy brown clay.

The final unit in Hole 829A is lithostratigraphic Unit XVI (517.2–590.3 mbsf; Bigwan Fo, tectonic Units G and H), an interval of unknown age that is composed of alternating layers of sed-lithic breccia with igneous fragments (basalt, microgabbro, and gabbro). Preliminary geochemical studies suggest affinities with the igneous rocks from Site 828 on the North d'Entrecasteaux Ridge. Thus, we suspect that the drill may have penetrated the upper surface of the décollement, or was quite close to it.

Lithostratigraphic Unit XVII (0–19.5 mbsf; Bigwan Wan, tectonic Unit A), the only unit defined in Hole 829B, is a Pleistocene clayey sandy volcanic silt that may be correlated with lithostratigraphic Unit I. In Hole 829C, four additional lithostratigraphic units are defined (Units XVIII–XXI). Lithostratigraphic Unit XVIII (0–54.6 mbsf) contains Pleistocene clayey, sandy, volcanic silt, and clayey volcanic silt with a basal interval of silty foraminiferal mixed sediment; this unit correlates with Unit I of Hole 829A and is a member of Bigwan Wan and tectonic Unit A. Lithostratigraphic Unit XIX (54.6–57.3 mbsf) is a lower Miocene foraminiferal ooze; this unit is correlatable with lithostratigraphic Unit II in Hole 829A and is a member of Bigwan Tu and tectonic Unit A. Lithostratigraphic Unit XX (57.3–58.3 mbsf) is a Pleistocene silty foraminiferal mixed sediment that belongs to Bigwan Wan and tectonic Unit A. Lithostratigraphic Unit XXI (58.3–58.4 mbsf) is a foraminiferal chalk found at the total depth of Hole 829C.

Initial interpretations of the cores suggest that many of the lithostratigraphic units identified in Hole 829A are similar to those observed in Hole 828A. For example, the calcareous chalk and the pale brown chalk of Bigwan Tu are similar in age and lithology to the nannofossil chalk of lithostratigraphic Unit III from Hole 828A. Igneous rocks collected at both Sites 828 and 829 are similar. Therefore, we tentatively conclude that we drilled through an accretionary prism that is composed in part of offscraped rocks and sediments from the downgoing NDR. As at Site 828, a middle to upper Miocene hiatus appears to exist at Site 829.

Foraminifers and nannofossils provided the only source of age information, based primarily on core-catcher samples. Unconsolidated samples recovered were principally of Pleistocene age; some material of Pliocene age was also found. The more lithified samples of calcareous chalk revealed an age of Oligocene to possible early Miocene and Eocene. Paleomagnetic polarity is normal (Brunhes Chron) from 0 to 50 mbsf; below this depth cores were too tectonically deformed for accurate measurements to be made. At 100–150 mbsf the volcanic silt (Subunit IA) showed very high magnetic susceptibility values; susceptibilities of different lithostratigraphic units are quite distinct.

Analyses of fluids from whole-round samples of the core indicate a sharp decrease in magnesium concentration within the upper 10 m, suggesting a high fluid flux up through the sediments. Chloride was constant from 0 to 250 mbsf. Solutes related to organic carbon appear low in the upper 100 m of core (in lithostratigraphic Units I and II) but increase in concentration beneath the thrust fault that separates Units I and II. Beneath this fault, to a depth of about 500 mbsf, the core is extremely dry and devoid of water. However, below this depth, the fluid content increases, minor amounts of methane occur, and chloride concentrations are low. Initial interpretations indicate that Hole 829A may have terminated close to the décollement because the fluid chemistry, showing an increase in methane accompanying low chloride concentration, is similar to that found along other subduction zones such as Barbados (Mascle, Moore, et al., 1988) and Nankai (Taira, Hill, Firth, et al., 1991). The brecciated sequence (Unit XVI, 517.2–590.3 mbsf) may then represent the sheared and deformed rocks that lie within the décollement just above the basement rocks of the NDR. Above the wet zone, the area of dry rocks suggests that dewatering has taken place here, being the result of compressional pressures exerted onto the forearc slope by the impingement of the NDR. Fluid migration may be taking place along the thrust fault (100 mbsf) that separates Unit II from Unit III.

Extensive logging was done in Hole 829A and provided excellent results. The digital borehole televiewer and magnetic susceptibility tool were run for the first time in Ocean Drilling Program (ODP) and resulted in the collection of good data that appear to correlate well with the formation microscanner (FMS) and other logging tools. The FMS, seismic stratigraphy combination, and geochemical tools correlated very well with each other and the lithostratigraphic units. Thrust faults and lithologic contacts were well defined in all logs collected. Physical properties measurements of the cores in Hole 829A also show excellent correlation with the lithostratigraphic units. Calcium carbonate measurements correlate well with water-rich zones defined by the fluid analyses.

SITE 830

Site 830 (proposed site DEZ-4) is located at 15°57.00'S, 166°46.7'E, to 15°57.00'S, 166°46.8'E, in water depths ranging from 1018.4 to 1008.9 meters below sea level (mbsl). This site is located on the forearc slope of the central New Hebrides Island Arc immediately east of where the Bougainville Guyot is impinging upon the forearc slope, 30 km south of the southern tip of Espiritu Santo Island and 6.5 km east of the Australia-India convergence boundary (Fig. 2). Here the SDC is colliding with the arc. East of the point of impingement, the upper forearc slope is folded and faulted, with the most intense area of deformation being immediately east of the impact zone, in an area that exhibits an anticlinal dome. To the east of the anticlinal dome a series of imbricated thrust sheets, gently dipping to the east, can be seen in the seismic reflection profiles. Site 830 is located just east of the anticlinal dome and at the westward toe of the most westerly thrust sheet.

Three holes were drilled at Site 830. Hole 830A was cored with the APC and XCB to 96.9 mbsf, recovering 53.8 m for a recovery rate of 55.5%. Hole 830B was washed to 48.5 mbsf and drilled with the RCB to a total depth (TD) of 281.7 mbsf, but cored only 233.2 m, recovering 48.8 m for a recovery rate of 20.9%. Hole 830C was washed to 235.0 mbsf and drilled with the RCB to a TD of 350.6 mbsf, cored 115.6 m, recovering 19.4 m for a 16.8% recovery rate (Table 1).

Two major lithostratigraphic units were defined and described for this site (Fig. 3). Lithostratigraphic Unit I (0–96.9 mbsf in Hole 830A; 48.5–174.9 mbsf in Hole 830B) is a very dark gray volcanic silt and siltstone of Pleistocene age that is subdivided into three subunits. Subunit IA consists of a 21-m-thick, fine-grained, nearly structureless, unlithified silt; it appears to represent a near sea-surface, oxidized former sediment/water interface overlain by a turbidite, the upper 9.5 m being a calcareous volcanic silt. Subunit IB is a 26.0-m-thick clayey sandy silt with numerous normally graded interbeds of black sand. Subunit IC is a 127.9-m-thick sequence of interbedded sandy silt and sands.

Lithostratigraphic Unit II (174.9–281.7 mbsf) is a colorful sequence of partially lithified, very poorly sorted, very coarse, volcaniclastic, silty sed-lithic sandstones. The sequence is highly altered and contains intervals of grayish green to greenish gray and reddish black clayey silts, isolated pebbles of volcanic rocks, and fine-grained, well-lithified volcanic sandstone and ig-lithic breccias. The upper part (174.9–184.9 mbsf) of the unit is an ig-lithic breccia with 3- to 5-cm clasts of breccia and sandstone. Two types of igneous rocks are found in Unit II: lavas and volcanic breccia. The lavas are moderately olivine-clinopyroxene-phyric and plagioclase-phyric basalts or basaltic andesites. The volcanic breccia is composed of volcanic rock fragments; two fragments of fine-grained gabbro were also found within this breccia. Rocks of Unit II appear to be the product of explosive events, based on the brecciated and quenched nature of the rock, perhaps formed in association with the volcanic activity that built Espiritu Santo and Malakula islands. The petrology of Unit II is similar to the monolithic volcaniclastic coarse breccias of the lower Miocene Buvo Division of the Lower Santo Volcanics Subgroup exposed along the southwest end of Espiritu Santo Island that were derived by fragmentation of basaltic and andesitic lavas and regarded as submarine accumulations near volcanic source vents (Mallick and Greenbaum, 1977). Similar types of rocks were formed in the central region of Malakula Island and consist of volcanic breccias and sorted, unstratified submarine and subaerial autobreccias of the lower Miocene Matanui Volcanic Series, which are the product of submarine volcanoes (Mitchell, 1971). In addition, patches of highly oxidized volcanic matrix observed throughout Unit II suggest that subaerial erosion may have taken place.

Structural analyses of cores obtained at Site 830 indicate that the stratigraphy can be divided into two tectonic units. These tectonic units correlate well with the lithostratigraphic units. Tectonic Unit A corresponds with lithostratigraphic Unit I, and tectonic Unit B corresponds with lithostratigraphic Unit II; the boundary of both the tectonic and lithostratigraphic units is at 174.9 mbsf. Tectonic Unit A is disturbed only by minor, steeply dipping faults and fractures, whereas tectonic Unit B has undergone cataclastic deformation. Bedding in the upper part of tectonic Unit A is horizontal at 15 mbsf, dips from 5°–40° southeast between 45 and 80 mbsf. Tectonic Unit B (lithostratigraphic Unit II) is a coarse-grained, volcaniclastic, silty sed-lithic sandstone that has undergone brittle deformation and is considered a cataclasite. The distinct differences in the tectonic style of the two units at this site suggest that either tectonic Unit A (lithostratigraphic Unit II) was structurally deformed before deposition of tectonic Unit B (lithostratigraphic Unit I) or that differential deformation of both units may have occurred within a common stress field.

Nannofossil and foraminiferal biostratigraphic analyses indicated that lithostratigraphic Unit I is Pleistocene in age; however, because of barren samples in Unit II, age could not be determined. Both reworked Pliocene foraminifers and reworked Miocene and Pliocene nannofossils were found throughout the samples examined at Site 830. Paleomagnetic studies indicate that strata cored within lithostratigraphic Unit I (0–30 mbsf) were deposited during the Brunhes Chron. On the basis of benthic foraminifers the depositional environment of lithostratigraphic Unit I appears to have been in the middle bathyal zone. Because of the poor age control, accurate sediment accumulation rates could not be determined.

Initial interpretation of the cores obtained at Site 830 and preliminary comparison with rock units defined on the islands (Mitchell, 1971; Mallick and Greenbaum, 1977) indicate that the sedimentary rocks penetrated by the drill are derived from the New Hebrides Island Arc and appear to have been deformed by the collision of the DEZ, and more recently by the Bougainville Guyot. Seismic reflection profiles show the location of this site to be near the western edge of a gentle, easterly dipping thrust sheet, one of several imbricated thrusts that accommodate the foreshortening of the forearc slope by collisional processes. A series of east-dipping reflectors exists at the site, and two strong reflectors, one at 1.5 s and another at 2.0 s two-way traveltime, were the objectives of drilling. These reflectors are interpreted as stratigraphic horizons, wholly within arc rocks and disrupted by thrust faulting, which represent surfaces of carbonate blocks or the debris apron of the subducted and buried eastern part of the guyot accreted to the arc. Because of hole collapse, we were unable to reach these deeper reflectors and confirm the existence of guyot fragments. However, we did penetrate the upper surface of the shallower strong reflector (1.5 s). The existence of a cataclasite at this horizon suggests that severe mechanical stress has occurred here, perhaps along the plane of the stratigraphic horizon (bedding plane movement) and in association with the foreshortening of the forearc.

Lithostratigraphic Unit II is a very poorly sorted, very coarse volcaniclastic sand with an overlying volcanic breccia and sandstone of unknown age that has been subjected to cataclastic deformation. Severe mechanical stress within Unit II has sheared and fractured New Hebrides Island Arc rocks, and most likely this unit represents a primary deformation zone associated with the foreshortening of the arc slope. Lithostratigraphic Unit I overlying the cataclasite appears to represent volcanic silts and sands that have been eroded from the arc and deposited along its forearc by turbidity currents during the Pleistocene. Alternating grain size suggests either changes in source or shifts in the slope where deposition took place. Although tectonic deformation observed in the lithostratigraphy of Site 830 appears to be associated with the collision of the DEZ, and more recently, perhaps, with the Bougainville Guyot, actual timing of this deformation is difficult to determine based on the data available solely from this site.

The study of pore fluids in samples obtained from the cores at Site 830 were found to be significant in the understanding of diagenetic and hydrologic origins of fluids in accretionary wedges. Similar to what has been found in other accretionary wedges, such as in the Barbados (Biju-Duval, Moore, et al., 1984; Mascle, Moore, et al., 1988) and Nankai (Taira, Hill, Firth, et al., 1991) regions, dewatering of the sediments appears to have occurred as the water yield decreased sharply from the seawater interface to 50 mbsf, but chlorides increased in Hole 830B to 620 mM at 214 mbsf in lithostratigraphic Unit II, within the cataclasite of tectonic Unit B. Methane concentrations from headspace samples were higher at this site than those observed in any of the previous sites of this leg. This methane was found within lithostratigraphic Unit I, but not along the cataclastic zone. Along with this methane, at 30–90 mbsf, heavier hydrocarbons (ethane and propane) were found; another strong maximum of methane without the heavier hydrocarbons, however, was also found at 145 mbsf. At these depths the foraminifer *Bulimina striata,* which may indicate the existence of methane during the time of deposition (Akimoto et al., 1990), was found in the cores as well. The steepest concentration gradients of magnesium, calcium, sodium, and potassium found at Site 830 occurs across the contact of lithostratigraphic Units I and II. This is attributed to the alteration of volcanic ash and basement rocks beneath the contact with diffusion away from the zones of intense reaction. The deepest sample taken at this site contains an extraordinarily high calcium concentration of 229.2 mM.

The extreme fluid compositions witnessed at Site 830 may result from the intense tectonic deformation that is occurring from the impact of the Bougainville Guyot with the New Hebrides Island Arc. A strong decrease in water content downsection implies compressional dewatering. Fracturing of volcanic rocks from collision facilitates increased alteration and fluid flow. Foreshortening of the forearc, resulting in the formation of imbricate thrust sheets, appears to have stacked small fragments of highly fractured basement rocks on fluid-rich sediments. The sandy intervals then form conduits for flow of the mineral-rich fluids, and the thrust zones themselves also act as conduits.

SITE 831

Site 831 (proposed site DEZ-5) is located at 16°00.56′S, 166°40.36′E, in a water depth of 1066.4 mbsl. This site is located in the center of the summit platform of Bougainville Guyot, about 42 km southwest of the southern tip of Espiritu Santo Island, about 5 km west of the collision zone between the Bougainville Guyot and the New Hebrides Island Arc and approximately 15 km due west of Site 830 (Fig. 2). The Bougainville Guyot is a carbonate-capped, flat-topped seamount that represents the eastern end of the South d'Entrecasteaux Chain. It is being subducted beneath, or accreted to, the New Hebrides Island Arc where it impinges upon the forearc slope, forming a 10-km indentation. In response to the eastward-dipping subduction zone, the carbonate cap of the guyot is tilted ~5° to the east. Seismic reflection profiles indicate that about one-third of the guyot is buried beneath sediments of the forearc (Fisher et al., 1991). Seismic reflection data also show that about 700 m of well-layered sediments make up the carbonate cap, and these data, along with Seabeam data, dredge samples, and submersible observations and sampling, show the cap to be lagoonal deposits in an atoll setting (Daniel et al., 1986; Collot et al., 1989; Fisher et al., 1991). Site 831 drilled this lagoon.

Two holes were drilled at Site 831. Hole 831A was drilled to a TD of 115.5 mbsf, with 115.5 mbsf cored and only 25.85 m recovered for a recovery rate of 22.4%. Hole 831B was drilled to a TD of 852 mbsf, washed down to 102.4 mbsf, and cored for 749.6 m, recovering only 87.25 m of core for an 11.6% recovery rate (Table 1).

Four major lithostratigraphic units were defined and described from the two holes of Site 831 (Fig. 3). Lithostratigraphic Unit I (0–16.9 mbsf) is a 16.9-m-thick, Pleistocene, pelagic, brown foraminiferal ooze with partially lithified grainstone clasts. This unit has an upper (0.4–3.0 mbsf) sed-lithic conglomerate layer and grades downhole into a light yellowish brown bioclastic foraminiferal ooze. Pteropods are especially abundant in the upper part of Hole 831A and were found to constitute an ooze that contains thin laminae of volcanic ash. A prominent black ash layer is present at 14.4 mbsf and is composed of pale brown glass (53%) and opaque grains (25%) that may have resulted from reworking or fractionation during subaerial or submarine settling. The contact between lithostratigraphic Units I and II is marked by an abrupt faunal transition from pelagic microfossils of Unit I to neritic microfossils of Unit II.

Lithostratigraphic Unit II (16.9–429.6 mbsf; 412.7 m thick) is identified and described from both holes at Site 831 (16.9–100 mbsf, Hole 831A; 102.4–429.6 mbsf, Hole 831B) and is a neritic carbonate deposit with a wide diversity of shallow-water organisms. The unit has also been divided into four subdivisions. Subunit IIA (16.9–100 mbsf) is an 83.1-m-thick Pleistocene white coral and bioclastic grainstone and foraminiferal wackestone; it contains specimens of *Acropora* and *Porites* corals. Subunit IIB (102.4–256.0 mbsf) is a 153.6-m-thick Pliocene(?) to Pleistocene coral rudstone and mollusc floatstone with fragments of white *Acropora* and *Porites* corals and a large fragment of a tridacnid shell; the mollusc floatstone is partially lithified by marine cementation and has abundant primary porosity. Subunit IIC (256.0–352.3 mbsf) is a 96.3-m-thick coral rudstone and mollusc floatstone of indeterminate age with extensive carbonate dissolution (moldic and vuggy porosity forms 10%–15% of the rock); a well-preserved *Porites* head coral and tridacnid shell fragment were recovered from this unit. Subunit IID (352.3–429.6 mbsf) is a 77.3-m-thick, white, well-lithified bioclastic floatstone of indeterminate age with marine and abundant secondary carbonate cement that may have been deposited by meteoric waters.

Lithostratigraphic Unit III (429.6–727.5 mbsf) is a 297.9-m-thick neritic carbonate rock that contains an abundance of molluscs and large benthic foraminifers. The contact between lithostratigraphic Units II and III is a distinct facies change: Unit II is a coral- and mollusc-rich facies, and Unit III is a mollusc- and foraminifer-rich facies. This contact is also distinguishable by a sharp increase in carbonate dissolution and cementation. Lithostratigraphic Unit III is further subdivided into four subunits. Subunit IIIA (429.6–592.6 mbsf) is a 163-m-thick, white bioclastic floatstone of indeterminate age that is highly altered and extensively dissolved with abundant secondary cement and contains coralline algae; this subunit was hard to drill. Subunit IIIB (592.6–621.6 mbsf) is a 29-m-thick, lower Miocene, well-cemented bioclastic floatstone and foraminiferal grainstone with abundant vuggy and moldic porosity; mottling suggests burrowing (bioturbation). This subunit was easily drilled compared to Subunits IIIA and IIIC. Subunit IIIC (621.6–669.2 mbsf) is a 47.6-m-thick, upper Oligocene, white to very pale brown bioclastic and foraminiferal grainstone with minor amounts of moldic porosity. This subunit was hard and drilling was slow. Subunit IIID (669.2–727.5 mbsf) is a 58.3-m-thick, upper Oligocene, well-lithified bioclastic and algal packstone and foraminiferal grainstone with distinct burrowing in the packstone. This subunit has marine cement and abundant veins of chlorite; 40% of the rock is composed of coralline algae (both encrusting and branching forms), and 15% of the rock shows moldic and vuggy porosity. Two soil horizons occur within Subunit IIID: the first consists of a reddish brown silty clay, sensu stricto Terra Rosa, with high water content (45%) and porosity (57.7%) and a low bulk density (1.90 Mg/m^3) at 688.3 mbsf, and the second horizon is a very pale brown foraminiferal wackestone with yellowish brown and red streaked clays at 707.3 mbsf that has a lower water content (11.8%) and porosity (25.5%) and a higher bulk density (2.46 Mg/m^3) than the upper soil horizon.

Lithostratigraphic Unit IV (727.5–852 mbsf) is an andesitic hyalo-breccia composed of two-pyroxene andesite clasts or blebs in a matrix of lithic fragments, crystals, and glass; in places it is a palagonite breccia. Hole 831B penetrated 125 m of the andesites; the TD of the hole is within this unit at 852 mbsf. Unit IV is barren of microfossils, and hence its age is unknown at present. Five subunits were defined for Unit IV based on what appears to be a cyclicity of eruptive events or depositional conditions. Subunit IVA (727–741 mbsf) is a 14-m-thick andesitic breccia with thin beds of reworked grit and sandstone, strongly oxidized at the top of the subunit (probably the result of subaerial weathering); large clasts of volcanic fragments become progressively more abundant (20%) near the bottom of the subunit. Subunit IVB (741–789 mbsf) is a 48-m-thick andesite breccia composed of subrounded, wispy andesite blebs within a pale green matrix. Subunit IVC (789–822 mbsf) is a 33-m-thick coarse-grained breccia that includes pale reddish fragments interbedded with grits and sandstone. Subunit IVD (822–838 mbsf) is a 10-m-thick breccia that consists almost exclusively of well-defined gray, fresh andesite blebs with distinct coronas or reaction rims in a grayish matrix; near the base (837 mbsf), blebs become more diffuse and exhibit irregular or wispy outlines. Subunit IVE (838–852 mbsf) is a 14-m-thick breccia with reddish lava fragments in a pale green matrix that includes abundant sand-sized fragments of lava with varying degrees of oxidation. Cross-bedded sandstone and grits mark the base of this subunit.

Nannofossils and foraminifers, including large foraminifers preserved in the neritic carbonate rocks, are the only indicators of age. However, because of the soupy nature of much of the pelagic carbonate sequence and poor core recovery of the neritic carbonate sequence, dating of cores was sketchy at best. Only the upper 20 m could be dated by both nannofossils and foraminifers. Assemblages of microfossils analyzed in cores from Site 831 revealed an age of Pleistocene for lithostratigraphic Unit I (0–16.9 mbsf) and the upper part (16.9–20 mbsf) of Unit II. The middle part of Unit II (20–246.4 mbsf) was dated as Pliocene or Pleistocene. From 246 to 563.6 mbsf (the lower part of lithostratigraphic Unit II to the upper part of Subunit IIIA) the cores were barren of microfossils, and their age cannot be determined. From 563.6 to 621.6 mbsf (lithostratigraphic Unit III, from the lower part of Subunit IIIA through Subunit IIIB), an early Miocene (~21.8–23.6 Ma) age was determined based on large foraminifers. Finally, from 621 to 735.7 mbsf (lithostratigraphic Units III and IV, Subunits IIIC, IIID, and the upper part of IVA), a late Oligocene (~23.6–28.2 Ma) age was determined based on large foraminifers. This interval includes the base of the carbonate sequence and the upper surface of the andesite basement rocks.

Depositional environments for the 727.5 m of epiclastic, hemipelagic, and carbonate sediments overlying the andesitic basement rocks of Bougainville Guyot were determined using benthic foraminifers in epiclastic and hemipelagic sequence and corals and larger foraminifers, as well as the type of carbonate cementation (marine or meteoric) within the carbonate sequence. The Pleistocene pelagic sediments in the upper part (0–6.4 mbsf) of lithostratigraphic Unit I (Subunit IA) were deposited in the middle bathyal zone (500–2000 mbsl) and Subunit IA sediments from 6.4 to 16.9 mbsf were deposited in an outer sublittoral zone. At 16.9 mbsf, foraminifers indicate that a shallow lagoon environment existed prior to the drowning of the guyot. From 16.9 to 246.4 mbsf, Subunits IIA and IIB were deposited in an inner sublittoral environment. Below 246.4 mbsf, an inner or outer sublittoral zone appears to be the depositional environment based on both smaller and larger foraminifers. Lithostratigraphic Subunits IIC and IID (256–429.6 mbsf) appear to have been deposited in a shallow-water environment based on the presence of shallow-water fauna. At 612 mbsf, a foraminiferal assemblage indicates an inner shallow platform condition. Pervasive alteration and abundant secondary cement within lithostratigraphic Unit III (429.6–727.5 mbsf) suggest subaerial or near-surface conditions with alteration from meteoric processes.

Only two pore-fluid samples were collected from cores obtained at Site 831. Both samples exhibited solutes that approximate seawater concentrations with the exception of magnesium, calcium, and sulfate. Calcium is slightly enriched at 135 mbsf and magnesium is depleted, suggesting calcium carbonate diagenesis. Organic carbon contents are low, which may account for the minor sulfate reduction.

Based on the preliminary interpretation of the drilling results from Site 831, a general geologic history of the Bougainville Guyot can be inferred. During the late Oligocene, or sometime before, late-stage volcanic eruptions completed the building of the submarine edifice or island that has become Bougainville Guyot. Andesitic hyalo-breccias were emplaced in a manner similar to the formation of pillow lavas and the associated hyaloclastic deposition. Chilled margins or coronas around the clasts of the breccia suggest that miniature pillows developed and that the quenching in seawater caused chilled rinds to spall and to be incorporated into a glassy matrix. Oxidized clasts and more vesicular fragments suggest a shallow-water origin and perhaps the input of subaerial material from an island source. The maximum depth of deposition is, therefore, estimated to be around a few hundred meters. The wispy shapes of the blebs suggest that the magma was still reasonably fluid or plastic at the time of deposition. Deposition of this volcanic rock probably formed an apron around the submarine volcano with some of the more chaotic breccias having been deposited by avalanches or debris flows. Petrographic characteristics of the two-pyroxene andesites show calc-alkaline or island-arc tholeiite affinity, indicating that the guyot is unequivocally of island-arc origin.

The Bougainville Guyot appears to have formed along a volcanic island arc that is represented by the SDC. As proposed by Daniel et al. (1977) and Maillet et al. (1983), the DEZ may be an Eocene subduction/obduction zone. The oxidized andesitic rocks of the guyot indicate that the guyot was probably an island prior to subsidence during the late Oligocene, when it started accumulating the 727.5 m of carbonate rocks. Neritic carbonate sediments were deposited during the Oligocene to early Miocene, and at least two episodes of emergence, as indicated by the soil horizons at 688.3 and 707.3 mbsf, occurred during this time. No middle to upper Miocene sediments were identified; the absence of these sediments at Site 831 is consistent with a major Miocene hiatus similar to that observed at Site 828 and at DSDP Site 286 (Andrews, Packham, et al., 1975). This hiatus may coincide with a facies change in the neritic carbonate sequence at 429.6 mbsf: a coral and mollusc facies (16.9–429.6 mbsf) overlying a mollusc and foraminifer facies (429.6–727.5 mbsf). The Pliocene to Pleistocene neritic carbonates represent lagoonal sediments associated with an atoll. Eastward transport of the guyot upon the Australia-India plate is documented by its submergence/emergence history. As the guyot approached the outer rise of the New Hebrides Island Arc it became quite shallow, similar to the condition that Sabine Bank is experiencing today (Dubois et al., 1988). Then, during the late

Pliocene (~2 Ma) or early Pleistocene, the shallow-water carbonate platform drowned as indicated by the foraminiferal assemblage recovered from 30 mbsf. Foraminiferal assemblages examined from cores at 20 mbsf indicated that paleodepths were no greater than about 100 mbsl. Major subsidence, or sea-level rise, and pelagic sedimentation occurred throughout the Pleistocene as indicated by the foraminiferal assemblages examined from 20 to 4.5 mbsf. Ash layers found within the pelagic sediments between 0 and 15 mbsf exhibit the influence of volcanic events along the Central Chain of the New Hebrides Island Arc on the guyot. Pelagic deposition and continued subsidence represent the transport of the guyot away from the outer rise and down the subduction zone to its present position on the forearc slope.

SITE 832

We arrived at Site 832 (proposed site IAB-1) on 21 November 1990 at 0645 UTC. After 10 days and 15.5 hr on site drilling two holes (Holes 832A and 832B), we departed Site 832 at 2215 UTC on 1 December 1990. Because we penetrated into older sedimentary rocks sooner than expected in Hole 832B and were having good core recovery, we requested and received permission to drill past 700 mbsf. The early recovery of upper Pliocene or lower Pleistocene sediments at about 550 m suggested that the intra-arc basin of the central New Hebrides Island Arc may have formed earlier than most workers anticipated. We were unable to log Hole 832B as fully as desired because of infilling problems in the upper part of the hole, near the seafloor.

Site 832 is located on the flat intra-arc basin floor at 3089.3 mbsl in the central part of the NAB, approximately 50 km northeast of the Queiros Peninsula of Espiritu Santo Island and 45 km due south of the smoking volcanic island of Santa Maria (Gaua) (Fig. 2). The NAB lies between the uplifted bedrock masses of Espiritu Santo and Maewo islands and is separated from the northern Vanikolo summit basin by Santa Maria Island and from the South Aoba Basin by the active volcanic island of Aoba.

After a brief seismic reflection survey to confirm site location, we began drilling without problems. In Hole 832A we cored 215.9 mbsf and recovered 146.3 m for a recovery rate of 67.8%. Hole 832B was drilled to a TD of 1106.7 mbsf, coring 962.3 m and recovering 450.95 m for a recovery rate of 46.9% (Table 1).

Seven lithostratigraphic units were identified in the cores collected at Site 832 (Fig. 3). Lithostratigraphic Unit I (0–206.2 mbsf in Hole 832A; 144.4–385.6 mbsf in Hole 832B) is a 385.6-m-thick series of Pleistocene volcanic clays, silts, and sands. It was subdivided into two subunits (IA and IB) based on differences in grain size. Subunit IA (0–141.0 mbsf) is a 141-m-thick, coarse vitric volcanic-ash layer with sandy to clayey volcanic silts. Subunit IB (141.0–206.2 mbsf in Hole 832A; 144.4–385.6 mbsf in Hole 832B) is a 244.6-m-thick unit similar to Subunit IA but with finer vitric ashes.

Lithostratigraphic Unit II (385.6–461.5 mbsf) is a 75-m-thick Pleistocene sequence of sandstone, siltstone, and claystone that is largely volcanic in the upper part and more calcareous in the lower part. Lithostratigraphic Unit II is a transitional unit between a more volcanic unit above and a more calcareous unit below.

Lithostratigraphic Unit III (461.5–625.7 mbsf) is a 164.2-m-thick upper Pliocene or lower Pleistocene sequence of chalk, limestone, and calcareous mixed sedimentary rocks interbedded with volcanic siltstone, sandstone, and sed-lithic breccia containing volcanic clasts. Lithostratigraphic Unit IV (625.7–702.0 mbsf) is a 76.3-m-thick upper Pliocene or Pleistocene sequence of basaltic breccias with subordinate volcanic siltstone and sandstone. Lithostratigraphic Unit V (702.0–865.7 mbsf) is a 163.7-m-thick upper Miocene to Pliocene sequence of foraminiferal, nannofossil, calcareous, and silty limestone with some clayey siltstone, mixed sedimentary rocks, and vitric ash layers overlying a 1.5-m-thick basaltic breccia. Lithostratigraphic Unit VI (865.7–952.6 mbsf) is an 86.9-m-thick middle to upper Miocene lithified volcanic sandstone that grades downward to coarser material. Lithostratigraphic Unit VII (952.6–1106.7 mbsf) is a 154.1-m-thick layer of lithified basaltic breccia with subordinate lithified volcanic sandstone, siltstone, and vitric ash. The top of Unit VII is early to middle Miocene in age.

Foraminifers and nannofossils were the only source of age information. Ages determined range from Pleistocene to Holocene to latest early Miocene. Foraminifers provide the first evidence of lowermost middle Miocene fauna between 933.3 to 962.2 mbsf and the first evidence of uppermost lower Miocene fauna between 990.8 and 1010.1 mbsf. Ages assigned to sediments at Site 832 are as follows: Holocene and Pleistocene (0 to ~600 mbsf), late Pliocene or early Pleistocene(?) (600–711 mbsf), late Pliocene (711–740 mbsf), early Pliocene (740–856 mbsf); and Miocene (924–1010 mbsf). Benthic foraminifer evidence indicates a depositional environment of lower bathyal for most sediments at Site 832.

Sediment accumulation rates determined from the biostratigraphic data indicate an important change at ~710 mbsf, where the rates vary from approximately >100 m/m.y. between 710 and 875 mbsf to greater than 286 m/m.y. above this depth. Interpretations of seismic reflection profiles and lithostratigraphic examinations of cores from Hole 832B indicate an unconformity at about 700 mbsf, but the biostratigraphic data do not indicate a hiatus that would be longer than about 0.2 m.y. Between the lower Pliocene at 817 mbsf and the lowermost Miocene at 972 mbsf there may be another unconformity.

Correlation between biostratigraphic and paleomagnetic data suggests that the lower boundary of the Olduvai is near 707 mbsf and consequently that the Matuyama-Brunhes transition (early Pleistocene) is missing between 640 and 700 mbsf. Several other magnetic reversals that were observed between 707 mbsf and the TD of Hole 832B appear to correlate with Pliocene to late Miocene ages. Benthic foraminifers, where found, indicate that sediments of Site 832 were deposited in the lower bathyal zone.

More than 10 volcanic ash layers >3 cm thick and several tens of reworked volcanic ash layers were recovered at Site 832. Fragments of clinopyroxene-phyric basalt or ankaramite were found in the cores between 395 and 1100 mbsf and show vesicular texture and little oxidation, indicating that they underwent little weathering or seawater alteration before burial. Between 1050 and 1100 mbsf, the altered volcanic breccia of lithostratigraphic Unit VII consists of clasts of scoria and lavas within a matrix of chloritized glass, clay minerals, and zeolite. This volcanic breccia was probably derived from submarine volcanism, as suggested by the abundant alteration products contained in the matrix.

Structural studies indicate that deformation observed in cores from Site 832 appears to result from small- to large-scale slumping, normal microfaulting, and compaction processes. Five structural units were identified. Structural Unit A (0–415 mbsf) includes lithostratigraphic Unit I and the upper part of Unit II and is characterized by subhorizontal bedding, rare slump features, vertical normal microfaults, contorted bedding, and load features that developed in a finely laminated siltstone. Structural Unit B (415–626 mbsf) includes the lower part of lithostratigraphic Unit II and all of lithostratigraphic Unit III, which is characterized by abundant slump folds.

Structural Unit C (626–702 mbsf) corresponds to lithostratigraphic Unit IV, which has laminated siltstone beds dipping 30°–65°, suggesting the presence of slumps. Structural Unit D (702–866 mbsf) corresponds to lithostratigraphic Unit V and exhibits mainly horizontal bedding, a few veins filled with gypsum, and normal microfaults with well-developed slickensides. Some sigmoidal features oblique to the bedding are interpreted as forming in response to bedding-parallel extension. Structural Unit E (866–1107 mbsf) corresponds to lithostratigraphic Units VI and VII and is characterized by rarely observable bedding that dips between 20° and 40°, microfaults, and an overturned layer are indicative of slumping.

The concentrations of all measured solutes at Site 832 range widely, particularly those of calcium (1.9–215.9 mM), magnesium (0–50.6 mM), sodium (344–501 mM), potassium (2.3–15.2 mM), and chloride (551–742 mM). Each solute exhibits distinct maxima and minima, and the calcium minimum corresponds to the maxima in the concentrations of other solutes. The changes in concentrations probably result from diagenetic alteration of volcanogenic material and from precipitation of authigenic carbonate and phosphate minerals. Sulfate concentration decreases to 0.6 mM in the upper 40 mbsf, but exhibits two maxima at 520.7 mbsf (23.8 mM) and 802.3 mbsf (22.9 mM), which correspond to the calcium minimum and the sodium, potassium, magnesium, and chloride maxima. Accompanying the decrease in sulfate at approximately 75 mbsf, resulting from sulfate reduction, are maxima of phosphate, ammonia, methane, and alkalinity. These maxima probably reflect organic matter diagenesis, and the solutes may provide a source of phosphate and bicarbonate for the authigenic minerals. Organic carbon contents are low, mostly less than 0.5%, but rapid sediment accumulation rates cause high concentrations of the various solutes. Pore fluids show no evidence of meteoric water flow from the surrounding islands. This lack of hydrologic flow implies that any hydrocarbons generated will not be flushed from the sediments, but the low content of organic carbon suggests that the sedimentary rocks penetrated may not contain large amounts of source material.

Physical properties measurements at Site 832 were constant from the mud line to below 300 mbsf. This uniformity and the constancy of shear-strength values (around 50 kPa from 0 to 260 mbsf) indicate underconsolidation, which is typical of an area of rapid sedimentation. Porosity and water content have high values that vary from 50% to 80%. Silty ash layers in lithostratigraphic Unit I are the most porous, least consolidated, and contain the greatest amount of fluid of all material at Site 832. Below 300 mbsf, downhole porosity and water content decrease but maintain high values that are rarely below 40% and 25%. Bulk density increases from 1.60 Mg/m^3 to 2.00 Mg/m^3 in the upper 300 mbsf of Hole 832B and varies between 2.00 Mg/m^3 and 2.40 Mg/m^3 from 300 to 1103 mbsf. A decrease in porosity (~20%) and an increase in bulk density (>2.50 Mg/m^3) are associated with the breccias and sandstones in lithostratigraphic Units II and IV between 300 and 400 mbsf and 600 and 700 mbsf. Sonic velocities are generally low in the upper silty ash of lithostratigraphic Unit I, where they range from 1520 m/s near the seafloor to 1600 m/s at 260 mbsf. Velocity varies between 2000 and 3500 m/s from 260 mbsf to the TD of Hole 832B at 1103.3 mbsf. However, the interval between 600 and 700 mbsf exhibits an increase in velocity to over 4000 m/s, which correlates with a bulk density increase and the presence of a volcanic sandstone in lithostratigraphic Unit IV.

Because of deteriorating hole conditions, including bridging and rapid infilling from the upper parts, the complete complement of logging tools could not be used. However, the geophysical string and the FMS were run and produced good data.

Initial heat-flow analyses indicate that a high thermal gradient exists within the intra-arc basin, and this, along with porous and fractured volcaniclastic rocks, caused the anomalous alteration and diagenesis reported above. The volcaniclastic rocks encountered at this site are surprisingly unlithified with the exception of isolated layers, as indicated by the high porosity and water content.

Initial interpretations of the drilling results at Site 832 indicate that basin formation is the product of island-arc volcanism and tectonic deformation. The unconformity at about 700 mbsf appears to represent the time uplift of the central part of the Western Belt occurred in response to the collision of the DEZ. The existence of clayey foraminiferal and nannofossil limestones interbedded with the ash and silty volcanic sandstones of lithostratigraphic Unit V beneath the unconformity suggests deposition in relatively quiet water (compared to the overlying unit) that is devoid of volcanic and terrestrially derived material. In contrast the coarser grain site of the basaltic breccias of the overlying lithostratigraphic Unit IV suggests uplift of a volcanic province near Site 832 that supplied the breccia. Central Chain volcanoes, either Aoba or Santa Maria islands, are the likely source of these materials. Timing of the uplift and formation of the unconformity are not well constrained, but biostratigraphic analyses indicate that the hiatus is near the upper Pliocene/lower Pleistocene boundary. In contrast, the basaltic breccia encountered at the bottom of Hole 832A (lithostratigraphic Unit VII) appears to represent submarine eruptions associated with the volcanic formation of Espiritu Santo Island. The upper 385 mbsf (lithostratigraphic Unit I) represents recent (Pleistocene) basin-filling from the effusive products of the Central Chain volcanoes, specifically from Aoba, Santa Maria, and Mere Lava islands. Structural analyses of the cores indicate that several tectonic events have changed the inclination of the flanks of the NAB, thereby dislodging sediments and forming slumps. These events appear to have been particularly active during the earliest middle Miocene, late Miocene to early Pliocene, latest early Pliocene to earliest late Pliocene, and middle Miocene. Many of the lithostratigraphic units identified at Site 832 can be correlated with the lithostratigraphic units of Site 833.

SITE 833

We arrived at Site 833 (proposed site IAB-2) on 2 December 1990 at 0500 UTC. While on site we drilled two holes (Holes 833A and 833B). We departed Site 833 at 0030 UTC on 14 December 1990. Site 833 (proposed site IAB-2) is located on the lower east-central flank of the NAB, along the northwestern flank of Maewo Island, approximately 24 km northwest of the northern tip of Maewo Island and about 72 km southeast of the active volcanic island of Santa Maria (Fig. 2), which was observed on 4–5 December 1990 to be emitting whitish gray smoke from a vent near Mount Garat. The NAB lies between uplifted bedrock masses of Espiritu Santo and Maewo islands and is separated from the northern Vanikolo Basin to the north by Santa Maria Island and from the South Aoba Basin to the south by the volcanic island of Aoba.

After a seismic reflection transect across the NAB connecting Site 832 with Site 833 and a brief survey around Site 833, we began drilling without problems. In Hole 833A we cored 199.5 mbsf and recovered 97.75 m for a recovery rate of 49.0%. Hole 833B was drilled to a TD of 1001.1 mbsf, coring 923.7 m and recovering 519.54 m for a recovery rate of 56.2% (Table 1).

Five lithostratigraphic units were identified in the cores collected at Site 833 (Fig. 3). Lithostratigraphic Unit I (0–84.0 mbsf, Hole 833A) consists of numerous interbedded unlithified volcanic ashes and volcanic silt; ash layers are thinner and more numerous in the upper part of the unit, and the carbonate content increases to about 15% near the seafloor.

Lithostratigraphic Unit II (84.0–199.5 mbsf in Hole 833A and 77.4–375.8 mbsf in Hole 833B) contains calcareous siltstones and claystones that are highly bioturbated. Unit II is more lithified and finer grained than Unit I. Volcanic ash and volcanic sand are negligible, suggesting a period of fairly slow sedimentation and minimal volcanic activity.

Lithostratigraphic Unit III (375.8–577.8 mbsf) is composed of black volcanic sand and fine-grained basaltic breccia with a low carbonate content. Sediment accumulation rates average 313 m/m.y.

Lithostratigraphic Unit IV (577.8–830.3 mbsf) is composed of black volcanic sandstones and siltstones interbedded with sandstones, siltstones, and claystones that are both finer grained and more calcareous than the volcaniclastic sedimentary rocks. Packages (30 cm to several meters in thickness) of fining-upward sequences of volcanic sediment with coarser grained basal layers and sharp top and bottom boundaries characterize this unit.

Lithostratigraphic Unit V (830.3–1001.1 mbsf) is characterized by sediments similar to those in Unit IV except that the sediments in Unit V are interbedded with basaltic sills with thicknesses of 65 m or more. Sedimentary rocks in Unit V show minimal structural deformation; minor evidence of contact metamorphism is exhibited primarily by the increase in chlorite content of the calcareous volcanic siltstone in proximity to the sills.

The keys to the divisions within the lithostratigraphic units include the grain size of volcanic ash and epiclastic volcanic sediments, carbonate content, and bioturbation. These characteristics are closely related. When the sediment accumulation rates of volcanic ash and sand are high, the carbonate content is low and bioturbation is suppressed in response to enhanced influx of volcanic sediments. When the volcanic ash input decreases, sediment accumulation rates are low (97 m/m.y.) and volcanic silt and clay dominate. Carbonate sediments then form a significant portion of the total sediment accumulation, and burrowing organisms have sufficient time to rework the sediments.

Four structural units were defined at Site 833. Structural Unit A (0–376 mbsf) includes lithostratigraphic Units I and II and contains only a few deformational structures. Structural Unit B (376–616 mbsf) correlates primarily with lithostratigraphic Unit III and is defined on the basis of little structure and poorly developed bedding. Structural Unit C (616–830 mbsf) corresponds to lithostratigraphic Unit IV and is characterized by abundant veins and normal faults. Structural Unit D (830–1001.1 mbsf) corresponds to lithostratigraphic Unit V and is also defined by the existence of strike-slip faults.

Volcanic ash layers are abundant in the upper 150 m of Site 833, becoming increasingly sporadic downhole. These are potassium-rich pyroclastic sediments similar to those found at Site 832 and are attributed to eruptions from the Central Chain of volcanoes. Deeper in Hole 833B, scattered basaltic tuffs were recovered from between 308 and 317 mbsf. These are of a different type, having low-potassium, island-arc tholeiite affinity. Volcanic clasts from the coarse sandstones and breccias at about 400 mbsf include ankaramitic basalts, resembling those of Site 832, and are also of island-arc tholeiite type. At 830 mbsf, calcareous volcanic siltstones are cut by a highly plagioclase-phyric (highly potassic) basaltic sill with a distinctly chilled upper contact. Basaltic sills of similar composition make up much of the succession below this and are interstratified with calcareous volcanic siltstones and bioturbated mixed sedimentary rocks. There is sufficient evidence of chilling to establish the intrusive nature of the basalt. Although the sills could be interpreted as a series of separate intrusions, their compositional uniformity suggests that a large body of magma may have invaded the unlithified sediments simultaneously at several stratigraphic levels.

Foraminifers and nannofossils were again the only source of age information; however, the use of these fauna and flora was severely limited by the abundance of volcaniclastic sediments. A Pleistocene age is assigned to the interval from 0 to 375 mbsf (in both Holes 833A and 833B), late Pliocene for the interval from 375 to 635.6 mbsf, and early Pliocene for the interval from 635.6 to 945 mbsf. The Pliocene/Pleistocene boundary lies in the interval from 250 to 375 mbsf but the exact location is uncertain.

For the overall sedimentary sequence above the volcanic sill (lithostratigraphic Unit V) a very high sediment accumulation rate of 97–322 m/m.y. was estimated, using mainly the first appearance datums of foraminifers and nannofossils in sequences in which reworking is common. Analyses of benthic foraminifers indicate that most of the sediments found at Site 833 were deposited in the lower bathyal zone; however, some shallow-water fauna were found sporadically throughout Hole 833B.

All undisturbed cores from Hole 833A and most consolidated sediments in Hole 833B were measured with the cryogenic magnetometer and alternating-field (AF) demagnetized at 10 mT. Paleomagnetic results at Site 833 show normal polarity from 0 to 80 mbsf. Because of poor core recovery, few magnetic measurements could be obtained from 80 to 200 mbsf, and no evidence for reversed polarity exists in this interval. The first interval of reversed magnetic polarity was found between 220 and 250 mbsf, and the transition from the Matuyama to the Brunhes Chron (0.73 Ma) may be represented between 210 and 220 mbsf. Intervals of positive or negative inclinations are found between 250 and 430 mbsf. From 435 to 655 mbsf, only normal polarity was found.

Magnetic susceptibility in the volcanic sandstone (lithostratigraphic Unit IV) at Site 833 is high (0.02 SI), and this nearly normal magnetization may have been acquired during diagenesis and consolidation; viscous magnetization of these rocks appears to be quite strong as well. The interbedded sills at the bottom of Hole 833B also have high magnetic susceptibility (0.04–0.08 SI) and a high intensity (100 A/m) of magnetization. However, this magnetization is very soft and easily removed with low AF demagnetization. Results from the most stable samples indicate a shallow positive inclination that may correspond to a reversed polarity.

Fluid geochemistry at Site 833 revealed extremely wide-ranging values in chloride (568–1241 mM, ~2.2 times seawater concentration at 494.5 mbsf), sodium (150–534 mM), potassium (0.4–14.7 mM), magnesium (0–39.7 mM), and calcium (2.6–548.5 mM; ~52 times seawater concentration at 494.5 mbsf) concentrations in the pore fluids. Each of these solutes is characterized by either its maximum (chloride and calcium) or minimum (sodium, potassium, and magnesium) value at depths between 490 and 630 mbsf. These depths correspond to the location of the well-cemented volcanic sandstone and sed-lithic rocks. Diagenesis and cementation of the volcanogenic sediment presumably cause the variations in solute concentrations. These are similar to the diagenesis observed at Site 832, but the most altered calcium, chloride, and sodium concentrations are nearly two times more extreme at 833. The maximum concentrations of alkalinity (19.9 mM), phosphate (55.2 mM), and ammonia (1794) occur between depths of 20 and 40 mbsf. The concentrations are not extremely high, probably reflecting the low (generally <0.5%) organic carbon content of the sediments and slightly lower sediment accumulation rate at this site.

Similar to Site 832, physical properties measurements of cores at Site 833 correlate well with the lithostratigraphic units. Values of index properties vs. depth for the upper 375 mbsf show porosity and water content from 50% to 80% and low shear strengths. Sediments at Site 833 are slightly drier and less porous than at Site 832. From 200 to 375 mbsf bulk density increases from 1.60 to 2.00 Mg/m^3. At 376 mbsf a distinct sharp decrease in porosity to 20% and a sharp increase in bulk density to 2.50 Mg/m^3 occurs and is associated with a lithologic change from Pleistocene volcanic siltstone and calcareous claystone to upper Pliocene coarse volcanic sandstone and basaltic breccia. From 600 to 830 mbsf, porosity increases to 40% or more and bulk density drops to about 2.00 Mg/m^3. At 830 mbsf, the upper contact of the basaltic sill, bulk density sharply increases to 2.60 Mg/m^3, as porosity and water content drops to less than 5%.

Sonic velocities at Site 833 range from 1535 m/s at the seafloor to 2038 m/s at 377 mbsf. From 379 to 600 mbsf, velocities increase sharply to between 3000 and 4500 m/s in volcanic sandstone breccia. They increase sharply again, to above 5000 m/s, in the basaltic sill from 830 to 1000 mbsf.

Because of partial hole collapse and filling problems after drilling ceased, not all of the hole could be logged, and constraints on time prevented us from using the complete complement of logging tools. However, good results were obtained from the geophysical and geochemical tools between 250 and 900 mbsf, with distinct increases in resistivity and velocities taking place between 380 and 430 mbsf, which correlates with the volcanic sandstones and breccia found at these depths. The contact of the basaltic sill with the overlying sedimentary rocks is easily distinguished in the logs, with sharp increases in resistivity, velocities, thorium, and potassium at 830 mbsf.

Initial interpretations of the drilling data at Site 833 indicate that a thick (nearly 400 m) Pleistocene volcanic sandstone and ash sequence exists. Although not as thick as that found at Site 832 (<600 m), this sequence represents a rapid accumulation of Pleistocene effusive volcanic material emitted from the active Central Chain volcanoes. The existence of volcanic breccia at about 400–560 mbsf suggests uplift and erosion of volcanic rocks on Maewo Island. A much thicker (>350 m) Pliocene sequence exists at Site 833 compared to only about 70 m recovered at Site 832; however, nearly half of this sequence is composed of basaltic sills that may have been intruded into the Pliocene sedimentary rocks as late as the Pleistocene. Initial evaluation of this sill complex indicates that the rocks are highly potassic and share similar petrology with the Central Chain.

CONCLUSION

Tentative interpretations of the drilling results from Leg 134 in the collision zone of the central New Hebrides Island Arc suggest that each ridge of the twin-ridge DEZ causes different forearc deformation. The sedimentary and surficial basement rocks of the more continuous and morphologically streamlined NDR, whose basaltic basement rocks are denser than those of the Bougainville Guyot, appear to have been scraped off and accreted to the forearc during its passage down the subduction zone and beneath the forearc. This accretion has formed the Wousi Bank, which consists of uplifted forearc rocks and stacked thrust sheets. The SDC impacts the forearc in a different manner: drilling in this collision zone reveals a narrower zone of deformation and a deeper forearc indentation compared to the NDR collision zone, although the SDC is converging at the same rate and at the same angle as the NDR. The more buoyant andesitic island-arc basement rocks may allow the guyot to rise up onto the forearc slope before being subducted or accreted to the slope.

The major compositional change affecting pore fluids analyzed from sediments and rocks cored in the central New Hebrides Island Arc results from diagenetic alteration of volcanic sediment and rocks and is manifest in chloride and calcium concentrations greater than seawater values and sodium, potassium, and magnesium concentrations lower than seawater values. Variations in these solute concentrations correspond to structural features, particularly across thrust faults at Site 829 and in a fractured zone at Site 830. More fluid is present below thrust faults penetrated at Site 829, which implies that the faults may channelize fluid flow similar to the Barbados accretionary wedge (Mascle, Moore, et al., 1988). Moreover, the deepest samples at Site 829 are characterized by low chloride and high methane concentrations, a covariance that also characterizes the pore-fluid chemistry within the décollement at the Barbados accretionary wedge (Gieskes et al., 1990). Thus, the fluid near the deep thrust fault at Site 829 may have been derived from the décollement and subduction-related processes.

Two holes deeper than 1 km in the intra-arc basin recovered middle Miocene to Pleistocene sedimentary and volcaniclastic rocks. At Site 832 more than 1106 m of basin-fill deposits were penetrated and at Site 833 over 1001 m of basin material were drilled. A strong reflector observed in the seismic reflection data around 700 mbsf correlates with an apparent upper Pliocene or lower Pleistocene unconformity in the sediment record. This suggests a change in the base of the basin and may indicate that uplift of Espiritu Santo Island in response to the collision of the DEZ occurred then. Beneath this unconformity, calcareous siltstone and chalk beds with scattered ash layers suggest deposition in fairly quiet water during a time of possibly waning Eastern Belt volcanism, which may have produced the volcanic breccia at the base of Hole 832B. Above the unconformity a thick sequence (150 m) of igneous breccia and interlayered breccia with calcareous siltstones indicates increased erosion of Espiritu Santo Island after initial DEZ collision, followed by deposition of fine-grained material in quiet waters. Over 600 m of Pleistocene sediments were found at Site 832, with the upper 400 m apparently being the contribution of active Central Chain volcanism.

At Site 833 a basaltic sill, recovered below 840 mbsf, intrudes lower Pliocene sedimentary rocks, indicating that volcanism was active along the Eastern Belt during the early Pliocene to Pleistocene, as previously thought (Carney and Macfarlane, 1977, 1978, 1980, 1982, 1985; Carney et al., 1985; Macfarlane et al., 1988). Unlike Site 832, where only 70 m of lower Pliocene sedimentary rocks was found, over 350 m of lower Pliocene sedimentary and volcanic rocks was penetrated at Site 833. However, an equal amount (nearly 400 m) of Pleistocene sediments was recovered at Site 833. The existence of volcanic breccia at about 450 mbsf in Hole 833B suggests uplift and erosion of the volcanic rocks of Maewo during the late Pliocene, perhaps in response to the DEZ collision.

The large quantity of mostly undiluted volcanic sediment within the NAB has been diagenetically altered, producing some of the most altered and concentrated fluids yet drilled on an ODP or DSDP leg. The concentrations of calcium, chloride, potassium, sodium, and magnesium are most affected by this alteration.

REFERENCES

Akimoto, K., Tanaka, T., Hattori, M. and Hotta, H., 1990. Recent foraminiferal assemblages around Calyptogena colony off Hatsushima Island, Sagami Bay, central Japan. *Technical Reports of the Symposium of Deep-sea Research Using Submersible* Shinkai *2000 System*. Jpn. Mar. Sci. Tech. Center, Yokosura.

Andrews, J. E., Packham, G., et al., 1975. *Init. Repts. DSDP*, 30: Washington (U.S. Govt. Printing Office).

Biju-Duval, B., Moore, J. C., et al., 1984. *Init. Repts. DSDP*, 78A: Washington (U.S. Govt. Printing Office).

Carney, J. N., and Macfarlane, A., 1977. Volcano-tectonic events and pre-Pliocene crustal extension in the New Hebrides. *Int. Symp. on Geodynamics in South-west Pacific, Noumea, New Caledonia, 1976*. Paris (Editions Technip), 91–104.

———, 1978. Lower to middle Miocene sediments on Maewo, New Hebrides, and their relevance to the development of the Outer Melanesian Arc system. *Australas. Soc. Explor. Geophys. Bull.* 9:123–130.

———, 1980. A sedimentary basin in the central New Hebrides Arc. *Tech. Bull.—U. N. Econ. Soc. Comm. Asia Pac., Comm. Co-ord. Jt. Prospect Miner. Resour. South Pac. Offshore Areas*, 3:109–120.

———, 1982. Geological evidence bearing on the Miocene to Recent structural evolution of the New Hebrides Arc. *Tectonophysics*, 87:147–175.

———, 1985. Geology and mineralisation of the Cumberland Peninsula, north Espiritu Santo. *Vanuatu Dept. of Geol., Mines, and Rural Water Suppl. Rep.*

Carney, J. N., Macfarlane, A., and Mallick, D.I.J., 1985. The Vanuatu island arc—an outline of the stratigraphy, structure, and petrology. *In* Nairn, A.E.M., Stehli, F. G., and Uyeda, S. (Eds.), *The Ocean Basins and Margins* (Vol. 7): New York (Plenum), 685–718.

Collot, J.-Y., Pelletier, B., Boulin, J., Daniel, J., Eissen, J.-P., Fisher, M. A., Greene, H. G., Lallemand, S., and Monzier, M., 1989. Premiers résultats des plongées de la campagne SUBPSO1 dans la zone de collision des rides d'Entrecasteaux et de l'arc des Nouvelles Hébrides. *C. R. Acad. Sci. Ser. 2*, 309:1947–1954.

Daniel, J., Collot, J.-Y., Monzier, M., Pelletier, B., Butscher, J., Deplus, C., Dubois, J., Gérard, M., Maillet, P., Monjaret, M. C., Récy, J., Renard, V., Rigolot, P., and Temakon, S. J., 1986. Subduction et collision le long de l'arc des Nouvelles-Hébrides (Vanuatu): résultats préliminaires de la campagne SEAPSO (Leg 1). *C. R. Acad. Sci. Ser. 2*, 303:805–810.

Daniel, J., Jouannic, C., Larue, B., and Récy, J., 1977. Interpretation of d'Entrecasteaux zone (north of New Caledonia). *Int. Symp. on Geodynamics in South-west Pacific, Noumea, New Caledonia, 1976*. Paris (Editions Technip), 117–124.

Dubois, J., Deplus, C., Diament, M., Daniel, J., and Collot, J.-Y., 1988. Subduction of the Bougainville seamount (Vanuatu): mechanical and geodynamic implications. *Tectonophysics*, 149:111–119.

Fisher, M. A., Collot, J.-Y., and Geist, E. L., 1991. The collision zone between the North d'Entrecasteaux Ridge and the New Hebrides Island Arc. Part 2: structure from multichannel seismic data. *J. Geophys. Res.*, 96:4479–4495.

Gieskes, J. M., Vrolijk, P., and Blanc, G., 1990. Hydrogeochemistry of the northern Barbados accretionary complex transect: Ocean Drilling Program Leg 110. *J. Geophys. Res.*, 95:8809–8818.

Kroenke, L. W., Jouannic, C., and Woodward, P. (Compilers), 1983. Bathymetry of the southwest Pacific, Chart 1: *Geophysical Atlas of the Southwest Pacific*, Scale 1:6,442,192 at 0°, Suva, Fiji. U. N. Econ. Soc. Comm. Asia Pac., CCOP/SOPAC Tech. Secretariat.

Macfarlane, A., Carney, J. N., Crawford, A. J., and Greene, H. G., 1988. Vanuatu—a review of the onshore geology. *In* Greene, H. G., and Wong, F. L. (Eds.), *Geology and Offshore Resources of Pacific Island Arcs—Vanuatu Region*. Circum-Pac. Counc. Energy and Miner. Resour., Earth Sci. Ser., 8:45–92.

Maillet, P. M., Monzier, M., Selo, M., and Storzer, D., 1983. The d'Entrecasteaux zone (southwest Pacific): a petrological and geochronological reappraisal. *Mar. Geol.*, 53:179–197.

Mallick, D.I.J., and Greenbaum, D., 1977. *Geology of Southern Santo*. Regional Rept.—New Hebrides Geol. Surv., 1–84.

Mascle, A., Moore, J. C., et al., 1988. *Proc. ODP, Init. Repts.*, 110: College Station, TX (Ocean Drilling Program).

Mitchell, A.H.G., 1971. *Geology of Northern Malekula*. Regional Rept.—New Hebrides Geol. Surv.

Taira, A., Hill, I., Firth, J., et al., 1991. *Proc. ODP, Init. Repts.*, 131: College Station, TX (Ocean Drilling Program).

Ms 134A-114