Carter, R.M., McCave, I.N., Richter, C., Carter, L., et al., 1999
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6. Site 1122: Turbidites with a Contourite Foundation[1]

Shipboard Scientific Party[2]

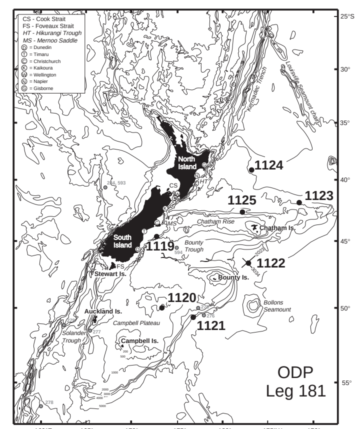
BACKGROUND AND OBJECTIVES

General Description

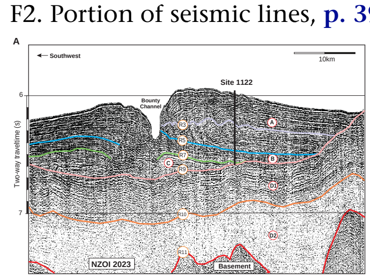
Site 1122 is located 275 km south of the Chatham Islands, midway between the Chatham and Bounty Islands, and 830 km east of Dunedin, eastern South Island (Fig. **F1**). The site was drilled in a water depth of 4432 m on the left (north) bank levee of the abyssal Bounty Fan. The fan is located in the most seaward axial deep of the Bounty Trough, a Cretaceous rift basin formed during the separation of New Zealand and Antarctica across the newly forming mid-Pacific Rise (Carter and Carter, 1993, 1996; Davey, 1993). The Bounty Channel feeds sediment along the axis of the trough and onto the adjacent 95-Ma oceanic crust of the Southwest Pacific abyssal plain.

Site 1122 is located on New Zealand Oceanographic Institute (now NIWA) single-channel seismic and 3.5-kHz line 88-2023 (Figs. **F2A, F2B, F3**). The three main units that compose the Bounty Fan at this crossing (seismic Units C–A; Table **T1**) all show strong angular onlap onto the folded surface of pre-Unit C sediments. In ascending order, and at the drill site (Fig. **F2B**), these units consist of 150 ms of irregularly and lightly reflective sediment (Unit C, capped by a strong reflector, R-7), 110 ms of thin-bedded and regularly reflective sediment passing up into strongly reflective sediment (Unit B, capped by reflector R-5), and upper Unit A which is 470 ms thick and comprises a field of spectacular sediment waves. The waves initiate as small features just above reflector R5, (the Unit B/A boundary), and grow in both wavelength (up to 6 km apparent) and height (up to 17 m) as they rise through the sediment pile to the seabed, where they were apparently still active in the recent past (Carter et al., 1990). The sediment waves are best developed, and

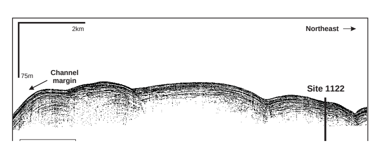
F1. Locality map for Site 1122, **p. 38.**



F2. Portion of seismic lines, **p. 39.**



F3. Portion of 3.5-kH line, **p. 41.**



[1]Examples of how to reference the whole or part of this volume.
[2]Shipboard Scientific Party addresses.

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were drilled, beneath the 315-m-high north bank levee of the Bounty Channel. Similar waves, though of smaller amplitude, occur underneath the 90-m lower crest of the south bank of the Bounty Channel. Sediment waves have been described from a number of Northern Hemisphere deep-sea environments, including submarine fans where they are most prominent on channel right banks (Damuth, 1979; Normark et al., 1980; Brew, 1995). Fan levees are inferred to have been built by overspilling turbidity currents, whose top surfaces are deflected right or left, according to the effect of Coriolis force on fluids in motion in the Northern and Southern Hemispheres, respectively (Menard, 1955; Komar, 1969). As a turbidity current overtops its levee, it may develop a series of antidune surges that cause the formation and growth of sediment waves across the levee crest (Normark et al., 1980).

The sediment waves form the upper unit (A) of the fourfold seismic stratigraphy we describe (Table **T1**). A zone of harder acoustic reflection extends down from the floor of the present-day channel obliquely to the left (south), where it has its initiation at or a little above reflector R9 (Fig. **F2A)**. This zone marks the movement through time of the axis of the paleo-Bounty Channel. Seismic Units C–A compose the core of the Bounty Fan, and all appear to have been deposited as part of the north bank levee of the Bounty Fan's main sediment feeder, the Bounty Channel. The fan sediments rest on a regional unconformity (Y), here equivalent to reflector R9, below which the sediments of Unit D are gently folded and eroded. The lateral equivalents of Unit D are exposed in the inner and outer sills of the Bounty Trough, where dredged samples have provided Miocene microfossils, suggesting that the deformation and unconformity formation were of middle late Miocene age. The lower part of Unit A has been dated previously as late Pliocene (Mangapanian), on the basis of a microfauna cored from the lower north wall of the channel (Carter et al., 1994).

T1. Summary of seismic unit depth and reflectors, **p. 83.**

Site Objectives

Site 1122 was drilled to establish the history of deposition of the Bounty Fan, and the degree to which fan-growth has been affected by the fact that the current fan is building out into the path of the Southwest Pacific Deep Western Boundary Current (DWBC). For instance, a breach in the left bank levee of the fan, at depths of ~4650 m, may have been caused by DWBC erosion or may be a turbidity current avulsion point maintained by the boundary flow. The current may also be causing sediment unmixing and sand mobility across the middle and lower fan (Carter and Carter, 1996). The sediment waves under the left bank levee are the subject of an earlier study by Carter et al. (1990), who described core and 3.5-kHz profile evidence for the presence of alternating cycles of glacial turbidite deposition and interglacial biopelagic ooze accumulation. Carter and Carter (1992) therefore interpreted the pattern of regular reflectors on deep seismic profile NZ01 2023 as evidence for a similar glacial/interglacial pattern of lithologic change with depth, and, by comparison with the global isotope stage record, predicted an isotope Stage 100 (~2.4 Ma) age for reflector R7 of this study (Table **T1**). The Site 1122 cores were expected to yield a test of this prediction. Finally, because of the location of the site just south of the Subtropical Convergence (STC), information from Site 1122 should help test for the stability of position of the STC between glacial and interglacial times (Fenner et al., 1992; Nelson et al., 1993; Weaver et al., 1998).

OPERATIONS

Hole 1122A

The 341-nmi voyage to Site 1122 (proposed site SWPAC-8A) was accomplished at an average speed of 9.6 kt. The vessel proceeded directly to the Global Positioning System coordinates of the location. The positioning beacon was dropped at 2254 hr on 5 September. The hydrophones and thrusters were extended and the vessel settled on location. The advanced hydraulic piston core/extended core barrel (APC/XCB) bottom-hole assembly (BHA) was assembled using a 9-⅞-in PDC bit. Hole 1122A was spudded with the APC at 1210 hr on 6 September. The recovery indicated that the water depth was 4435.00 meters below sea level (mbsl). Piston coring advanced to refusal at 75.8 mbsf, and Cores 1H through 8H were taken (Table T2, also in ASCII format). The hole was deepened with the XCB to 123.9 mbsf, which was considered the objective for the initial hole of the site. APC cores were oriented starting with Core 181-1122A-3H. The bit cleared the seafloor at 0415 hr on 7 September, ending operations at Hole 1122A.

T2. Site 1122 expanded coring summary, p. 84.

Hole 1122B

The vessel was offset 20 m to the west and the second hole of the site was spudded with the APC at 0615 hr on 7 September. To obtain a stratigraphic overlap for interhole correlation, the bit was positioned 5 m higher than at Hole 1122A. However, the recovered core barrel was full, which required another attempt to obtain a mudline core.

Hole 1122C

The bit was raised at the same location by an additional 5 m, and Hole 1122C was spudded with the APC at 0740 hr. The mudline core indicated that the water depth was 4431.80 mbsl. The APC was advanced by recovery to 103.7 mbsf and Cores 1H through 13H were obtained (Table T2). The last three cores (11H, 12H, and 13H) did not achieve a full stroke.

Coring was switched to the XCB and advanced without incident to 204.3 mbsf with good to poor recovery (Table T2). Very rapid XCB coring continued with recovery ranging from 1% to 97% from 204.3 to 627.4 mbsf. After making a drill pipe connection following the retrieval of Core 68X (617.8 to 627.4 mbsf), the drill string became stuck and could not be rotated with up to 700 A of top drive current. The driller worked the pipe for over an hour with overpulls as large as 200 kilopounds (kips), while maintaining a circulation rate of 1000 gal/min at 2200 psi pressure before the drill string came free. It was considered imprudent to attempt to deepen the hole past this depth, and preparations for logging were started.

Logging Operations at Hole 1122C

In preparation for logging, the hole was swept with 60 barrels of high-viscosity mud. The bit was pulled back in the hole to 520 mbsf and the hole was displaced with 175 barrels of sepiolite mud. The bit was then pulled back and positioned at 83 mbsf. At 0700 hr on 11 September, the logging equipment was rigged up and the first tool suite (triple combination: DIT/HLDS/APS/HNGS) was deployed in the drill pipe. The tool string was unable to pass the bit more than 12 m and after repeated attempts by the logging winch operator, it was decided to recover the logging tool in rapidly deteriorating weather conditions. After the logging tool was disassembled, operations at the site were terminated because of heavy seas and high winds. The combined sea state was exceeding 10 m and wind gusts were recorded as high as 55 kt.

When overpulls as large as 200 kips were unable to free the drill string, the top drive was picked up. For 2 hr, the stuck drill pipe was worked with 200 kips of overpull while maintaining a circulating rate of 1000 gal/min. At 1530 hr on 11 September, the pipe was free and the drill string was recovered. The bit cleared the seafloor at 1625 hr. By 0800 hr the drilling equipment was secured for the voyage to the next site and the beacon was recalled and recovered. At 0800 hr on 12 September, the vessel was under way on a northeasterly course to Site 1123.

LITHOSTRATIGRAPHY

Introduction

Bounty Fan is the terminus for a sediment-transport system that begins in the rapidly rising Southern Alps of New Zealand. During glacial periods of low sea level, large quantities of terrigenous sediment were delivered by rivers to an emergent continental shelf. These rivers continued across the shelf to discharge their loads at the paleoshoreline which, in major lowstands such as those that occurred during isotope Stage 2, was near to the shelf edge. There, sediment was captured by a suite of submarine canyons as well as being deposited on the upper continental slope. Mobilization of the sediment periodically generated turbidity currents that swept down canyons and into the Bounty Channel system (Carter and Carter, 1987, 1993). These currents traveled 900 km along the channel to eventually disgorge onto Bounty Fan at the mouth of Bounty Trough. En route, the overspilling turbidity currents deposited an extensive levee complex, characterized by a higher left bank (facing downchannel) that formed in response to deflection by the Southern Hemispheric Coriolis force. Instability within the overspilling currents ultimately was responsible for the formation of an extensive field of sediment waves (Carter et al., 1990).

In sharp contrast to this glacial regime of active transport and deposition, interglacial periods were previously thought to have been times of relative quiescence in Bounty Trough, judging by piston cores described by Griggs et al. (1983), Neil (1991), and Carter and Carter (1988). Under the Holocene highstand of sea level, the cores suggest that terrigenous sediment was diverted from the trough head, thereby allowing the deposition of mainly calcareous pelagite. The exception is near the head of Bounty Trough, where small turbidites accumulated in the upper reach of the channel system.

The abyssal Bounty Fan has developed across the path of the DWBC near the zone where the modern Antarctic Circumpolar Current (ACC) turns east from the margin of Campbell Plateau. Acoustical facies derived from 3.5-kHz profiles suggest that the outer Bounty Fan has been eroded by the abyssal currents (Carter and Carter, 1996). Ostensibly, the dominant flow was the DWBC, but there is an argument that this flow may have been reinforced by the ACC in glacial times when the Subantarctic Front, marking the northern limit of the ACC, probably migrated northward (Nelson et al., 1993). Such a change would presumably have been a response to a northward expansion of subantarctic waters and equatorward migration of strong winds (e.g., Nelson et al., 1993).

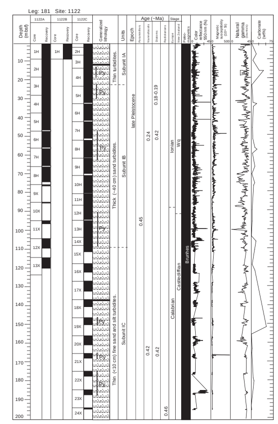
Site 1122 was positioned on the crest of a prominent left bank levee containing a 350-m thick sequence of Pleistocene sediment waves, resting on an additional 240 m of normally layered sediment interpreted as extending back to the Miocene (Carter et al., 1994). Coring at Site 1122 obtained a detailed record of Quaternary climatically controlled turbidite sedimentation on the levee, underlain by Pliocene and Miocene contourite drift deposits recording earlier DWBC flow across most of Bounty Trough.

Description of Lithostratigraphic Units

Unit I

Unit I consists predominantly of a thick sequence of turbidites, which is subdivided into four subunits (Fig. F4). The upper three subunits are distinguished mainly by the thickness and grain size of the turbidites. The lowest subunit, Subunit ID, shows the transition from a turbidity current–dominant to bottom current–influenced depositional environment in its lower half. Unit I extends from 0 to 386.9 mbsf.

F4. Summary log for Site 1122, p. 42.



Subunit IA

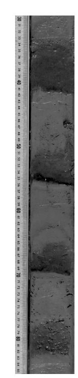
Interval: Sections 181-1122A-1H-1 through 2H-5; Sections 181-1122B-1H-CC; Sections 181-1122C-1H through 4H-6
Depth: 0–16.6 mbsf (Hole 1122A); 0–9.5 mbsf (Hole 1122B); 0–22.7 mbsf (Hole 1122C)
Age: Holocene to late Pleistocene

The upper 20 cm of Subunit IA is composed of light brownish gray (2.5Y 6/2) silty clay, which may represent Holocene sediments. Because of an offset between Holes 1122A and 1122C, the Holocene sediments and the upper ~8 m are absent from Hole 1122A (see "Operations," p. 3). Underneath, Subunit IA is composed of greenish gray (5GY 6/1) silty clay with intercalations of gray (5Y 5/1) very fine sand turbidites. These turbidites are generally <15 cm thick (Table T3), sharp based and normally graded, fining upward into greenish gray (5GY 5/1) silty clay (Fig. F5).

T3. Turbidite thicknesses, p. 97.

At 4.2 mbsf, an interval appears where the bases of the turbidites are pyritized. A similar pyritization zone occurs between 15 and 18 mbsf. These zones of pyritization are typical features throughout the upper three subunits of Unit I.

F5. Sequence of turbidites in Subunit IA, p. 46.



A tephra layer occurs at 11.93 mbsf, which probably is the Kawakawa Tephra, dated at 22,590 radiocarbon years (26,000 calibrated years; I.N. McCave, pers. comm., 1998). The base of Subunit IA is probably close to the isotope Stage 3/Stage 4 boundary at 59 ka.

Subunit IB

Interval: Sections 181-1122A-2H-5 through 11X-1; Sections 181-1122C-4H-6 through 15X-1
Depth: 16.6–95.0 mbsf (Hole 1122A); 22.71–109.35 mbsf (Hole 1122C)
Age: late Pleistocene

Subunit IB is composed of greenish gray (5G 4/1) silty clay that is interbedded with dark greenish gray and greenish gray (5BG 4/1, 5G 5/1) sand and fine sand turbidites. The thickness of the turbidites is greater than in Subunit IA, varying from 10 to 100 cm (Fig. F6). This subunit also contains three intervals with significant pyrite in the basal sands of the turbidites (23.5–28 mbsf, 47.2–62 mbsf, and 91.7–109.5 mbsf). Subunit IB is moderately bioturbated throughout; only the top of the Section 181-1122C-14X (103.7–104.2 mbsf) represents heavy bioturbation and may reflect an interglacial stage. The lower boundary of Subunit IB is marked by a color change at 109.35 mbsf from greenish gray (5GY 5/1) to grayish green (5BG 5/1). The base of this subunit is estimated to be close to the isotope Stage 8/9 boundary at 285 ka.

F6. Sand turbidite in Subunit IB, p. 47.

Subunit IC

Interval: Sections 181-1122A-11X-1 through 13X-CC; Sections 181-1122C-15X-1 through 31X-1
Depth: 95.0–123.9 mbsf (Hole 1122A); 109.35–261.7 mbsf (Hole 1122C)
Age: middle to late Pleistocene

Subunit IC is composed of sequences of dark greenish gray (5GY 4/1) silt and very fine sand turbidites with intercalations of grayish green (5GB 5/1) and greenish gray (5GY 5/1) silty clay. The thickness of the turbiditic layers is <20 cm. It is probable that the apparent decrease in turbidite thickness, compared to Subunit IB, is an artifact of the change from APC to XCB drilling. Low recovery rates (averaging ~40%) indicate the likelihood of washout of the thicker sand beds. Three intervals of higher pyrite content are present in Subunit IC (at 146.5–150.43 mbsf, 157.2–166.4 mbsf, and 242.9–245 mbsf). Below 245 mbsf, zones of pyritization are not observed. On average, bioturbation is moderate throughout the entire subunit. In Core 181-1122C-20X there occurs a heavily bioturbated, light greenish gray and light gray (5BG 6/1, 2.5Y 8/1) nannofossil-rich, silty clay. A tephra layer occurs in Section 181-1122C-18X-1 at 138.24 mbsf.

Subunit ID

Interval: Sections 181-1122C-31X-1 through 44X-1
Depth: 261.7–386.9 mbsf (Hole 1122C)
Age: early to middle Pleistocene

Subunit ID includes greenish gray and gray (5GY 5/1, 5Y 5/1) silty clay interbedded with dark greenish gray (5GY 4/1) very fine sand and silt turbidites of <10-cm thickness. The top of Subunit ID, Core 181-1122C-31X (261.7–271.36 mbsf), marks the first appearance of turbidites with eroded upper contacts and planar lamination. A lighter colored interval with color change from light gray to olive-yellow (5Y 7/1 to 5Y 6/6) coincides with heavier bioturbation. In Section 181-1122C-34X-2, another gradational color change to olive (5Y 5/3) is observed, which is followed by an interval of higher bioturbation in Core 181-1122C-35X (300–308.01 mbsf). There are two tephra layers in Subunit ID, in Section 181-1122C-37X-1 (320.3 mbsf) and in 37X-6 (327.92 mbsf) (Fig. F7).

F7. Tephra layer in Subunit ID, p. 48.

Subunit ID shows a gradational transition upward from a current-influenced depositional environment to a more turbidite-dominated facies. The higher intensity of bioturbation in the hemipelagic sediment separating turbidite units may indicate a slower rate of deposition or a lower frequency of turbidity currents compared to Subunits IA–IC.

Unit II

Unit II represents bioturbated, pelagic/hemipelagic sediments interspersed with current-laminated deposits. This unit extends from 386.9 to 550.4 mbsf and is divided into the three Subunits IIA, IIB, and IIC, according to compositional changes.

Subunit IIA

Interval: Sections 181-1122C-44X-1 through 52X-6
Depth: 386.9–472.3 mbsf (Hole 1122C)
Age: Pleistocene to late Pliocene

Poor core recovery in Core 181-1122C-43X suggests that a suitable upper boundary for Subunit IIA lies at the top of Core 44X. The improved core recovery downhole, starting at Core 44X, produced sediments quite distinct from Unit I. The mottled, greenish gray (5G 5/1 to 5GY 5/1) olive-gray (5Y 5/2) or light greenish gray (5BG 7/1) pelagic/hemipelagic silty clay beds are commonly bioturbated with *Zoophycos, Planolites, Terebellina, Chondrites, Anconichnus,* and *Gyrolithes*. Pyritization is very sporadic being typically limited to pyritized *Zoophycos* traces. Interbedded with the silty clay is dark gray (N 4) or dark greenish gray (5GY 4/1) fine sand and silt beds that commonly exhibit scoured basal contacts and conspicuous planar and cross laminations. Such structures suggest a stronger, episodic benthic flow regime, in contrast to that of the decelerating turbidity currents. Laminae are accentuated by concentrations of foraminifers and carbonate debris. Sporadic ripples were observed in the thicker beds (>10 cm) (Figs. F8, F9). Top and bottom contacts of the fine sand and silt beds are generally sharp, with few gradational boundaries. These sand and silt beds are tentatively interpreted as contourite deposits (see "Interpretation and Discussion," p. 9). Interspersed among the contourites are sporadic fine sand beds with sharp basal contacts and normal grading, which suggests a turbidity current origin. These beds may have been deposited during periods of weak contour-current activity.

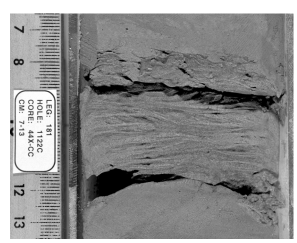
F8. Contourite with planar and cross laminae, Subunit IIA, p. 49.

Pinkish gray (5YR 6/2) tephra occurs in Sections 181-1122C-44X-2 (388.96–388.99 mbsf), 50X-5 (450.82–450.86 mbsf), and 51X-1 (454.48–454.52 mbsf). Drilling disturbance increases toward the base of Subunit IIA with moderate to heavy biscuiting starting in Core 181-1122C-47X.

Subunit IIB

Interval: Sections 181-1122C-52X-6 through 55X-2
Depth: 472.3–494.5 mbsf (Hole 1122C)
Age: early Pliocene

F9. Planar and cross laminae, Subunit IIA, p. 50.



Subunit IIB is heralded by a sudden downcore increase in detrital chlorite. The contact between Subunits IIA and IIB is marked by the occurrence of a pale olive (5Y 6/3) silty clay. Dark greenish gray (5GY 4/1 to 5G 4/1) to greenish gray (5G 5/1 to 5GY 6/1) pelagic/hemipelagic silty clay beds are interspersed with light brownish gray (2.5Y 6/2) to gray (5Y 6/1), nannofossil-rich layers. Bioturbation is common throughout the silty clay beds and includes an ichnofauna of *Zoophycos, Chondrites, Planolites, Terebellina, Thalassinoides,* and *Teichichnus*. The interbedded dark greenish gray (5G 4/1) to greenish gray (5GY 5/1) fine sand and silt beds contain sharp, typically scoured basal contacts, sharp upper contacts, and planar laminations; gradational boundaries are not common.

We suggest that the sand and silt beds are contourites (see **"Interpretation and Discussion,"** p. 9) Intense disturbance has caused brecciation in Core 181-1122C-53X, and moderate biscuiting is observed in Core 54X.

Subunit IIC

Interval: Sections 181-1122C-55X-2 through 60X-CC
Depth: 494.5–550.4 mbsf (Hole 1122C)
Age: middle Miocene

The top of Subunit IIC occurs in Core 181-1122C-55X at a distinct color change from the normal greenish gray (5G 4/1) silty clay of Subunit IIB. The color changes gradationally to a yellowish brown to light reddish brown (10YR 6/4) in Section 181-1122C-55X-2, to (10YR 6/3) in Section 55X-3, to a 20-cm white (10YR 8/1) bed to pale yellow (5Y 7/3) in Section 55X-4, and finally to pale olive (5Y 6/3) in Section 55X-5. The suggested location of the boundary between Subunit IIB and Subunit IIC is placed at the beginning of the gradational color change in Section 181-1122C-55X-2 (494.5 mbsf). The extensive bioturbation in Section 55X-2 by *Thalassinoides* suggests the possibility of a firmground or discontinuity in deposition. The interval of distinct color variability (494.5–499.15 mbsf) is rich in nannofossils and foraminifers and coincides with the unconformity separating the early Pliocene and the middle Miocene.

The dominant lithology of Subunit IIC is dark greenish gray (5GY 4/1 to 5G 4/1) to greenish gray (5G 5/1 to 5GY 6/1) pelagic/hemipelagic silty clay beds that are interspersed with white (5Y 8/1) nannofossil ooze layers. Detrital chlorite is observed in smear slides (see the **"Core Descriptions"** contents list). Bioturbation is common throughout the silty clay beds and includes an ichnofauna of *Zoophycos, Chondrites,* and *Planolites*. The *Thalassinoides* at the upper boundary of the subunit are interpreted to be ichnofaunal (Pliocene?) reworking of the Miocene-age sediments. The interbedded dark greenish gray (5G 4/1) to greenish gray (5GY 5/1) fine sand and silt beds contain sharp, typically scoured basal contacts, sharp upper contacts, and planar laminations; gradational boundaries are not common. We suggest that the sand and silt beds are contourites (see **"Interpretation and Discussion,"** p. 9). Moderate biscuiting is observed throughout Subunit IIC.

Unit III

Unit III represents bioturbated, pelagic/hemipelagic sediments interspersed with laminated current deposits common to drift deposits. Toward the bottom of the hole, two probable debris-flow deposits have been identified. This unit extends from 550.4 to 617.85 mbsf and is divided into Subunits IIIA and IIIB, according to a change in lithification and the appearance of debris-flow deposits. Recovery was poor, averaging <25%.

Subunit IIIA

Interval: Sections 181-1122C-61X-1 through 64X-1
Depth: 550.4–580.62 mbsf (Hole 1122C)
Age: middle Miocene

Because of the poor recovery in Core 181-1122C-60X the upper contact of Subunit IIIA is located at the top of Core 181-1122C-61X. The green

(5G 5/1, Munsell plant color chart) to greenish gray (5G 5/1, Munsell soil color chart) clayey silt to silty clay, composing these pelagic/hemipelagic sediments, tend to be coarser grained than those of Unit II. Sediments are commonly bioturbated with observed traces of *Zoophycos, Chondrites, Planolites, Terebellina,* and *Gyrolithes*. Interbedded throughout are distinctive fine sand and silt beds of a greenish hue (5G 5/1, Munsell plant color chart) and greenish gray (5G 5/1-5G 6/1) to dark greenish gray (5G 4/1) as well as interspersed white (10Y 8/1) or gray (10YR 5/1) to dark gray (10YR 4/1) nannofossil-bearing foraminifer sand (Fig. **F10**). Sand and silt beds have pronounced planar laminae. Top and bottom contacts of the sand and silt beds are sharp with normal grading only sporadically in sand beds. The sand and silt interbeds are interpreted as contourite deposits with intermittent, unreworked turbidites (see **"Interpretation and Discussion,"** p. 9).

F10. White foraminifer sand with bioturbated top, Subunit IIIA, **p. 51.**

Subunit IIIB

Interval: Sections 181-1122C-64X-CC through 68X-CC
Depth: 580.62–617.8 mbsf (Hole 1122C)
Age: early Miocene

The upper contact of Subunit IIIB is located in Section 181-1122C-64X-CC at the top of a poorly sorted, greenish gray (5G 5/1) fine sand that is reverse graded to gravelly coarse sand. This bed has greenish gray (5GY 6/1) intraclasts of silty clay up to 1.2 cm long, and the beds also contain abundant wood fragments that are typically <1 cm. These features suggest the deposits were emplaced as debris flows. Another debris-flow deposit with similar composition is observed in Section 181-1122C-67X-1, 608.8 mbsf (Fig. **F11**). Between the two debris flows is a series of heavily bioturbated, interbedded greenish gray (5GY 5/1) to dark greenish gray (5GY 4/1) fine sand–bearing siltstones and light greenish gray (5BG 7/1) foraminifer-bearing nannofossil chalks, which appear to be the lithified equivalents of Subunit IIIA. The siltstone beds in Core 181-1122C-65X contain abundant wood fragments. Observed trace fossils in the chalk and siltstone beds include *Chondrites* and *Planolites*. Interspersed among the siltstone and chalk beds are greenish gray (5GY 5/1) laminated, fine sand beds. The fine sand beds have sharp top and bottom contacts and are usually not graded. Drilling disturbance is pronounced throughout the subunit, with moderate to heavy biscuiting and very poor recovery (averaging <20%).

F11. Reverse-graded debris-flow deposit, Subunit IIIB, **p. 52.**

Interpretation and Discussion

The overall pattern of deposition at Site 1122 exhibits the interplay between the DWBC, possibly reinforced by the ACC, and the inflowing turbidity currents carrying their high sediment load from the Bounty Channel.

Unit III contains pelagic/hemipelagic sediments interbedded with contourites and a few turbidites. The debris-flow deposits in Subunit IIIB indicate a closer source than the South Island. Unit II continues to be affected strongly by boundary currents, with most of the sand and silt beds containing fine planar laminae and cross laminae, which imply steady flow conditions. The presence of chlorite-bearing sediments in Subunit IIB suggests either (1) a source off the Campbell Plateau that has been eroded by the DWBC and redeposited as contourites at Site 1122, or (2) a South Island source in the Bounty Trough catchment. Isolated turbidites do occur throughout Units II and III, but are a minor component of the coarser grained deposits.

Unit I shows the stronger influence and greater sediment load brought by the Bounty Channel. Subunit ID contains mainly thin turbidites that have been eroded and slightly reworked, with typically sharp top contacts. Subunits IC to IA contain sequences of turbidites that represent the emplacement of the prograding channel/levee complex of the Bounty Fan.

Units II and III have distinctive nongraded, laminated fine sand and silt beds indicating the presence of a persistent but variable current. This flow caused basal scouring, yet allowed alternating deposition of cross-laminae and planar laminae. It is likely that sporadic influxes from the Bounty Channel interacted with the DWBC, which was (1) reinforced at times by benthic storms such as those recorded at the High Energy Benthic Boundary Layer Experiment (HEBBLE) site off Nova Scotia (Hollister and McCave, 1984), (2) affected by glacial/interglacial cyclicity, or (3) periodically reinforced by the ACC.

The reverse-graded, coarse-grained sediments containing clay intraclasts and wood fragments are interpreted as debris-flow deposits. Several lines of evidence suggest the debris flows carried sediment from proximal sources into deep water: (1) the deposits are interbedded with pelagic sediments, (2) the composition is different from the distal turbidites of the Bounty Fan, and (3) the benthic foraminiferal fauna is shallow water (see **"Biostratigraphy,"** p. 13). The most likely sources of the debris flows are the flanks of the Chatham Rise and the Campbell Plateau. Several of the fine sands and white foraminifer sands appear to be turbidites, which may also represent shallower material originally deposited on Chatham Rise or Campbell Plateau.

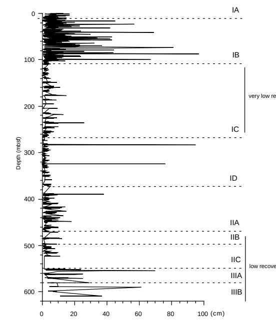
The observed changes in the depositional environments also document the changes in the character of DWBC and its effect on the area. The DWBC was a dominant factor in the depositional history of Units II and III. The chlorite-bearing sands and muds within an abyssal flow sequence may reflect erosion upstream by the combined DWBC/ACC. These sediments may represent the unroofing of chlorite-bearing sediments at the base of the Campbell Plateau (see **"Lithostratigraphy,"** p. 3, in the "Site 1121" chapter). The presence of reworked Eocene diatoms also suggests erosion of earlier deposits (see **"Biostratigraphy,"** p. 13).

The ACC can be argued to have reinforced the DWBC at least during the time of deposition (and erosion) in Subunit IIC where the foraminifers in the silty clay located in Section 181-1122C-55X-4 comprise almost entirely well-sorted, cold-water Antarctic taxa.

Subunits IA–IC consist of a 262-m-thick Pleistocene turbidite sequence in which the sediment was delivered to the shelf and slope by river input during glacial sea-level lowstands and deposited by turbidity flows that may coincide with eustacy, seismicity, or other triggering mechanisms. The base of Unit I approximates seismic reflector R2a, which is the contact between large-amplitude sediment waves above and a planar bedded sediment wedge below. It appears that the turbidite-dominant Unit I marked the main period of levee growth by the Bounty Channel.

One of the major concerns in separating out the lithostratigraphic units and subunits is the generally poor core recovery. This is particularly related to the observed changes in thickness and grain size of the turbidite intervals throughout Unit I (Fig. **F12**). Four variables control fan sediments, namely the degree of glacial sea-level lowstands, seismic-

F12. Thickness of turbidites and sand, fine sand, and silt layers, **p. 53.**

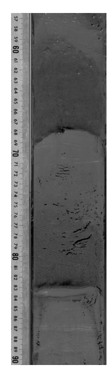


ity affecting the slope, sediment supply, and the influence of the passing DWBC. However, any evaluation of these variables must be made with due consideration of the drilling operations. Of significance is the apparent change in both turbidite thickness and coarsest grain size from Subunit IB to Subunit IC. With the beginning of XCB coring at Core 181-1122C-14X, the amount of recovered core dropped significantly (<50% recovery). It is likely that the use of XCB coring washes out the less cohesive and thicker sand layers, causing only the fine-grained, thinner sands and muds to be recovered in the core. Because of the lack of supporting data such as downhole logs, it is imprudent to interpret the lithology of the missing intervals. When defining the units and subunits, changes that were apparent in lithology, deposition, or composition were considered primarily; core recovery was a necessary secondary consideration, as the definition of the units could not be based entirely on what was observed. For example, it is uncertain if a lithologic change exists between Subunit IB to IC, or whether the change rather represents an artifact of the drilling method.

The transition from a current-influenced (Unit II) to a more turbiditic-influenced environment (upper part of Subunit ID) is marked by an abrupt increase in coarser sand and silt beds. There, the very fine sand and silt turbidite intervals are relatively thin (<10 cm) and sometimes are truncated and reworked. These coarser beds probably represent an early stage of the Bounty Fan with a less distal sedimentation of the terrigenous material. The overlying Subunit IC contains slightly thicker silt and very fine sand turbidites (~10 to 20 cm thick). An erosional influence from the DWBC is not apparent because the turbidites are normally graded. Compared to the overlying turbidites of Subunit IB, Subunit IC beds are relatively thin and could indicate a slow progradation of the fan. Subunit IB has thick (<100 cm) sandy turbidites, implying more rapid fan progradation. Subunit IA is composed of thinner, fine-grained turbidites and could represent either a marked restriction in sediment supply through the Bounty Channel or that the height of the levees allowed only the fine fraction of the turbidity currents to overspill. Another possibility is that the alternation in turbidite thickness is tied to deposition on a migrating sediment wave field. The migration of these antidunes would cause the deposition of thicker turbidites on the upcurrent side and thinner turbidites on the lee side of an antidune. As the sediment waves migrated relative to the location of the drill site, a periodic pattern of thicker and thinner turbidites might be expected.

Pyritized bases of the turbidites appear in distinct intervals of several decimeters to several meters thickness throughout Unit I (Fig. **F13**). These intervals probably depend on the content or concentration of organic matter being deposited and its degradation under reducing conditions. There appears to be a connection at ~260 mbsf between the last interval of pyritized bases and the elevated methane content (see **"Inorganic Geochemistry,"** p. 27), which would confirm a higher organic content in Unit I. Total organic carbon, however, does not show a clear trend of higher values, but the reason for this could be the low-resolution sampling.

F13. Turbidites with pyritized bases in basal Subunit IA, **p. 54.**



Pyritized zones develop best in the bases of sand turbidites but also occur in the very fine sand and silt turbidites. This leads to the possibility that organic detritus carried within the turbidity currents is percolating through the sand bed and is reduced at the contact with the underlying fine-grained deposit. This slows down the interstitial-water circulation. However, the mechanism is not supported by the occurrence of pyritized bases in fine-grained turbidites. Therefore, a more likely explanation is the rapid burial of organic-rich surface sediment (silty clay hemipelagic sediment below turbidites), thereby causing a sudden change from oxidizing to reducing conditions during degradation of organic matter. Still another explanation for the pyrite zones is that the higher permeability of the basal turbidite sands promotes the concentration of reducing pore waters expelled from the muds below. Only in distinct intervals is the supply of organic matter higher; this may be correlated with glacial periods in which productivity and organic carbon content of hemipelagic sediments is higher (Lean and McCave, 1998).

Trace Fossils

In Unit III, the observed trace fossils in the lithified pelagic sediments of Subunit IIIB and the unlithified pelagic sediments of Subunit IIIA include *Zoophycos, Planolites, Chondrites, Terebellina,* and *Gyrolithes*. The low diversity and the high abundance imply a *Zoophycos* ichnofacies, which indicates a fairly low depositional rate in a slightly oxygen-poor, deep-water environment (Pemberton and MacEachern, 1995).

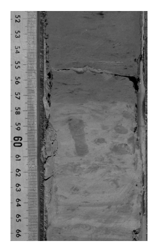
Subunit IIC contains an ichnofauna abundant with *Zoophycos, Planolites,* and *Chondrites,* continuing the *Zoophycos* ichnofacies from Unit III. The top of the subunit in Core 181-1122C-55X is likely to be directly related to the unconformity separating early Pliocene age sediment in Core 181-1122C-54X from the middle Miocene age sediments in Core 181-1122C-56X. The unconformity is marked by the start of a gradational color change in Section 181-1122C-55X-2. The presence of *Thalassinoides* at the top of Subunit IIC is interpreted as later (possibly Pliocene) burrowing into the Miocene sediment.

Subunit IIB possesses a more variable depositional history. The trace fossil assemblage in the subunit includes *Zoophycos, Chondrites, Planolites, Terebellina, Thalassinoides,* and *Teichichnus*. The presence of *Thalassinoides* and *Teichichnus* suggests a transition from *Zoophycos* ichnofacies to a *Cruziana* ichnofacies, signifying a more energetic and oxygenated environment (Fig. **F14**). The carbonate sediments of Core 181-1122C-55X mark the first (last downcore) occurrence of *Thalassinoides*.

In Subunit IIA, the presence of *Chondrites, Terebellina, Anconichnus,* and deep-spiraling *Zoophycos* in relatively high abundance, but low diversity, again implies a *Zoophycos* ichnofacies. Nannofossil-bearing sediments increase in this unit and may represent glacial-interglacial periods of higher carbonate levels relative to terrigenous input into the ocean.

Unit I contains few identifiable trace fossils; those observed traces are generally robust burrows of opportunistic colonization (primarily *Skolithos,* with singular occurrences of *Thalassinoides* in Core 181-1122C-16X and *Gyrolithes* in Core 181-1122C-17X). The lack of identifiable trace fossils in the hemipelagic silty clays suggests the depositional rates were high, thereby preventing a well-developed ichnofabric from being established. Starting at 280 mbsf and occurring more consistently from 300 mbsf to 389.9 mbsf is an ichnofauna limited to *Chondrites,* which suggests a lower depositional rate accompanied by a restriction in oxygen (Pemberton et al., 1992) (Fig. **F15**).

F14. *Teichichnus, Zoophycos,* and *Planolites* in Unit IIB, **p. 55.**



F15. *Chondrites* in Subunit ID, **p. 56.**

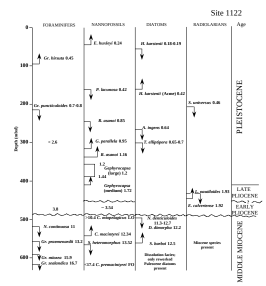
BIOSTRATIGRAPHY

Introduction and Summary

The stratigraphic sequence recovered at Site 1122 consists of Miocene through Pleistocene strata, consisting of lower and middle Miocene sediments (~130 m), overlain by a thin and stratigraphically highly condensed and incomplete upper Miocene and Pliocene section (<50 m) and a 450-m-thick Pleistocene section. The uppermost few meters at the site include the Holocene. Calcareous and siliceous microfossils are present throughout the whole section. The preservation of microfossils is good or very good in the upper part of the sequence but deteriorates downward.

The main paleontological results are summarized in Figure **F16.** The sequence of biohorizons indicates an apparently continuous section at the top, ranging from the upper Quaternary to the upper Pliocene. Calcareous nannofossil data indicate a slight unconformity at ~454 mbsf, which separates the Pleistocene–upper Pliocene sediments from a short lower Pliocene interval. A more pronounced hiatus is detected at ~490 mbsf. Below this unconformity, the sediments are middle Miocene in age, ranging from ~10.9 Ma (based on the last occurrence [LO] of *Coccolithus miopelagicus,* which is still present in the section) down to 16.7 Ma (last common occurrence [LCO] of *Globorotalia zealandica*).

F16. Biostratigraphic summary chart, **p. 57.**



In the Pliocene–Pleistocene interval, the planktonic foraminiferal assemblages are characteristic of an oceanic environment, and benthic assemblages are a mixture of deep-water and redeposited shelf forms. The upper part of the Miocene sequence is characterized by almost barren sediment or by rare deep-water benthic species, while the lowermost part of the section has a normal oceanic plankton fauna and mixed mid-shelf and deep-water benthic assemblages.

In the late Pleistocene interval, diatoms are represented by a mixture of autochthonous pelagic species and neritic-nearshore species (probably derived from the inner part of the Bounty Trough). The early Pleistocene and Pliocene sediments are rich in reworked older Pliocene and Miocene Antarctic/subantarctic species as well as some Paleogene diatom valves. The Miocene sediments yield again higher numbers of autochthonous Antarctic and subantarctic species, whereas in the lowermost part of the section only reworked Paleogene diatoms (Eocene and Oligocene in age) occur.

Age

The micropaleontological biostratigraphy of Site 1122 is mostly based on the onboard study of core-catcher samples. Hole 1122A samples were used for the uppermost part of the section and Hole 1122C samples for the lower part. Additional samples were taken from within selected cores to address specific age and paleoenvironmental questions. The absolute ages assigned to biostratigraphic datums follow the references listed in Tables **T2,** p. 59, **T3,** p. 60, **T4,** p. 63, and **T5,** p. 64, all in the "Explanatory Notes" chapter).

Calcareous Nannofossils

Nannofossils obtained from Cores 181-1122A-1H to 13X (0–119.97 mbsf) and from core catchers of Cores 181-1122C-15X to 68X (111.28–617.80 mbsf) were analyzed. There is an 8.6-m overlap between the two holes in our analysis. Additional samples were selected and investigated strategically to increase biostratigraphic resolution. The occurrence of taxa are presented in Table **T4.** Because of the paucity of major marker species, especially during the Miocene, we did not attempt to correlate the sequence with Martini's (1971) standard zonation.

T4. Identification and abundance of nannofossils, **p. 116.**

Calcareous nannofossils are common and well preserved in the upper part of the sequence (0–400 mbsf), except for several short turbidite intervals where only a few nannofossils were found. The preservation of nannofossils deteriorates downward from Core 181-1122C-46X (400–617.8 mbsf) at the same time as the concentration of nannofossils in sediments increases. Reworked nannofossils occur frequently throughout the sequence. The common presence of reworked species makes it hard to use last occurrence datum levels, as, for instance, with *Helicosphaera sellii* and *Cyclicargolithus floridanus*.

Thirteen nannofossil biohorizons were recognized and used for dating the drilled sequence. The upper 420 m represents apparently a continuous sequence of Pleistocene–late Pliocene age, if small diastems were negligible. The absence of marker species as well as the frequent occurrence of reworked nannofossils makes it difficult to date the lower part of the sequence (420–617.8 mbsf). Nevertheless, two hiatuses were detected at ~454 mbsf and 490 mbsf. A short early Pliocene interval (~3.5 Ma in age) is sandwiched between these two hiatuses (Fig. **F16)**. Beneath the lower hiatus, a middle Miocene sequence (between 11 to 17.4 Ma as constrained by nannofossils) was recovered.

Samples 181-1122A-1H-CC to 7H-CC contain abundant, moderately preserved nannofossils characterized by the presence of *Emiliania huxleyi*. This interval is correlated with Zone NN21 (Martini, 1971), with its bottom estimated at 0.24 Ma (Naish et al., 1998). Because of the dilution effect of terrigenous influx caused by turbidites, it was difficult to assess the dominance of *E. huxleyi,* and, therefore, the acme zone of this species was not recognized within Zone NN21. The base of NN20, the LO of *Pseudoemiliania lacunosa,* estimated at 0.42 Ma (Sato and Kameo, 1996; Naish et al., 1998), was recognized at Sample 181-1122C-22X-CC.

From Samples 181-1122C-22X-CC to 44X (176.9–391.5 mbsf), the sequence contains assemblages diagnostic of the early to late Pleistocene (e.g., Matsuoka and Okada, 1989; Takayama, 1993; Sato and Kameo, 1996). Sato and Kameo's (1996) recent revision of the estimated ages of Pleistocene nannofossil datum levels was adopted for dating this core section. The LO of *Helicosphaera sellii* was assessed to be at Sample 181-1122C-44X-3, 13 cm, which is inconsistent with other biohorizons, and, therefore, was not included in the age-depth model.

A biostratigraphic break occurs between Samples 181-1122C-50X-CC and 51X-2, 58 cm. Below this break, well-preserved *Sphenolithus neoabies* and *Dictyococcites antarcticus* occur commonly and persistently. The occurrence of *Sphenolithus neoabies* (mean LO estimated to be slightly younger than 3.54 Ma; Spencer-Cervato et al., 1994) and *Pseudoemiliania lacunosa* (FO at 3.54 Ma; Spencer-Cervato et al., 1994) in Sample 181-1122C-51X-2, 58 cm, to 51X-CC (452.2–463.6 mbsf) suggests a correlation of this interval to the NN15 Zone of the late early Pliocene. The break itself might represent a small hiatus separating the late Pliocene from early Pliocene. Sample 181-1122C-52X-CC yields a few *Helicosphaera sellii,* whose first appearance was reported to be at the basal boundary of Zone NN12 (de Kaenel and Villa, 1996), indicating an age younger than 5.5 Ma (Berggren et al., 1995).

Samples taken from Core 181-1122C-54X are almost barren of nannofossils and, therefore, no age assessment can be made for this core.