43. SYNTHESIS — SEDIMENTS OF THE SOUTHWEST PACIFIC OCEAN, SOUTHEAST INDIAN OCEAN, AND SOUTH TASMAN SEA

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ABSTRACT

The Leg 29 sediment sequences are dominated by burrow-mottled, open-ocean biogenic sediments and by burrow-mottled, very fine-grained terrigenous sediments. Coarse detritus, primary sedimentary structures and turbidites are rare. Silicification and chertification is characteristic of the upper part of the fine-grained terrigenous facies. Clear-cut evidence for contemporary volcanism was recorded at only one site.

The succession of facies generally reflects the gradual evolution of the three ocean basins by sea-floor spreading and the related development of the oceanic circulation patterns as they now exist.

INTRODUCTION

The sediments drilled in the area covered by Leg 29 (Figures 1 and 2), generally reflect the gradual evolution of the three major ocean basins and the development of the oceanic circulation systems now characteristic of the basins.

Terrigenous silt and clay accumulated during the first phase of basin evolution. With continued sea-floor spreading, the ocean basins enlarged, the supply of terrigenous sediment diminished greatly, and persistent current systems evolved. In the southwest Pacific (Site 275) and south Tasman Sea (Sites 280 and 283), terrigenous silt and clay was succeeded by siliceous ooze, indicating that cool Antarctic waters had penetrated into these areas. However, contemporaneous nannofossil ooze and mixed foraminiferal and nannofossil ooze that accumulated at Site 277 suggest that siliceous-rich Antarctic waters never penetrated this area. With two notable exceptions (Sites 278, and 283) succeeding Neogene time is characterized by calcareous oozes (mostly nannofossil oozes).

With the exception of rare occurrences of detrital sand or glauconitic sand, the sediments can be grouped into three facies: terrigenous silt and clay, siliceous ooze, and calcareous ooze/chalk. At several sites they succeed each other in that order, thereby reflecting the gradual development of the three ocean basins.

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TERRIGENOUS SILT AND CLAY FACIES

This sediment was the first to accumulate on both oceanic basement and continental basement during Late Cretaceous and Paleogene time. It rests on basalt at deep positions in the Tasman Sea and southeast Indian Ocean. It also appears to have been the first sediment to accumulate on the continental rocks of the Campbell Plateau. Here, the facies appears to underlie an acoustically reverberant surface that is widespread throughout the Campbell Plateau. At Site 275 (eastern Campbell Plateau) late Campanian semilithified silt and clay underlie this surface. On the western Campbell Plateau (Site 277), drilling ceased about or just above the same acoustic surface. The lowest sediments sampled were clay nannofossil chalk of middle Paleocene age. It is reasoned that within a short stratigraphic interval in Hole 277, this clay nannofossil chalk would have passed down into terrigenous silt and clay, the top of which would coincide with the reverberant surface. Seismic profiles show that acoustic basement lies 1500 meters below the reverberant surface at Site 277 and 500 meters below it at Site 275. It is likely that these intervals (to acoustic basement) consist largely of terrigenous silt and clay; the lowest part of the sequence may consist of coarser terrigenous sediment. Such a sequence is exposed on Campbell Island, midway between Sites 275 and 277.

On Campbell Island, the Garden Cove Formation consists of quartz pebble conglomerate and pebbly sand, which rest unconformably on the Complex Point Schist. The Garden Cove Formation grades up into interbedded pebbly sandstone and mudstone, then into dark gray, unbedded though locally laminated carbonaceous mudstone (Oliver et al., 1950). It is regarded as Late Cretaceous at the base, and Paleocene at the top (A. R. Edwards, personal communication). The upper part of the sequence appears comparable with the terrigenous silt and clay facies of Leg 29.

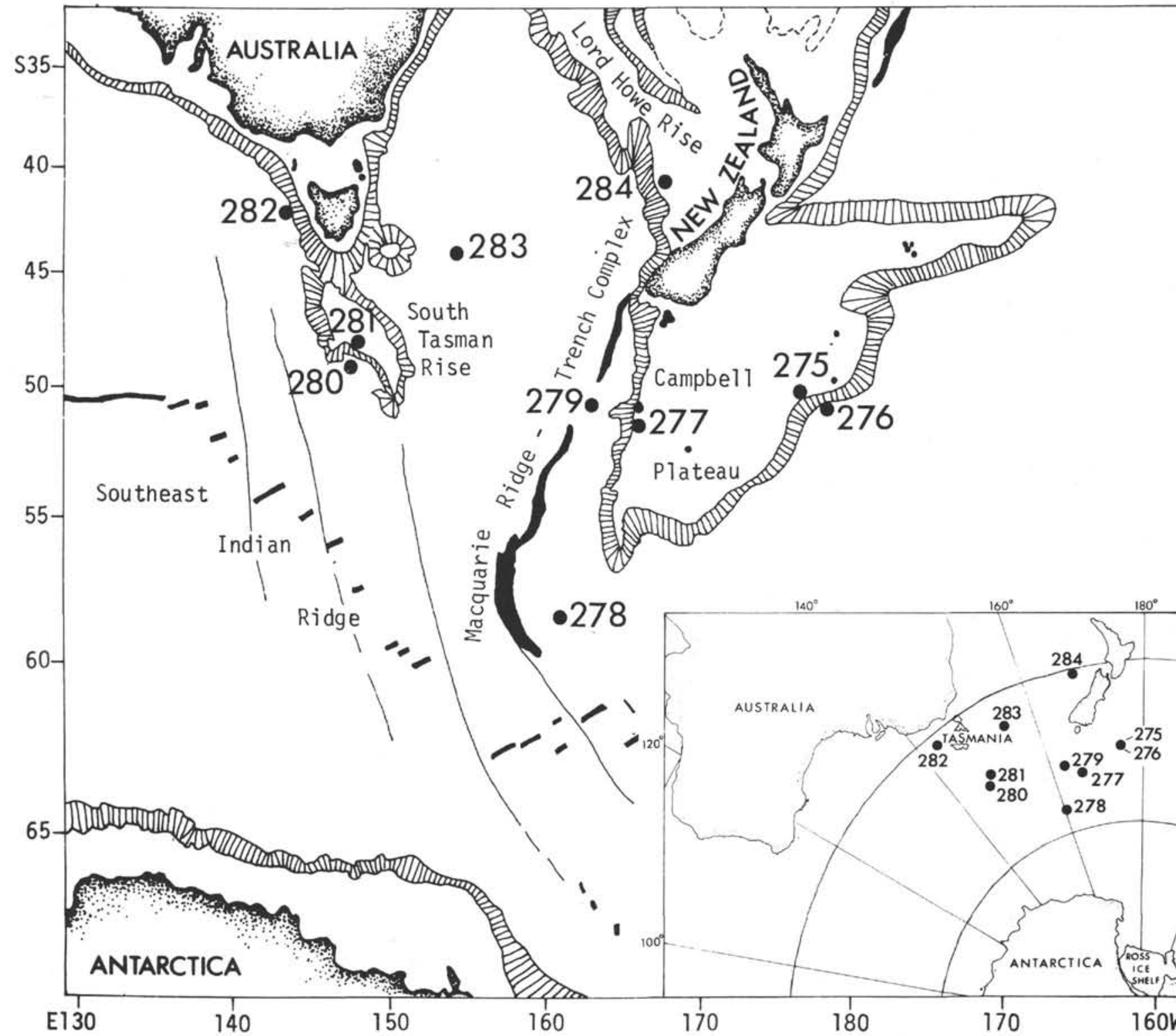

Figure 1. *Sketch map showing location of the Leg 29 drill sites.*

The terrigenous silt and clay facies is characteristically a dark olive-gray to dark brown, organic carbon-rich, burrow-mottled, poorly sorted silty clay, with subordinate clay and clayey silt. The facies has been described in detail (Andrews and Ovenshine, Chapter 31, this volume) so only a brief review of its characteristics are presented here. The intensity of burrow-mottling varies stratigraphically. Some distinctive burrow forms occur and primary stratification of any form is extremely rare.

Diagenetic and authigenic minerals are very characteristic of the facies and include: glauconite, microspheres of manganese and/or iron, and pyrite.

The facies also is characterized by a very restricted fauna and flora. The restricted epibenthic fauna, and planktonic fauna and flora, include small numbers of siliceous and agglutinating foraminifera. Planktonic foraminifera do not occur, but other pelagic microfossils are present in modest numbers and varying diversity at several horizons. The facies does not contain skeletal remains of an infauna; however, its burrowed nature suggests the former presence of a relatively rich, soft-bodied infauna.

The facies is exceptionally developed at the foot of the continental slope west of Tasmania (Site 282) in that it contains moderate amounts of sponge spicules and nannoplankton, scattered low diversity planktonic foraminifera and scattered shallow-water fossils.

At all sites except 282, siliceous microfossils (especially diatoms) appear in the uppermost part of the facies. They are few in number, poorly preserved and commonly broken at first, but at some locations become increasingly diverse, abundant, and well-preserved at the top of the facies. The facies grades up into terrigenous silt and clay-rich siliceous oozes, in which well-preserved diatoms are dominant.

The zone below the diatom-rich upper part of the terrigenous facies is extensively silicified. The zone is rich in the silica minerals cristobalite and tridymite, and

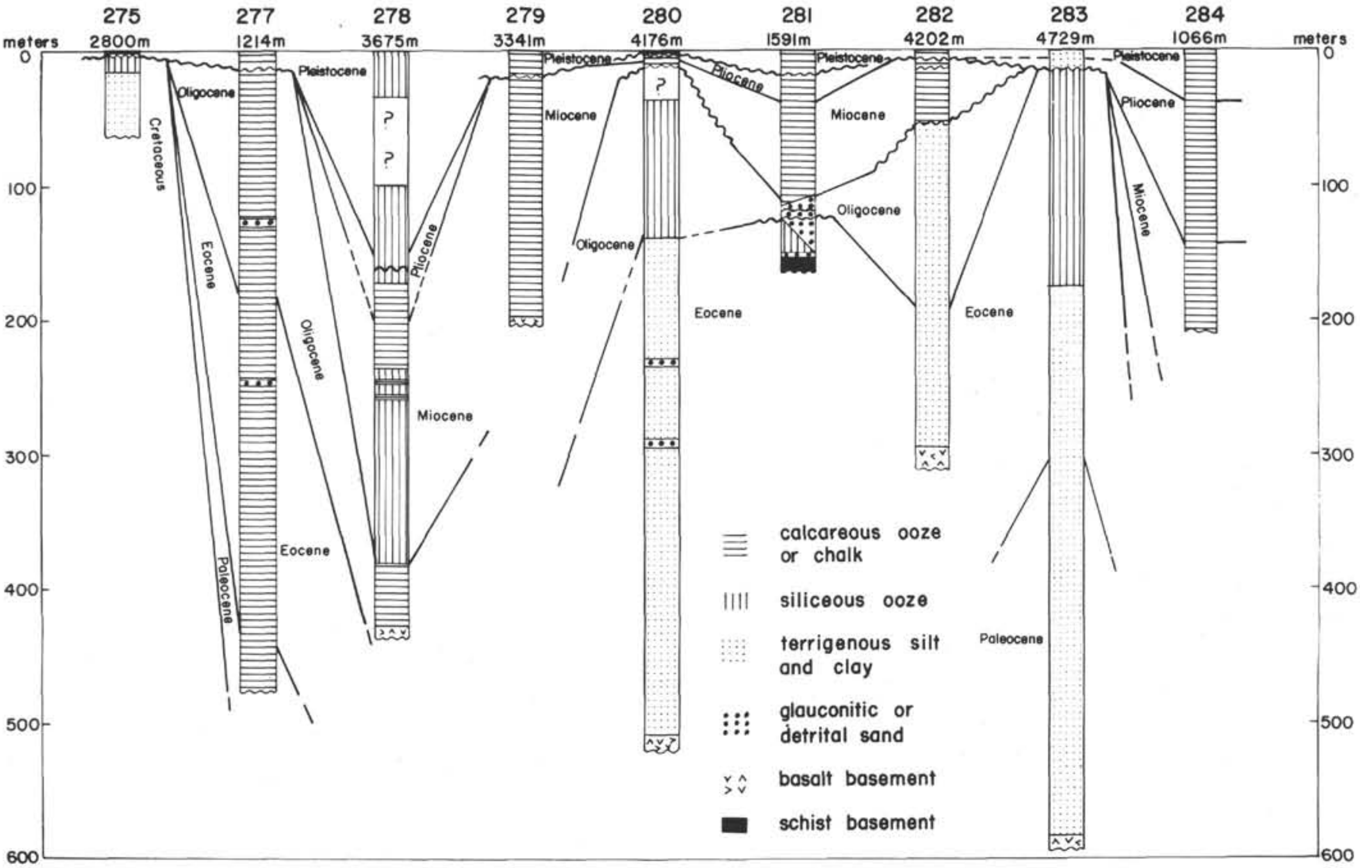

Figure 2. *Simplified stratigraphy for each of the sites drilled, Leg 29.*

at Site 280 is succeeded by interbedded chert and silicified clay silt, both of which also contain cristobalite, tridymite, and microcrystalline quartz. This sequence supports the thesis that chertification of oceanic silt and clay is a three-step process. The details of this process are further presented in Chapter 31 (this volume), Heath and Moberley (1971), and Greenwood (1973).

A variant of the terrigenous silt and clay facies occurs at Site 282, which lies at the foot of the continental slope west of Tasmania. Here, units of a bedded subfacies alternate with the burrow-mottled subfacies. Thin (20-90 cm) color-graded and commonly size-graded beds characterize the subfacies. The beds consist of silty clay and clayey silt low in organic carbon; they are siltier than the burrow-mottled interbeds and rich in nannofossils. Only small numbers of poorly preserved nannofossils occur in the interbeds. The presence of limited numbers of neritic nannofossils and shallow-water benthonic foraminifera, and the size-graded character of many beds, suggest that the beds are distal turbidites. The turbidites must have originated on the outer continental shelf or upper continental slope and accumulated at the foot of the slope. In the absence of turbidites the burrow-mottled facies is deposited.

The terrigenous silt and clay facies is coarsest near land and in shallower positions, and finest in distant and deep oceanic positions. It consists of detrital minerals, and the sediment is land derived. However, the presence of extensive burrow-mottling and manganese and iron micronodules indicates that bottom waters were oxygenated. The lack of primary sedimentary structures indicate that bottom currents were weak.

SILICEOUS OOZE FACIES

Siliceous ooze is variable in character. Three types were encountered during Leg 29 drilling. One type is characteristic of the late Eocene and early Oligocene at three of the four South Tasman Rise and south Tasman Sea sites. At Sites 280 and 283 siliceous ooze succeeds the terrigenous silt and clay facies, and at Site 281, it forms the first thick unit to cover the thin basal units of angular pebble gravel and nannofossil chalk that overlie the schist basement of the South Tasman Rise. At these sites the facies contains abundant detrital sediment, which appears to be responsible for the characteristic greenish-gray and grayish-olive color. Silt and clay-size detritus comprises 40%-45% of the facies at Site 280, and 10%-25% at Site 283. The facies is soft to stiff, massive to faintly fine mottled silty diatom, or siliceous ooze. At Site 283 it is a silt-bearing nannofossil siliceous ooze at the base, a silt-rich diatom ooze over much of the rest of the unit, and a silty diatom ooze at the top. At Site 280 the facies alternates between silty diatom ooze and diatom detrital silt. The facies at Site 281 is nannofossil, foraminifera, and detrital sand-rich siliceous ooze at the base, gradually changing to a glauconite-rich, siliceous detrital sand-silt-clay at the top. Here, it is succeeded unconformably by glauconitic sand. Stratification is rare at all sites, although 1-cm-thick distorted beds occur in the upper third of the facies at Site 281, and horizontal, sometimes discontinuous laminae occur at Site 280. Mottles are relatively rich in glauconite and micronodules (280), or detritus (281).

At these three sites the facies is mineralogically very similar to the terrigenous silt and clay facies. Diagenetic and authigenic minerals such as, glauconite, manganese micronodules, and pyrite are widespread, although glauconite is not always present.

The facies at Sites 280, 281, and 283 contains rich, highly diverse, and moderately to well-preserved diatom assemblages. Radiolaria, sponge spicules, and silicoflagellates are moderately preserved and are common at Site 283, but rare at Sites 280 and 281. Foraminifera and nannofossil content and character vary markedly, according to the depth of the sites. At the deep sites (280 and 283), planktonic foraminifera are effectively absent. Nannofossils are poor to moderately preserved; they are rare at Site 280 and throughout all but lower most part of the sequence at Site 283 where they are abundant but show low diversity. Nannofossil character is consistent with accumulation close to the carbonate compensation depth. In contrast, at the shallow Site 281, nannofossils are abundant, moderately diverse, and well preserved. Benthonic foraminifera are well developed, representing outer neritic to outer bathyal depths. Planktonic foraminifera are poorly to moderately preserved and of low diversity.

A second type of siliceous ooze occurs at Site 275 and near the top of the sequence at Site 280. Here the ooze is a soft, pale yellow to yellowish-gray or olive, slightly to intensely coarse mottled, silt-rich diatom ooze. At Site 275 the facies conformably overlies terrigenous silt and clay, is 13 meters thick, and late Campanian in age. At Site 280 the facies is at least 1 meter thick and conformably overlies the widespread greenish-gray silty diatom ooze. It is late Oligocene in age. The detrital fraction at Site 275 consists of angular and fresh, well-sorted silt and fine sand-sized grains. It includes quartz, schistose and sedimentary rock fragments, brown (oxidized) glauconite, some biotite and muscovite, and subequal amounts of plagioclase and potassium feldspar. A similar range of minerals occurs at Site 280 where montmorillonite is also abundant. The biogenic fraction largely consists of unbroken and unworn diatoms, which comprise a very diverse, and well-preserved flora. Well-preserved radiolarians, archeomonads, sponge spicules, and silicoflagellates are rare to common. Foraminifera are absent, and nannofossils are absent or extremely rare.

The types of siliceous ooze described above are Cretaceous to Oligocene in age and overlie or are associated with detrital sediments. A quite different type of siliceous ooze occurs at Site 278. It is light bluish or greenish-gray, very pale brown, or white, and commonly is rich in nannofossils and foraminifera. It comprises most of the sequence drilled at Site 278, occurring at most stratigraphic levels (middle Oligocene to Pleistocene).

Site 278 is the most southerly drilled (latitude 56°33′S) and is at the present latitude of the Antarctic Convergence. The siliceous-rich nature of the sediments is interpreted to reflect the intensification of the Antarctic Convergence during the Neogene. Variations in the proportion of nannofossils and foraminifera through the sequence are interpreted to reflect fluctuations in the development and location of the Antarctic Convergence (Site Report, Chapter 5, this volume).

Most of the facies is a sparsely burrow-mottled, nannofossil-rich siliceous ooze, in which diatoms predominate. The late Pliocene to early Pleistocene part of the sequence is a detrital silt, micarb, and nannofossil-bearing siliceous ooze. Foraminifera become increasingly common through the Pleistocene part, until towards the top, the facies is a foraminifera-bearing siliceous ooze. Mottled dark layers in the thick Pliocene and Pleistocene part of the sequence are rich in fresh, angular sand and silt-size grains. The grains are regarded as ice-rafted in origin (Site Report, Chapter 5, this volume; Margolis, this volume).

At some horizons, nannofossils are so abundant that the sediment is classified as carbonate. The various units of this facies and their age are shown in Figure 2.

It is notable that despite its siliceous fossil-rich character, the basal chalk is neither chertified nor contains cristobalite and tridymite, as it does at Site 277. This occurs despite the fact that the site is deeper (3675 m versus 1214 m), and the overburden presently is greater (380 m versus 240 m) than at Site 277. Perhaps the chalk is still too young geologically (late Oligocene versus early-middle Eocene at Site 277) for silicification to have commenced. DSDP results show that cherts tend to be confined to the older parts of an oceanic sequence, being most common in Late Cretaceous and Eocene sequences (Berger and von Rad, 1972).

The sequence at Site 278 is characterized by very abundant, highly diverse, and excellently preserved siliceous microfossils, and sponge spicules. The wide variation in abundance of the poorly preserved and very low diversity calcareous nannofossils and planktonic foraminifera is original. It is greatly enhanced by the selective dissolution of microfossils as a result of their accumulation just above the carbonate compensation depth. Calcareous microfossil content decreases over the upper part of the sequence, indicating the intensification of the Antarctic Convergence at this latitude and shallowing of the compensation depth.

CALCAREOUS FACIES

With the exception of Site 278, where the oceanographic conditions are unique among the sites drilled, nearly all post-Oligocene sediments are calcareous. Nannofossil ooze predominates, and mixed foraminiferal and nannofossil ooze commonly characterize the Pleistocene.

Thick sequences of calcareous ooze form all or most of the sequence drilled at the three shallow sites (277, western Campbell Plateau; 281, South Tasman Rise;

284, Challenger Plateau), and at Site 279, which lies just off the crest of the Macquarie Ridge. These sequences range from 119 to 475 meters in thickness. Elsewhere calcareous ooze forms thin lag deposits, largely erosional remnants of Plio-Pleistocene age, which rest unconformably on siliceous ooze or terrigenous silt and clay (Sites 275, 280, 282).

Pleistocene and late Pliocene oozes are soft, variously colored, and of variable composition (from foraminiferal ooze to fairly pure nannofossil ooze). Foraminifera tend to be most abundant in the uppermost Pleistocene oozes, which as a consequence have a sandy texture. At Sites 275 and 280, the thin veneer of Pleistocene sediments is protected by abundant 3-5-cm-diameter, black nodules of manganese and phosphate (Margolis, this volume). Similar nodules are associated with Pleistocene zeolite clay at Site 283. The presence of a nodule pavement indicates that the modern sea floor is current-swept at these three sites.

The thicker Pleistocene sequences of calcareous ooze (Sites 277, 279, 281, 284) are commonly bedded. The beds range widely in thickness (10-90 cm) although thin beds predominate. Adjacent beds tend to be distinguished on the basis of color, which at some places reflects compositional differences. Volcanic glass is moderately abundant in some layers at Site 277, trace amounts of detrital grains occur in some beds at Sites 279 and 282, and bryozoa fragments and micarb distinguish some layers at Site 282. At scattered horizons, sparse mottles and streaky concentrations of pyrite, micronodules, or detritus partly mask the layering.

At many sites, especially southern sites, the highly variable color, the variable amount of minor constituents, and the presence of layering, which together characterize late Pliocene and Pleistocene sediments, probably result from the climatic and sea level fluctuations of the period. Ice rafting may have introduced much of the coarse detritus (Margolis, this volume).

Lower in the sequences, the calcareous oozes are very uniform in character. They are typified by pale colors, by burrow-mottling, and by relatively uniform composition (nannofossil ooze or foraminifera-bearing nannofossil ooze to foraminiferal nannofossil ooze). Minor amounts of siliceous fossils, discoasters, micarb, glauconite, fine-grained detritus, or fine tephra, may occur at any one site.

Burrow-mottling characterizes the facies, but is highly variable in intensity. Scattered zones are intensely mottled (elliptical mottles), some being entirely homogenized, whereas others are massive (burrow-free). The only definitive burrow recorded was *Zoophycos,* which is sparsely distributed in the stiff to semilithified lower parts of several sequences. It occurs sporadically throughout the late Paleocene to middle Eocene chertified chalk at Site 277, in the late Oligocene chalk that forms the base of the dominantly siliceous sequence at Site 278, in the stiff early Miocene nannofossil oozes of Site 279, and in the stiff, late Miocene to early Pliocene siliceous-rich nannofossil ooze at Site 280.

Tiny concentrations of colored minerals give a streaky appearance to the facies at some places, and glauconite and volcanic detritus give a peppered appearance to some zones at Site 279.

The only primary sedimentary structure seen was fine lamination, which occurs very sparsely at several sites, and indistinct banding, which occurs in the Miocene of two sequences.

The only significant pre-Miocene calcareous sequence encountered occurs on the western part of the Campbell Plateau. At Site 277, the entire Paleogene is represented by a thick conformable sequence of nannofossil ooze overlying chalk. Evidence from seismic profiling and from the stratigraphic sequence exposed on Campbell Island suggests that this Paleogene sequence formerly extended over most of the Campbell Plateau. However, it was eroded off the southern and eastern parts during the Neogene (Site Reports, Chapters 2 and 4, this volume). At Site 277 a thin layer of late Pliocene and Pleistocene nannofossil and foraminiferal ooze unconformably overlies middle Oligocene to late Eocene greenish-white foraminifera-rich nannofossil ooze. This foraminifera-rich nannofossil ooze is glauconite and radiolarian bearing at places, contains minor amounts of diatoms and sponge spicules, and is sparsely mottled. The sediment gradually becomes more and more lithified until the late Paleocene to middle Eocene part of the sequence (208 m thick) is a foraminifera-bearing nannofossil chalk (upper two-thirds), and micarb nannofossil chalk (lower third). Light gray nodules of chert are regularly distributed throughout, and siliceous microfossils are absent from the chalk. In turn the chalk is underlain by more than 22 meters of middle to late Paleocene lithified and pyritized, glauconite, and clay-bearing micarb nannofossil chalk, without chert. The entire chalk sequence is rich in the secondary minerals cristobalite and tridymite. The silica was probably supplied by dissolution of siliceous microfossils, which persist in the overlying oozes. Basement was not reached at Site 277.

Detritus is an important constituent of calcareous sediments at only a few places. It occurs throughout the lower third of the sequence (early Miocene) at Site 279. It is sparse over most of the interval, but abundant in the 12-30-meter interval above basalt basement. In this interval sand and silt-size calcic plagioclase, potassium feldspar, basaltic rock fragments, augite, and glass shards indicate contemporaneous volcanism. This is the only clear instance of contemporary volcanism encountered in the Leg 29 sequences.

DETRITAL AND GLAUCONITIC SAND

As is to be expected in deep-sea deposits, detrital and glauconitic sands are rare in the area covered. On the western side of Campbell Plateau (Site 277), two thin beds of sandstone form unusual intercalations in the mid to early Oligocene nannofossil ooze. The upper bed is 17 cm thick. It consists of gray, graded, chert and calcite-cemented, glauconite-bearing, quartzose coarse to medium sandstone. It contains fragments of bryozoa, corals, and shallow-water benthonic foraminifera and is probably a turbidite. A second sandstone occurs at the base of the nannofossil ooze and overlies the Paleocene and Eocene nannofossil chalk. It is 7-cm-thick, massive, coarse-grained, and of the same composition as the upper bed. Although it is not graded, it must be regarded as the product of a catastrophic event, such as a turbidity current.

Two striking greensand beds occur in the thick terrigenous silt and clay facies at Site 280. The glauconite of the upper bed appears to be diagenetic, but in the lower bed much of it appears reworked. The upper bed is late Eocene and 34 cm thick. It is a black, silicified, silty clay greensand, which grades up into a glauconitic sandy claystone. The glauconite is bright green and botryoidal, and appears to have diagenetically replaced the clay silt matrix.

The lower greensand, also late Eocene, is dark green-gray and graded. The bed is a glauconite-rich silty sandstone in which the lower 10 cm includes many 3 to 10-mm diameter rounded clasts of apparently glauconitized claystone. Sand and coarse silt-size quartz, mica, plagioclase, rock fragments, and probable volcanic glass comprise 35% of the sediment. Most of the glauconite grains are various shades of brown. The bed is regarded as a turbidite (see Andrews and Ovenshine, this volume).

Coarse detritus occurs at several horizons in the sequence drilled on the South Tasman Rise (Site 281), indicating that strong currents swept the rise again and again and that source rocks were probably exposed nearby. At Site 281, quartz-mica schist basement is overlain by approximately 2 meters of stratified sandy angular very fine pebble gravel. Some strata are graded. Most coarse clasts are angular, although sand-size grains are abraded. Some sand-size quartz grains are notably rounded and polished, and many exhibit glacial-type surface features (Margolis, this volume). Apart from schist and quartz, clasts consist of quartzite, glauconite, glauconitic sandstone, quartzose sandstone, chert, and granite. Many grains, especially the glauconite grains, are oxidized.

The gravel is overlain by 70 cm of late Eocene, light grayish-olive, glauconite-bearing detrital sandstone, and foraminifera-rich nannofossil chalk. The stratigraphic relationship of these sediments is unknown, as they were only found in drilling breccia. This material is succeeded by late Eocene detrital silty clay diatom ooze, which grades upwards into grayish-olive, moderately mottled, glauconite, foraminifera, radiolarian, and spicule-bearing diatom detrital silty sand. Only the upper 8 meters of the 28.5-meter-thick sequence is dominated by coarse detritus. No primary sedimentary structures are evident.

This detrital phase is overlain (probably unconformably) by a few centimeters of early Oligocene dusky green, massive, feldspar-rich, glauconite quartz sand. The detritus is angular and the surfaces of the glauconite grains pitted. The quartz, feldspar, and glauconite grains are the same size. Dolomite rhombohedrons occur throughout. An identical, but yellowish, glauconite quartz sand of late Oligocene age unconformably overlies it. With decreasing amounts of detritus, the latter grades over a 3 to 5-meter interval into a white, glauconite-bearing foram nannofossil ooze. The coarse size and pitted surfaces of the glauconite suggest that it has been transported into the area along with the detritus (Dudley and Margolis, this volume).

Of all the sites drilled, Site 281 is the only site where the repeated influence of strong bottom currents is reflected by the presence of coarse detritus. However, depositional conditions at some other sites have been influenced by strong bottom currents, although in a different manner. Currents have either prevented the deposition of sediment or have removed sediment by erosion over much of the Campbell Plateau. Nearly all of the Cenozoic is unrepresented over the eastern and southern part of the Campbell Plateau (Site 275) and the Neogene is unrepresented over much of the western part of the Plateau (Site 277). In contrast, the Challenger Plateau has not been affected by strong bottom currents, at least since late Miocene time. In the vicinity of Tasmania, even deep oceanic sites have been affected by strong bottom currents. At Sites 280, 282, and 283, the Neogene is represented only by thin sequences, which are divided repeatedly by unconformity surfaces.

CONCLUSIONS

The Leg 29 sediment sequences are dominated by burrow-mottled, by open-ocean biogenic sediments, and by burrow-mottled, very fine-grained detrital sediments. Coarse detritus, primary sedimentary structures, and turbidites are rare. Clear-cut evidence for contemporary volcanism was recorded at only one site.

The succession of facies suggests that sediment accumulation was very closely linked to the gradual development of the ocean basins by sea floor spreading, and to the related development of the oceanic circulation pattern as it now exists. During the early phase of sea floor spreading, the basins were relatively small and circulation was restricted; fine-grained land-derived sediments were deposited. Permanent circulation patterns developed first in the New Zealand region, where by late Campanian time siliceous oozes began to accumulate, indicating the intrusion of cool Antarctic water. By early Cenozoic time calcareous oozes began to steadily accumulate, especially in shallower situations (Campbell Plateau). Cool waters have persisted to the present day only in the extreme south, where siliceous ooze has accumulated at Site 278 (latitude of the present-day Antarctic Convergence).

Sea floor spreading occurred later in the Tasmanian sector, and a restricted circulation persisted until well into the Eocene (280, 283), or even the Oligocene (282). At the three southerly sites (280, 281, 283), the accumulation of siliceous oozes indicates that Antarctic waters penetrated to these latitudes during the late Eocene and Oligocene. These locations at present lie north of the Campbell Plateau site of Campanian siliceous ooze accumulation. This suggests that either Antarctic waters penetrated further north in the Tasmanian sector than in the New Zealand sector during the Paleocene time, or that the Tasmanian sector lay relatively further south during Paleocene time. The latter is probably the correct explanation. By Miocene time, calcareous oozes had begun to accumulate at most sites, indicating that sea floor spreading had continued sufficiently for fully integrated oceanic circulation systems to have evolved in both sectors.

REFERENCES

Berger, W. H. and von Rad, U., 1972. Cretaceous and Cenozoic sediments from the Atlantic Ocean: *In* Hayes, D. E., Pimm, A. C., et al., Initial Reports of the Deep Sea Drilling Project, Volume 14: Washington (U.S. Government Printing Office), p. 787-954.

Greenwood, R., 1973. Cristobalite: Its relationship to chert formation in selected samples from the Deep Sea Drilling Project: J. Sediment. Petrol., v. 43, p. 700-708.

Heath, G. R. and Moberley, R. Jr., 1971. Cherts from the western Pacific, Leg 7, Deep Sea Drilling Project: *In* Winterer, E. L., Riedel, W. R., et al., Initial Reports of the Deep Sea Drilling Project, Volume 7: Washington (U.S. Government Printing Office), p. 991-1007.

Oliver, R. L., Finlay, H. J., and Fleming, C. A., 1950. The geology of Campbell Island, Cape Expedition, Ser. Bull. 3: Wellington (Department Scientific and Industrial Research).