10. SEDIMENTARY STRUCTURES IN PELAGIC AND HEMIPELAGIC SEDIMENTS FROM THE CENTRAL AND SOUTHERN ATLANTIC OCEAN (DEEP SEA DRILLING PROJECT LEG 39)

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ABSTRACT

Sedimentary structures occur frequently in sediments sampled during Leg 39 of the Deep Sea Drilling Project in the central and southern Atlantic Ocean. Laminated or banded organic-carbon-rich sediments found in Albian sediments at Site 356 (São Paulo Plateau) and in Santonian deposits at Sites 356 and 357 (Rio Grande Rise) are indicative of a poorly oxygenated paleoenvironment. In contrast, the intensively burrowed pelagic and hemipelagic sediments of Late Cretaceous and Cenozoic age in the central and southern Atlantic Ocean, indicate well-oxygenated conditions in those paleoenvironments in the slowly widening longitudinal oceanic basin (Sites 354—Ceará Rise, 355—Brazil Basin, 356, 357, 358—Argentine Basin, 359—Walvis Ridge). Slumped sediments and intraformational conglomerates found at Site 356 on São Paulo Plateau seem to be typical of a depositional environment along a continental margin; the displaced volcanic breccia which contains shallow water sediment components witnesses the subsidence of an aseismic ridge and the erosional breakdown that occurred while the volcanic foundation crossed the water/air interface.

INTRODUCTION

Primary (physical or chemical) and secondary (here mainly biogenetic) sedimentary structures offer important information about depositional paleoenvironments. Although Leg 39 (Figures 1 and 2) cores contain a variety of sedimentary structures, they are limited in quality and in detail. The information presented here is based mainly upon macroscopic shipboard section descriptions which have been condensed in the core descriptions in the site reports of the volume. Additional data have been gained from study of cross and thin sections of core samples. The information is plotted against sedimentary facies and stratigraphy in Figure 3.

Although primary and secondary sedimentary structures are usually easy to identify, in fine-grained sediments it is sometimes problematic to identify original or primary colors from those that are diagenetic. A similar problem arises when trying to determine if consolidation of the sediment is the product of original compaction, or the result of diagenetic alteration of materials and/or cementation. Further, it is difficult to distinguish between natural and artificial bedding structures because they often are contorted over large sections of the cores during the drilling operation.

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SITE 353 (WITH HOLES 353A, 353B, VEMA FRACTURE ZONE)

Although sedimentary structures in late Pleistocene sediments from Site 353 holes (5165 m water depth) are minimal because of rather poor core recovery and high coring disturbance, the sediments consist of graded sand layers intercalated into calcareous muds. The sand layers are turbidites with terrigenous components which have been transported into the Vema Fracture Zone, probably from the South American continental margin (Amazon cone, Damuth and Kumar, 1975) across the Demarara Abyssal Plain (Heezen et al., 1964; van Andel et al., 1967). Some of the mud layers are intensively mottled, which is indicative of well-oxygenated bottom water conditions.

SITE 354 (CEARA RISE)

The sediments penetrated at Site 354 (4045 m water depth) on the Ceará Rise in the southwestern North Atlantic Ocean consist of very fine grained, texturally homogeneous, Late Cretaceous to Pleistocene terrigenous and biogenetic deposits containing horizons of sand-sized material (foraminifer sand) most likely displaced from upslope. Coarse-grained terrigenous material apparently never reached this location although coarse terrigenous components traveled via turbidity currents from the South American continental margin across the Ceará Abyssal Plain to the Vema Fracture Zone.

Biogenetic sedimentary structures are restricted to slight to moderate mottling and burrowing in cores

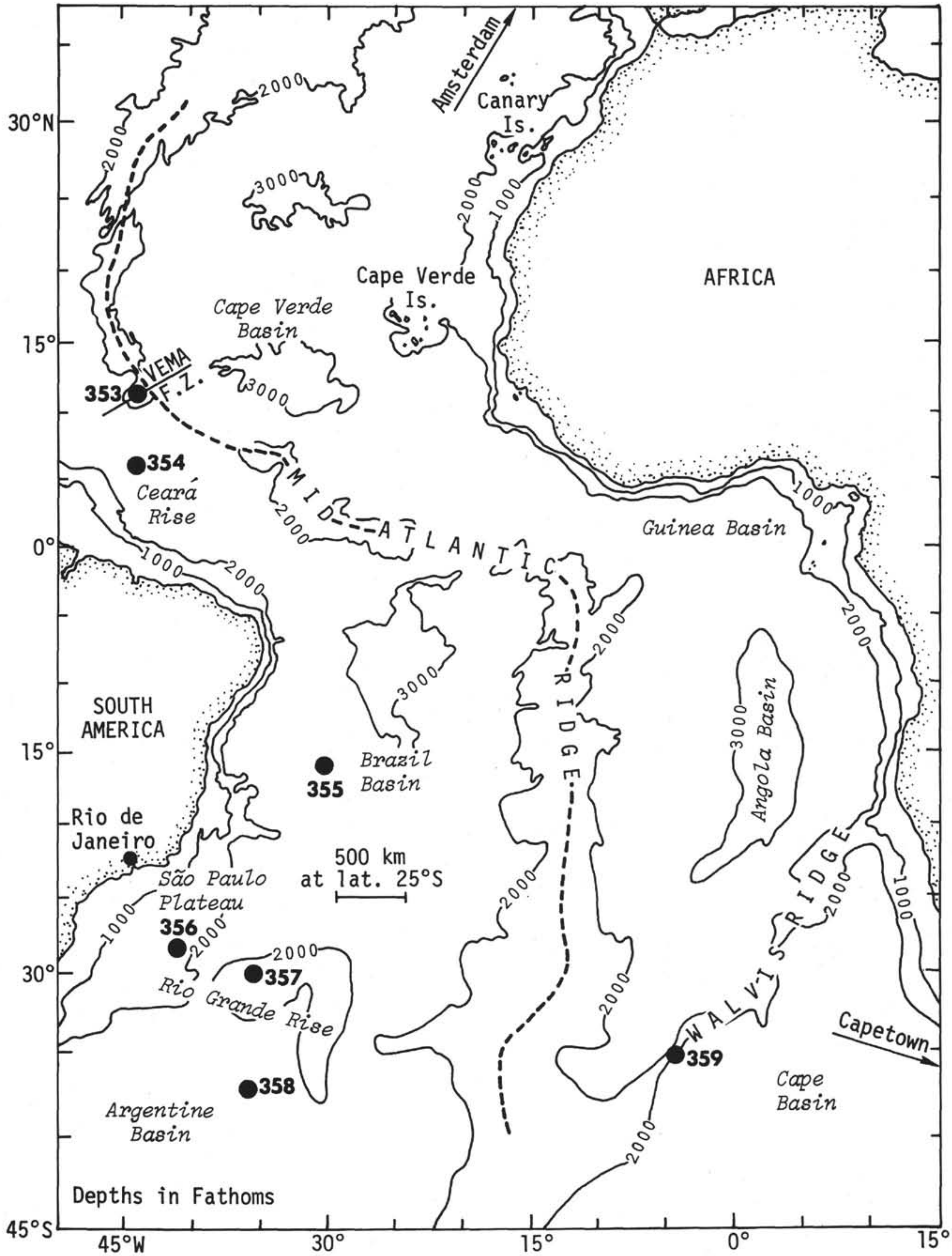

Figure 1. *Deep Sea Drilling Project Leg 39 drill sites in the central and southern Atlantic ocean. Numbers are drill site numbers. Only major topographic features which have been drilled or which are discussed in this study, have been labeled.*

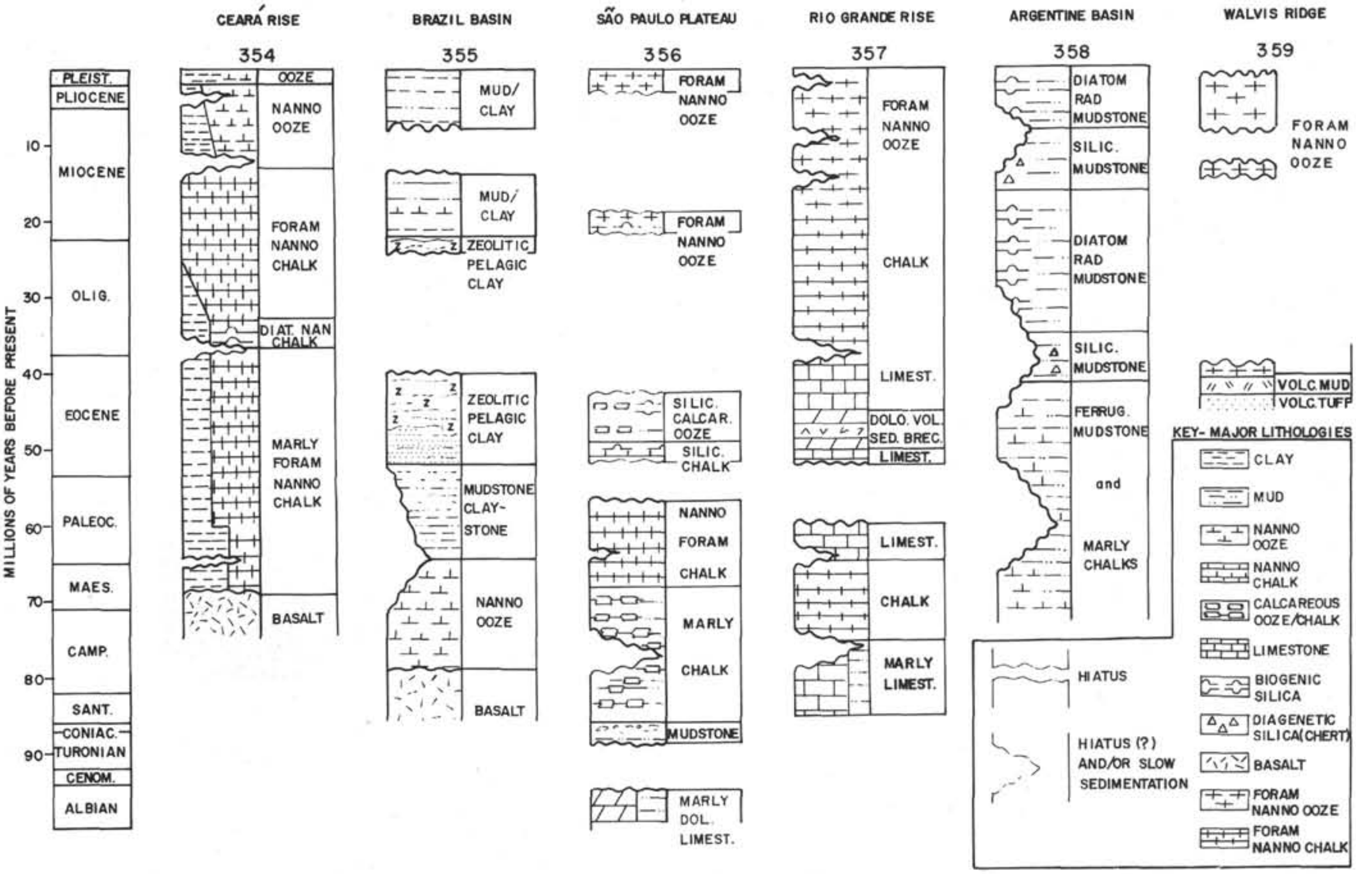

Figure 2. *Distribution of major sedimentary facies and of hiatuses through time in Deep Sea Drilling Project Leg 39 drill sites in the central and southern Atlantic ocean (from Perch-Nielsen, Supko, et al., 1975).*

recovered from this site. The bulk of the primary sedimentary structures consist of occasional color changes, and a faint layering (where probably silty material has been intercalated into the fine-grained sediment); contorted bedding appears in a few instances.

In the Oligocene zeolitic marly nanno chalks an intraformation clay pebble conglomerate occurs. The clasts are similar in composition to the surrounding sediment; they average 0.5-1 cm in diameter and are angular to subrounded in shape. Most likely the source of these clasts lay nearby. The sediment directly below the intraformational conglomerate bears evidence of several thin zones of contorted bedding.

SITE 355 (BRAZIL BASIN)

Late Cretaceous to Pleistocene sediments penetrated at Site 355 (4901 m water depth) in the Brazil Basin consist of fine-grained terrigenous and pelagic clays/muds which are underlain by Late Cretaceous nannofossil ooze and chalk on top of oceanic basaltic basement. The visible biogenic sedimentary structures are small and few in numbers, most of them being observed in the Late Cretaceous and early Tertiary part of the cored section. The overlying light brown zeolitic muds and pelagic clays, which are indicative of a well-oxygenated paleoenvironment, have low sedimentation rates and may well be totally homogenized by bioturbation.

Primary sedimentary structures are restricted almost entirely to color changes and a faint layering. Clear and distinct layering has been observed only where the calcareous Late Cretaceous facies grades into the Tertiary noncalcareous facies (below the CCD) and where a few sandy horizons occur in the Eocene pelagic clays and Miocene nanno clays. The Eocene sand horizon consists dominantly of quartz, indicating a continental source, whereas the Miocene horizon is composed dominantly of foraminifers (with only minor quartz) and is overlain by white nannofossil ooze. A source of these displaced sediments must be sought in a region considerably shallower in water depth if, as is believed, the CCD in the Atlantic Ocean during Miocene time was well above 4 km (van Andel, 1975).

SITE 356 (INCLUDING HOLE 356A, SOUTHEASTERN SÃO PAULO PLATEAU)

Sedimentary structures recovered from the Early Cretaceous to Pliocene sediments at Site 356 (3175 m water depth) on the southeastern São Paulo Plateau comprise a wealth of biogenic and primary types which have not been found to be that well developed in any other site drilled during Leg 39. Since late Albian time this location has received its input of biogenic components from normal pelagic sedimentation diluted to varying degrees by fine-grained terrigenous admixtures transported in suspension, by displaced larger components of volcanic (Fodor et al., this volume) or

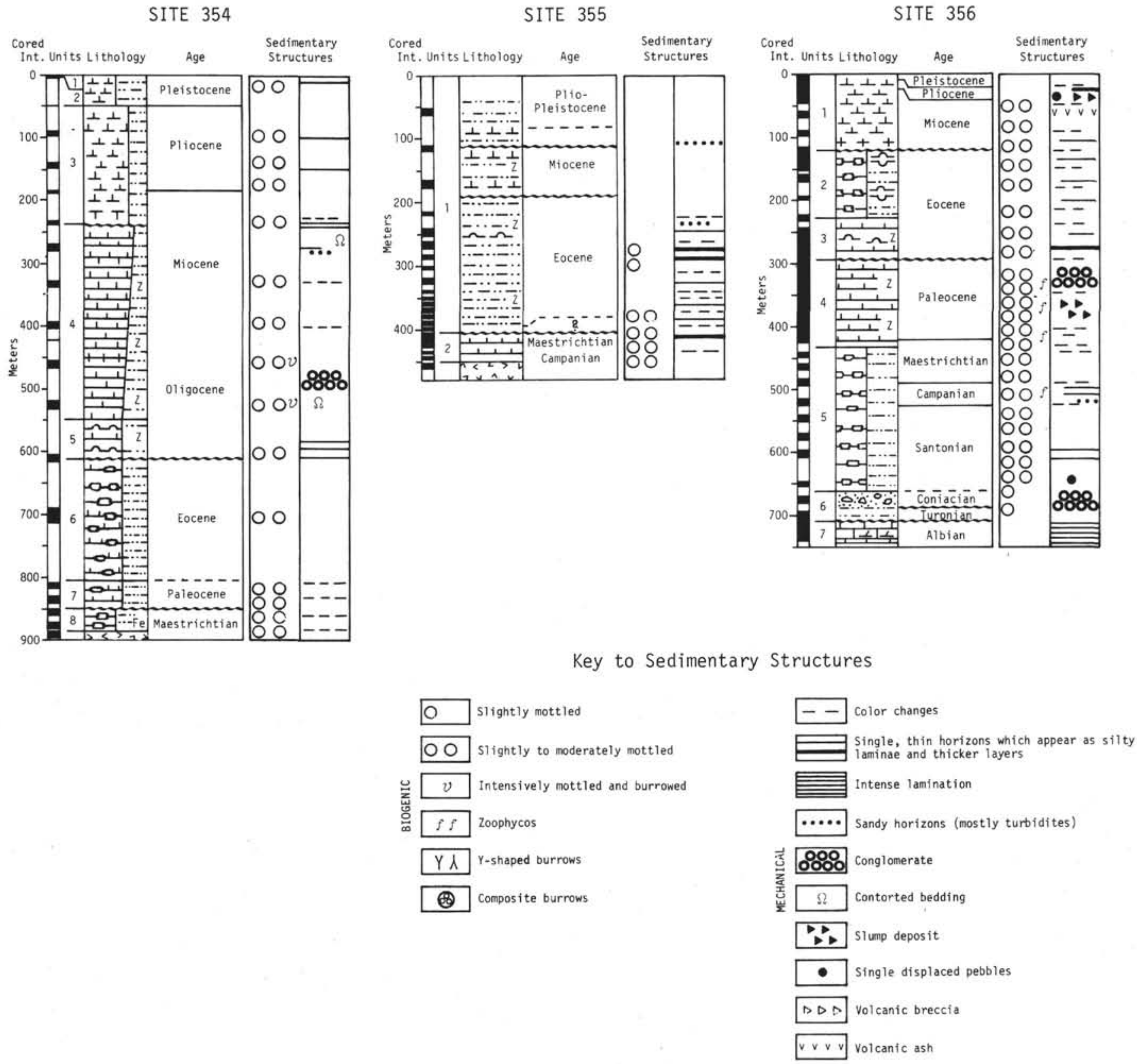

Figure 3. *Distribution and main biogenic and primary sedimentary structures in DSDP Leg 39 cores.*

sedimentary origin which have come from upslope São Paulo Ridge and which are now found in these sediments either as single pebbles, as conglomerate horizons, or as thick slump deposits.

The biogenic sedimentary structures are dominantly small (approximately 1-2 mm in diameter) to intermediate (5-10 mm in diameter) pipe-shaped burrows, round or elliptical in cross section (they consist of two parallel lines if cut along their axis), and coated many times with layers of very fine grained pyrite. *Zoophycos* are especially well developed and common in the Late Cretaceous and early Tertiary sediments. At several levels, Y-shaped burrows have been observed. In contrast, the laminated Albian sediments lack any sign of bioturbation, even though they contain epibenthic bivalves which appear to be autochthonous to the site location (Thiede and Dinkelman, this volume).

The primary sedimentary structures comprise faint color changes and slight textural or compositional changes in almost all cores. A volcanic ash of early Miocene age occurs in Core 4. Displaced sediments and volcanic components are interspersed into the otherwise homogeneous pelagic/hemipelagic sediments at irregular intervals and in varying amounts: a slumped layer of Eocene nannofossil ooze is present in the Pliocene of Core 2, a single limestone fragment of undetermined age in Core 3, a breccia of angular to subrounded pebble-size limestone/chalk fragments (late Campanian/Maestrichtian in age) in Core 19 (late Paleocene in age), a slump of Late Cretaceous marly

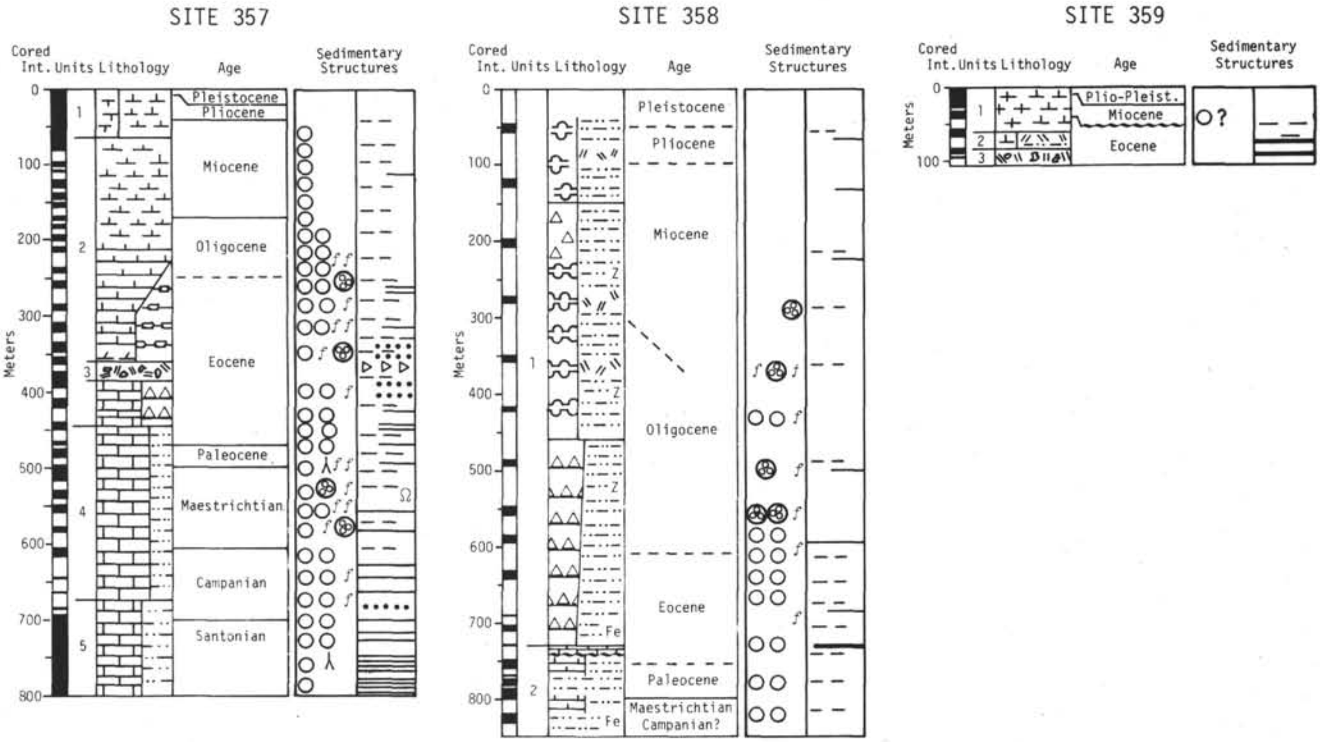

Figure 3. *(Continued).*

siliceous chalk is intercalated into the Paleocene sediments of Cores 24 and 25, a basalt pebble in Core 38 (Santonian), clay pebble horizons (Figure 4) occur in Core 39 (late Coniacian), and a conglomeratic layer in Core 40 (Coniacian, see Figure 5). Bed load structures have been observed under several graded beds in Cores 43 and 44 (late Albian) in a part of the sediment column which is otherwise characterized by intensively laminated sediments and which is lacking any biogenic sedimentary structures (Figure 6). These laminations seem to be evidence for an anaerobic Early and Late Cretaceous depositional paleoenvironment. Large *Inoceramus* fragments which are conspicuous megafossils in the fine-grained sections of the Coniacian through late Campanian deposits, might be either displaced or autochthonous sediment components; they are found together with a modest content of glauconite grains. Because the thin laminae around the large pieces of the prism layer of the *Inoceramus* remains are not disturbed it is concluded that the origin of these components is autochthonous. *Inoceramus* is also known to have lived as epibenthos at the sediment-water interface and to have preferred upper bathyal to outer sublittoral paleoenvironments (for further details see Thiede and Dinkelman, this volume).

The wealth of sedimentary structures found in the cores from this drill site seems to be especially characteristic for the depositional environment along continental margins where the sediment column is interrupted by numerous, lengthy hiatuses (Figure 2) whereas the bulk sedimentation rates of other portions of the same sediment column are expanded due to displaced material. Displacement of sediment components from upslope happens either as fine-grained suspensions, as turbidites, as intraformational conglomerates (clay pebble conglomerates) or as thick slump deposits, all of which can be observed in the cores of this site. The source region for the displaced material was either the São Paulo Ridge (volcanic components) or the continental margin itself.

SITE 357 (NORTHWESTERN FLANK OF RIO GRANDE RISE)

Sedimentary structures found in Site 357 cores (2086 m water depth, Santonian-Quaternary) are almost as variegated as those of Site 356; whereas only few observations could be made in the soft to soupy cores of Lithologic Unit 1 and in the upper part of Lithologic Unit 2, the semiconsolidated to lithified sediments of all deeper cores are replete with biogenic and primary sedimentary structures recording changes of the depositional paleoenvironment with time along the flank of Rio Grande Rise.

Biogenic structures comprise moderate burrowing and mottling in the upper part of Lithologic Unit 2; in its lower part, however, and in Lithologic Units 4 and the upper part of 5, numerous *Zoophycos* occur in addition to small (1-2 mm in diameter) and intermediate (5-20 mm in diameter) simple pipe-shaped burrows. The outer rims of most burrows are slightly darker than the surrounding sediment, both outside or inside the burrows, probably due to the precipitation of fine-grained pyrite. This phenomenon enhances the megascopical observation of composite burrows which consist of large, mostly round, but also irregularly shaped "envelopes" around a pocket of sediment which has been penetrated by numerous small (0.5-1 mm in diameter), often chondroid traces. In the lower part of

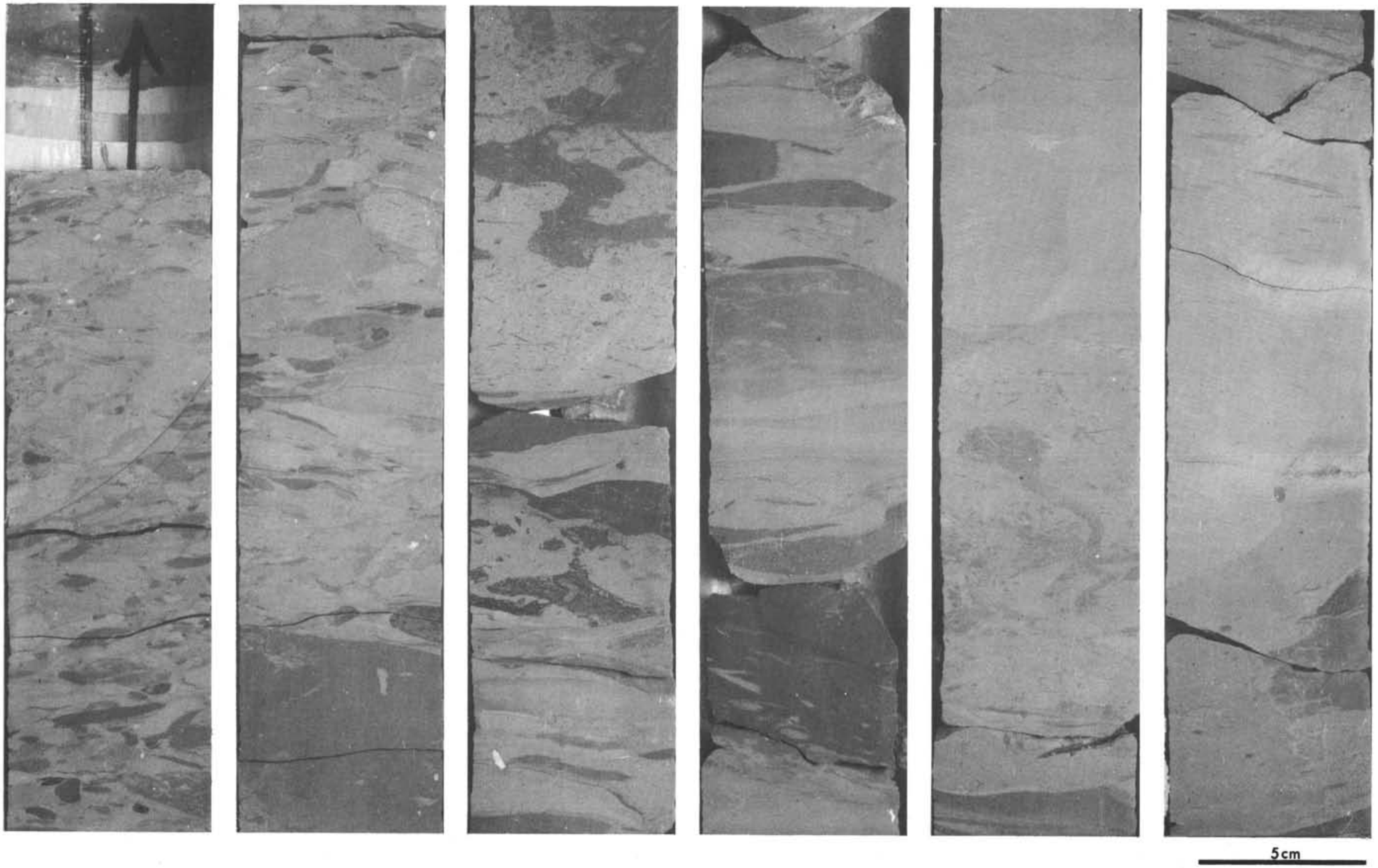

Figure 4. *Clay pebble conglomerate in late Coniacian sediments of Site 356, Core 39, Sections 2 and 4 (from the southeastern edge of São Paulo plateau). For further details see Supko, Perch-Nielsen, et al. (this volume).*

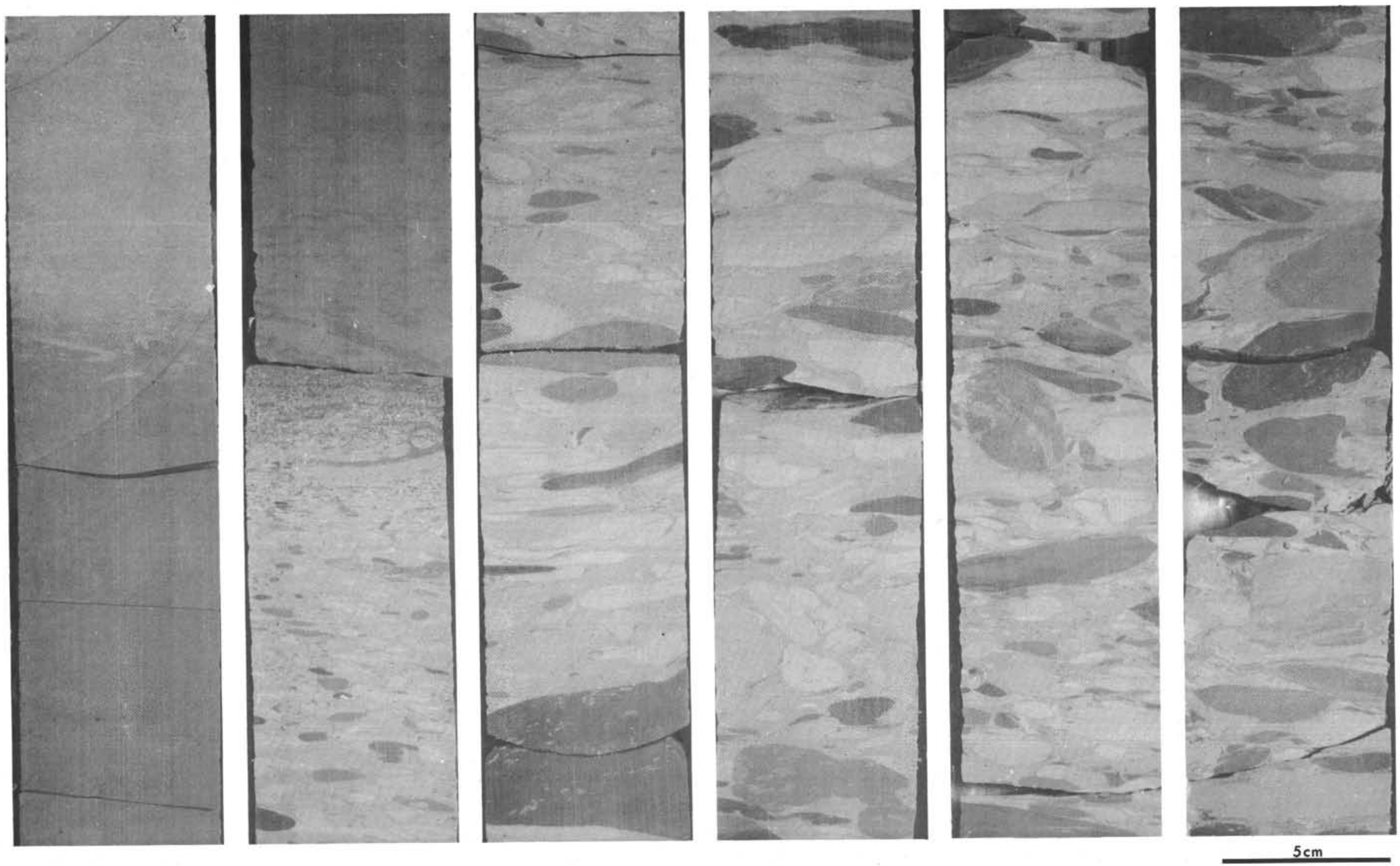

Figure 4. *(Continued).*

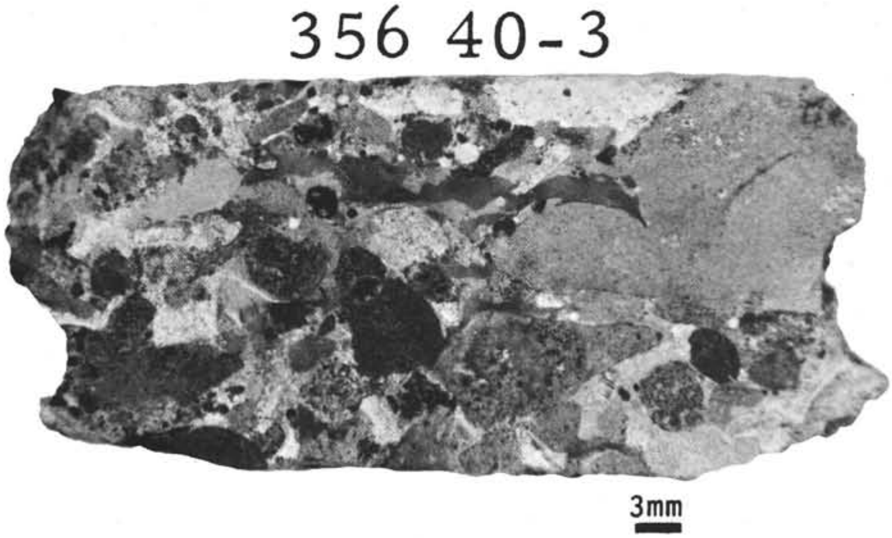

Figure 5. *Cross-section of conglomerate intercalated into Site 356 (São Paulo plateau) Coniacian sediments (Core 40, numbers on photograph are site, core and section identification; scale: numbers are originally 3 mm high). The conglomerate is composed of volcanic and sedimentary clasts (for further details see Fodor et al, this volume).*

Lithologic Unit 5, where laminated portions of the sediment column become the dominant element, biogenic sedimentary structures become less numerous or are restricted to thin horizons which are intercalated into the otherwise intensively laminated sediments.

Two primary sedimentary structures at this site deserve special attention in addition to the faint color changes and slight compositional variations that can be seen throughout most of the cores. They present evidence for a high influx of displaced sediments into the deposits of Lithologic Unit 2 which is Eocene in age. The evidence consists of thin, glauconitic sand horizons in Cores 22, 23, 24, 27, and 28 and a several-meter-thick volcanic breccia which has been penetrated in Cores 24 and 25 (Supko, Perch-Nielsen, et al., this volume; also see Figures 7 and 8).

The breccia was encountered about 375 meters below the sea floor; it is intercalated into middle Eocene pelagic sediments. The upper contact has not been retrieved, but the lower contact consists of a thin zone of chalk grading into a siliceous limestone (Figure 7). The breccia is well indurated and consists of shell and limestone clasts (Figure 8) and dark volcanic components, as well as individual black pyroxene grains; it has a clayey matrix. In general, it resembles hyaloclastites discussed by Bonatti (1967). All components of the breccia (except the matrix) are size-sorted resulting in graded bedding (Supko, Perch-Nielsen, et al., this volume). Throughout the 4 meters of breccia recovered in Cores 24 and 25, the fragment sizes range from an average of 0.5 to 1 mm in the upper portion, grading downwards to 1 to 3 cm diameter in the lower portion, suggesting that the breccia was deposited during one event. Because the volcanic material is altered too severely to allow absolute age dating, it remains uncertain whether the breccia represents an erosional (Thiede, in press) or a volcanic event. A detailed description and discussion of this breccia can be found in Supko, Perch-Nielsen, et al., this volume and in Fodor and Thiede, this volume.

Other important primary sedimentary structures are to be seen in the deepest cores (numbers 50 and 51) of Site 357 where the major part of the sediment column is intensively laminated, suggesting a quiet and possibly reducing depositional environment. Thin burrowed horizons are intercalated into these sediments. They increase in thickness and frequency in the overlying cores, until the dominant portion of the sediment column is mottled and burrowed throughout, indicating a considerable improvement of the Late Cretaceous benthic habitats. The lowermost cores of Site 357 frequently contain remains of *Inoceramus*, a late Mesozoic bivalve which was adapted to live as epibenthos on soft, and probably not well oxygenated, upper bathyal and other sublittoral mud bottoms (Thiede and Dinkelman, this volume) down to several hundred meters water depths. Although these fossils are somewhat problematic because they may be displaced, the accompanying benthic foraminifer faunas seem to support this interpretation (Sliter, this volume).

SITE 358 (ARGENTINE BASIN)

The fine-grained sediments recovered from Site 358 (4962 m water depth) in the Argentine Basin, south of Rio Grande Rise, contain only three different types of burrows: *Zoophycos*, composite burrows similar to those observed at Site 357, and small to intermediate unspecified pipe-formed traces. All of them seem to be absent in the uppermost three cores. They are most diverse in the part of the sediment column sampled in Cores 2 to 4; trace fossil assemblages are poor below this interval.

The primary sedimentary structures consist only of color changes and of a faint banding of the sediment which can be observed here and there. Major lithologic breaks have been found only at the transition from the calcareous to the noncalcareous facies in Core 11 (middle Eocene).

SITE 359 (SOUTHWESTERN WALVIS RIDGE)

The sandy, coarse-grained, soft, late Eocene to Plio-Pleistocene deposits sampled at Site 359 (1665 m water depth) have been disturbed so intensively during the coring process that almost no sedimentary structures are preserved. Only the late Eocene volcanic sediments and volcanic tuff in Cores 3 through 5, in which the original layering is preserved, have been recovered largely intact (Fodor et al., this volume).

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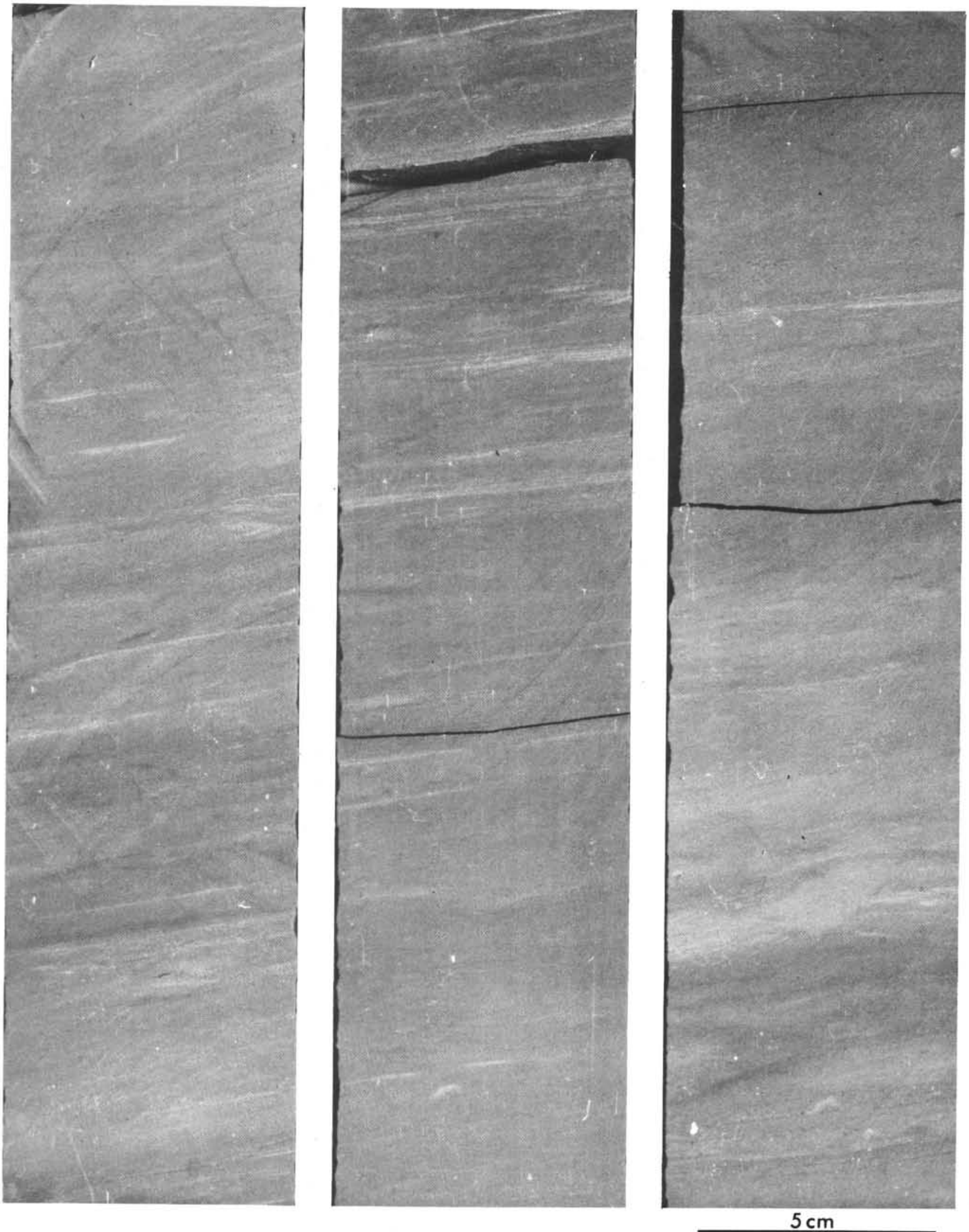
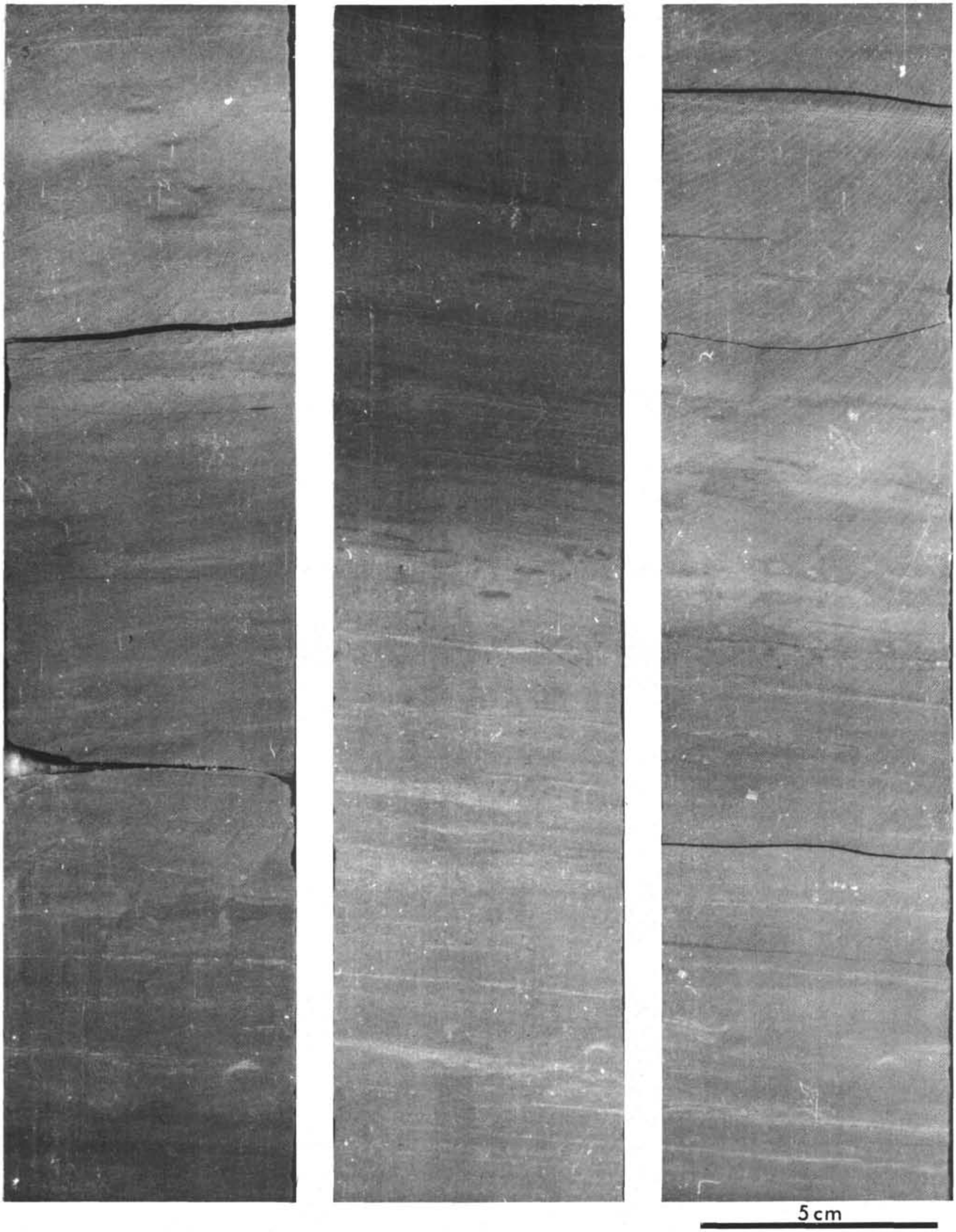


Figure 6. *Intensively laminated sediments from Site 356 (southeastern edge of São Paulo plateau), Core 42 of late Albian age.*



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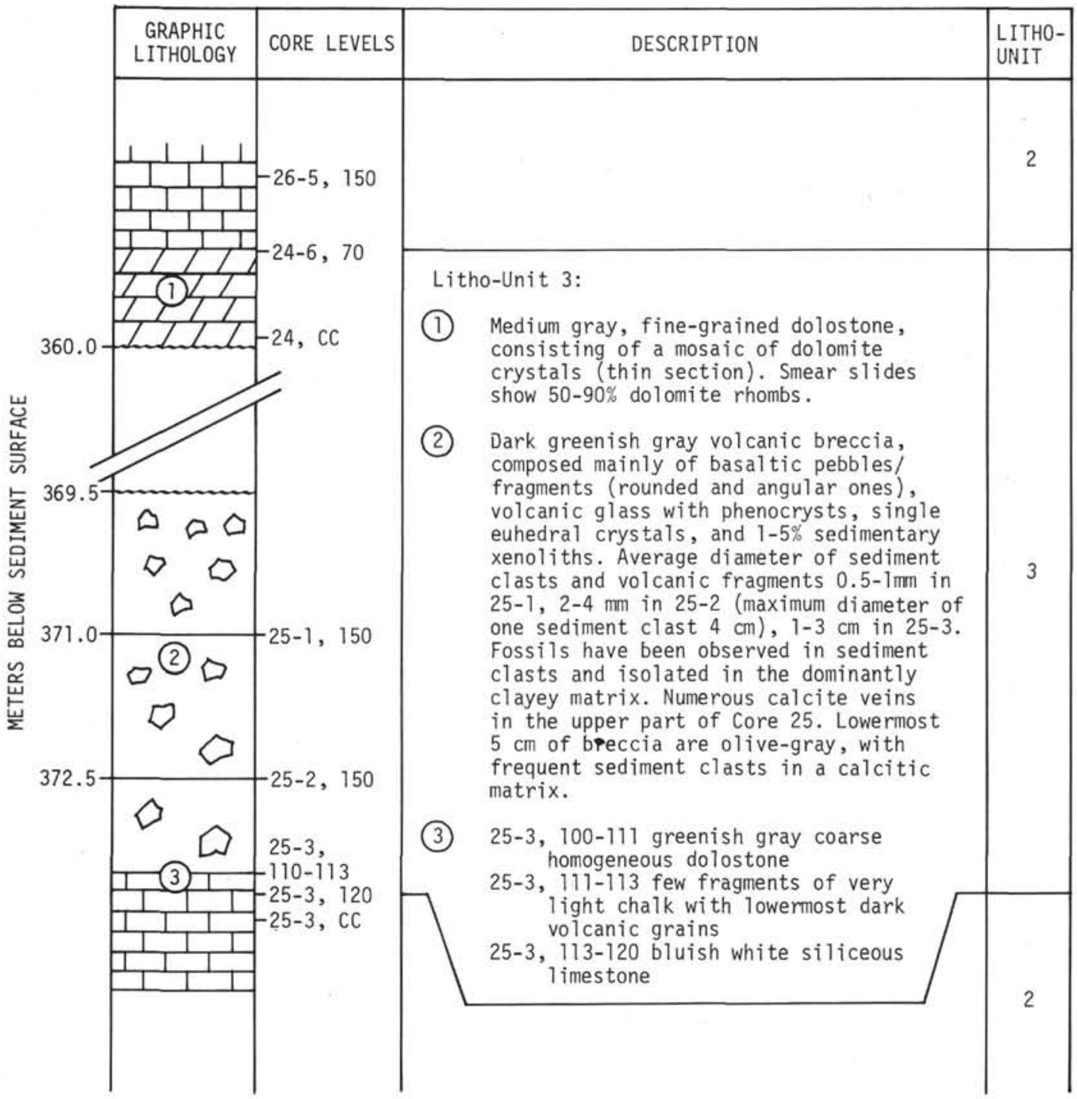

Figure 7. *Details of Lithologic Unit 3, Site 357 (northwestern Rio Grande Rise): Volcanic breccia intercalated into middle Eocene pelagic sediments of Lithologic Unit 2 (for details see Supko, Perch-Nielsen, et al., this volume).*

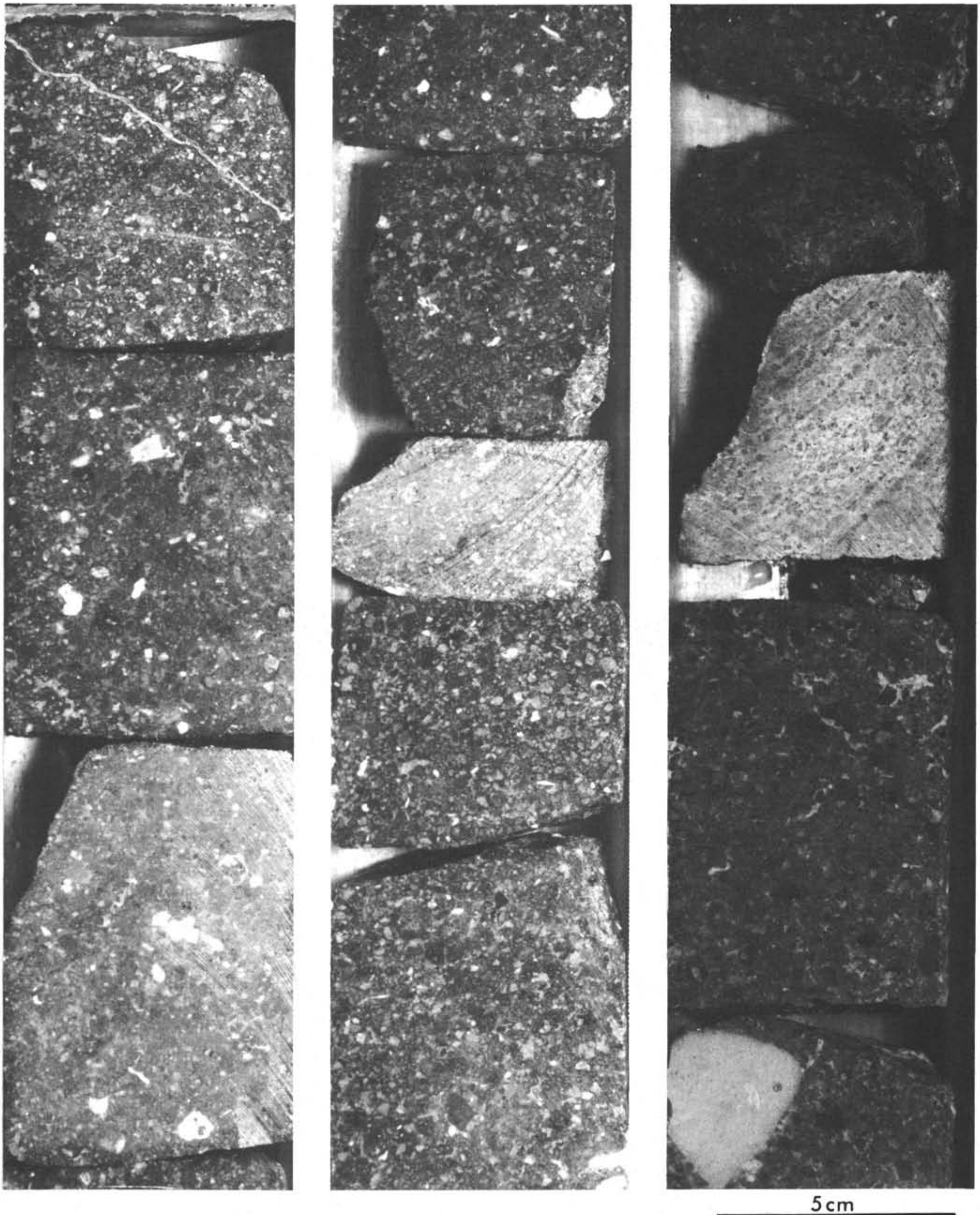

Figure 8. *Detail of the volcanic breccia intercalated into middle Eocene calcareous pelagic sediments of Site 357 (Core 25, Section 3) on the northwestern Rio Grande Rise (for further details see Supko, Perch-Nielsen, et al., this volume, Fodor and Thiede, this volume).*

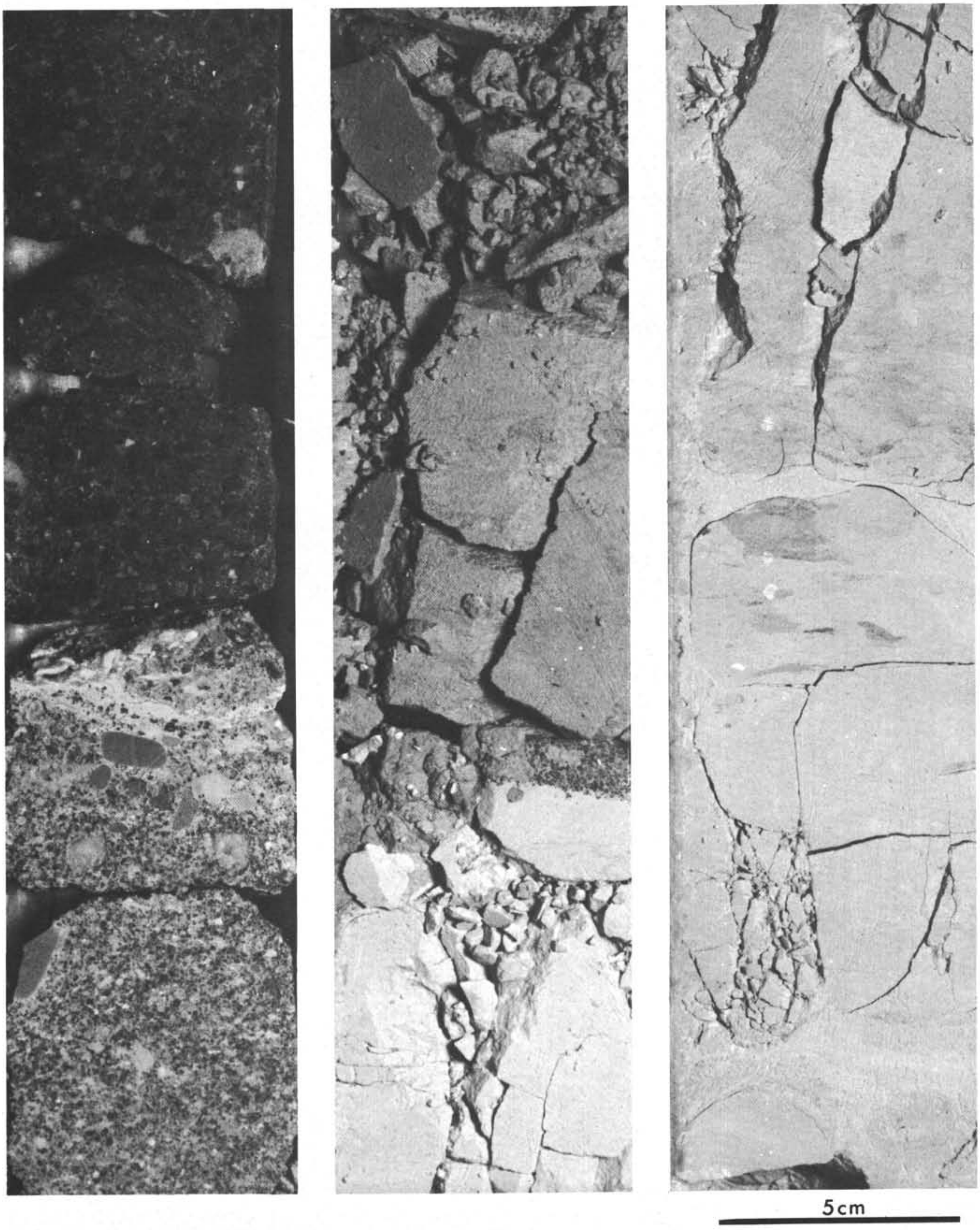

Figure 8. *(Continued).*