19. ANATOMY OF DEBRIS-FLOW DEPOSITS[1]

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ABSTRACT

Twenty-three "debrites" were recovered in the top 270 m of Miocene to Recent sediments at Site 530 in the southeast Angola Basin. They are closely associated with slumps and muddy biogenic turbidites in a proximal submarine fan sequence. They range from 0.15 m to 32.3 m in thickness, are composed of a variety of mud, marl, and ooze clasts up to 60 cm in diameter in a "smarl"[2] matrix, and have a random to graded fabric. The debris flows originated on the Walvis Ridge to the south and probably displaced very large volumes of unstable pelagic sediments.

INTRODUCTION

Debris flows are highly concentrated, highly viscous, sediment–fluid dispersions that move downslope under the influence of gravity. Most debris flows are composed of clasts carried in a watery mud matrix and supported by a combination of clast buoyancy and matrix yield strength (Johnson, 1970; Hampton, 1972). Submarine debris-flow deposits have been described from many ancient flysch successions, including those of the northern Apennines where they are commonly called olisthostromes (Abbate et al., 1970) and, more rarely, from the modern deep sea (Embley, 1976; Moore et al., 1976; Flood et al., 1979). Two very good examples have been reported previously at Deep Sea Drilling Project (DSDP) sites off northwest Africa (Arthur and von Rad, 1979) and in the Blake-Bahama Basin (Benson, Sheridan, et al., 1978).

Submarine debris flows are commonly considered as part of a continuum between slumping and turbidity currents (Rupke, 1978) and may be a very important process of resedimentation in the deep sea (Hampton, 1972). Their sedimentary characteristics have been summarized by Middleton and Hampton (1973, 1976), but they are not always readily recognized in narrow-diameter sediment cores. The purpose of this chapter is to document in some detail the very clear and colorful examples of Miocene to Recent debris-flow deposits recovered by both hydraulic piston coring and conventional rotary coring at Site 530 in the southeast Angola Basin (see Site summary chapter, this volume).

We also propose that the term "debrite" replace the more cumbersome "debris-flow deposit."

STRATIGRAPHIC SEQUENCE

The upper 270 m of sediments at Site 530 were deposited over the past 10 m.y. as part of a small submarine fan, informally named the "brown fan" (Stow, this volume). The sediments comprise calcareous and siliceous biogenic muds, marls, sarls, and oozes (see sediment classification in Introduction and Explanatory Notes, this volume) and were deposited as turbidites, debrites, pelagites, and probable slumps. The mass flow deposits were derived from similar pelagic facies, rich in organic matter and biogenic remains, that accumulated on the Walvis Ridge to the south under the influence of a nutrient-rich upwelling zone (see Site 532 summary chapter, this volume). Over 20 individual debrites of varying thickness were cored at Site 530 in the brown fan sequence (Fig. 1).

SEISMIC CHARACTER

Seismic reflection profiles over Site 530 (Fig. 2) reveal chaotic and discontinuous weak reflectors and irregular transparent zones interspersed with stronger, more continuous reflectors throughout acoustic Unit 1 (0–270 m, 0–0.35 s sub-bottom). Immediately adjacent to the site to the east and south there is a transparent lenticular zone between about 100 and 200 m depth. These weak reflections and transparent zones probably represent debrites and chaotic slumps interbedded with turbidite and pelagic sediments. I estimate, from very limited seismic coverage, that the debrites have travelled a minimum of 30 km from the foot of the Walvis Ridge and probably an additional 10 km from the crest of the Ridge.

SEDIMENTARY ANATOMY

Of the 23 debrites recovered, seven are 2 m or more in thickness and the rest vary from 0.15 to 0.60 m. The maximum possible thickness of one debrite is 32.3 m, but as this spans eight separate cores with only 75% recovery it is possible that two or more debrites are represented in this interval. In a number of cases coring disturbance of variable intensity has obscured the original sedimentary features of the debrites; however, several undisturbed or minimally disturbed sections allow us to describe their textural, structural, compositional, and geotechnical characteristics. Core photographs illustrating these features are shown in Figure 3.

[1] Hay, W. W., Sibuet, J.-C., et al., *Init. Repts. DSDP*, 75: Washington (U.S. Govt. Printing Office).
[2] See sediment classification in Introduction and Explanatory Notes, this volume.

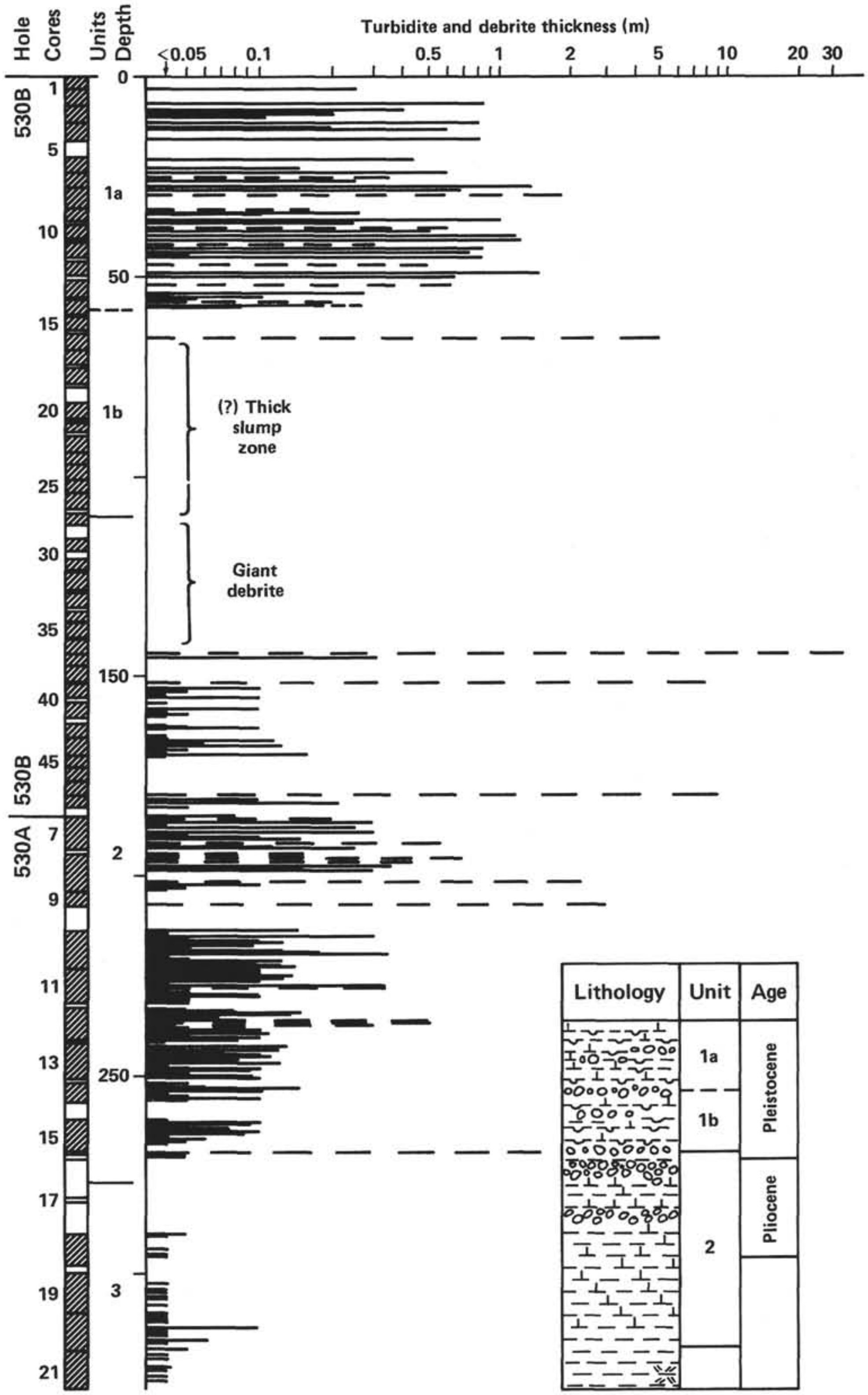

Figure 1. Stratigraphic and lithologic sequence through the brown fan (Units 1 and 2) at Site 530 (Holes A and B) in the SE Angola Basin. Thickness of debrites is shown by dashed lines and that of associated turbidites is shown by solid lines. Logarithmic scale. Depth in meters.

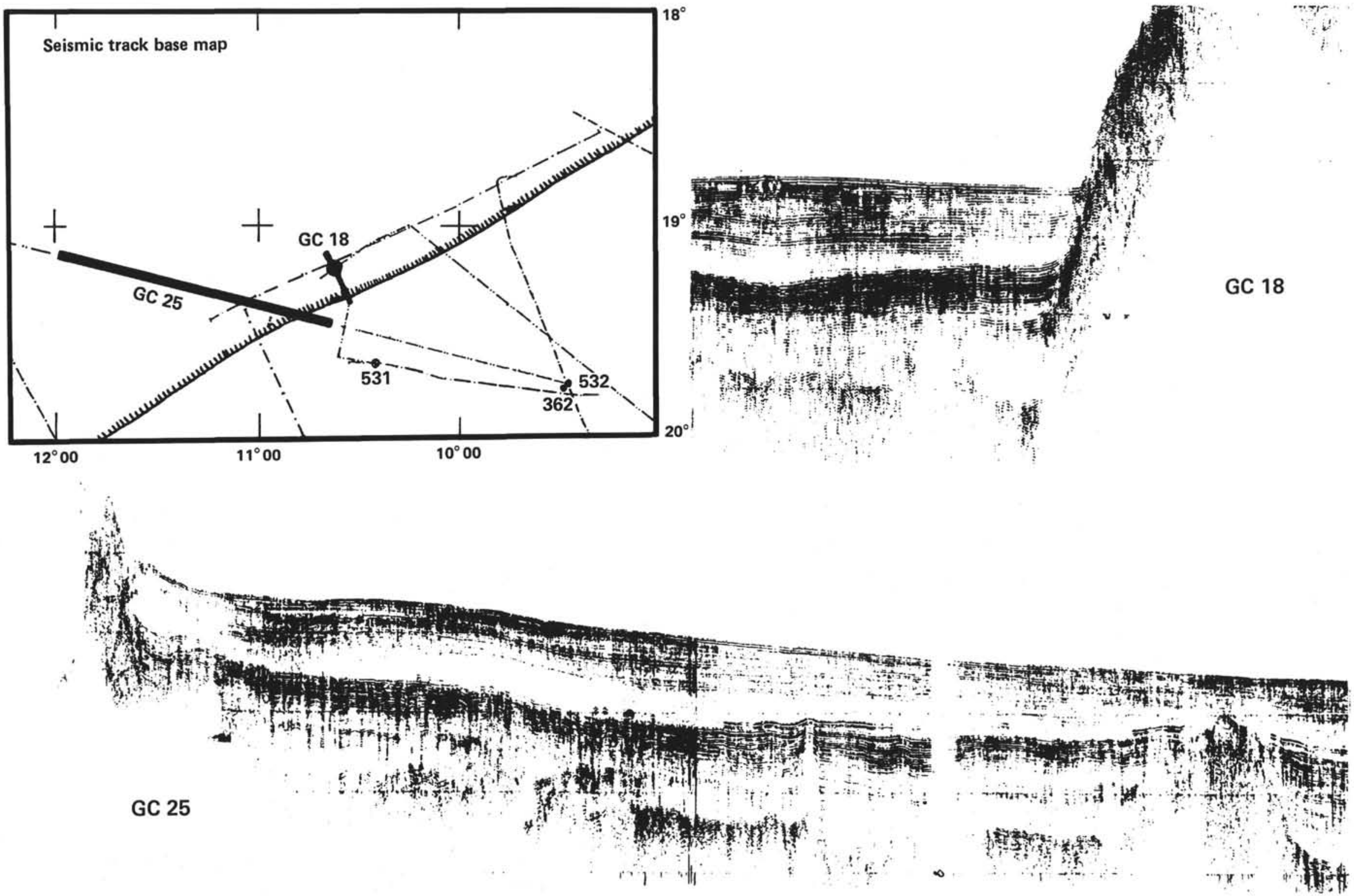

Figure 2. Seismic reflection profiles through Site 530 showing seismic facies characteristics of debrite-slump association. Hachured line on base map marks scarp edge of Walvis Ridge.

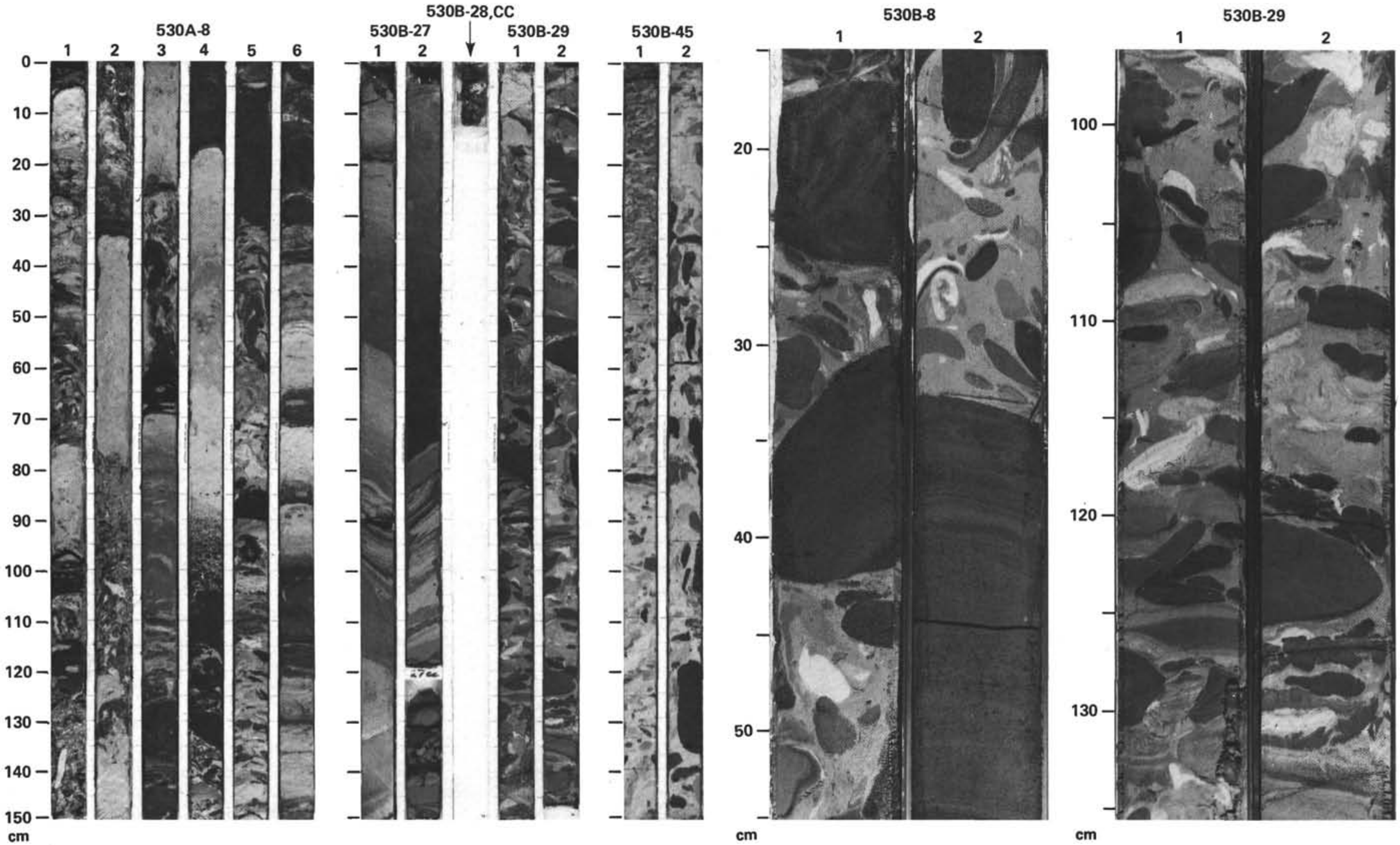

Figure 3. Core photographs showing range of sedimentary features in debrites. Note grading, clast size and shape, clast alignment, and possible imbrication, as well as relative proportions of matrix and clasts.

Textures

All the debrites at Site 530 are very poorly sorted mixtures of mud-size matrix and highly variable-sized clasts. Mostly they are clast-rich to clast-supported, although in some cases the matrix is dominant especially towards the middle and base of thick beds. Limited grain-size analyses of the matrix show sand:silt:clay in the proportions 1:30:69, and no obvious vertical graduation through individual beds. The clast size varies from 1 cm to an estimated maximum of about 60 cm; a common mean being between 3 and 10 cm. Maximum clast size (long axis) appears to show a regular increase with bed thickness (Fig. 4), although the larger clasts are subject to greater errors of estimation in small diameter cores.

Clasts are also very variable in shape within individual debrites, from sub-spherical to very elongate. The average long- to short-axis ratio (A/C) is ~2. The clasts vary from well preserved and well rounded through various degrees of margin disintegration and increasing angularity or raggedness to clasts that have been almost completely streaked out into the matrix. This variability is presumably related to the degree of lithification of clasts as well as to their size and distance of transport. Some clasts of laminated lithologies show evidence of having been rolled into mud balls, whereas in others the lamination is truncated abruptly at the clast margin. More rarely, semilithified clasts appear to have broken by (semi-)brittle fracture into two or more pieces.

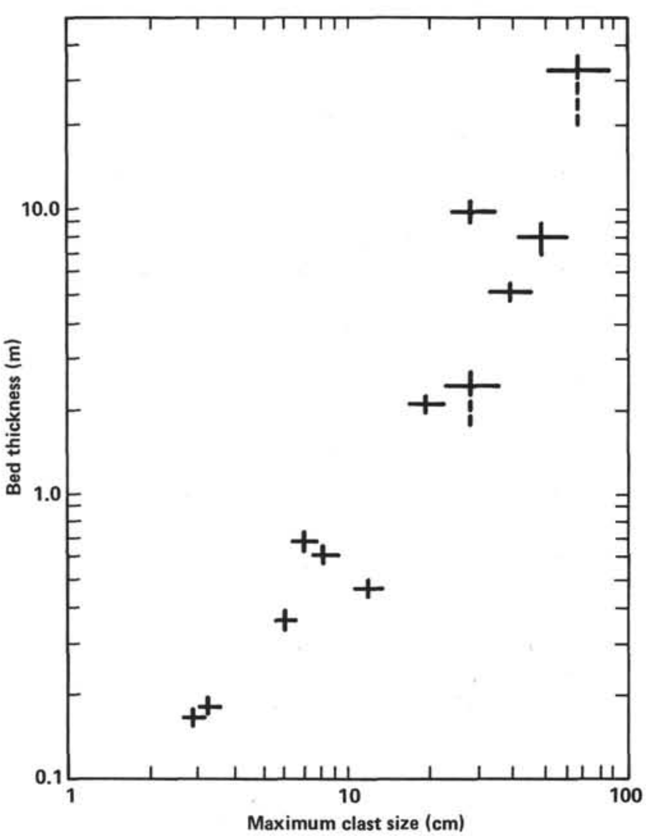

Figure 4. Relationship between bed thickness and maximum clast size (estimated diameter of long axis). Logarithmic scale.

Structures

The most notable structural attribute of most debrites is a more or less random distribution of poorly sorted clasts throughout the bed, regardless of bed thickness. However, in a number of cases there is marked normal grading through the upper 1 to 3 m, and through a thin layer of foraminifer ooze overlying the debrite proper. Reverse grading over 5 to 50 cm at the base is less distinct but commonly apparent. Plots of maximum clast sizes over 20 cm intervals for selected beds (Fig. 5) show this vertical grading and also the distribution of the largest "floating" clasts. These can be very near the top or in the middle and, less commonly, towards the base.

Lamination is not detectable in the narrow-diameter cores, except within the overlying foram sands, although subhorizontal clast alignment is common and, where clasts are small, may suggest a crude parallel stratification. Clast imbrication is rare. The vertical orientation of some clasts and some rotational features as well probably result from coring disturbance. Some scouring and erosion at the base of several of the debrites is evident.

Composition

Eight to ten different clast types can be identified, although not all are present in each debrite. There are calcareous and siliceous oozes, marls, sarls, smarls, and muds, and, more rarely, sandy muds, shell fragments, and highly altered basaltic debris. These clast lithologies are the same as those associated with the debrites in the brown fan sequence and also equivalent to those recovered on the Walvis Ridge to the south (Site 532 summary, this volume; Site 360 summary, Bolli, Ryan et al., 1978).

The matrix is of more uniform biogenic-rich ooze and smarl composition with carbonate content mostly in excess of 50%. Nannofossils and diatoms are the dominant biogenic form with minor foraminifers, sponge spicules, radiolarians, etc. Clay minerals include illite, chlorite, kaolinite, and smectite, with minor to trace amounts of clay and sand-sized quartz, feldspar, pyrite, and glauconite. Systematic compositional variation through single beds was not observed, but there is marked increase in the ratio of siliceous to calcareous biogenics in the matrix of debrites from the upper half of the sequence (above about 150 m depth). This change matches approximately that seen at Site 532 on the Walvis Ridge. The organic carbon content of the debrites, particularly of the more siliceous matrix and clasts, is commonly 3% and markedly higher than normal for oceanic sediments. This, too, reflects the organic-rich sediments on the Ridge.

Age

Preliminary examination of a variety of clasts and matrix shows a mixed late Miocene/Pliocene microfos-

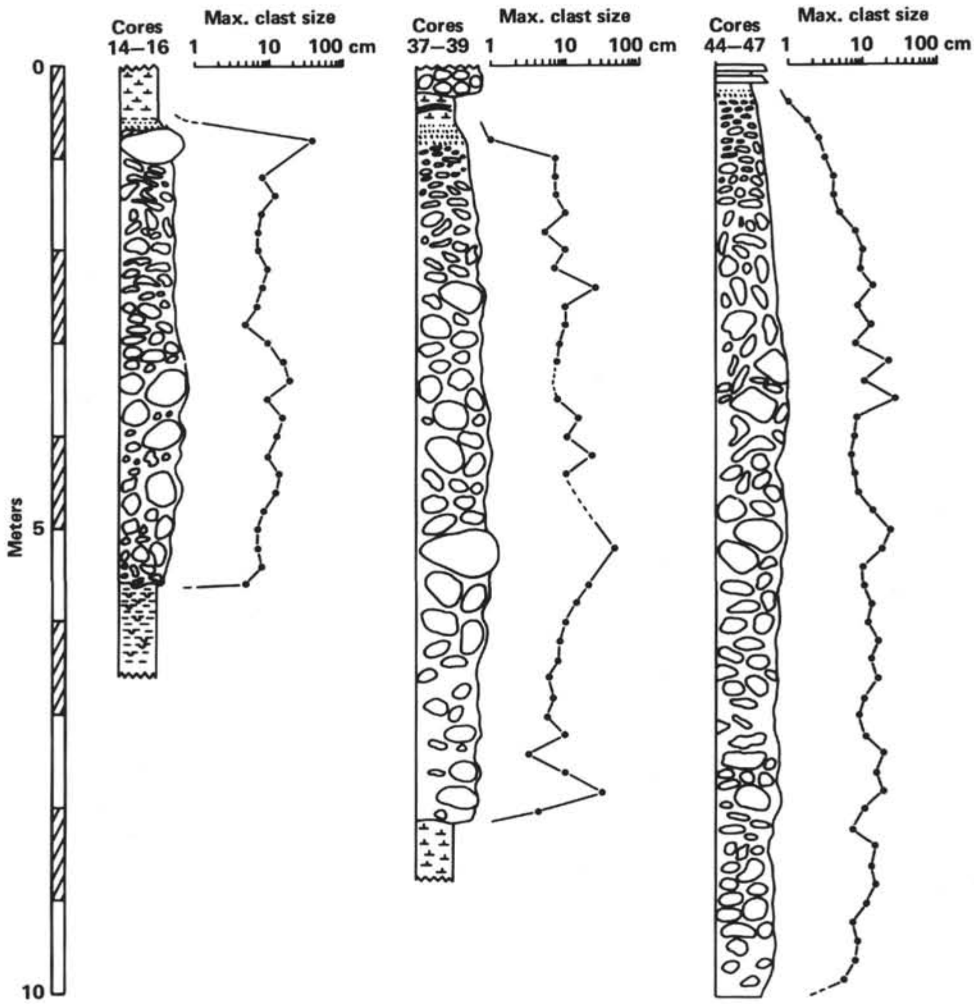

Figure 5. Sedimentary characteristics of selected debrites, Hole 530B.

sil assemblage in the debrites of lithologic Unit 2 (deeper than 100 m), and a Pleistocene to Holocene assemblage for lithologic Unit 1 above. No microfossils were recovered that indicated a significantly older age for any of the clasts than that of the associated lithologies.

Geotechnical Properties

GRAPE bulk-density measurements were conducted through all the debrites cored, but other physical property determinations (vane shear strength, water content, porosity etc.) were limited to a few selected clast and matrix samples (Boyce, this volume). The clasts vary in density from low (1.5–1.6 g/cm^3) for the dark-colored siliceous oozes, through intermediate values (1.6–1.8 g/cm^3) for the medium-dark marls and smarls, to higher values (1.8–2.0 g/cm^3) for the light-colored calcareous oozes. The altered basaltic clasts have densities of 2.0–2.2 g/cm^3 and the smarl matrix an average value of about 1.75 g/cm^3. From limited measurements the clasts appear to have the same range of shear strengths (500–2000 g/cm^2), water contents (35–45% wet weight), and porosities (55–65%) as the associated facies. The matrix appears relatively weak (shear strength 1000 g/cm^2) and with a low to moderate water content (~40% wet weight).

No systematic variation of clast or matrix density is observed within individual debrites, but more random changes are evident. The largest clasts (>20 cm diameter) are invariably of low-density material, whereas the basaltic clasts are mostly very small (average 2–3 cm, maximum 10 cm).

DISCUSSION

Debris-flow deposits constitute nearly 25% of the brown fan sediments and are closely associated with slumps and thick muddy biogenic turbidites. There is no direct evidence for a slump passing into a debrite, although such a vertical relationship is probably not to be expected. The thickest debrites are associated with the thick slump zone, and the passage of either slump or debrite may have been the trigger mechanism initiating the other mass flow process. Several of the debrites grade upwards into a biogenic-rich turbidite similar to the other turbidites in the section. The process continuum of slumping–debris flow–turbidity current seems, on the basis of present evidence, very plausible.

The sedimentary characteristics of these debrites are generally similar to those summarized by Middleton and Hampton (1973, 1976) although the variation of structural attributes superimposed on an otherwise random fabric is notable. The presence or absence of grading, the possibility of crude stratification, the near perfect rounding of some clasts, and the regular increase of maximum clast size with bed thickness are all features that require physical explanation in terms of debris-flow dynamics.

The debris flows originated on the Walvis Ridge to the south and must clearly have involved large areas and/or thicknesses of sediment in order to produce the compositional variety, thickness, and probable extent of individual debrites. A very approximate estimate of the sediment volume involved for the thicker debrites is 6.10^9 m^3 (= 6 km^3), based on an areal extent of 20 km × 30 km and thickness of 10 m. This is quite comparable with the volumes of slumps estimated by Dingle (1980) and others.

The debrites appear on seismic reflection profiles as chaotic, discontinuous reflectors and irregular transparent zones. They were easily recognized in the hydraulic piston cores because of the clast variability and lack of disturbance. In some of the rotary-drilled cores, however, they are more easily confused with drilling breccia.

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