SEDIMENTOLOGY OF LARGE OLISTOLITHS, SOUTHERN CORDILLERA CENTRAL, HISPANIOLA[1]

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ABSTRACT: More than 500 large, well exposed, calcareous olistoliths of Paleocene to Eocene age are exposed in the Eocene deep-water Rio Ocoa Formation of southern Hispaniola. Due to the low degree of tectonic overprint, their sedimentary characteristics can be studied in detail. The olistoliths reach up to 6 km in length and are largely conformable with regional bedding. Slump folds formed within some semiconsolidated blocks during downslope transport. Olistolith age, geometry, lithology, facies, orientation of slump fold axes, and regional geology indicate provenance from a carbonate platform and slope environment that overlay the Cretaceous island-arc rocks of the Cordillera Central to the northeast. The blocks were transported as far as 15 km and a show a logarithmic size-distance relationship. Seismicity associated with the initiation of strike-slip faulting along the subsiding, inactive arc during the Middle Eocene is likely to have triggered the detachment and mobilization of the olistoliths.

INTRODUCTION

Olistostromes and their megaclasts (olistoliths) derived from carbonate environments are common in the northern Caribbean (e.g., Palmer 1963; Robinson 1967; Bourgois et al. 1980; Tikhomivov et al. 1987). Along the southwestern margin of the southern Cordillera Central on the island of Hispaniola, one of these olistostrome deposits includes a large number of unusually well exposed olistoliths in a setting of low tectonic overprint (Fig. 1). While large olistoliths alone are not extraordinary and megaclasts of similar size have been reported from numerous other carbonate environments at orogenic margins, e.g., from northwestern Venezuela (Renz et al. 1955) the Pyrenées (Johns et al. 1981), the Canadian Rocky Mountains (Cook et al. 1972), eastern Australia (Conaghan et al. 1976), the western U.S.-Cordillera (Heck and Speed 1987), the Apennines (Wood 1981; Naylor 1982; Teale and Young 1987), and the Avalonian Terrane of New England (Bailey et al. 1989), the degree of exposure and preservation of the olistostromes in southern Hispaniola is comparable to a few locations only and allows detailed study of the mechanisms of transport and emplacement.

This article describes the geometric, lithologic and stratigraphic characteristics of the olistoliths, discusses provenance indicators and the mechanisms of transport and deposition, and concludes with remarks on trigger and detachment mechanisms.

GEOLOGIC SETTING AND METHODS

The Cordillera Central of Hispaniola (Massif Central of Haiti) represents an uplifted block of Upper Cretaceous igneous and metamorphic rocks of island-arc association (Bowin 1966; Lewis et al. 1991; Fig. 1, inset). The southwestern flank of the Cordillera Central became a seismically active fault zone in the Middle Eocene in response to the collision of the arc with the Bahamas Platform in the Early Eocene and its subsequent disruption by sinistral strike-slip faulting (Mann et al. 1984; Burke 1988; Rosencrantz et al. 1988; Pindell and Barrett 1990). Transtensional and transpressional tectonics in the plate boundary zone created a number of rapidly subsiding deep-water basins. Parts of these fault-bounded basins are exposed onshore in Jamaica, Hispaniola, and Puerto Rico (Dolan et al. 1991). The basins were largely filled by sediment gravity flows carrying detritus from the adjacent upthrown fault blocks.

Large limestone olistoliths occur in the basal 1.4 km of the approximately 2.5 km thick Eocene Rio Ocoa Formation (Bourgois et al. 1979; Vila and Feinberg 1982; Eva 1980; Biju-Duval et al. 1983). This formation represents the base of an Eocene to Early Miocene turbiditic basin fill sequence with a maximum thickness of up to 12 km (Heubeck et al. 1991; Fig. 1). The Rio Ocoa Formation was subjected to regional folding on a kilometer scale and minor thrusting during the Early Miocene which shortened the basins approximately 25% perpendicular to strike (Heubeck and Mann 1991). The olistoliths are concentrated in several regionally mappable and a large number of smaller stratigraphic horizons (Fig. 1). Regional mapping shows that the horizons are not likely to be repeated by faulting ~~or folding~~.

OLISTOLITH DESCRIPTION

A total of 502 olistoliths in the basal Rio Ocoa Formation were mapped from aerial photographs. Out of these, 193 olistoliths were field checked (Heubeck 1988). The smallest clast size recognized from aerial photographs was about 100 m^2. Data from clasts down to ca. 10 m^2 surface outcrop area were recorded during the field checks in cases where their exotic character with respect to the host rock lithology was apparent. Hand samples were taken from 47 olistoliths and from eight cobble-sized clasts of associated carbonate-clast conglomerates for petrographic and age analysis.

The apparent length of the olistoliths was estimated in the field or measured from 1:25,000-scale geologic maps with an error of about 10% for the smaller blocks and less for the larger ones (Fig. 2). Six of the olistoliths reach an apparent length of > 1 km, with the largest block

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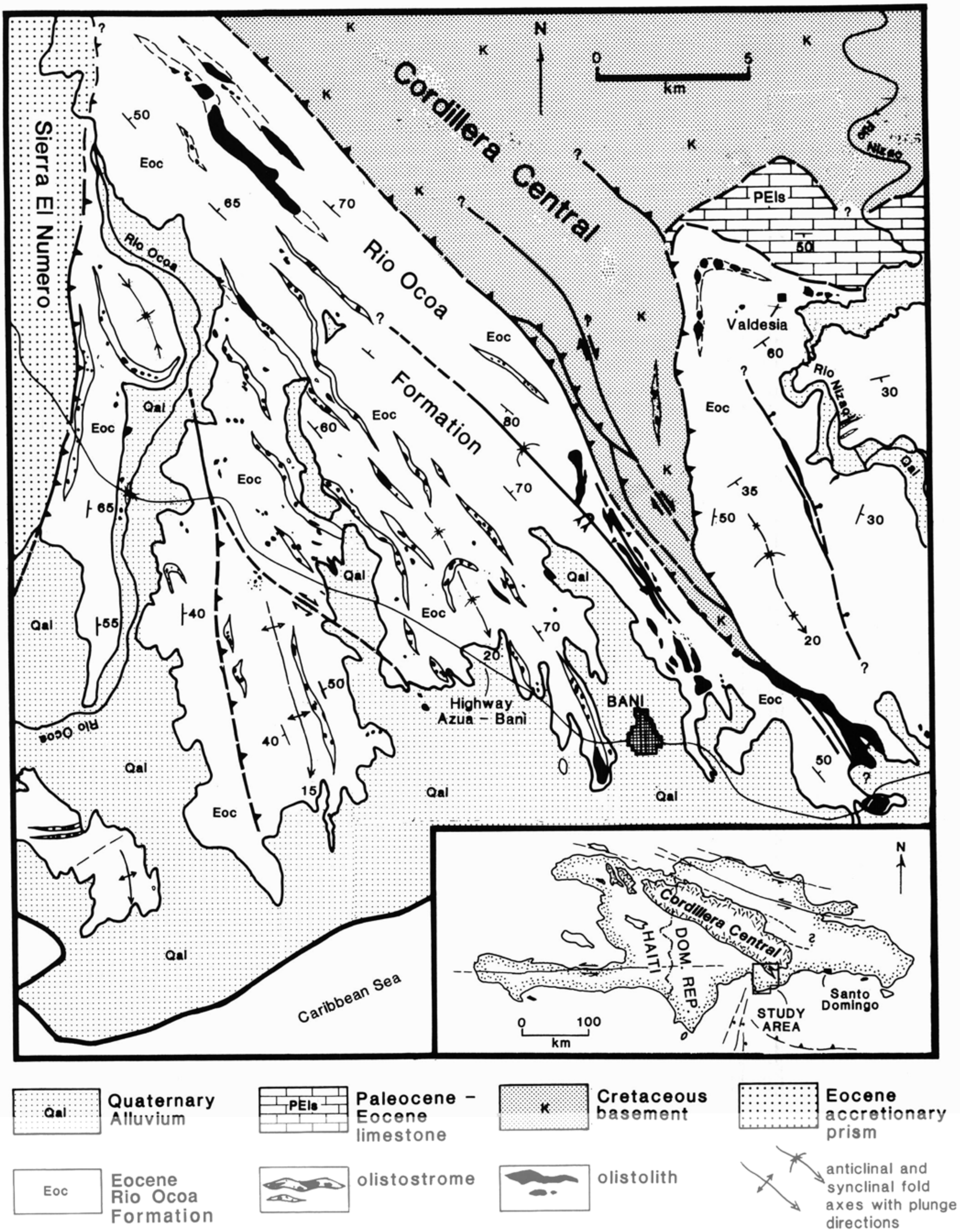


FIG. 1.—Location map showing extent of the Eocene olistostromes in southern Hispaniola and deformation of the Rio Ocoa Formation. The olistostromes form linear bodies rich in olistoliths, encased in a commonly massive or chaotic siliciclastic matrix; they are interbedded between turbidites and debris flows of the Rio Ocoa Formation. Some horizons are likely to be repeated by folding. Inset map shows location of study area, outcrop area of the Cordillera Central, and active faults of Hispaniola.

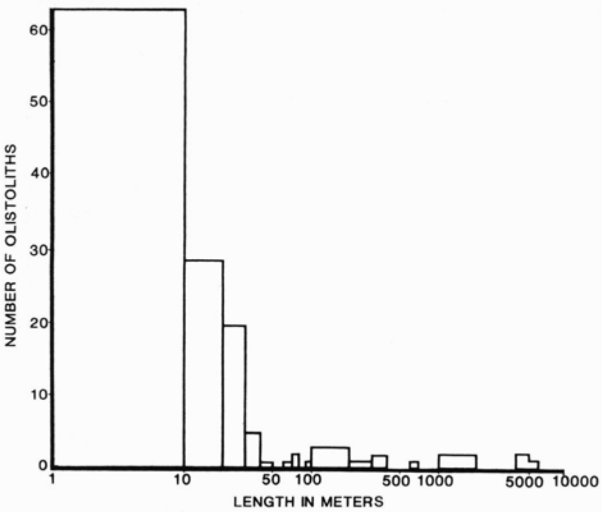


FIG. 2.—Log-normal histogram showing the apparent maximum length of 135 olistoliths. Six slide blocks exceed 1 km in length. Blocks with lengths between 10 and 50 m are common.

exceeding 6 km. Up to 200 m of stratigraphic thickness is represented within individual olistoliths. The largest blocks have the greatest aspect ratio; their largest diameter lies in the plane of intra-olistolith bedding. The orientation of the largest olistoliths and their internal bedding is parallel to regional strike.

Most olistoliths are composed of white to cream, thin- to thickbedded, well-indurated, slightly cherty micrite (Fig. 3A). Other lithologies include massive and flaserbedded marls, calcareous siltstones, and purple calcareous mudstone. Bedding in the limestones and marls is defined by clay partings and can usually be traced over a distance of about 20 to 40 m. No siliciclastic olistoliths were observed.

In thin section, two petrographic groups are apparent (Fig. 3B). The first group is composed of a pelagic foraminiferal wackestone or mudstone which contains common to abundant radiolaria and rare to common sponge spicules in a micritic mud matrix (Fig. 4A). The ratio of benthic to pelagic foraminifera is low. Reworking is slight or negligible. The second group is represented by a red algae-benthic foraminiferal packstone whose main framework constituents include coralline (red) algae, benthic foraminifera, and intraclasts (Fig. 4B, C). Intraclasts are commonly encrusted by layers of coralline algae. Sponge spicules are rare. Gastropod, mollusk, and echinoderm fragments are very rare. The degree of reworking is high.

Twenty-four age estimates, based on benthic and pelagic foraminifera, were obtained from thin sections of foraminifera-rich limestone. Nine ages were determined for this study by Dr. E. Robinson, Rice University. Additional data were compiled from Vaughan et al. (1921; one sample), Bourgois et al. (1979; two samples), Dominguez (1987; nine samples), and Biju-Duval (personal communication; three samples). Biostratigraphic ages range from the Late Paleocene to the Middle Eocene. No particular part of this age range correlates with either the mudstone-wackestone or the packstone facies of the olistoliths. The age range of the blocks is thus older than or coeval with the early Middle Eocene to Late Eocene age of the host rocks (Bourgois et al. 1979; Heubeck et al. 1991).

Twenty-eight thin sections and associated hand samples were interpreted and assigned to one of eight carbonate facies. These facies were defined by ecological associations of identified Eocene benthic foraminifera in thin sections, following the classification of Eva (1976), or by carbonate texture and composition in thin section and hand sample (E. Robinson, personal communication). The relative proportions of these facies groups allows a qualitative facies reconstruction of the olistolith source area (Fig. 5). More than half of the samples represent a reef margin or shallow slope association. About 30% of the samples indicate a bathyal to abyssal environment on the mid- and lower slope and basin plain. Back-reef and lagoonal associations comprise about 15% of the examined group (Fig. 5).

SEDIMENTOLOGY

Source Area

The Cordillera Central is the most probable source region of the limestone olistoliths. Provenance assignments

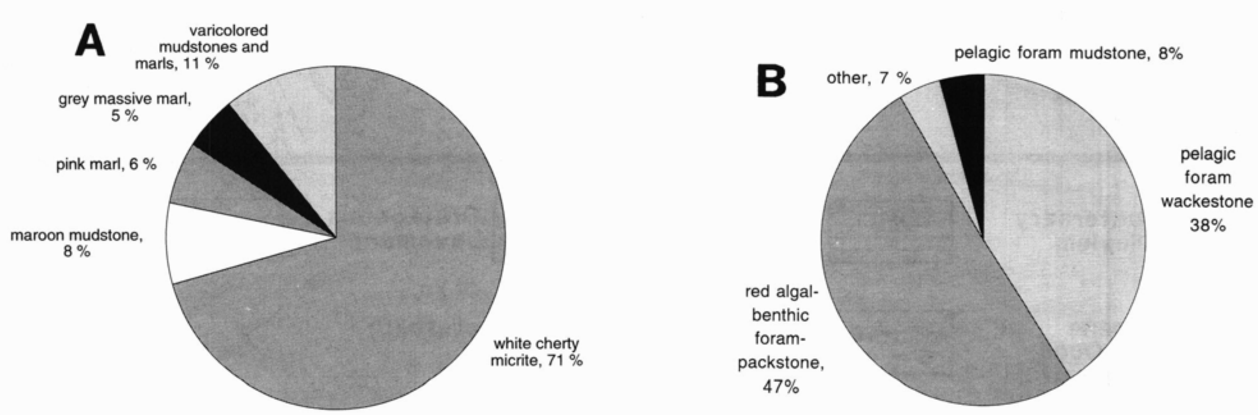
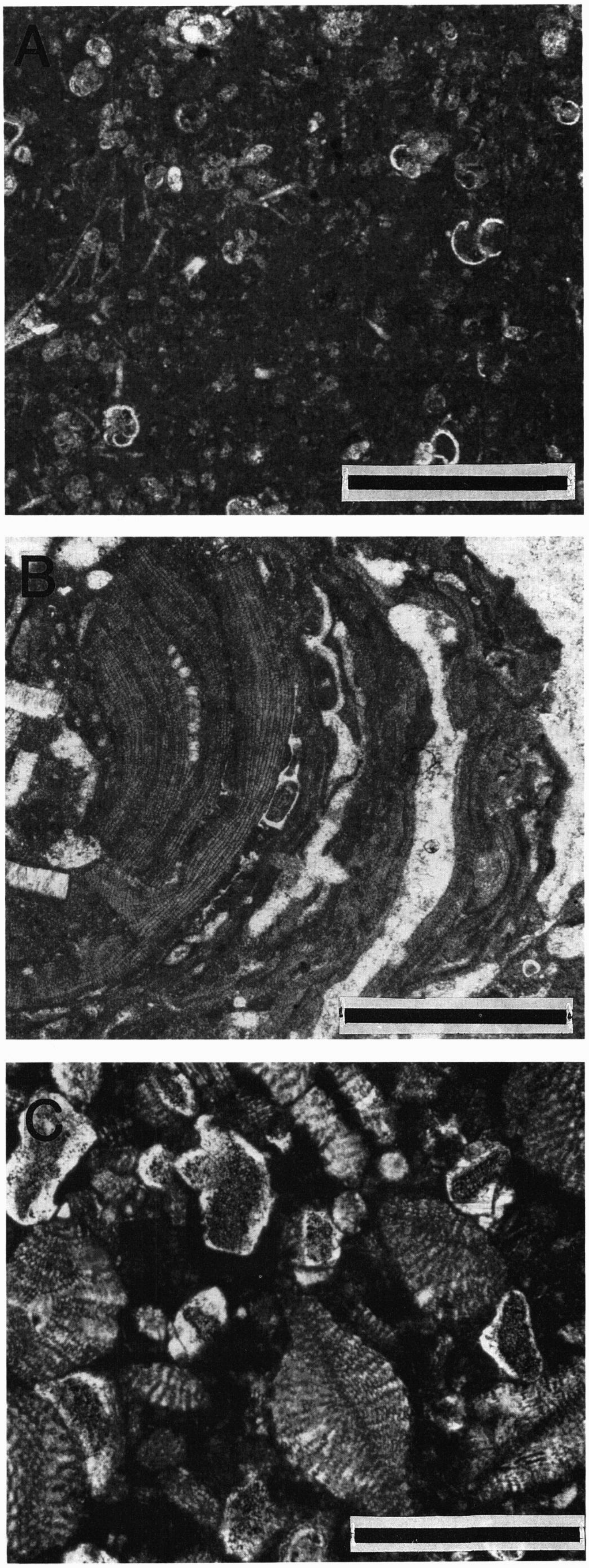


FIG. 3.—Pie diagrams of olistolith lithology. **A)** Outcrop lithology of 181 olistoliths. **B)** Thin section lithology of 40 olistoliths. Note the strong bimodality, defined by a packstone and by a wacke-/mudstone.



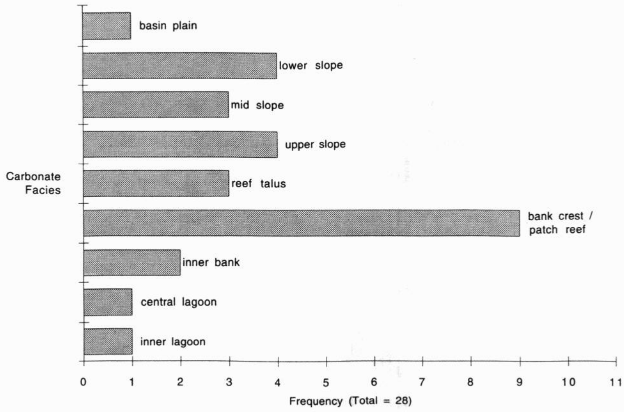


FIG. 5.—Carbonate facies histogram of 28 olistoliths. The facies distribution is dominated by a shallow-water bank margin association. Slope and basin plain deposits are common; inner platform deposits (bank and lagoon) are rare.

are complicated by the late Tertiary-Quaternary uplift of the Cordillera Central, which has stripped most sedimentary rocks from the igneous basement. A narrow, poorly defined band of Late Maestrichtian to Late Middle Eocene limestones, however, is preserved from north of Valdesia eastward (Bowin 1966; Vila and Feinberg 1982; Biju-Duval et al. 1983; Heubeck 1988; Fig. 1). These well-bedded, white to cream-colored deep-water limestones unconformably overlie the igneous basement and range from approximately 230 to 350 m in thickness (Bowin 1966; Vila and Feinberg 1982). Vila and Feinberg (1982) documented a pelagic and hemipelagic assemblage of foraminifera from these rocks.

Plunge-corrected paleocurrent indicators, measured from fine- and medium-grained turbidites of the Eocene Rio Ocoa Formation, indicate that the dominant paleoflow paralleled the southeast-northwest-trending margin of the Cordillera Central (Fig. 6; Heubeck et al. 1991). Measurements from conglomerates, in contrast, exhibit an additional northerly component, oblique to the basin axis, suggesting a source of coarse input from the flanks of the Cordillera Central. Such an inference is also suggested by logarithmically decreasing size of the olistoliths with increasing distance from the margin of the Cordillera Central (Fig. 7).

The olistolith size distribution is consistent with the paleocurrent patterns obtained from conglomerates, while the paleocurrents from finer-grained sediments are more indicative of the axial flow typical of elongate, narrow submarine basins. In addition, the location, lithology, and age of an identified potential source area support a prov-

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FIG. 4.—Thin-section photomicrographs (plane light) of typical olistolith samples. Scale bar approximately 2 mm. Figure 4A represents the wackestone-mudstone of Figure 3B, a deep-water facies; B and C are characteristic of the packstone of Figure 3B, a shallow-water facies. **A)** Pelagic foraminiferal wackestone. Accessory framework components include sponge spicules and radiolaria. **B)** Echinoid-mollusc-fragment intraclast encrusted by red algae. Voids are filled with clear calcite. **C)** Benthic foraminiferal packstone.

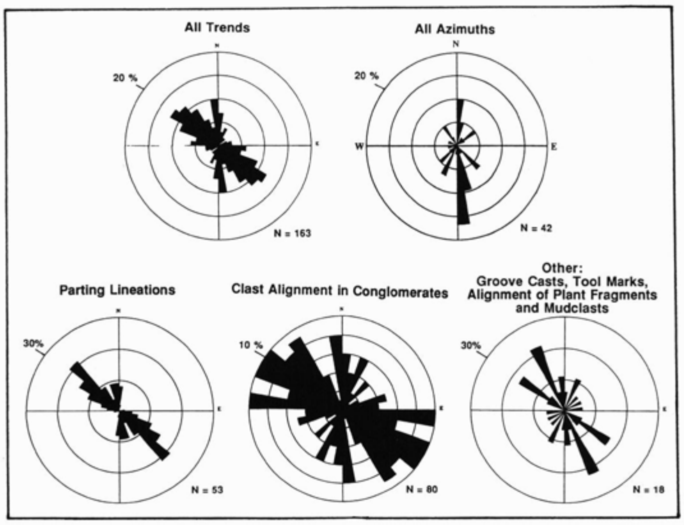

FIG. 6.—Paleocurrent rose diagrams from the turbidites and debris flows of the Rio Ocoa Formation, host rock to the olistoliths. The coarse clastic deposits show, in contrast to the paleocurrents of the finer-grained deposits, a well-developed bimodality, supporting a partial derivation of the conglomerates and olistoliths from the Cordillera Central (from Heubeck et al. 1991).

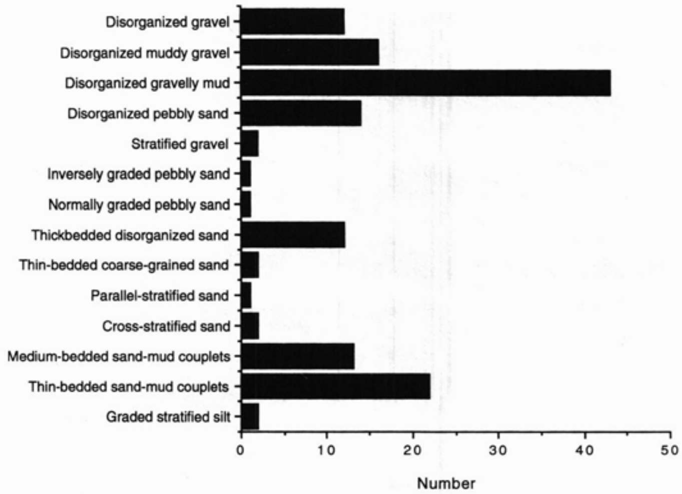

FIG. 8.—Host rock lithology adjacent to 142 olistoliths. Classification of clastic sediment type after Pickering et al. (1986). The slide blocks are preferentially associated with gravelly muds, interpreted as products of debris flows, or with thin-bedded sand-mud couplets, interpreted as mid-fan turbidites. Most likely, olistoliths were transported by debris flows of varying thickness; their protruding tops were later covered by turbidites.

enance from a source overlying the island-arc derived rocks of the Cordillera Central.

Transport

The lithology of the host rock in which the olistoliths are embedded indicates their mode of transport. Where no matrix was exposed immediately adjacent to an olistolith, observations were made at the nearest outcrop, but no farther than 20 m from the olistolith. Olistoliths are generally associated with either gravelly and unsorted deposits, or with shaly, fine-grained, well-sorted sediments (Fig. 8). Arenites are generally poorly represented.

In 66 cases, outcrop exposure allowed the comparison of the bedding attitude within an olistolith with bedding in the adjacent host rock. After individual correction of the olistolith bedding planes for tectonic tilt, poles to olistolith bedding cluster about the center of the stereonet, indicating that host rock bedding and olistolith bedding planes parallel each other closely (Fig. 9). This near-conformable relationship between olistolith bedding and host rock bedding has also been reported from similar ex-

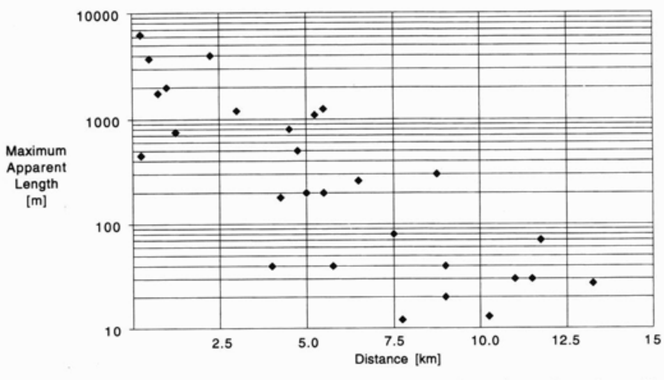

FIG. 7.—Log-normal scatter plot of olistolith size plotted against distance from the margin of the Cordillera Central. The well-defined logarithmic decrease in size with increase in distance strongly suggests a provenance from the Cordillera Central. Distance measurements are not corrected for an estimated 25% shortening perpendicular to strike because other, potentially more significant factors (paleotopography, slope steepness, clast shape) cannot be adequately accounted for.

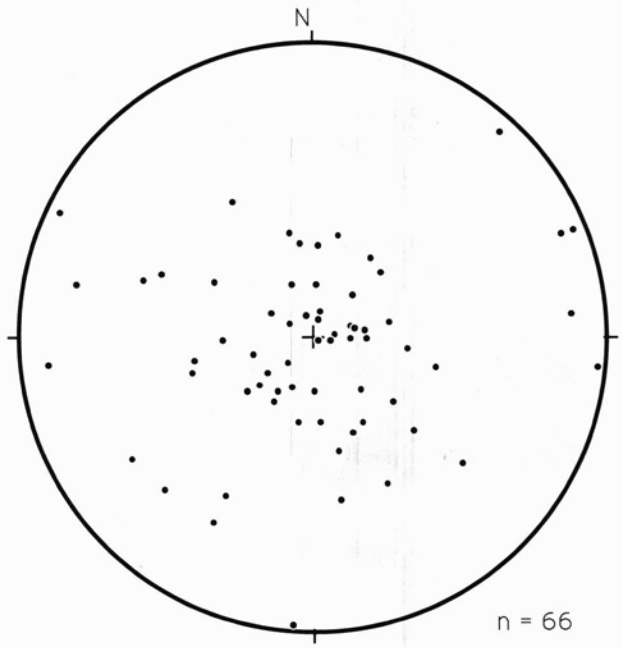

FIG. 9.—Lower-hemisphere stereographic projection of poles to olistolith bedding planes. To correct for tectonic tilt, local bedding in enclosing turbidites was rotated to the horizontal. The resulting poles cluster around the center of the stereonet, indicating that the olistolith bedding planes lie statistically parallel to the bedding planes of the host rock.

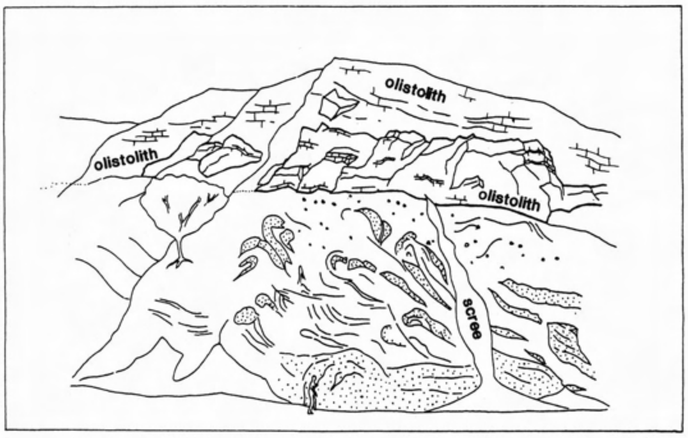

FIG. 10.—Line drawing of outcrop showing disrupted and sheared stratigraphy in massive, medium- to thick-bedded sandy turbidites below a planar limestone olistolith (at top of the outcrop). Emplacement of the olistolith and its subsidence into a plastic substrate disrupted an originally coherent and well stratified, but unlithified, substrate. Person for scale.

amples in the northern Apennines (Naylor 1982), the Antarctic Peninsula (Ineson 1985), and southern Italy (Teale and Young 1987).

Mud matrix encasing the olistoliths is commonly scaly at the contacts, even where no structural overprint is evident in the outcrop. Underlying shaly and sandy beds are disrupted. At one outcrop, sandstone beds below an olistolith can be observed elongated into wisps and rootless fragments, suggesting drag and soft-sedimentary deformation beneath the base of the olistolith during its emplacement (Fig. 10).

Most olistoliths are internally deformed by gentle to isoclinal folding or bedding-plane slip (Fig. 11A, B). The folds observed in the olistoliths are interpreted as slump folds because 1) their meter-scale, disharmonic fold style is distinct from the kilometer-scale regional deformation and is also absent from the rocks the olistoliths were derived from; 2) folds in the olistoliths are commonly truncated by unfolded beds and cannot be traced into the host rock; and 3) the mean orientation of fold axial planes measured in the olistoliths is virtually identical to the orientation of slump folds in adjacent turbidites but is distinctly different from the orientation of tectonic folds (Fig. 12). The coincidence of intra-olistolith slump fold fabric with paleoslope orientation has been described by Woodcock (1979) and Heck and Speed (1987) from similar environments.

DISCUSSION

Transport and Deposition

Because regional dip is commonly between 40° and 70° and most olistoliths are conformable with strike, their third dimension is usually only poorly exposed. This precludes a quantitative assessment of their down-dip dimension or of a preferred orientation of their long axes, which has been demonstrated for an occurrence of slide blocks in the Apennines by Naylor (1982; also see Savage 1983). It is likely, however, that many olistolith have a considerable down-dip extent, because an overall oblate shape is a more stable geometry which increases the chance of clast survival during downslope transport.

The conformable orientation of the olistoliths relative to host matrix bedding (Fig. 9) indicates that the base of many olistoliths closely parallels sheared and folded bedding planes in the host rock. The strong spatial association of the blocks with unsorted, gravel-bearing mudstones suggests that the olistoliths were supported by mechanisms active in mass gravity flows (Fig. 8). The cohesive strength of the encasing clay matrix alone is clearly not sufficient to carry olistoliths with surface areas of hun-

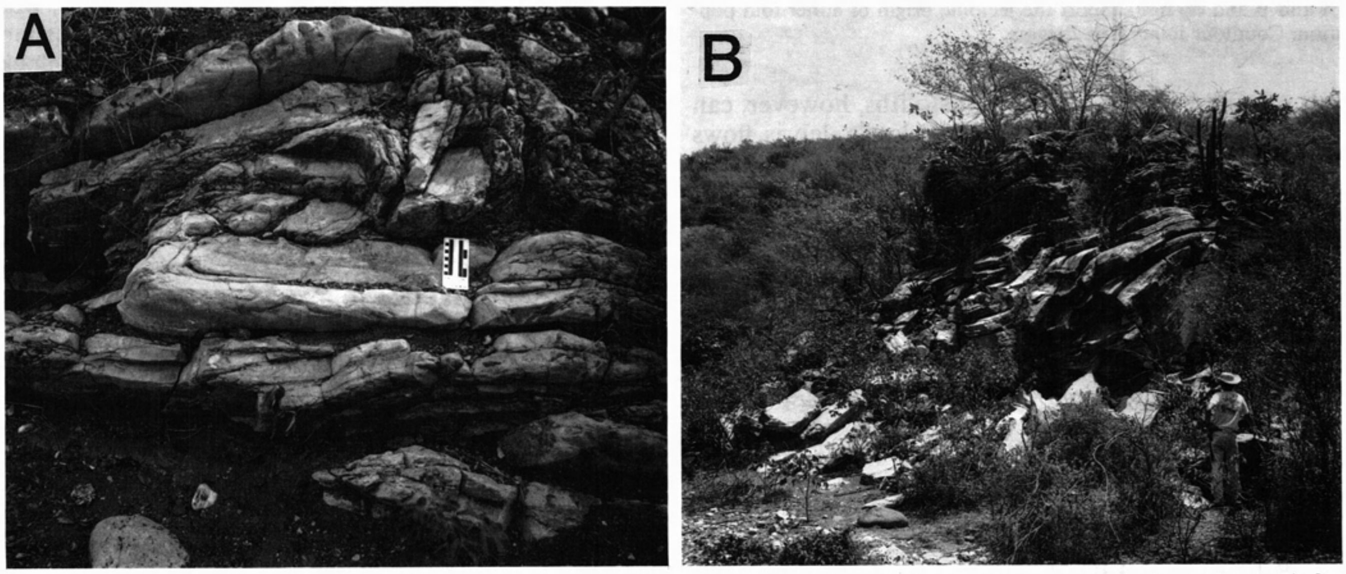

FIG. 11.—Slump folds in olistoliths. **A)** Recumbent, isoclinal slump fold in medium-bedded micritic limestone. Scale = 10 cm. **B)** Gently folded beds of an isolated, poorly exposed limestone olistolith. Person (in foreground) for scale.

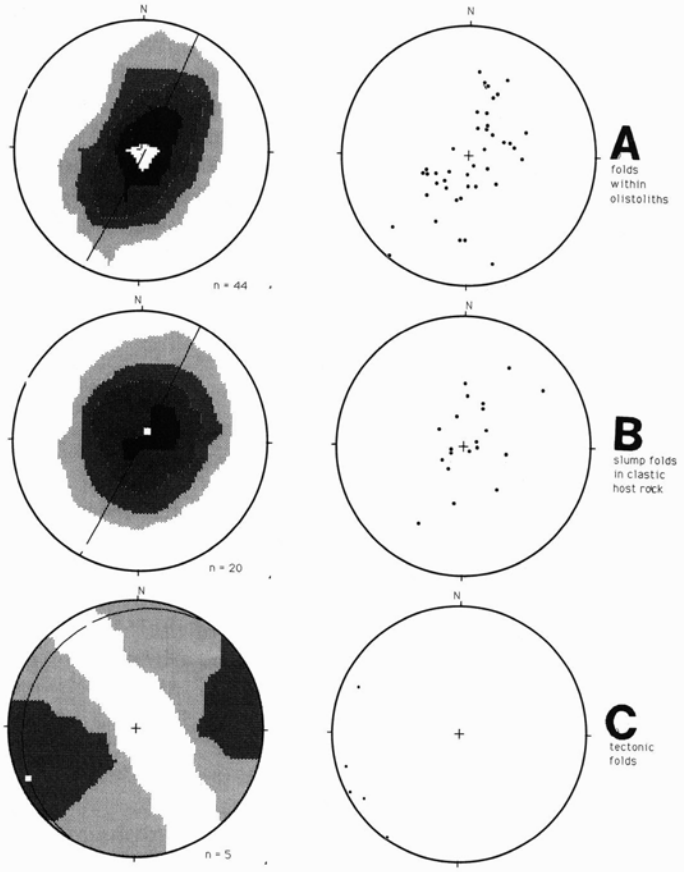

FIG. 12.—Olistolith fold analysis, using contour plots (left column) and scatter plots (right column) of lower-hemisphere stereographic projections. The stereonets show **A)** poles to axial planes of folds in limestone olistoliths; **B)** poles to axial planes of unambiguous slump folds from the siliciclastic turbidites of the Rio Ocoa Formation; **C)** poles to axial planes of large tectonic folds in the study area. Fold axis orientations (not shown) for all three fold classes are similar and cannot distinguish between their origins because tectonic shortening occurred perpendicular to the strike of the paleoslope. However, data shown in A and B are similar and thus suggest that intra-olistoliths folds originated by soft-sedimentary slumping. Data shown in C are clearly dissimilar to A and B and do not support the tectonic origin of either fold population. Countour interval = 2 sigma.

dreds of square meters. Smaller olistoliths, however, can be observed fully immersed in siliciclastic debris flows (Fig. 13). For those, their relative buoyancy is likely to have effectively reduced their weight, such that the remainder could be taken up by other mechanisms. The transport of the large blocks may have been facilitated by an overpressured cushion of mud which would have effectively reduced the resistance to basal shear. The best recent analogue to this process was given by Prior et al. (1982, 1984), who described "outrunner blocks" of a submarine slide in British Columbia. These authors speculate about a similar mechanism, stating, "it is conceivable that the water-saturated upper layers of marine clay develop temporary high pore-fluid pressure directly under the moving block, sufficient to support it. At the same time, these overpressured sediments may provide a lifting force that encourages the forward movement of a block" (Prior et al. 1982, p. 982). Teale and Young (1987), based

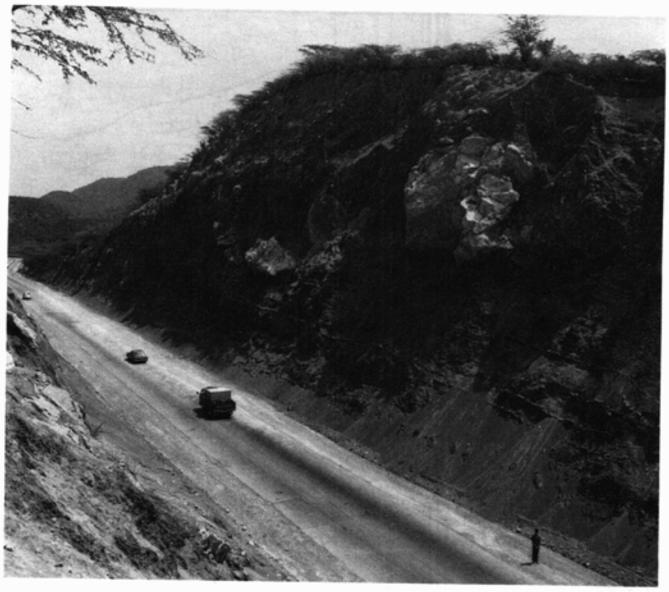

FIG. 13.—Roadcut in the eastern Sierra El Numero, about 15 km west of Baní (Fig. 1). Person and vehicles for scale. The roadcut exposes a debris flow horizon of > 20 m thickness, carrying limestone olistoliths of ca. 10 m diameter. The debris flow overlies horizontal, thinly-bedded turbidites of the Rio Ocoa Formation.

on their examination of isolated blocks in the Longobucco Basin, southern Italy, argue for a similar process involving relatively rapid "skidding" of olistoliths on overpressured mud. When the blocks slow down sufficiently to sink into the underlying sediments, the increased resistance to motion would cause them to disrupt underlying sediments as described above.

While the sheared clay matrix at the base of olistoliths is typically only about 10 to 30 cm thick, drag structures extend for a considerable distance below that. In some areas, as much as 5 m of apparently unconsolidated sediment were disrupted and dragged upward as the limestone block sank into its plastic substrate (Fig. 10). Clastic, pebble-bearing dikes, observed in other olistoliths, were probably also injected during this final stage of transport. In most cases, nevertheless, the bases of the slide blocks remained parallel to the overall bedding orientation observed at or near the outcrop.

It is likely that the olistoliths were derived from a line source rather than from a point source, because they are spread fairly evenly over a length of at least 35 km within (at present) only a few kilometers from the margin of the Cordillera Central (Fig. 1). The margins of carbonate platforms form natural line sources (Schlager and Chermak 1979). This linear source was probably deeply dissected by canyons, enabling the siliciclastic sediments and clasts which dominate the Rio Ocoa Formation to bypass the carbonate environment. Such a mixed carbonate/siliciclastic environment has numerous modern analogues along the coast of the larger Caribbean islands.

Trigger and Detachment

Several trigger mechanisms can provide the detachment of large slide blocks along submarine bank margins:

gravity-driven mass wasting, storm waves, and earthquakes (Cook et al., 1972). The regional extent of the olistostromes and their repetitive occurrence in about seven mappable horizons imply that the trigger mechanism acted recurringly and simultaneously along the entire length of the carbonate bank margin. Only seismic events exhibit such regional and recurring characteristics. Cyclic loading by seismic waves probably induced the rapid buildup of pore pressure in poorly cemented or shaly horizons, resulting in widespread failure along these beds (Séguret et al. 1984). Slope steepness may have been considerable, because foraminiferal analyses from the Rio Ocoa Formation, palinspastically less than 8 km from the reverse-faulted margin of the Cordillera Central, yield deep bathyal and abyssal depths (E. Robinson, personal communication 1988). Once detached, however, slide blocks can move even on very gentle slopes (Rodine and Johnson 1976; Kraft et al. 1979).

CONCLUSIONS

The olistoliths at the southern margin of the Cordillera Central provide unusually clear evidence of the detachment, transport, and deposition of large submarine slide blocks. Detailed observations along the margin of the southern Cordillera Central indicate that:

1) Large bedded olistoliths slid on their basal bedding planes, on or within a plug of lubricating, probably overpressured, mud.
2) Olistolith lithology, facies, and age, and the orientation of intra-olistolith slump folds are consistent with paleocurrent indicators and slump fold orientation in the largely turbiditic host rock. Olistolith size is a logarithmically decreasing function of distance from the suspected basin margin. The data support a derivation of the blocks from a largely eroded carbonate environment which overlies island-arc rocks of the Cordillera Central to the northeast.
3) Seismicity associated with the onset of strike-slip faulting in the Eocene started to dismember the carbonate environment. Seismic waves may have caused rapid buildup of pore pressure in shaly or poorly cemented horizons along the basal parts of the carbonate platform. The resulting simultaneous and instantaneous failure of such a horizon along the bank margin was the most probable mechanism to trigger the detachment of large planar slide blocks.

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