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21. PHYSICAL PROPERTIES OF CARBONATE TURBIDITE SEQUENCES SURROUNDING THE BAHAMAS—IMPLICATIONS FOR SLOPE STABILITY AND FLUID MOVEMENTS[1]

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ABSTRACT

Along the slopes and in adjacent basinal areas of Bahamian platforms, periplatform ooze forms the host sediment for variable proportions of carbonate turbidites. In unlithified sections, these turbidites appear as unconsolidated layers intercalated with stiffer ooze. Within an individual turbidite, differences in grain size result in variations in consolidation and physical properties. With decreasing grain size, water content and porosity decrease, and two distinct surfaces develop at the lower and upper boundaries of the turbidite. These surfaces are potential instability horizons where mass-wasting can occur. Therefore, a relation between turbidites and slumping frequency is proposed. The higher proportion of turbidites in sediments deposited on low-angle, accretionary terrains, such as the toe of the northern slope of Little Bahama Bank, probably facilitates frequent, small-scale slumping and creeping, as seen in seismic profiles. In contrast, slumping is less frequent along the steeper (12°) bypass slope in Exuma Sound, where turbidites are rarely found.

Where the background sediment was initially a pelagic nannofossil ooze rather than a periplatform ooze, mineralogical composition results in lithification differences. In lithified sections having chalk as the background sediment, turbidites display a higher sonic velocity, indicating that they are the more competent beds. This lithification variation is the result of differential diagenesis between the platform-derived turbidites, enriched in metastable carbonates, and the calcitic nannofossil ooze of the background sediment.

The different lithification owing to dissimilar mineralogical composition could also influence fluid migration in carbonate sequences. In a periplatform sequence, the more porous turbidite might be the fluid conduit, whereas in a pelagic sequence the chalky background sediment allows for fluid migration.

INTRODUCTION

The slopes connecting the shallow-water carbonate platforms of the Bahamas with the deeper water areas show extreme gradient variations, ranging from almost vertical to less than 4°. Accumulation rate and sediment type on these slopes are related to their height, declivity, and distance from the platform source (Schlager and Ginsburg, 1981; Mullins et al., 1984; Schlager and Camber, 1986). During Leg 101, these relationships and the transition to the adjacent basins were studied in two three-hole transects. Sections recovered comprise fine-grained carbonate ooze with a variable amount of interbedded gravity-flow deposits. Redeposited beds were abundant along the toe-of-slope and in the basin, but they were rare on the slope with a declivity of more than 3°, suggesting that most gravity flows bypassed these slopes. Seismic evidence indicates that slumping and creeping are important even in the gently sloping part of the drilled transects (Austin, Schlager, et al., 1986). In a seismic line along the transect north of Little Bahama Bank, imbricated thrust faults, which indicate such downslope movements, appear most frequently between the toe-of-slope (Site 628) and the basinal area (Site 627) (Austin, Schlager, et al., 1986). Cores from these sites contain a high proportion of redeposited beds. Visual inspection of the cores aboard *JOIDES Resolution* revealed that, in unlithified and semilithified sections, redeposited beds, mainly calciturbidites, are much less indurated than the surrounding periplatform ooze (Austin, Schlager, et al., 1986).

The aim of this study is to quantify these lithification differences using physical-property data and to evaluate a possible connection between gravity-flow deposits and larger scale mass-wasting. In addition, the relationship between the redeposited beds and the background sediment is investigated in lithified sections, where the calcarenites, especially where silicified, are denser than the background sediment. Results of these analyses have implications for slope stability, as well as for development of possible fluid conduits in carbonate deposits.

SAMPLE LOCATIONS

During Leg 101, two slope transects were drilled, each with three sites: one north of Little Bahama Bank (Sites 627, 628, and 630) and one in Exuma Sound (Sites 631, 632, and 633). Furthermore, in two channels between the platforms, the Straits of Florida (Site 626) and Northeast Providence Channel (Sites 634, 635, and 636), drilling operations attempted to penetrate a prominent seismic horizon interpreted as the top of a shallow-water carbonate platform (Sheridan et al., 1981) (Fig. 1).

Site chapters (Austin, Schlager, et al., 1986) contain the results of the systematically measured physical properties used to construct downhole distribution curves. This study focuses on additional physical-property data from 16 well-preserved, redeposited beds and compares them with the background sediment (Table 1). Some of the sediment gravity flows investigated herein were deposited along the accretionary slope transect north of Little Bahama Bank—at the modern toe-of-slope (Site 628) and the basinward end of the transect (Site 627) (Austin, Schlager, et al., 1986). In these two holes, pre-Oligocene sediments were characterized by periplatform ooze with numerous turbidites and debris-flow and slump deposits. The site nearest the platform (Site 630), within the middle to upper slope on an interfluve, was unsuitable for this study because the upper 124 m of the recovered core was dominated by periplatform ooze containing primarily bank-derived aragonite intercalated only with rare and thin turbidites (Austin, Schlager, et al., 1986). In Exuma Sound, most of the sediment gravity flows bypassed the mid-slope and were deposited on the basin floor (Crevello and Schlager, 1980; Austin, Schlager, et al., 1986). As a result, only Site 632 in central Exuma Sound was deemed suitable for this study.

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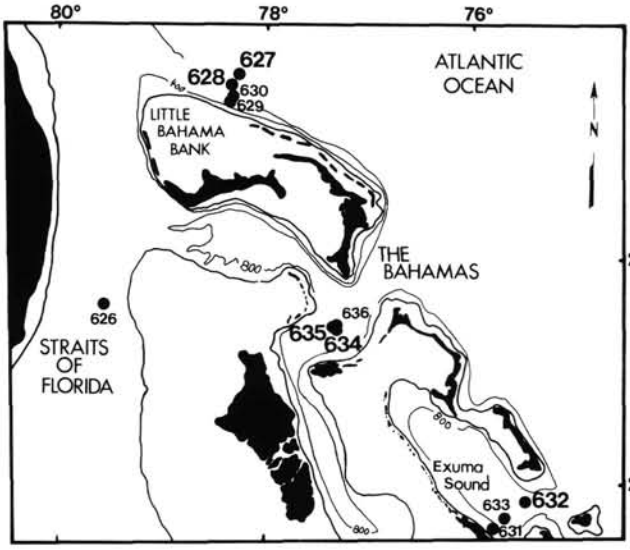

Figure 1. Location map of the sites occupied during Leg 101. Large numbers indicate sites where physical-property data were collected for this study.

In addition to these slope transect sites, Sites 634 and 635 in Northeast Providence Channel also provided data. At Site 634, alternations of nannofossil chalk with detrital limestone, primarily turbidites and debris flows, were used to investigate physical-property differences in a completely indurated section.

SEDIMENTOLOGY

Background Sediment

Along the carbonate slopes of the Bahamas, periplatform ooze is the background sediment. This is a fine-grained (clayey-silt) mixture of platform-derived sediment and tests of planktonic organisms (Schlager and James, 1978; Boardman and Neumann, 1984; Mullins et al., 1984; Droxler and Schlager, 1985). The large proportion of metastable carbonates (aragonite, high-Mg calcite) in the periplatform ooze enhances the potential for dissolution and diagenetic alteration (Droxler et al., 1983; Droxler, 1984; Mullins et al., 1985). This leads to an earlier induration of the periplatform ooze compared with the normally coarser, redeposited beds. In Leg 101 sediment, rapid burial diagenesis is indicated by shallow, partly lithified ooze and chalk (Austin, Schlager, et al., 1986; Swart and Guzikowski, this volume; Dix and Mullins, this volume).

Turbidites

Layers of grainstone, packstone, and rare rudstone with sharp basal contacts and graded bedding are interpreted as deposits from turbidity currents (Crevello and Schlager, 1980; Mullins et al., 1984; Austin, Schlager, et al., 1986). Other sedimentary structures are rarely seen in the unlithified beds, whereas in the indurated beds other structures, such as cross-bedding and lamination (Figs. 2 and 3), are occasionally visible. Beds range in thickness from 0.01 to 2.0 m. Grain size ranges from silt to very coarse sand but is commonly medium to fine sand. The high percentage of total carbonate (75%–86%) within the turbidites documents the minor input of terrigenous material. Nevertheless, the composition of these carbonate turbidites varies. Along the windward, open-ocean margin of Little Bahama Bank, turbidites are dominated by deep-water pelagic components. They consist of abundant planktonic foraminifers having varying percentages of skeletal fragments, aggregate clasts, pteropods, and minor amounts of coarse-grained shallow-water material (Austin, Schlager, et al., 1986). The protected Exuma Sound is surrounded by shallow-water platforms and contains more platform-derived debris. In particular, the composition of the coarse-grained turbidites reflects this protected setting, as they comprise abundant platform-derived skeletal debris, including *Halimeda* plates and *Homotrema* fragments, echinoid spines, and bivalve fragments (Site 632 chapter, Austin, Schlager, et al., 1986). In Northeast Providence Channel, well-cemented grainstone and rudstone in the deeper part of Hole 634A consist of platform-derived skeletal debris as well as chalk and chert clasts from slope sediments. In some of the chert, ghosts of former carbonate grains, particularly rudist clasts, are visible (Fig. 3).

Sedimentary Column

Compositional and grain-size differences between background sediment and turbidites produce an initially heterogeneous sedimentary column. In carbonate-slope sections of the Bahamas, this heterogeneity is enhanced as a result of differing rates of lithification between the periplatform ooze and the interbedded turbidites. As will be shown, this lithification difference is also reflected in the physical-property data. The early diagenetic alteration of the periplatform ooze leads to a shallow, partial lithification of the ooze in the upper parts of the sections and occasionally produces chalk/ooze couplets, spaced regularly at 5- to 25-cm intervals (e.g., Site 631, Austin, Schlager, et al., 1986). With increasing sub-bottom depth, hard layers become more abundant, and, ultimately, well-indurated limestone occurs. The interbedded carbonate turbidites have a larger grain size and contain fewer metastable carbonate minerals. As a result, they resist lithification longer than do the adjacent partly or completely indurated chalk (e.g., Site 632, Austin, Schlager, et al., 1986).

Diagenetic gradients and, consequently, the depths of complete induration vary at different sites (Swart and Guzikowski, this volume). In Exuma Sound, total lithification occurs at considerably shallower depths (104 mbsf, Hole 632A) than along the Little Bahama Bank transect, where the oldest slope sediments at 181 mbsf (Hole 627B) are incompletely indurated (Austin, Schlager, et al., 1986). In the latter, carbonate sand remains unlithified even where the interlayered ooze has been altered to chalk. The physical-property data suggest that development of instability horizons along the flanks of carbonate platforms is a function of a differing degree of lithification.

PHYSICAL-PROPERTY DATA

METHODS

Unconsolidated sediments were sampled from cores retrieved using the hydraulic piston corer (HPC). Although this technique was designed to produce minimal artificial compaction, core disturbances, especially dewatering, have been reported from unconsolidated calcareous sediments (Walton et al., 1983). Therefore, only well-preserved turbidites with a minimum thickness of 0.1 m were used in this study to ensure accurate physical-property data. Immediately after the cores were split on board the *Resolution*, three samples were taken in each selected turbidite: one near the bottom, one in the middle, and one near the top (Fig. 4). In addition, one sample of the background sediment was taken above and another below the turbidite. These latter samples sometimes coincide with the systematically collected data for the physical properties vs. depth curve listed in Leg 101 site chapters (Austin, Schlager, et al., 1986).

Physical-property measurements were performed on board the *Resolution* using standard procedures described by Boyce (1976, 1977). Compressional-wave velocity was measured using the Hamilton Frame device. Water content, porosity, and density were determined using a compensated-balance technique and a pycnometer for volumetric measurements with helium as the penetrating (pore-filling) gas. All index properties were corrected for an interstitial salinity of 35‰ resulting in an accuracy of 2% to 4% (Austin, Schlager, et al., 1986).

Table 1. Physical-property data of calciturbidites and periplatform ooze. Water content is given as percentage of water weight relative to weight of the dry solids.

Hole	Core interval (cm)	Depth (m)	$CaCO_3$	Bulk density (g/cm)	Grain density (g/cm)	Porosity (%)	Water content (%)	Velocity (m/s)	Lithology
627B	15-2, 114–116*	132.94	79.16	1.81	2.59	56.16	45.26		Ooze
627B	15-2, 129–131*	133.09	82.75	1.83	2.74	53.71	41.73		T top
627B	15-2, 136–138	133.16	82.27	1.94	2.7	48.87	34.08		T middle
627B	15-3, 03–05*	133.33	85.52	1.88	2.71	49.82	36.26		T bottom
627B	16-2, 70–72*	142.4		1.84	2.74	49.5	37.02		Ooze
627B	16-3, 90–92*	143.80	80.63	1.81	2.67	54.35	43.07		Ooze
627B	16-3, 132–134*	144.22	85.20	1.86	2.71	53.30	40.26		T top
627B	16-4, 13–15	144.53	85.43	1.85	2.69	53.98	41.34		T middle
627B	16-4, 65–67	145.05	82.73	1.85	2.7	53.14	40.37		T middle
627B	16-4, 70–72	145.10		1.87	2.72	52.66	39.4		T middle
627B	16-4, 94–96*	145.34	85.79	1.71	2.84	65.83	62.31		T bottom
627B	16-6, 70–72*	148.05		1.82	2.89	56.37	45.15		Ooze
628A	4-4, 75–77*	28.10		1.78	2.72	60.81	51.86		Ooze
628A	4-6, 05–07*	30.45	83.83	1.69		58.29	34.88		T top
628A	4-6, 14–16	30.54	84.68	1.70		64.92	56.87		T middle
628A	4-6, 31–33*	30.71	83.20	1.71		62.56	55.49		T bottom
628A	4-6, 35–37*	30.75	84.48	1.69		62.82	35.75		Ooze
628A	4-6, 70–72	31.00	82.95	1.78	2.66	59.09	49.75		Ooze
628A	12-2, 70–72	100.7		1.81	2.88	57.2	43.4		Ooze
628A	12-4, 57–59*	103.57	82.40	1.72		60.07	53.49		T bottom
628A	12-4, 70–72*	103.80	83.04	1.90	2.88	43.48	57.27		Ooze
632A	2-2, 70–72*	9.1		1.65	2.74	62.79	61.08		Ooze
632A	2-3, 66–68*	10.57	79.6	2.05	2.77	49.6	32		T top
632A	2-3, 145–147*	11.35	81.31	1.71	2.81	63.33	58.62		T bottom
632A	2-4, 70–72*	12.10		1.69	2.75	56.02	60.77		Ooze
632A	2-6, 70–72*	15.10		1.68	2.76	55.67	60.11		Ooze
632A	3-2, 70–72*	18.9		1.86	2.78	54.73	41.89		Turbidite
632A	3-2, 109–111*	19.29	79.51	1.84	2.77	52.01	39.54		Ooze
632A	3-2, 133–135*	19.53	83.23	1.93	2.81	51.05	36.29		T top
632A	3-3, 05–07	19.75	83.09	1.92	2.87	53.61	38.96		T middle
632A	3-3, 32–34	20.02	84.14	1.86	2.81	54.19	41.27		T bottom
632A	3-3, 112–114	20.91	86.2	1.74	2.79	62.31	55.64		T top
632A	3-3, 135–137*	21.05	80.20	1.79	2.24	77.87	75.65		T bottom
632A	3-4, 70–72*	21.9		1.68	2.71	62.35	59.04		Ooze
632A	4-1, 94–96*	27.24	81.60	1.76	2.85	61.59	53.78		T top
632A	4-2, 70–72	28.5		1.68	2.81	63.03	60.36		Ooze
632A	4-3, 63–65*	29.93	81.56	1.85	2.95	56.21	43.59		T bottom
632A	4-4, 70–72*	32		1.74	2.82	61.36	54.42		Ooze
632A	4-5, 105–107	33.35	86.72	1.70	2.75	61.54	56.12		Debris flow
632A	4-5, 115–117	33.45	83.98	1.74	2.76	58.64	50.53		Debris flow
632A	4-6, 64–66*	34.44	86.68	1.77	2.81	59.19	50.28		T top
632A	4-6, 70–72	34.5		1.73	2.7	60.87	54.03		T middle
632A	4-6, 94–96*	34.74	82.93	1.66	2.78	65.48	64.51		T bottom
632A	6-2, 70–72*	47.6		1.73	2.74	60.83	54.01		Ooze
632A	6-6, 70–72	53.6		1.74	2.72	63.07	56.93		Turbidite
634A	4-2, 70–72	168.30	75.60	1.96	2.75	42.49	33.24	1877	Chalk
634A	6-1, 40–42	182.50	82.51	1.84	2.74	53.39	40.89	1895	Chalk
634A	11-1, 10–12	230.00		1.99	2.68	29.27	44.91	2159	Poorly lithified grainstone
634A	11-1, 55–57	230.45		1.91	2.67	35.26	49.41	1661	Chalk
634A	13-1, 54–56	249.14	82.33	2.43	2.66	11.40	24.50	4638	Cemented rudstone
634A	14-1, 8–10	258.3						1559	Chalk
634A	16-CC, (10–12)	287		2.45		17.9		6350	Chert (silicified turbidite)
634A	22-1, 10–12	354.7						2100	Chalk
634A	22-1, 42–44	355.00		2.26	2.59	16.38	31.32	3395	Lithified grainstone
634A	28-1, 57–59	422.37	82.14	2.30	2.7		24.40	4224	Cemented grainstone
634A	28-2, 6–8	423.4						2260	Chalk
634A	29-1, 25–27	441.35	84.01	1.99			42.90	4443	Lithified rudstone
634A	30-1, 20–22	450.9						3055	Partly lithified packstone
634A	31-1, 35–37	460.6						3699	Silicified grainstone
634A	31-1, 40–42	461.1						3468	Packstone
635A	1-1, 70–72*	0.7		1.66	2.72	65	64.29		Ooze
635A	1-1, 135–137*	1.35	75.35	1.58	2.77	64.60	62.33		Turbidite
635A	1-2, 58–60	2.08	83.37	1.77	2.8	60.50	51.84		T top
635A	1-2, 70–72	2.2		1.79	2.77	59.87	50.23		T middle
635A	1-2, 95–97	2.45	82.73	1.78	2.78	59.20	49.54		T bottom
635A	2-1, 110–112	3.90		1.78	2.74	51.53	37.89		T top
635A	2-2, 80–82	5.10		1.74	2.8	62.13	55.45		T bottom

Asterisks indicate samples used to compare physical-property values of the bottom and top parts of the turbidites (*T*) with their corresponding background sediment (Fig. 5 and Table 2). Data from Hole 634A are from Austin, Schlager, et al. (1986).

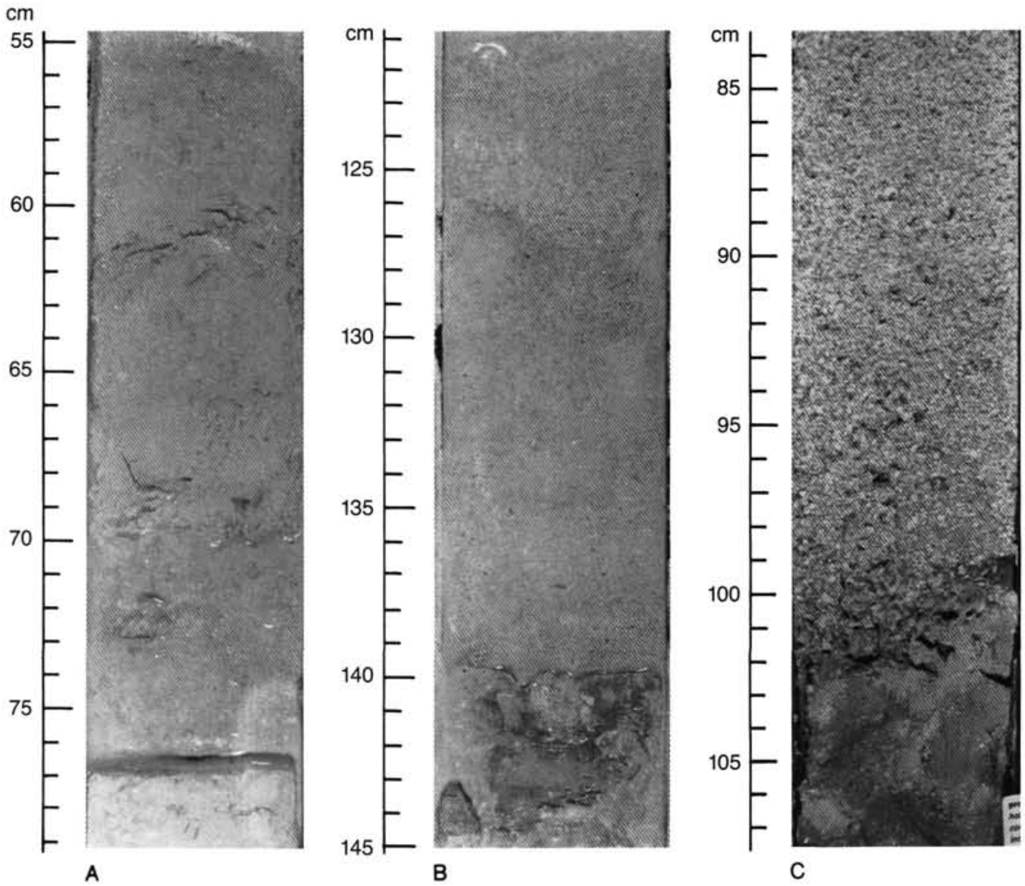

Figure 2. Examples of unlithified calciturbidites within white, stiff periplatform ooze. A. Sample 101-632A-3H-3, 70–76.5 cm. Thin, fine-grained turbidite with a sharp lower boundary at 76.5 cm and an indistinct upper boundary at 70 cm. B. Sample 101-632A-3H-3, 140 cm. Base of a medium-to-fine sand calciturbidite with a possible erosional basal groove of approximately 5 mm at 140 cm. C. Sample 101-635A-1R-2, 101 cm. Base of a dry, coarse-grained turbidite at 101 cm.

Calcium carbonate content of the turbidites (Table 1) was determined onshore using a vacuum-gasometric technique with an accuracy of 0.25% (Jones and Kaiteris, 1983). To compare these results with measurements obtained aboard ship using the carbonate-bomb technique, several samples were remeasured onshore. Data obtained onshore showed an average of 7% lower carbonate content values. The discrepancy might be the combined result of two factors: (1) accuracy of the carbonate-bomb technique is only 4.0% (Müller and Gastner, 1971), although it is probably the best technique for routine carbonate content determinations (Chaney et al., 1982); (2) the sea-state-dependent weighing aboard ship might have added further error. Carbonate contents listed in Table 1 display the values obtained using the vacuum-gasometric technique.

Results

Curves of physical properties vs. depth given in ODP Leg 101 site chapters (Austin, Schlager, et al., 1986) show that the different diagenetic gradients at various sites are reflected in physical-property data. For example, all Exuma Sound holes show steeper diagenetic gradients than those of Little Bahama Bank holes (i.e., lithification occurs at shallower depths below the seafloor). As a result, water content and porosity decrease more rapidly and bulk density and sonic velocity are higher than at similar depths in the Little Bahama Bank holes (Austin, Schlager, et al., 1986). These same parameters are used here to quantify the lithification differences between the background sediment and the turbidites.

Unlithified Sections

Turbidites in the first 20 mbsf tend to have lower water contents and porosities and higher densities than does the background sediment. Downhole these parameters are reversed, the turbidites showing increased water contents and porosities (up to 22% and 17%, respectively) and decreased (by as much as 0.4 g/cm^3) bulk densities, over the values for the periplatform ooze.

However, individual turbidite beds display internal variations. A general trend from the base toward the top of a graded bed can be observed (Fig. 4). The coarse-grained base usually has the highest water content and porosity and lowest bulk density, whereas, toward the top of the bed, water content and porosity decrease and bulk density increases. For example, in the 1.5-m-thick turbidite starting at 145.4 mbsf in Hole 627B (Section 101-627B-16H-4), water content decreases by 22.05% (from 62.31% to 40.26%) and porosity drops by 12.53% (from 65.83% to 53.30%) from the bottom to the top of the turbidite. Within the same interval, density increases by 0.15 g/cm^3 (from 1.71 to 1.86 g/cm^3) (Table 1). These internal variations are probably directly related to upward-decreasing grain size within the graded turbidites, which results in better sorting and denser packing in the fine-grained fraction of the bed.

When comparing physical-property values of the turbidites with those of the background sediment, variations within the turbidite must be considered. To account for the internal variations, each boundary of the turbidite is considered separately in its relationship to the host sediment. In addition, only immediately adjacent physical-property values (i.e., values within the same interval of the core) are compared in order to avoid the effect of downhole variations as a result of increasing overburden pressure. Therefore, the upper value within a turbidite is com-

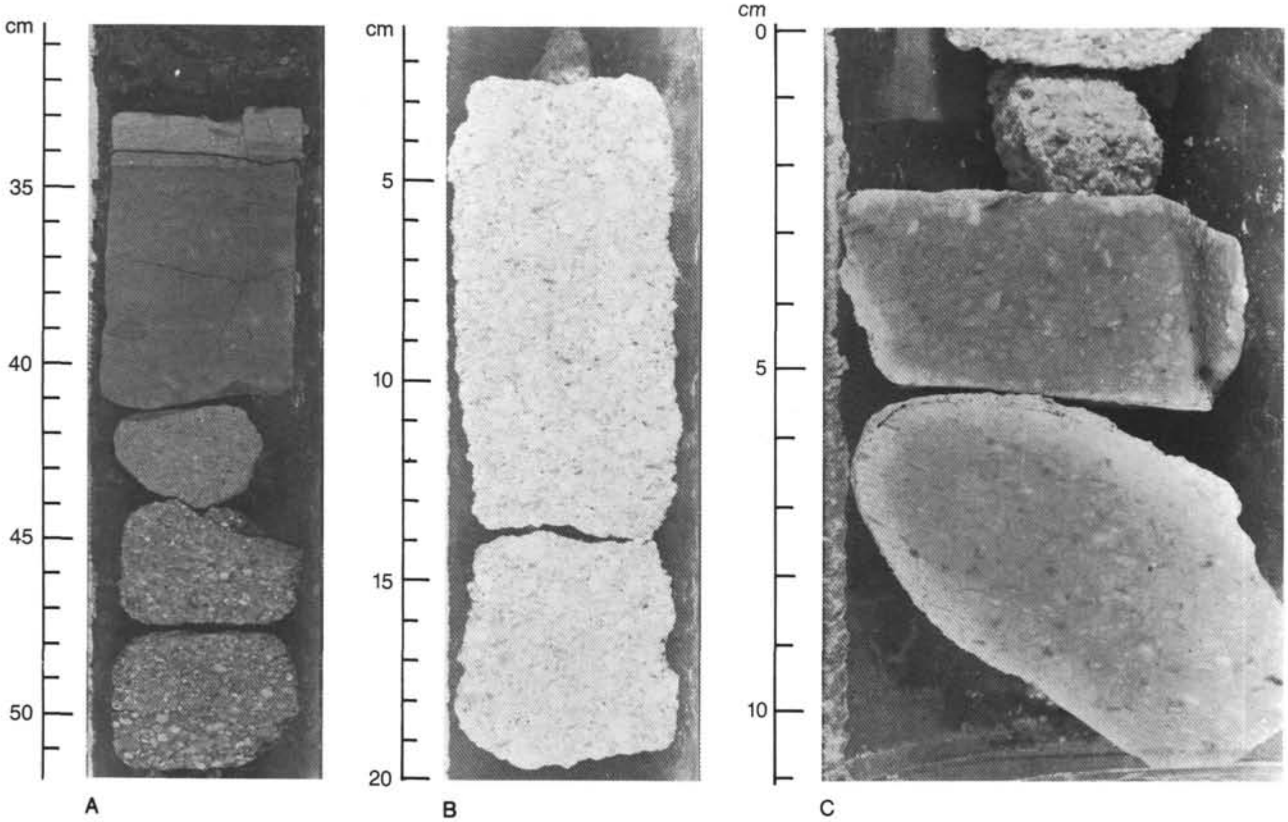

Figure 3. Examples of lithified calciturbidites. A. Sample 101-635B-12R-2, 30–53 cm. Calciturbidite displaying a complete Bouma cycle interbedded in black, nannofossil chalk. B. Sample 101-634A-29R-1, 0–20 cm. Lithified rudstone, probably deposited by a high-density turbidity current. C. Section 101-634A-16R, CC. Silicified fragment of turbidite with ghosts of lithoclasts and biodetrital debris.

pared only with the value of the overlying background sediment and the basal value only with the corresponding underlying background sediment. Thus, as the result of subtracting the physical-property value of the background sediment from the turbidite, a negative number means that the turbidite has a lower water content, porosity, or density than the periplatform ooze; a positive number indicates the opposite.

This procedure allows evaluation of both the upper and the lower boundaries of a turbidite while indicating the excursions of the turbidite values from those of the host sediment. Thicknesses of nine of the measured turbidites allow such a boundary evaluation (Table 1). The mean difference over each boundary of the nine turbidites reveals that a disparity between the two transitions exists (Fig. 5 and Table 2). The differences are most significant for water content and porosity, especially at the upper boundary, where all values show a consistent trend (Table 2). The wide range in standard deviation is partly the result of changing values downhole due to increasing overburden pressure. Data collected at constant depth would probably produce much smaller standard deviations but indicate a similar trend.

Water content displays the widest range; at the top of the turbidites it is on average 9.4% (43.7% and 53.1%, respectively) lower than that of the overlying background sediment, whereas at the bottom it is 5.4% higher than in the underlying background sediment (Fig. 5). However, the higher water content at the bottom is observed only in five of the nine measured turbidites. The coarse and medium sand-sized bottom part of the turbidites dewaters during splitting and sampling of the core; thus, the bottom part of the turbidites displays anomalously low but unquantifiable water content values. However, because most of the turbidites appear as soupy intercalations within the stiffer carbonate ooze, most sandy turbidite bottoms may have had an initially higher water content. In the upper part of most of the measured turbidites, dense, fine-grained packstone occurs. This lithology is often more indurated than the main body of the turbidite and consequently has a lower water content.

Porosity displays the most consistent trends. Compared with the corresponding background sediment, it is on average 5.7% higher (61.7% and 56.0%, respectively) in the bottom of the nine turbidites but 2.7% lower at the top (Table 2). Bulk density remains unchanged at the lower boundary, but seven of nine turbidites show a higher density ($+0.08$ g/cm^3) at the top of the turbidite as compared with the overlying periplatform ooze (Fig. 5 and Table 2). The weak consistency of the bulk-density trends is the combined result of (1) variable grain densities between the turbidites and (2) limited accuracy of individual measurements.

Lithified Sections

Below 140 mbsf in Hole 634A, nannofossil chalk is the host sediment for detrital limestone. The section is completely indurated, but recovery was poor. Apparently, the chalk disintegrated during drilling and was washed away, leaving only the harder grainstone and rudstone in the core barrel (Austin, Schlager, et al., 1986). This exemplifies an important characteristic of the lithified section, namely that the redeposited beds are more competent.

One consequence of the poor recovery was that sampling for the destructive gravimetric and volumetric measurements of the index properties was reduced. Therefore, compressional-wave velocity is used in this section (Hole 634A) to quantify the differences in physical properties of the background sediment with

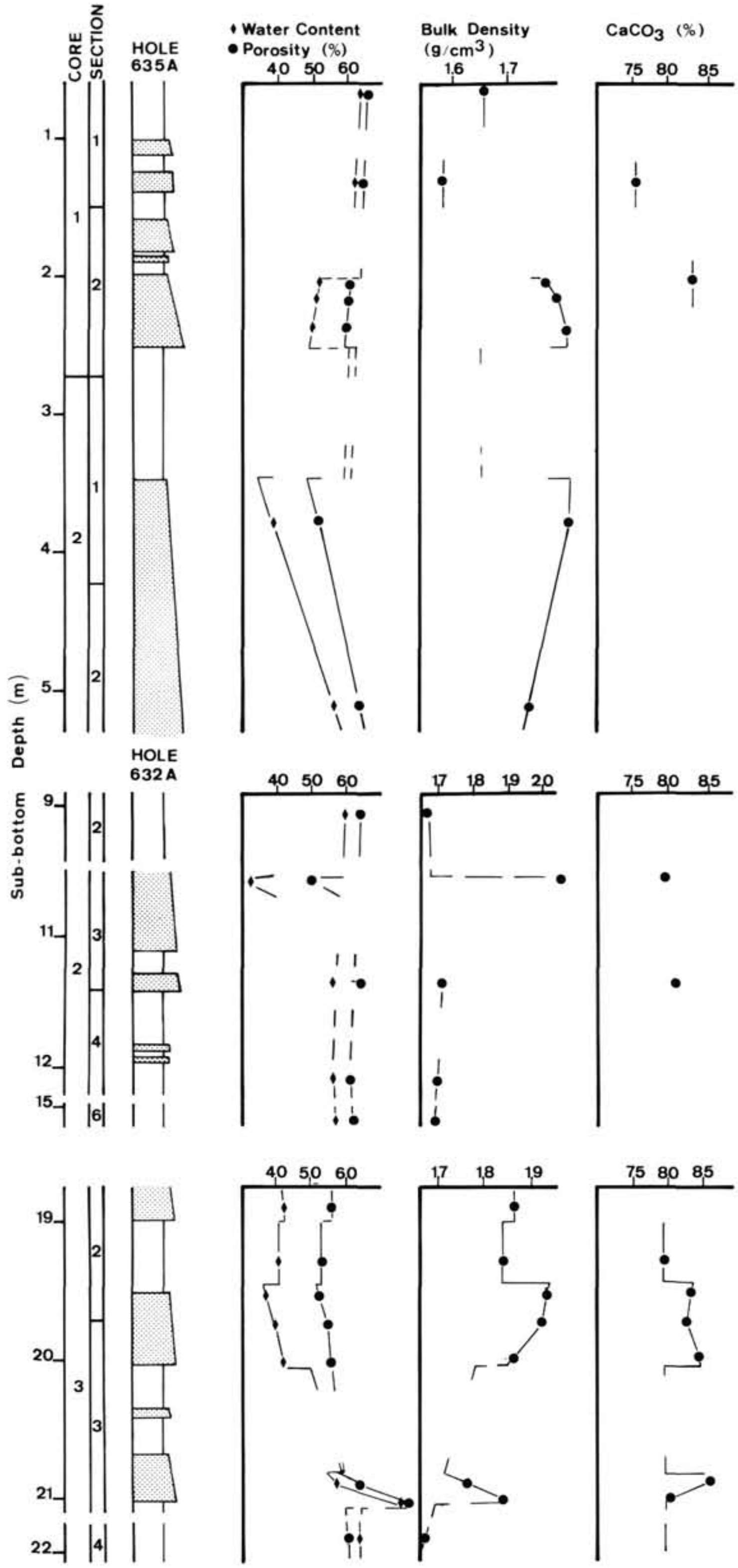

Figure 4. Index properties (water content, porosity, bulk density, and carbonate content) of the calciturbidite sequences, grouped according to burial depth. Sub-bottom depth, core, and section are given on the left; schematic drawing of the section indicates turbidites (shaded areas) and background sediment (blank space). Note the variation within the individual turbidites and resulting differences from the periplatform ooze.

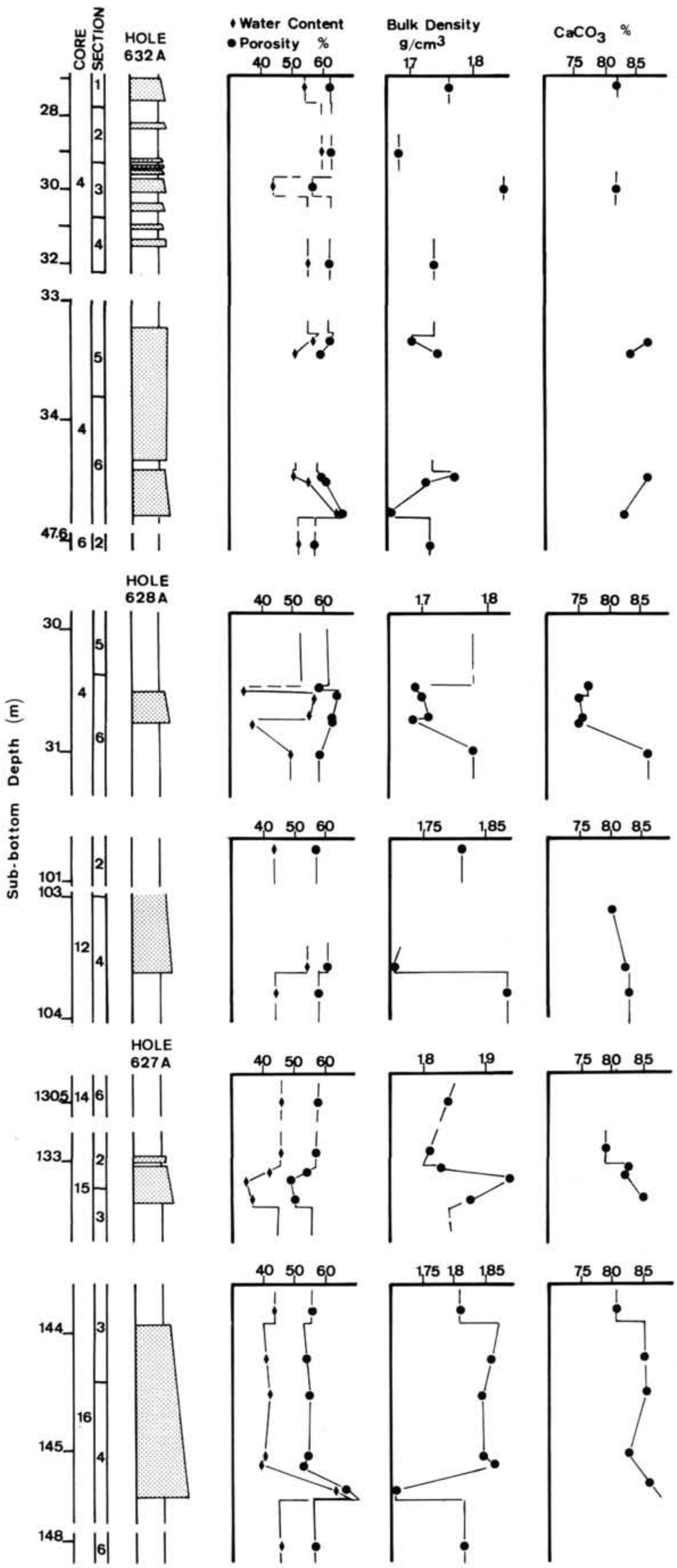

Figure 4 (continued).

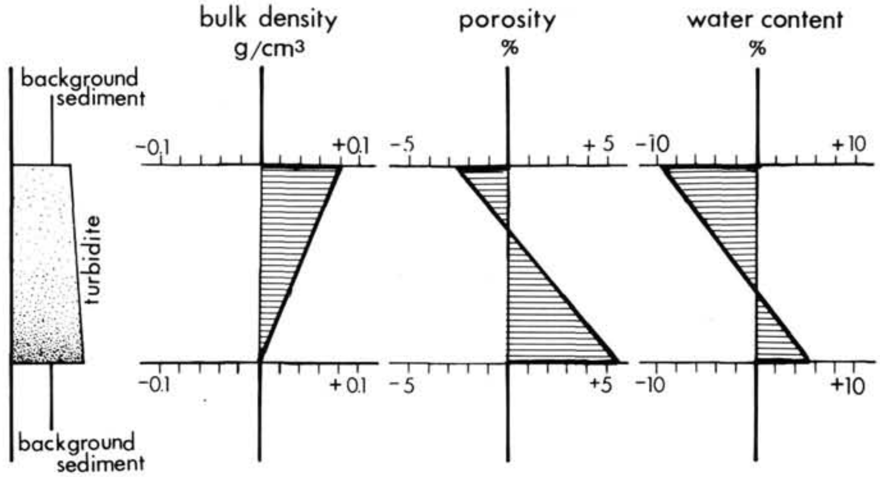

Figure 5. Excursion of the index-property values of the turbidites from the mean value of the background sediment (vertical line). As indicated by the positive excursion over the lower boundary of the turbidite, the bottom of the turbidites has, on average, a higher water content and porosity than does the underlying periplatform ooze. The negative excursion in the upper part of the turbidite indicates lower water content and porosity in the fine-grained top of the turbidites compared to the overlying background sediment. Density does not vary at the lower boundary, but the fine-grained upper part of the turbidites has a higher bulk density than the overlying ooze. These general trends indicate the great variation of the physical properties within the turbidites and the resultant development of two distinct surfaces at both the lower and the upper boundaries of each turbidite. For data base, see Table 1; for average numbers, see Table 2.

Table 2. Mean physical-property values ($\bar{x}$) from the bottom and top of nine turbidites and corresponding background sediment (Table 1).

	$\bar{x}$ Water content (%)		$\bar{x}$ Porosity (%)		$\bar{x}$ Density (%)	
Overlying ooze	$\bar{x}$ = 53.15 s = 8.7	$\Delta\bar{x}$ = −9.4	$\bar{x}$ = 58.94 s = 4.5	$\Delta\bar{x}$ = −2.7	$\bar{x}$ = 1.74 s = 0.07	$\Delta\bar{x}$ = +0.08
Turbidite top	$\bar{x}$ = 43.71 s = 9.8	n = 9(9)	$\bar{x}$ = 56.22 s = 5.0	n = 9(9)	$\bar{x}$ = 1.81 s = 0.14	n = 9(7)
Turbidite bottom	$\bar{x}$ = 54.64 s = 12.4	$\Delta\bar{x}$ = +5.4	$\bar{x}$ = 61.76 s = 8.1	$\Delta\bar{x}$ = +5.7	$\bar{x}$ = 1.76 s = 0.08	$\Delta\bar{x}$ = −0.004
Underlying ooze	$\bar{x}$ = 49.21 s = 9.9	n = 9(5)	$\bar{x}$ = 56.08 s = 6.6	n = 9(7)	$\bar{x}$ = 1.77 s = 0.08	n = 9(3)

Note: s = standard deviation. $\Delta\bar{x}$ = difference between turbidite values and corresponding background sediment. n = 9; numbers in parentheses indicate number of transitions following the trend given by $\Delta\bar{x}$. Note the number of consistent trends for water content and porosity, especially at the upper boundary.

respect to the turbidites. Sonic velocity of the host sediment (chalk) varies between 1600 and 2055 m/s, increasing downhole. Graded grainstone and rudstone (turbidites) have higher velocities, between 2100 and 4400 m/s (Fig. 6). The highest recorded velocity, 6350 m/s, was measured in a completely silicified fragment of a turbidite (Austin, Schlager, et al., 1986) (Fig. 3B). Within the chalk, chert nodules and pieces of reworked, lithified rudstone also display significantly higher velocities (Fig. 6). These velocity differences suggest that the turbidites form the more competent layers within the lithified section, thus supporting the explanation drawn from the recovery record. This is in contrast to the unlithified sections of the holes discussed previously, where turbidites are soupy intercalations within stiffer carbonate ooze.

However, the mineralogy of the background sediment is changed in Hole 634B, which suggests that the velocity difference between background sediment and turbidite is influenced by mineralogical composition. In the lithified section of Hole 634A, where the background sediment is a nannofossil ooze, a velocity difference is found (Fig. 6 and Table 1). In contrast, the lithified part of Hole 632A in Exuma Sound is an intercalation of lithified periplatform ooze and turbidites. In this case, the velocity differences are minimal, and both the white limestone and the interbedded grainstone have fairly high velocities (approximately 4000 m/s) (Austin, Schlager, et al., 1986).

Dissimilar mineralogies of turbidite and background sediment result in a differential diagenesis that causes differences in porosity and velocity. At Site 634, the mineralogical dominance of calcite in the pelagic ooze over metastable aragonite in the platform-derived turbidites results in an earlier diagenetic alteration of the turbidites. Consequently, the connecting pore spaces are interrupted in the coarser grained, aragonite-rich turbidite earlier than in the calcitic nannofossil ooze. This process is recorded in the porosity data. The chalk has porosities of between 35% and 53%, whereas in the aragonite-rich turbidite beds porosity is 11% to 30% (Table 1).

In contrast, in sections where both the background sediment and the turbidite are predominantly aragonitic, grain size determines the differential diagenesis and consolidation (Fig. 4). In this case, diagenetic alteration and cementation occur first in

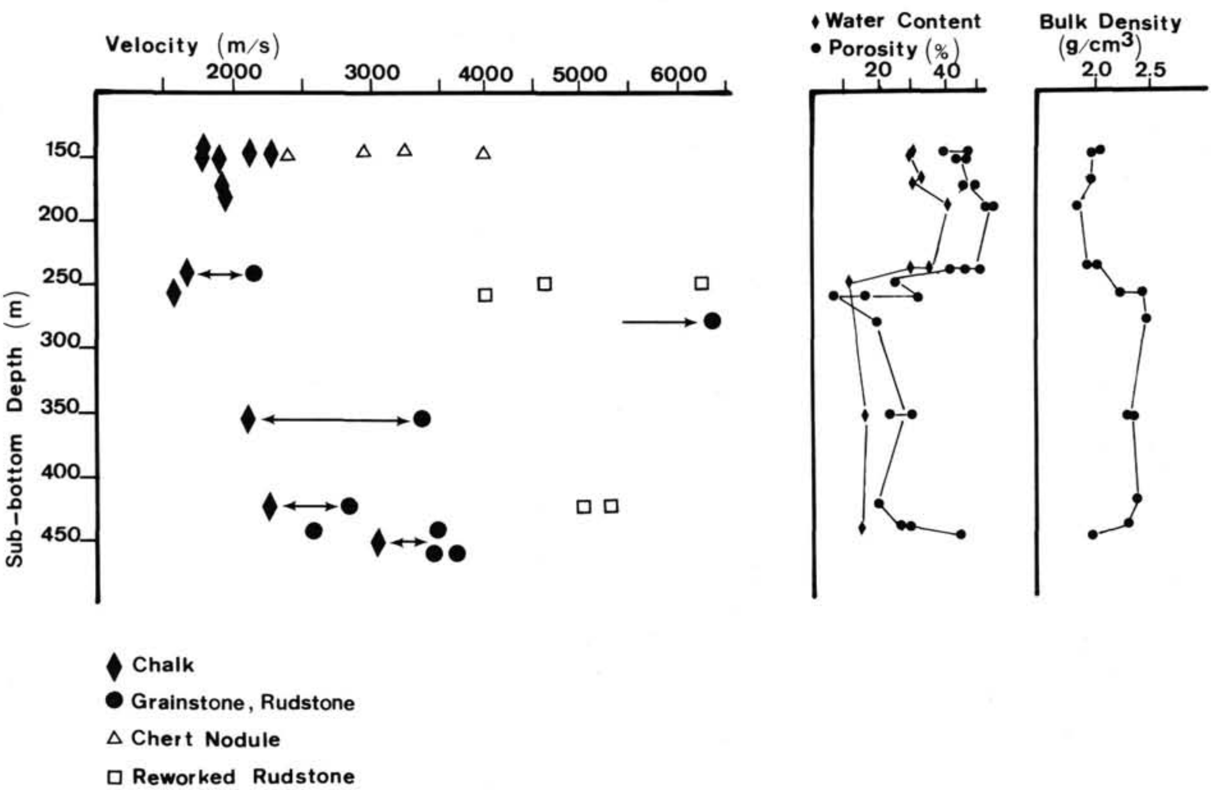

Figure 6. Sonic velocity and index properties in the lithified part of Hole 634A. Arrows in the velocity plot connect turbidites (solid points) with their corresponding background sediment (solid diamonds). Note the generally higher velocity in the platform-derived turbidites (grainstone, rudstone) compared to the nannofossil chalk.

the fine-grained periplatform ooze. For example, in the lithified section of Hole 632A below 104.7 mbsf, the background sediment is dense limestone, whereas the turbidites are porous grainstone and packstone (Site 632 chapter, Austin, Schlager, et al., 1986).

The differential diagenesis and the resultant disparity in porosity between the turbidites and the background sediment might also influence the development of fluid conduits. In the nannofossil/turbidite sequence of Hole 634A, more pore space is preserved in the calcitic, pelagic background sediment than in the interbedded turbidites. In the lithified periplatform/turbidite sequences of Holes 632A and 633A, the coarse-grained turbidites show secondary porosity and are locally impregnated with small quantities of tar (Austin, Schlager, et al., 1986), which suggests that fluid migration predominantly occurs in the redeposited beds.

DISCUSSION AND CONCLUSIONS

Differences in physical-property characteristics between redeposited and background sediment are a function of both grain size and mineralogical content. In unlithified and semilithified carbonate turbidite/periplatform sequences, the physical-property data indicate that dewatering occurs in the porous, sand-sized interval of the turbidites. This water-rich layer is sealed by the dense, fine-grained part of the turbidites. As a result, two distinct surfaces develop at both the lower and the upper boundaries of each turbidite. Both surfaces are overlain by more porous, water-rich layers. Such a relation within a sedimentary column can be crucial for slope stability, as the water-rich layers are prone to develop excess pore pressure, which leads to decreased shear strength and eventually to slope failure (Whitman, 1985). The data suggest that the bottom parts of the turbidites contain the most interstitial water and are therefore most likely to be horizons along which slope failure could occur.

Systematic shipboard measurements of shear strength, which coincide with the investigated turbidites, suggest a decreased shear strength within the turbidites below 20 m sub-bottom. At a depth of 35 m sub-bottom in Hole 632A (Section 101-632A-4H-6), the shear strength within the turbidite is approximately 10 times smaller than that in the underlying periplatform ooze (1.5 and 15.3 kPa, respectively; Austin, Schlager, et al., 1986, p. 40). In the 1.5-m-thick turbidite at 145 m sub-bottom in Hole 627B (Section 101-627B-16H-4), the difference is even greater (6.35 and 102.8 kPa, respectively) (Austin, Schlager, et al., 1986, p. 147).

Assuming that turbidites within the sedimentary column are possible instability horizons, major mass movements, such as slumping and creeping, would be expected in sections containing numerous redeposited beds. Sediments recovered along the two platform/basin transects drilled during Leg 101 indicate that turbidites start to accumulate on slopes with declivities of less than 3° and are preferentially deposited in the basinward area where the declivity is less than 1° (Austin, Schlager, et al., 1986). Along the Little Bahama Bank transect, seismic line LBB-18 displays more thrust faults, suggesting large-scale mass movements between the toe-of-slope (Site 628) and the basinward site (Site 627) than in the upper part of the slope (Site 630) (Austin, Schlager, et al., 1986). In Exuma Sound, most of the sediment gravity flows bypass both the steep, upper slope (declivity 12°) as well as the midslope and are deposited on the basin floor at Site 632 (Austin, Schlager, et al., 1986). In the slope area (Site 631), where turbidites are rare and thin, large slump masses are indicated by seismic and biostratigraphic data (Austin, Schlager, et al., 1986). The style and frequency of slumping on the slopes of Exuma Sound, however, differ from those of Little Bahama Bank. At the toe-of-slope north of Little Bahama Bank, mass movements are indicated by a series of small thrusts, whereas in Exuma Sound only three large slump masses are recognized in an analogous position on the slope (Austin, Schlager, et al., 1986). This difference could arise because gravitational stress along Little Bahama Bank is more frequently released at the abundant instability horizons (i.e., turbidites), whereas larger amounts of stress can be accumulated in the more homogeneous section in Exuma Sound, before larger slump masses are produced.

The physical-property characteristics of lithified sections indicate the influence of mineralogical composition on differential diagenesis and development of conduits. If platform-derived turbidites are emplaced in a pelagic nannofossil ooze rather than in a periplatform ooze, the metastable carbonates in the turbidite promote an earlier lithification relative to the background sediment. This differential diagenesis could result in dissimilar styles of fluid migration in these carbonate sequences. In the periplatform sequence the turbidites act as conduits, whereas in the more pelagic sequences interconnecting pore spaces are maintained longer in the nannofossil chalk.

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