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39. THE ORIGIN OF SMALL-SCALE BULK DENSITY ANOMALIES IN MIOCENE SEDIMENTS AT OCEAN DRILLING PROGRAM SITE 645, BAFFIN BAY[1]

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ABSTRACT

Terrigenous sediments between 800 and 1147 mbsf at Site 645 in Baffin Bay display intervals tens of centimeters thick, in which wet-bulk density either rapidly increases or decreases. Grain-size analyses were performed on multiple samples from these anomalous intervals to determine if the density change is a response to textural variation. Analyses indicate a weak correspondence at best between grain size and density variation. The correlation is not sufficiently strong to use the density records as direct grain-size indicators.

INTRODUCTION

Miocene sediments at Ocean Drilling Program (ODP) Site 645 in Baffin Bay display intervals of rapid increases and decreases in wet-bulk density in a section, 800–1147 mbsf, marked by a gradual increase in density with depth, 2.71×10^{-4}g/cm^3/m. These density anomalies, which range in thickness from 0.35 to 1.40 m, were identified from Gamma Ray Attenuation Porosity Evaluator (GRAPE) records. Visual estimates of sediment texture in the intervals suggest that the density variation corresponds with changes in grain size and sorting. Because the magnitude of the size change is small and the boundaries of the units gradational, it was usually easier to identify the extent of the intervals of textural change from the GRAPE records. Significant changes in composition that would affect wet-bulk density, such as variation in biogenic silica or abundance of organic carbon, are not present in the 800–1147 mbsf section at Site 645 (Srivastava, Arthur, et al., 1987). The objective of this study was to test the hypothesis that these density anomalies result from grain-size variation.

Determination of grain size was limited to the measurement of the size distribution of silt-size particles, 4–62 μm in diameter (8–4 ϕunits). This size fraction was chosen because the distribution of particles in this range could be determined precisely and rapidly. By limiting the analysis to silt particles, one can assume that size variation in this fraction will reflect size variation in the total population of sediment grains.

Sediments displaying the density anomalies at Site 645 are contained in lithologic Units IIIB and IIIC (Srivastava, Arthur, et al., 1987). Subunit IIIB (753.4–916.8 mbsf) is middle Miocene in age and consists of terrigenous silty mudstones, calcareous silty claystones, and muddy sandstones. Subunit IIIC (916.8–1147.1 mbsf) is early to middle Miocene in age and consists of terrigenous muddy sandstones and silty mudstones. Bottom-current transport is recognized as the dominant process during deposition of both subunits (Srivastava, Arthur, et al., 1987). Bottom-current activity waned during the deposition of lithologic Unit III, and the importance of turbidity currents and ice rafting increased. Mud turbidites are a minor component of Subunit IIIB.

METHODS

Continuous wet-bulk density profiles were obtained for all core sections from Hole 645E using the GRAPE device. Details concerning the operation and performance of the GRAPE system have been provided by Boyce (1976). A correction for nonuniform core diameter was not applied to the GRAPE data. A nearly full, uniform diameter characterizes the intervals selected for grain-size analysis. Core recovery was excellent for most of lithologic Units IIIB and IIIC, and many core sections are continuous and uniform in diameter.

Nineteen intervals from 12 cores were selected for grain-size analysis. Twelve intervals display an upward decrease in wet-bulk density (positive density gradient), and seven intervals display an upward increase in density (negative density gradient). Intervals were selected on the basis of the regularity of the density trends on the GRAPE records. Core photographs verified the core-diameter uniformity. Figure 1 shows the depths of the tops of the cores containing the intervals analyzed and the wet-bulk density profile of Subunits IIIB and IIIC. The density profile in Figure 1 is based on shipboard gravimetric and volumetric measurements of "chunk" samples taken from the cores.

Size distribution of the silt fraction was determined with an electroresistance particle analyzer (Elzone Model 180XY). The silt was isolated by wet sieving at 62.5 μm to remove sand and by centrifuging to remove clay-size particles. Before silt separation, the samples were treated with pH-neutralized, concentrated hydrogen peroxide to remove organic

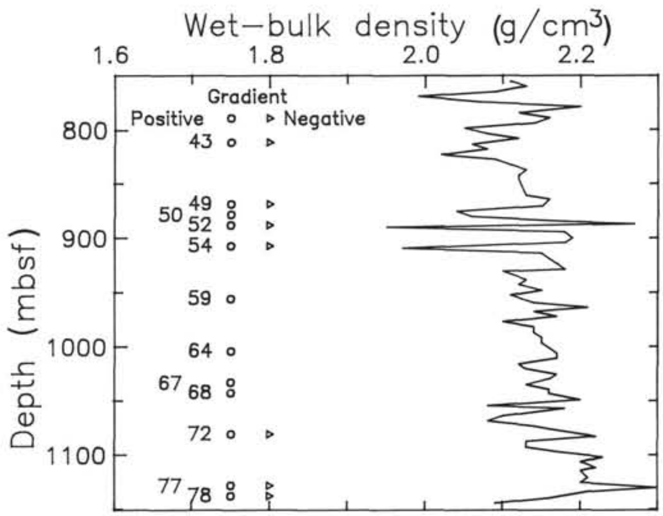

Figure 1. Depths of cores containing density anomalies for which the silt-size distribution was determined, and the wet-bulk density vs. depth for lithologic Units IIIB and IIIC at Site 645.

[1] Srivastava, S. P., Arthur, M., Clement, B., et al., 1989. *Proc. ODP, Sci. Results*. (*Pt. B*), 105: College Station, TX (Ocean Drilling Program).

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matter, rinsed to remove salts, and sonified in an ultrasonic bath to facilitate disaggregation. Size analysis consisted of counting 20,000 particles, using a 190 μm orifice and silt suspensions with concentrations of approximately 1100 particles/mL. Analyses were repeated until volumetric medians were duplicated within 0.10 ϕ.

RESULTS AND DISCUSSION

Figures 2, 3, and 4 show the plots for wet-bulk density, silt-fraction mean diameter, and standard deviation (sorting) vs. depth for the intervals analyzed. The density profiles shown in these figures depict the GRAPE data smoothed by applying a low pass filter set at a frequency of 0.30 cycles/point, equivalent to a resolution of approximately 2 cm. Comparison of the GRAPE data with the discrete-sample density profile (Fig. 1) reveals that the GRAPE densities are consistently lower. This difference may be the product of a core diameter less than that assumed when processing the GRAPE data. Grain densities measured in Subunits IIIB and IIIC are within 0.10 g/cm^3 of the 2.60 g/cm^3 used in the GRAPE data processing.

Intervals with positive density gradients on the GRAPE records range in thickness from 0.70 to 1.40 m and display gradients of 0.05 to 0.24 g/cm^3/m (Table 1). Patterns displayed by plots of mean silt size vs. depth for these intervals (Figs. 2 and 3) include (1) continuous upward decrease in grain size (Cores 105-645E-43R, -49R, and -54R); (2) discontinuous upward decrease in grain size (Cores 105-645E-50R, -52R, -59R, -67R, -68R, -77R, and -78R); and (3) discontinuous upward increase in grain size (Cores 105-645E-64R and -72R).

Intervals with negative density gradients are typically thinner than the positive-gradient intervals, ranging in thickness from 0.35 to 0.95 m, and display a wide range of gradients, -0.02 to -0.58 g/cm^3/m (Table 1). Grain-size–depth patterns for these

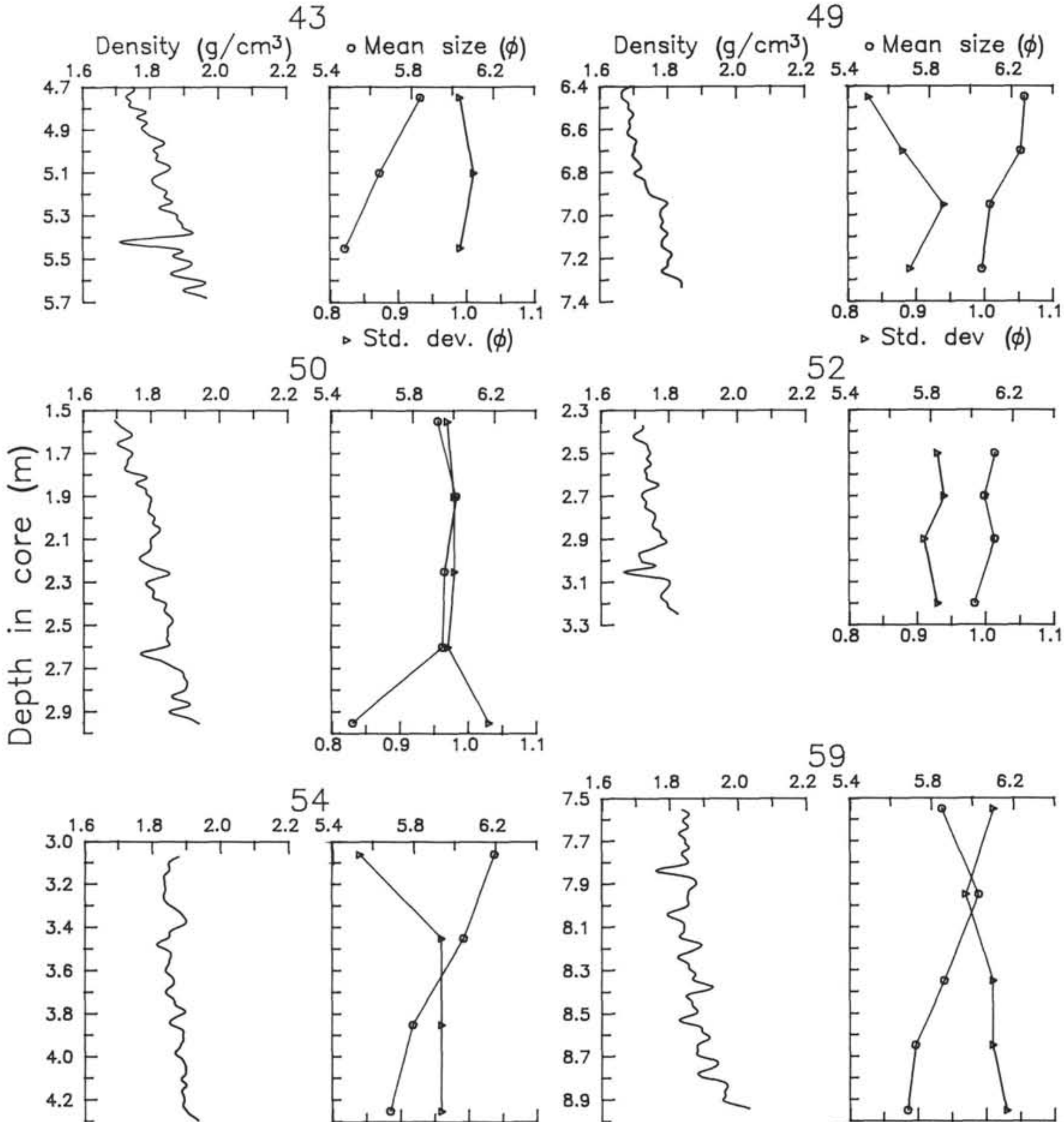

Figure 2. Wet-bulk density, mean diameter (silt), and standard deviation vs. depth in core for intervals displaying positive density gradients, Cores 105-645E-43R, -49R, -50R, -52R,-54R, and -59R. Grain size is expressed in ϕ units, where $\phi = -\log_2$ (diameter in millimeters).

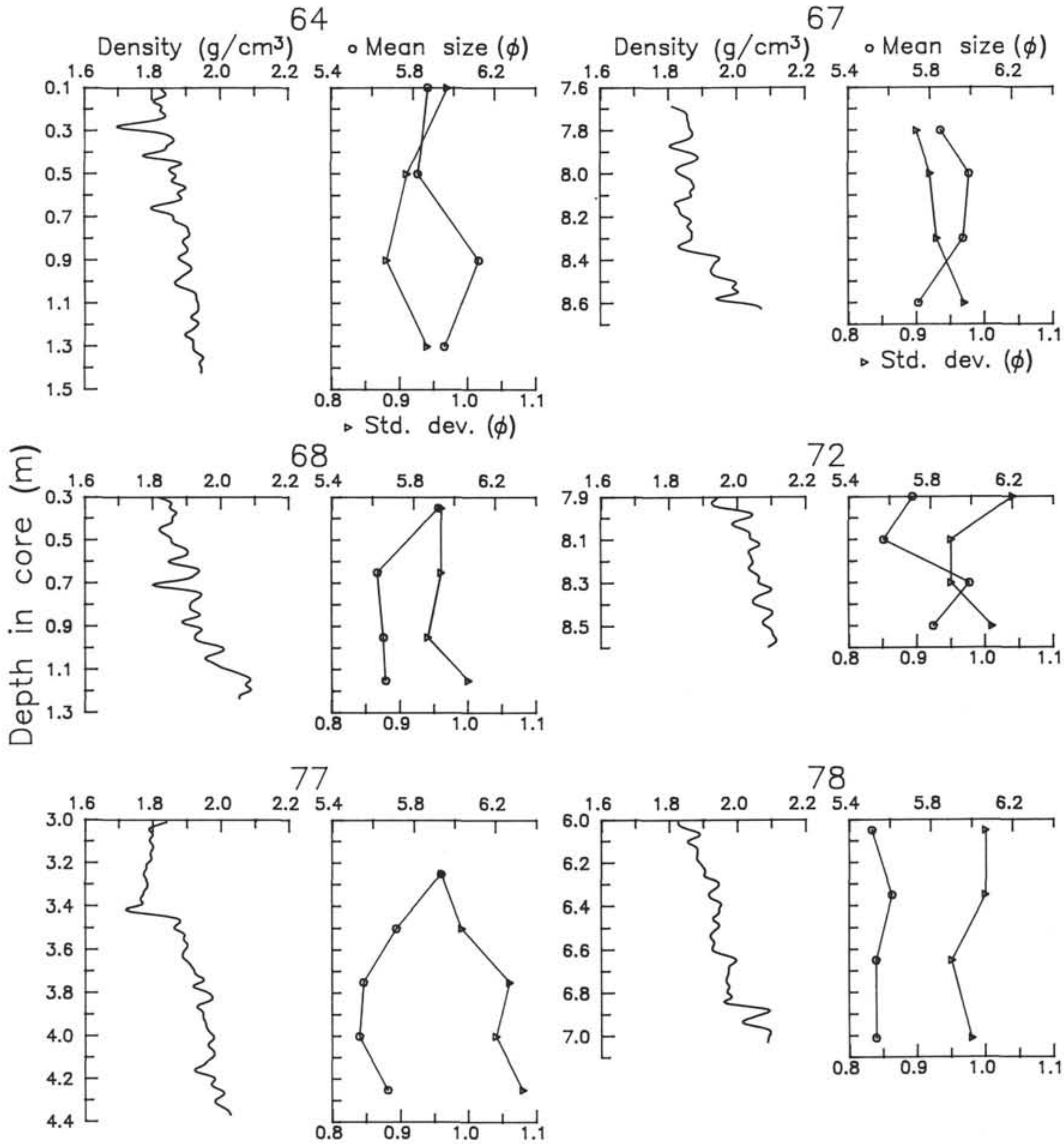

Figure 3. Wet-bulk density, mean diameter (silt), and standard deviation vs. depth in core for intervals displaying positive density gradients, Cores 105-645E-64R, -67R, -68R, -72R, -77R, and -78R.

intervals (Fig. 4) include (1) continuous upward increase in grain size (Cores 105-645E-72R and -77R); (2) discontinuous upward increase in grain size (Cores 105-645E-52R and -78R); and (3) continuous and discontinuous upward decrease in grain size (Cores 105-645E-43R, -49R, and -54R).

The slopes from linear best-fit lines through the size-depth data are used to estimate the change in grain diameter that can be compared with the bulk density gradients. Table 1 lists these silt-size gradients, and Figure 5 shows them plotted with the density gradients. Because of the limited number of particle-size analyses, the size gradients are a crude representation of the size change for the density anomalies. The data in Figure 5 display a wide range of variation, and the correlation coefficient between size gradient and density gradient is 0.48. However, if the data are divided into subsets, one being those data for which there is a direct relationship between size and density and the other a set with an inverse size-density relationship, the correlation coefficients for the subsets are 0.88 and 0.99, respectively.

Meade (1966) suggested that terrigenous sediments typically display a direct relationship between grain size and bulk density from the seafloor to burial depths near 1000 m, and that below 1000 mbsf the relationship is an inverse one. The occurrence of intervals in Hole 645E displaying direct and inverse size-density relationships is not depth dependent. One should view the high degree of correlation of density and size gradients for intervals displaying inverse relationships skeptically because of the large variation in the grain-size data.

The standard deviation (sorting) of the silt-size distribution displays little variation in the density anomaly intervals (Figs. 2, 3, and 4). Dependency of wet-bulk density on sediment sorting is not apparent from these data. The general trend of the sorting data for intervals displaying positive and negative density gradients is increasing standard deviation with increasing grain size.

Wet-bulk density determination by the GRAPE device is the only continuous data routinely collected from all intact sediment cores. Establishing factors that control the variation of

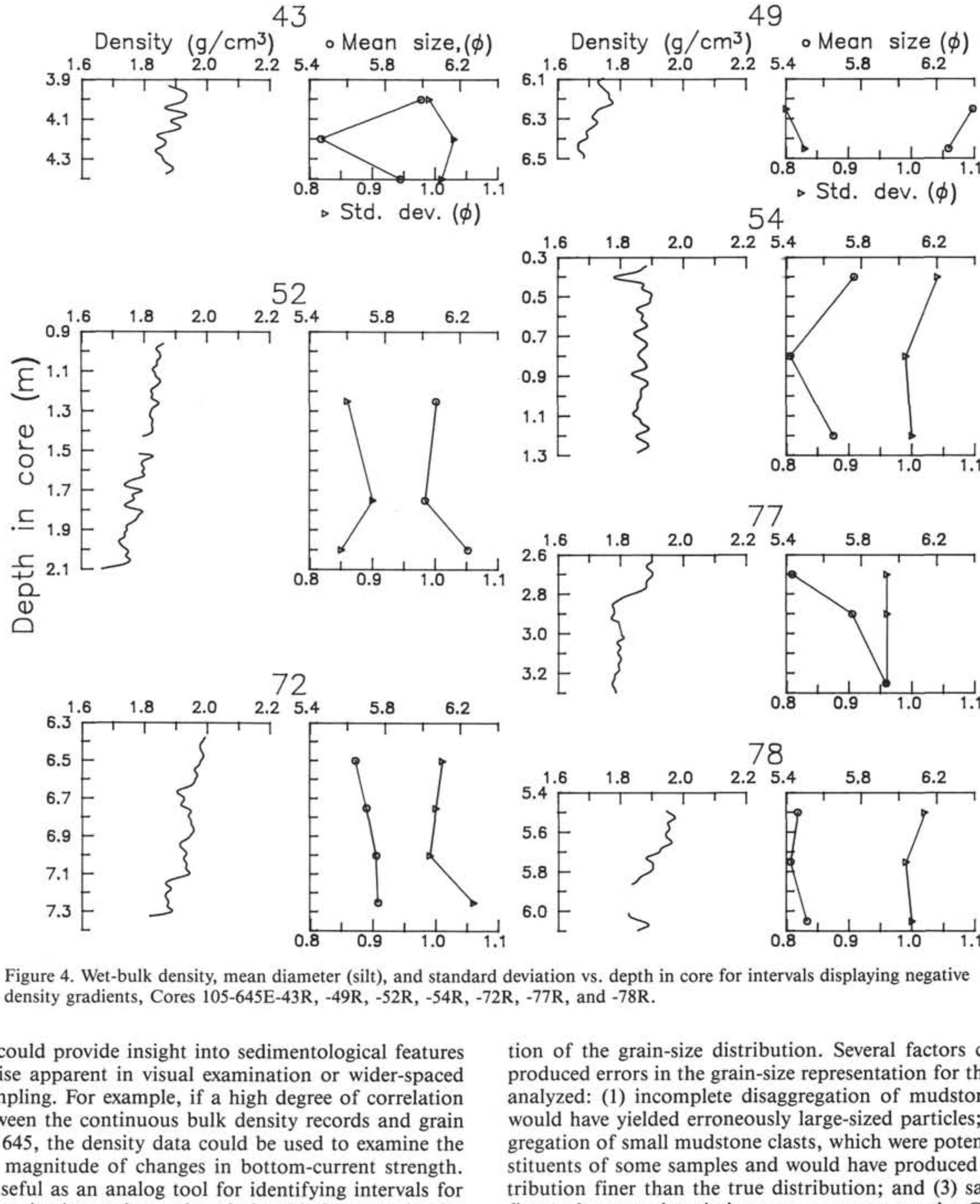

Figure 4. Wet-bulk density, mean diameter (silt), and standard deviation vs. depth in core for intervals displaying negative density gradients, Cores 105-645E-43R, -49R, -52R, -54R, -72R, -77R, and -78R.

these data could provide insight into sedimentological features not otherwise apparent in visual examination or wider-spaced discrete sampling. For example, if a high degree of correlation existed between the continuous bulk density records and grain size at Site 645, the density data could be used to examine the period and magnitude of changes in bottom-current strength. Although useful as an analog tool for identifying intervals for subsequent grain-size analyses, the relationship between density and grain size is not good enough to allow calibration of the density records. Grain size shows a continuous trend that matches the continuous trend of the density data in only five of the 19 intervals examined. Nine intervals display discontinuous grain-size variation and profiles marked by a reversal in the size trend at some point; five intervals display an apparent inverse relationship between grain diameter and wet-bulk density. The origin of an inverse relationship is enigmatic because intervals displaying this pattern are interbedded with intervals for which a direct correlation between grain size and density exists.

The reversal in size trends and inverse relationship between grain diameter and wet-bulk density may reflect misrepresentation of the grain-size distribution. Several factors could have produced errors in the grain-size representation for the intervals analyzed: (1) incomplete disaggregation of mudstones, which would have yielded erroneously large-sized particles; (2) disaggregation of small mudstone clasts, which were potentially constituents of some samples and would have produced a size distribution finer than the true distribution; and (3) sampling of fine-scale textural variations not apparent on the GRAPE records. The assumption that variations in the silt fraction reflect variations in the total amount of sediment might also be incorrect. Additional analyses of the other size fractions are needed to evaluate this assumption.

Errors associated with density determination are largely related to varying core diameter. Using relationships provided by Boyce (1976), one can estimate that a 10% variation in diameter will yield a 10% variation in the wet-bulk density. Dependency of the GRAPE data on core diameter is a severe limitation on the data quality. Development of continuous profiling systems that are not sensitive to core diameter, such as a continuous mode X-ray back-scatter device (P. Lysne, pers. comm., 1986)

Table 1. Wet-bulk density and mean silt diameter gradients for density anomaly intervals in Hole 645E.

Core	Depth in core (m)	Interval thickness (m)	Density gradient[a] ($g/cm^3/m$)	Size gradient[a] ($\phi/\mu m$)
105-645E-43R	3.93-4.38	0.45	−0.14	−0.28
43R	4.69-5.68	0.99	0.17	−0.53
49R	6.10-6.45	0.35	−0.27	−0.65
49R	6.45-7.33	0.88	0.19	−0.29
50R	1.55-2.95	1.40	0.13	−0.26
52R	0.96-1.45	0.49	−0.11	0.18
52R	2.37-3.25	0.88	0.10	−0.12
54R	0.35-1.28	0.93	−0.02	−0.14
54R	3.07-4.29	1.22	0.05	−0.45
59R	7.55-8.94	1.39	0.08	−0.18
64R	0.10-1.42	1.32	0.09	0.14
67R	7.69-8.62	0.93	0.16	−0.16
68R	0.30-1.24	0.94	0.24	−0.29
72R	6.38-7.33	0.95	−0.11	0.16
72R	7.90-8.60	0.70	0.14	0.36
77R	2.64-3.30	0.66	−0.58	0.87
77R	3.01-4.37	1.36	0.19	−0.28
78R	5.49-6.05	0.56	−0.22	0.10
78R	6.05-7.03	0.98	0.20	−0.01

[a] Gradients were derived from linear best-fit relationships.

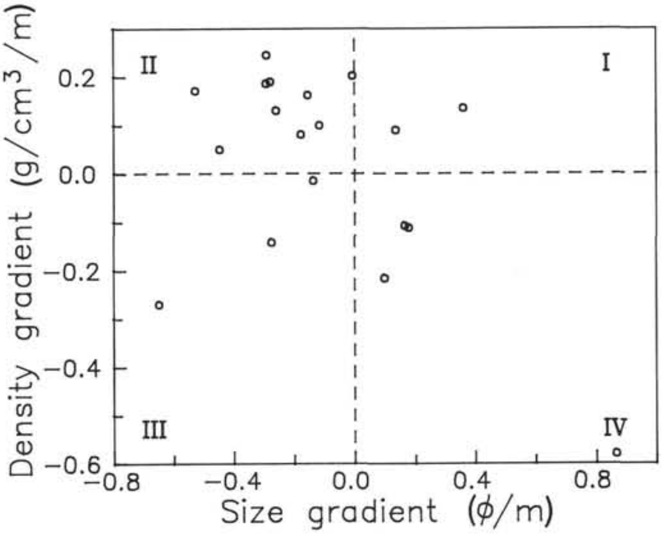

Figure 5. The mean diameter (silt)–depth gradient vs. the wet-bulk density–depth gradient. Data displaying a direct relationship between bulk density and grain size are contained in quadrants II and IV. Data displaying an inverse relationship between density and size are contained in quadrants I and III.

or a laser light-scattering logging system (Werner and Kitzis, 1986) could significantly improve the quality of continuous profiles of lithologic variation.

SUMMARY

Lithologic Units IIIB and IIIC (753.4–1147.1 mbsf) at Site 645 contain intervals 0.35–1.40 m thick that display wet-bulk density gradients ranging from −0.58 to 0.24 $g/cm^3/m$ in a section that displays an overall increase in density with a gradient of 2.71×10^{-4} $g/cm^3/m$. Size distribution of the silt fraction was determined for a series of samples from these intervals to test the hypothesis that density change is a response to grain-size variation. Agreement between the trend of the grain-size and bulk-density variations is weak and not sufficient to use the density profiles as unambiguous records of grain-size change.

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