5. DEVELOPMENT OF COMPOSITE DEPTH SECTIONS FOR SITES 844 THROUGH 854[1]

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INTRODUCTION

A primary objective of Leg 138 was the acquisition of high-resolution records of Neogene climatic change in the equatorial Pacific Ocean. Coincident with this objective was the importance of recovery of a continuous record. If properly done, drilling multiple adjacent holes at a given site helps assure recovery of a continuous record. In the past, confirmation of recovery of a continuous section only occurred after drilling had been completed and even then was difficult. During Leg 138, records from multiple holes were processed and examined during drilling at each site using continuously measured lithologic parameters. This process helped to ensure the recovery of a nearly complete stratigraphic sequence at each site and allowed for changes in drilling plans in real time. Although much of the final analysis of Leg 138 data is here discussed in terms of time, we found it essential that the stratigraphic sections cored were first expressed with a useful depth scale.

After being documented during several DSDP and ODP cruises (e.g., Legs 85, 86, 94, 108, 111, 115, 117, and 121), scientists now know that between successive APC cores in a given hole, part of the sedimentary sequence is often not recovered. To piece together a continuous sedimentary section at the Leg 138 sites, we developed a composite depth section. This depth section was formed by splicing together cores from adjacent holes at a given site. The purpose of the composite section was to describe the entire sedimentary sequence at a given site by referencing each hole to a common depth scale. By identifying the missing parts of the sedimentary sequence from each hole and by patching in from adjacent holes, a continuous record could be sampled. The construction of a complete composite section also provided an initial stratigraphic framework for the site, which allowed us to reference magnetostratigraphic and biostratigraphic events observed in different holes to a common depth scale.

METHODS

After we recovered a core, continuously measured lithologic parameters of the gamma-ray attenuation porosity evaluator (GRAPE) and magnetic susceptibility were measured in the core before it was split. These measurements were available for use almost immediately. In addition, automated color reflectance data (collected in the split sections) provided a third continuously measured lithologic parameter. The benefit of having three different data records available for correlation is clear; integration of these parameters allowed us to correlate among cores from adjacent holes with a high degree of confidence.

A detailed example of how the composite depth section accounts for a missing sequence among holes is presented Figure 1, which shows three GRAPE records from Site 849. At this site, a section of the sedimentary sequence that was missing between Cores 138-849B-10H and -11H was recovered in Cores 138-849C-10H and -849D-10H. Similarly, a section missing between Cores 138-849C-9H and -10H was recovered in Cores 138-849B-10H and -849D-9H. This type of overlapped offset among holes was maintained through almost all of the double or triple APC-cored sites during Leg 138 and through much of the double XCB-cored intervals. The process of correlation between each hole was continued by "sliding" successive cores along a composite depth scale. For each site drilled, a table of the amount of offset, or the amount a core was moved up or down the composite depth section relative to depths below seafloor, is presented in the "Sedimentation Rates" section of each site chapter.

The composite depth section for each site was created by moving cores relative to one another by a fixed amount. No differential stretching or squeezing within a core was performed. For example, Figure 1 shows a set of overlapping GRAPE records in which correlation is clear. In many instances, however, we noted distortion of one core relative to the corresponding core in a different hole. An example of this distortion can be seen at Site 848 (Fig. 2). The top part of Figure 2 shows GRAPE records from Cores 2 and 3 from Holes 848B, 848C, and 848D on the composite depth scale, with slight vertical offset of each hole. When the three records are superimposed (lower part of Fig. 2), the distortion among cores is apparent. Although in many cases compression or extension of one core relative to another can reduce these discrepancies, this step was not taken when making shipboard composite sections.

In general, distortion among corresponding cores from different holes is more pronounced in some parts of the sedimentary section than in others. During Leg 138, distortion among cores that appeared to represent the same interval was greater in the first few cores at each site, where sediments were less consolidated. Distortion among cores appeared to be minimal in the deepest part of the APC section, just before we switched to XCB coring. Similarly, the first few XCB cores drilled at the deeper sites (849, 851) appear to show much more distortion relative to one another than XCB cores deeper in the sedimentary sequence.

MBSF VS. MCD

The process of building a composite section produces a shift in the standard depths assigned to a sediment core. By long-standing convention, ODP and DSDP samples are recorded in terms of meters below seafloor (mbsf). Ideally, the first core of a hole will record the top of the section (the mud line) and will provide the zero reference horizon for the mbsf scale. In each successive core, the top of each core is normally taken 9.5 m below the top of the previous core. However, it is common for more than 10 m of apparently undisturbed sediment to be recovered, indicating that the coring process must somehow expand the section. Moreover, the exercise of developing a composite section shows that even with consistent recovery greater than 100%, more than 10% of the section is lost between each successive core. Because ODP convention does not account for these coring gaps, composite depths grow progressively deeper down the sequence than mbsf depths.

The "growth" of composite depths (mcd), as compared to ODP-measured depths (mbsf), is illustrated in Figure 3, which shows the amount of offset added to mbsf depth to form the composite depths for each site. The solid line in each figure represents a 10% increase in the composite depth scale over mbsf depths. In practice during Leg 138, the increase in the composite depth scale was always greater than 10% (becoming as high as 25% in XCB-cored intervals).

[1] Mayer, L., Pisias, N., Janecek, T., et al., 1992. *Proc. ODP, Init. Repts.*, 138: College Station, TX (Ocean Drilling Program).

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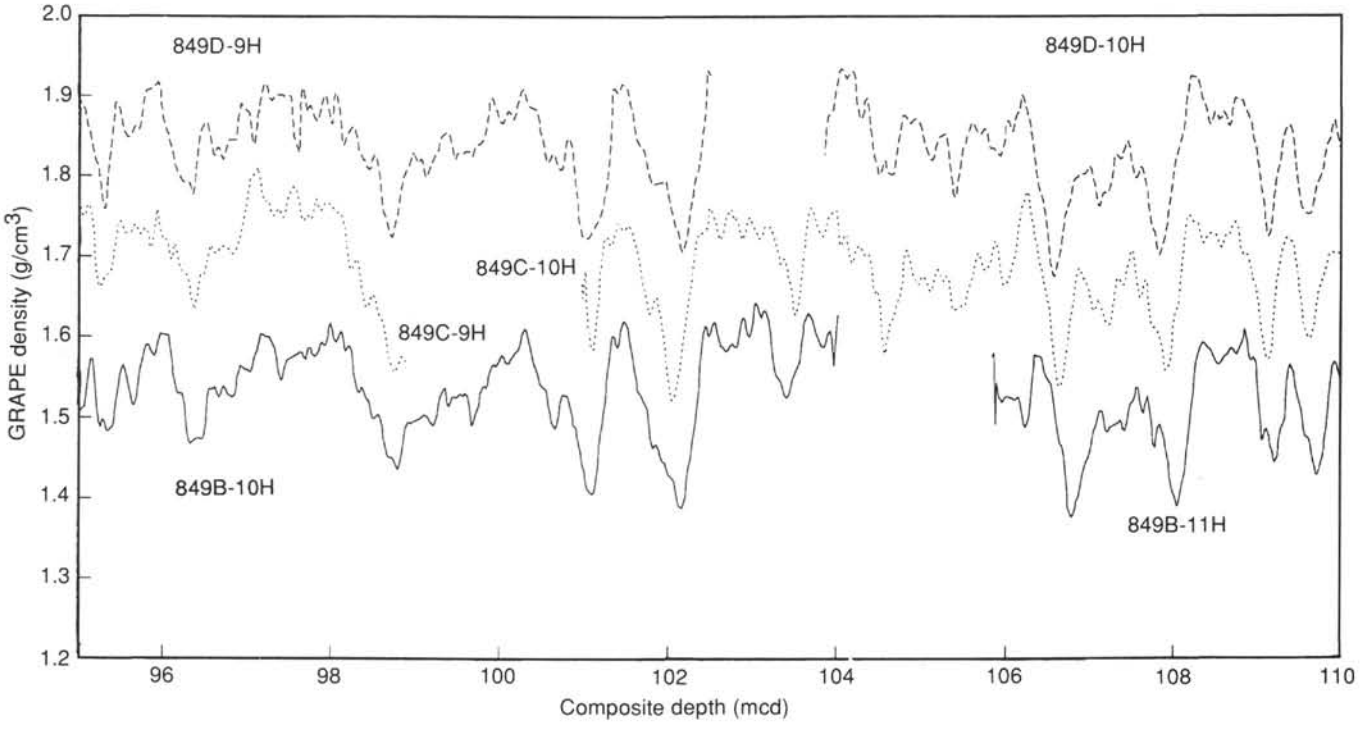

Figure 1. GRAPE records from Site 849 on composite depth scale, showing overlaps among holes. Hole 849B = solid line, Hole 849C = dotted line, Hole 849D = dashed line. Records are offset slightly to facilitate plotting.

While the process of constructing the composite depth section is straightforward and shipboard-measured mbsf depths can easily be converted to composite depths for any sample, it is important to be able to determine the "true" depth of any sample, particularly when determining sedimentation rates and mass fluxes. One strategy might be to use results of borehole measurements. In many sites, density logs can be compared directly to GRAPE density measurements; in some of these sections, one might consider developing a depth scale tied to log depth. Unfortunately, the smoothing inherent in the downhole log makes this operation difficult or impossible over some intervals. Comparison among GRAPE density and log density records shows that (as one might expect) log depth is closer to the mbsf scale than to the mcd scale (Fig. 4). On the other hand, comparison of log to GRAPE records of the equivalent hole confirms the validity of the exercise of developing a composite depth scale in that one can see in parts of the log (with good resolution) features that were not recovered, but which are present in the composite.

DEPTH OFFSETS

Ruddiman et al. (1985) reviewed the factors causing the absence of section among cores, although core recovery exceeds 100%. Several sources of error are involved when measuring depths. One important factor to consider is the motion of the ship. During Leg 138, one could observe from the bridge, sea and swell heights that ranged from 1 or 2 to 12 ft. Although the heave compensator is engaged during both APC and XCB drilling, changes in the ship's motion apparently influence the size of coring gaps. While the average coring gap for the entire leg (APC-cored intervals only) was 1.14 m, at Site 853, where the observed ship's heave averaged 7 ft, the range in coring gaps was from –2.7 m (coring overlap) to 2.3 m (on the composite depth scale).

Depth offsets were even more variable in XCB-cored intervals than in APC-cored intervals at Sites 846, 847, and 851. Because the heave compensator was engaged, relative motion occurred between the drill string and the base of the rig floor. Using a mark on the drill string as reference, a driller must judge when to stop coring with the XCB. Depending on the amount of ship's heave, one might expect this to produce more variable coring gaps in XCB-cored intervals. At Site 851, which was double XCB-cored to basement with overlap through most of the XCB-cored sequence, the range (where continuity of the section could be verified) was –1.4 to 7.15 m (ship's heave at Site 851 ranged from 2 to 11 ft). For comparison, the APC-cored intervals at Site 851 ranged in coring offsets from 0.70 to 2.0 m. However, this trend was not seen at two other double XCB-cored sites (Sites 846 and 849), although average swells observed at Site 848 were greater than those observed at Site 851.

Aside from vertical motion of the ship, several other factors may influence depth measurements, such as tides, positioning, and deviation of the borehole from vertical. However, all of these factors, including sea state, tend to impose a random variation in measured depths and should not account for the nearly systematic depth offsets among successive cores, as opposed to overlaps. One might see as many negative depth offsets (overlaps) as positive depth offsets were these factors the only ones affecting depth measurement. As shown in Figure 5, coring offsets were strongly biased to positive offsets (missing section among cores). In addition, one has the dilemma that although missing section among cores was identified routinely during Leg 138, recovery was often greater than 100%.

LOG DEPTHS AND SEDIMENTATION RATES (CONVERTING COMPOSITE DEPTHS TO REAL DEPTHS)

The mcd scale has several deficiencies. First, although it describes the real section completely, this scale does so at an incorrect scale. Second, it cannot be compared readily with downhole logs. Third, because of intercore distortion (Fig. 2), in some cases, "identical" events appear at slightly different mcd depths in several holes at one site.

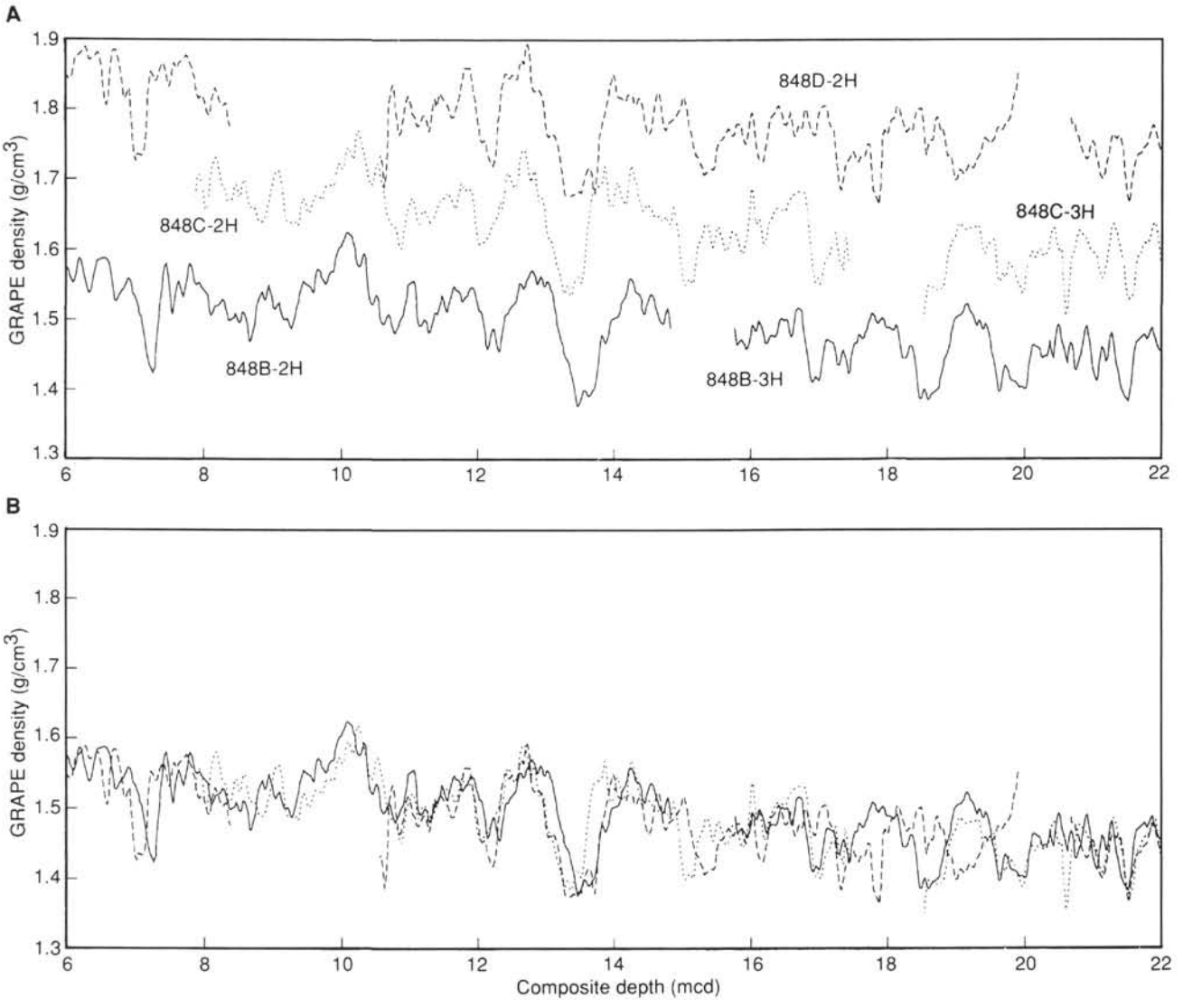

Figure 2. GRAPE records from Site 848 showing distortion among corresponding cores in different holes. **A.** Cores 2H and 3H from Holes 848B, 848C, and 848D, with vertical offset among the individual holes. **B.** Records from the three holes superimposed on one another.

A linear compression of the mcd scale proportional to the apparent stretching generated by the composite produces a depth scale that should be a good approximation of the real section. This scale probably is suitable for estimating linear sedimentation rates. Differences between this scale and the log-depth scale typically are of the order of 1 m to several meters and may arise from the same coring distortions that were noted in detail among the two or three holes at the same site. One might consider modifying this compressed mcd scale to better fit the log scale. However, on meter scales, uncertainties in the log depth might be caused by the ship's motion. Probably, at all length scales of less than about 10 m (and, hence, estimates of accumulation rates over such intervals), uncertainties will be inherently at least 10%.

A first-order estimate of the compression necessary to convert the mcd scale to the original mbsf scale was performed by fitting a linear trend to the records of coring offsets vs. mbsf depths shown in Figure 3. These transformations (Table 1) reduce the length scale of the composite section to that of the mbsf length scale. Comparison of these density records vs. density (as measured downhole) shows that the composite provides an excellent, nearly continuous record of density at each site and that a reasonable conversion to true depth below seafloor is possible (Fig. 6, back pocket).

RECOMMENDATIONS FOR FUTURE APC AND XCB CORING

In general, depth offsets among successive cores are randomly distributed about a mean of 1.4 m (for APC coring) and have a range of about 1.2 m. Therefore, if the second hole drilled is offset from the first hole by 4 or 5 m, barring any unusual occurrences, those two holes will provide, on average, overlap throughout the sequence. Although the variability of coring is higher in some XCB-cored intervals (Fig. 5), the same drilling strategy holds. In situations where motion of the ship is significant, adjusting the coring offsets in real time may not be a feasible exercise.

CONCLUSIONS

1. Results from Leg 138 demonstrated that with careful monitoring, complete recovery of sedimentary sequences is possible and consistent. By using the continuous, high-resolution measurements performed on unsplit sections, it is possible to verify the continuity of core recovery in near real time.

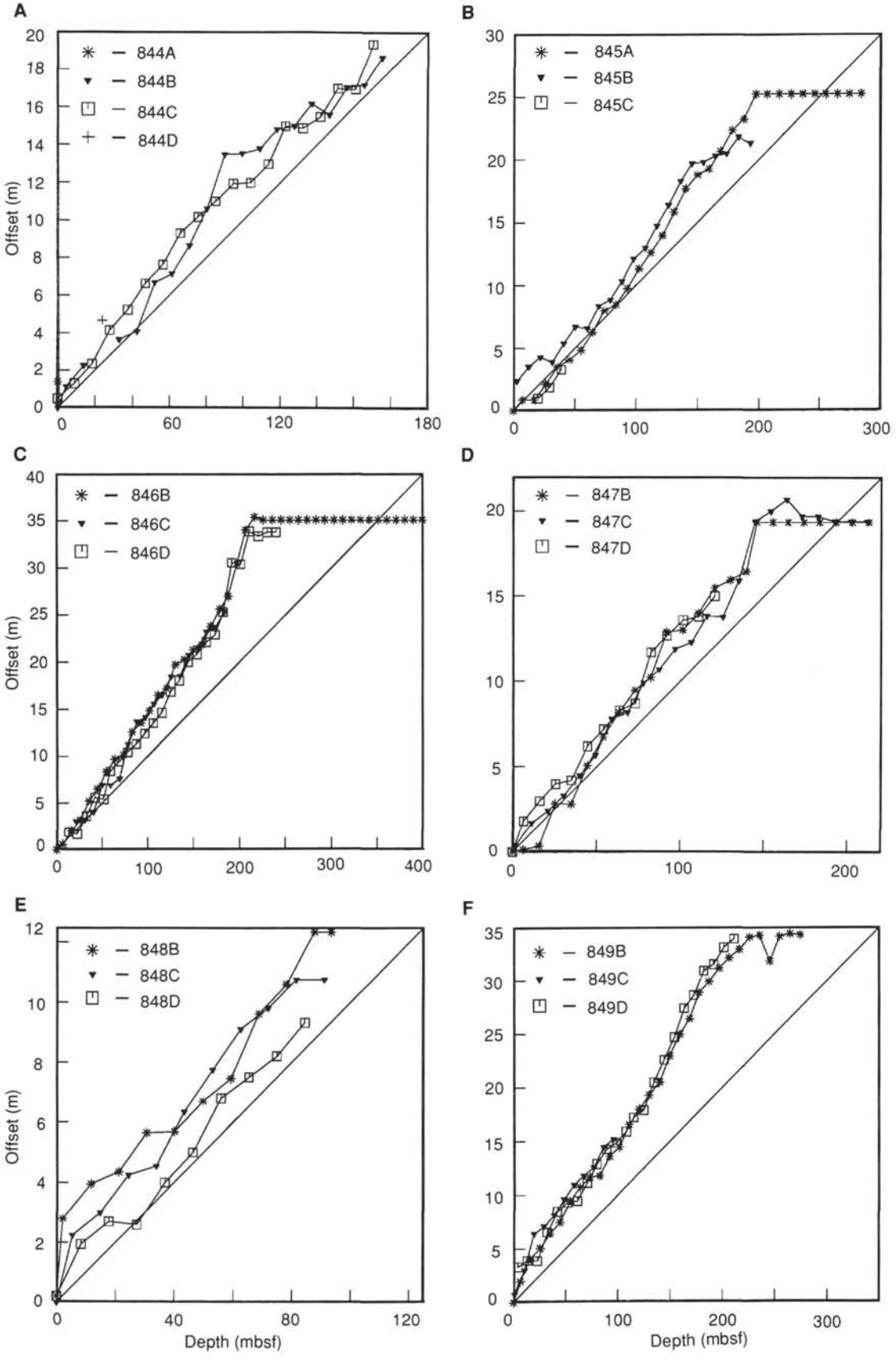

Figure 3. Offset (in mcd section vs. mbsf depth). **A.** Site 844. **B.** Site 845. **C.** Site 846. **D.** Site 847. **E.** Site 848. **F.** Site 849. **G.** Site 850. **H.** Site 851. **I.** Site 852. **J.** Site 853. **K.** Site 854.

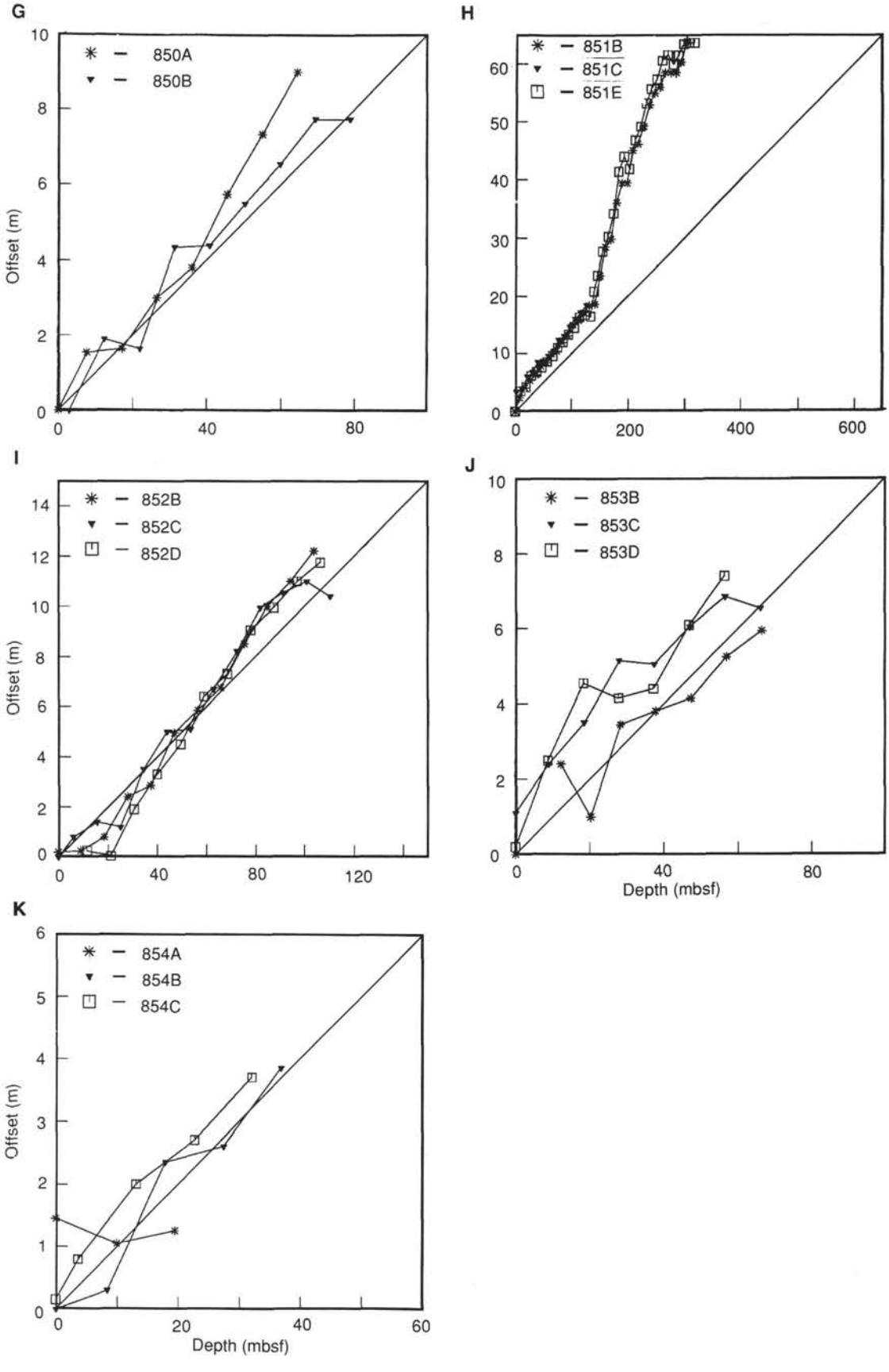

Figure 3 (continued).

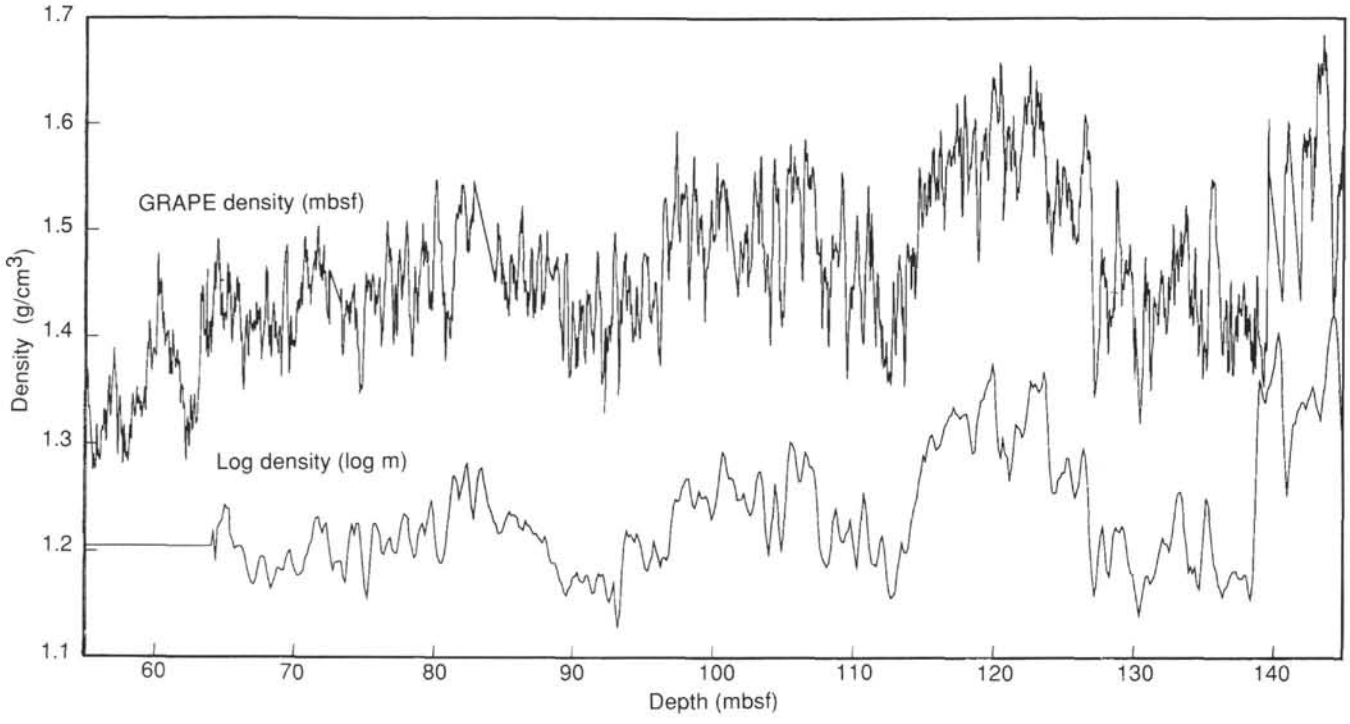

Figure 4. Comparison of GRAPE density record from Hole 847B with density log from Hole 847B.

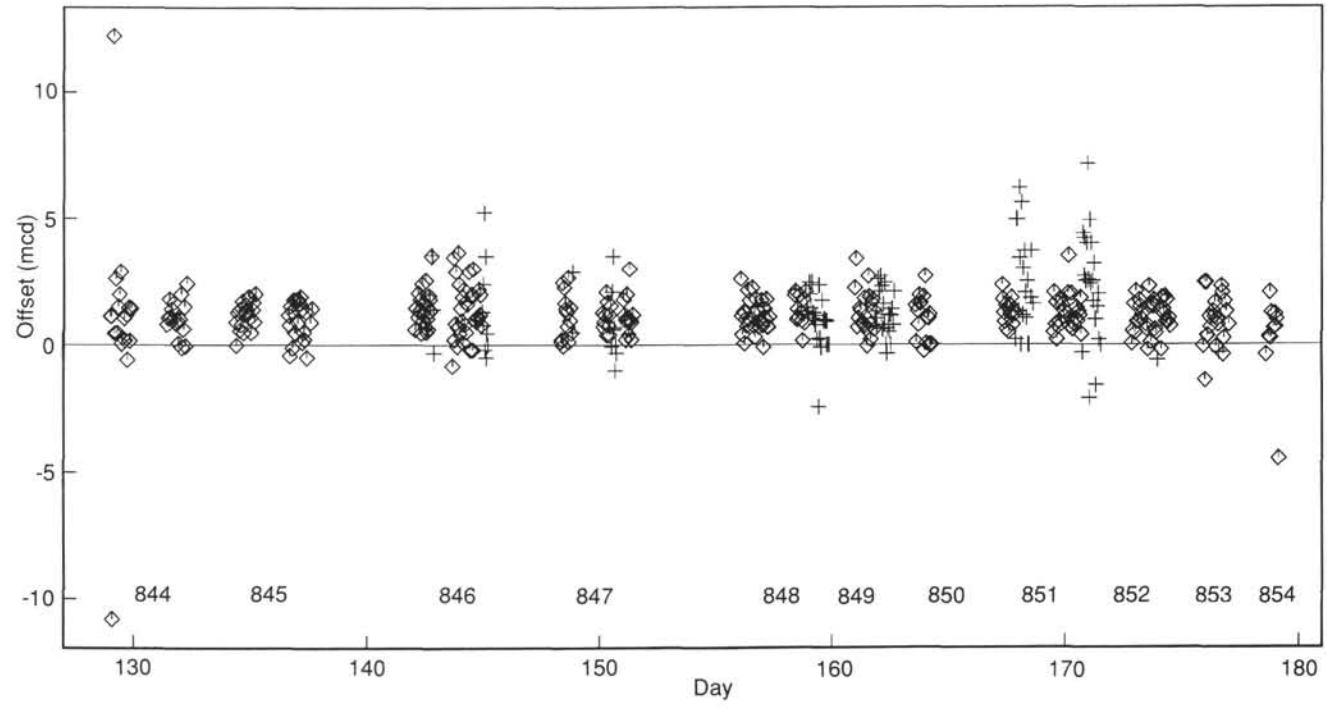

Figure 5. Offset (in mcd) of each core in the composite depth section, Sites 844 through 854. Diamonds indicate APC cores; plus marks indicate XCB cores.

Table 1. Tie points for linear transformation of mcd depth to mbsf at all Leg 138 sites.

Mcd (m)	Equivalent mbsf depth (m)
Site 844	
0	0
200.15	180.80
309.88	291.25
Site 845	
0	0
221.36	198.13
316.14	290.91
Site 846	
0	0
224.63	197.68
455.31	420.21
Site 847	
0	155.13
260.89	241.54
Site 848	
0	0
105.65	93.30
Site 849	
0	0
159.01	139.71
226.51	196.61
276.25	242.00
388.09	348.24
Site 850	
0	0
85.50	77.17
407.67	399.92
Site 851	
0	0
159.24	140.89
331.23	272.83
387.04	321.29
Site 852	
0	0
128.26	116.51
Site 853	
0	0
74.02	67.27
Site 854	
0	0
50.05	46.20

2. Use of the composite section provided a common depth scale for referencing biostratigraphic and magnetostratigraphic events at adjacent holes. This helped to produce a complete representation of the stratigraphic sequence at each Leg 138 site. Construction of a shipboard composite section can also be a way of guiding post-cruise, high-resolution sampling strategies.

3. Observations of depth offsets among successive cores indicate that ship's motion may be a significant factor in the variability of the size of coring gaps. However, no one factor (such as ship's motion) can account for the systematic occurrence of a missing section (1.14 m, on average) among cores.

REFERENCE

Ruddiman, W. F., Cameron, D., and Clement, B. M., 1985. Sediment disturbance and correlation of offset holes drilled with the hydraulic piston corer: Leg 94. *In* Ruddiman, W. F., Kidd, R. B., Thomas, E., et al., *Init. Repts. DSDP*, 94: Washington (U.S. Govt. Printing Office), 615–634.

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