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38. THE PROBLEM OF POROSITY REBOUND IN DEEP-SEA SEDIMENT CORES: A COMPARISON OF LABORATORY AND *IN-SITU* PHYSICAL-PROPERTY MEASUREMENTS, SITE 704, METEOR RISE[1]

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ABSTRACT

Previous comparisons of laboratory measurements and downhole geophysical logging have noted some discrepancies between the porosity derived from the neutron log and the porosity as determined from shipboard laboratory measurements. One proposed mechanism for the discrepancy has been called "porosity rebound": the cores undergo decompression upon recovery from the seafloor, and the porosity increases when the overburden pressure is removed. We compare laboratory and downhole geophysical measurements of the wet-bulk density and porosity for carbonate-rich sediments from ODP Site 704, on the Meteor Rise. We argue that the porosity calculated from the neutron log significantly underestimates the formation porosity for unconsolidated oozes, and we conclude that if relatively undisturbed samples are selected then the laboratory measurements are representative of *in-situ* conditions, and no correction for porosity rebound is required.

INTRODUCTION

Shipboard measurements of physical properties have been taken from the beginning of the Deep Sea Drilling Project. Whether or not those measurements are representative of the *in-situ* properties has been in question (see, e.g., Nobes et al., 1986, for a brief review). Previous comparisons of laboratory and downhole geophysical logging measurements have found discrepancies between the two sets of data (e.g., Gealy and Gerard, 1970; Fulthorpe et al., 1989), and some laboratory data have been modified to take into account such discrepancies (e.g., Shipley, 1983).

Some have explained the differences in terms of sediment core decompression after removal of the overburden pressure (e.g., Hamilton, 1976) whereas others have suggested that the differences could arise from drilling disturbance (e.g., Klein, 1984) or by preferential sampling of softer core segments (e.g., Manheim et al., 1974). Our purpose was to examine the physical-property data from Ocean Drilling Program Leg 114, in particular from Hole 704B, in order to estimate the effects of porosity rebound in carbonate-rich sediments. Corrections of approximately 8% have been proposed for porosity rebound in calcareous oozes recovered from depths of about 300 m below seafloor (mbsf) (Hamilton, 1976). Geophysical logging data from Hole 704B are available for comparison with laboratory-measured data in the depth range 155 to 500 mbsf. We find no evidence for significant discrepancies between the downhole geophysical and laboratory physical-property data of Hole 704B in the depth range for which comparative data are available, and we conclude that porosity rebound is not a major problem in carbonate-rich sediments. Instead, we find that the porosity estimated from the neutron log underestimates the true porosity for relatively unconsolidated formations.

SAMPLING

Site 704 is located in the eastern South Atlantic Ocean (Fig. 1). The site has a thick sedimentary sequence within a basin on top of the Meteor Rise (Fig. 2), which is near the Polar Front. The Quaternary sediments (0 to 93 mbsf) are characterized by alternating calcareous and siliceous (mainly diatom) oozes. The carbonate content tends to increase with depth, and the sediments are principally nannofossil ooze and chalk below about 250 mbsf.

The physical properties were sampled about once per section (about every 1.5 m) in Hole 704B. The sampling and analysis are described in Boyce (1976), in the "Explanatory Notes" (Shipboard Scientific Party, 1988a), and in detail in Nobes, Mienert, and Dirksen (this volume). The physical-property core samples were selected with a number of goals in mind: (1) we wanted samples that were representative of the lithologies present, even if we had to abandon a regular sampling interval; (2) we wanted samples that appeared to be relatively undisturbed, so to be as representative of *in-situ* conditions as possible; and (3) we wanted samples from each section, if practical, within the constraints of goals (1) and (2). Goal (2) is of particular importance here.

In summary, the procedure is as follows: soft sediments were sampled using a syringe. Small cylinders of relatively undisturbed sediments were placed in calibrated cylinders, weighed, and the volume was measured using a pycnometer. The samples were dried for 24 hr at 105°C, and the dry weight and volume were measured. The wet- and dry-bulk densities, grain density, porosity, and water content were then calculated using the salt-corrected weights and volumes. More consolidated but unlithified sediments were sampled by placing small chunks of the sediments in the calibrated cylinders and repeating the preceding process. For lithified sediments, chunks were cut from the core. Cubes were taken for the measurement of the acoustic velocity using the Hamilton Frame, and smaller portions from the bottom or sides of the cube were used for index property measurements, that is, for determination of the porosity, water content, wet-bulk density, dry-bulk density, and grain density.

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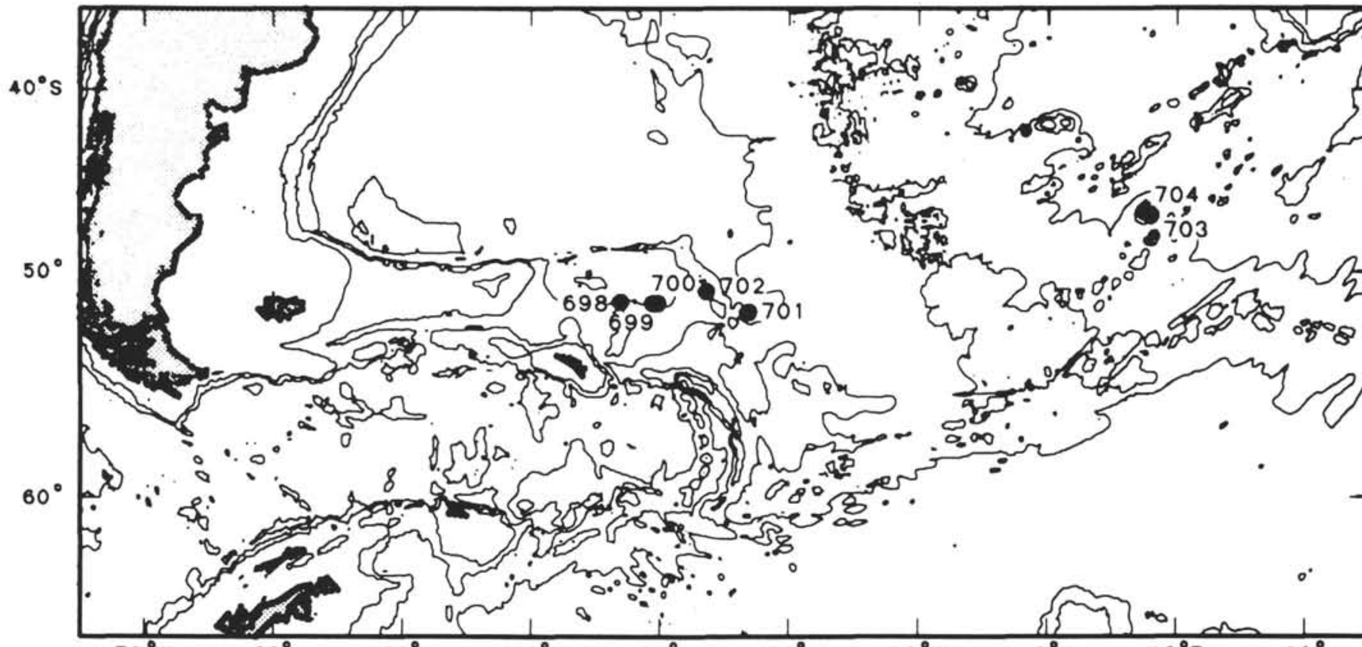

Figure 1. Bathymetric chart of the subantarctic South Atlantic showing the location of Site 704 and other Leg 114 sites. Contour interval = 1500 m. (From Shipboard Scientific Party, 1988b.)

Hamilton Frame measurements were also taken on the split core through the liner; however, the data from cores obtained with the extended core barrel (XCB) technique are suspect because of drilling disturbance. The process of XCB coring creates an annulus of disturbance between the core and the liner, and thus *P*-wave logger (PWL) and Hamilton Frame data taken through the liner are significantly affected (Pisciotto, Tamaki, et al., 1990). The GRAPE (gamma-ray attenuation porosity evaluator) is affected as well, but to a lesser degree. The index properties are not affected, because the disturbed annulus is not sampled. The depth range covered by the downhole geophysical logging was cored using the XCB method, so we have very little reliable Hamilton Frame velocity data for analysis. We have thus concentrated our efforts on comparisons of the density and porosity.

The downhole geophysical logging procedures are described in the "Explanatory Notes" (Shipboard Scientific Party, 1988a). In brief, measurements were taken every 15 cm. We are especially interested in the lithodensity log (also called the gamma-gamma density) and the neutron log (also called the neutron porosity). The density correction log was used to monitor the reliability of the gamma-gamma density. The lithodensity tool should be in contact with the borehole wall in order to obtain a valid result. If the tool is not in contact, then the density correction tool produces high values. The tools were calibrated onshore in a set of exploration industry standard holes. Attempts were made to calibrate the tools at sea for conditions more representative of unconsolidated marine oozes, but such attempts were unsuccessful. The logs were processed onshore by Schlumberger and by the Borehole Research Group of Lamont-Doherty Geological Observatory. In Hole 704B, lithodensity and neutron logging data are available from below the bottom-hole assembly (approximately 155 mbsf) to about 500 mbsf. The tools apparently malfunctioned between 450 and 500 mbsf, where the response of the lithodensity and neutron tools is almost flat.

DATA COMPARISON

Comparisons between shipboard laboratory and downhole logging data have been made previously. Gealy and Gerard (1970), for example, compared the neutron porosity log with porosity values derived from the density determined with the GRAPE. In order to derive porosities from the GRAPE density, the grain density must be known. If the grain density is not well constrained, then errors can occur. In addition, if the GRAPE data are from XCB cores, the core disturbance can affect the results. Fulthorpe et al. (1989) compared porosity, density, and velocity data from laboratory and logging measurements. They made no distinction between samples taken using advanced piston coring (APC), XCB, or rotary core barrel (RCB) techniques. We do not have velocity measurements for comparison here, because of the lack of logging data from the APC section, but results from Leg 127 (Pisciotto, Tamaki, et al., 1990) indicate that the PWL velocity is generally in agreement with the sonic log velocity for APC cores and that the Hamilton Frame velocity is in agreement for sediments that are sufficiently consolidated that a competent cube may be cut from the core. However, as noted previously, the PWL and Hamilton Frame velocity results are not valid for less competent sediments cored using the XCB.

We have compared laboratory measurements of porosity and wet-bulk density with neutron porosity and gamma-gamma density logging results. Because the density varies linearly with the porosity (Boyce, 1976; Nobes, Mienert, and Dirksen, this volume), we have two independent sets of data to compare for the determination of porosity rebound effects. The grain density has been determined for the depth interval 155 to 450 mbsf, and can be used to estimate the porosity from the wet-bulk density. The mean grain density is 2.75 ± 0.12 g/cm^3, a value consistent with a high carbonate content.

The raw data are plotted in Figure 3 using the American Petroleum Institute (API) standard log presentation format,

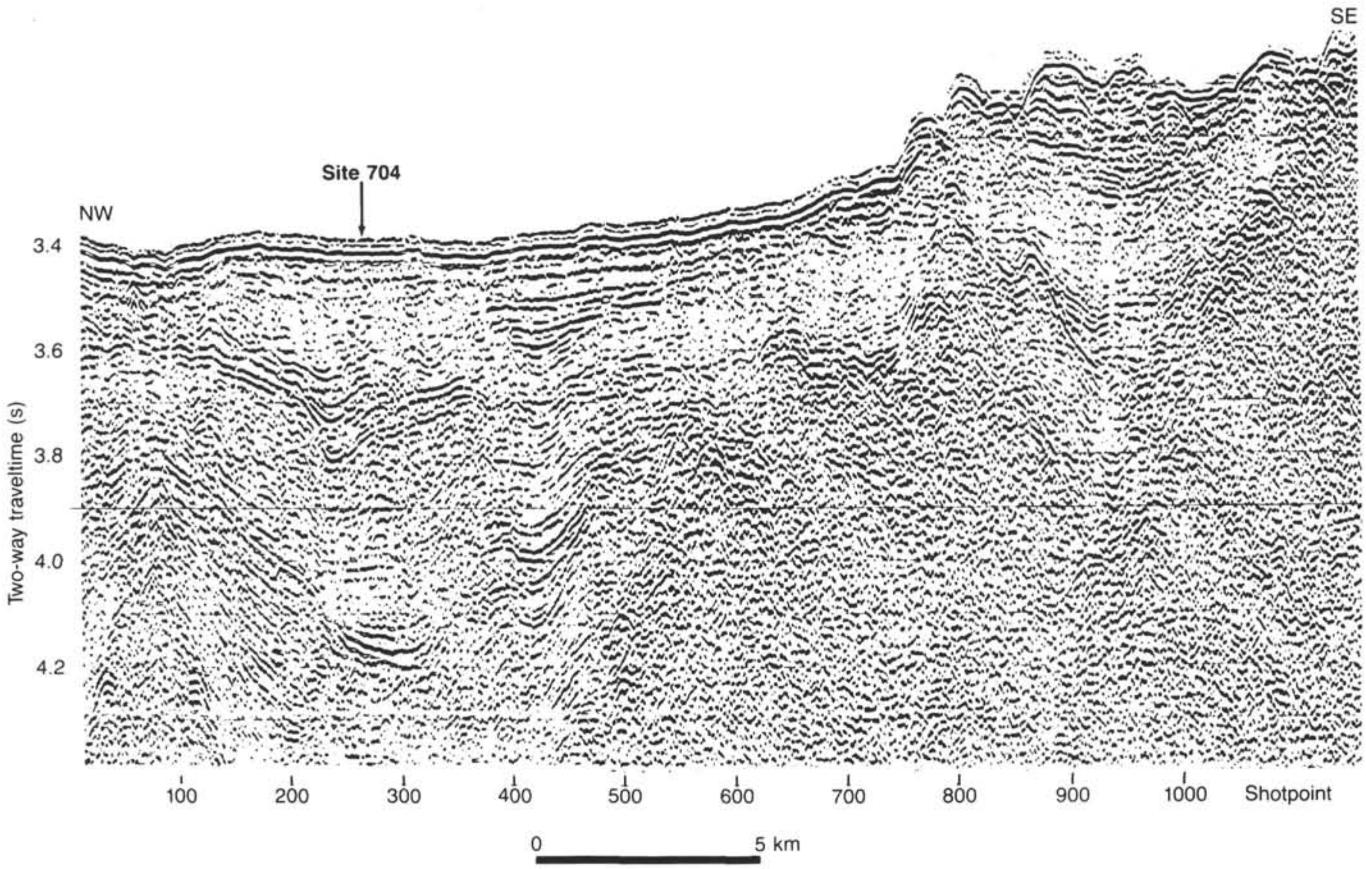

Figure 2. *JOIDES Resolution* single-channel seismic-reflection profile with the general location of Site 704. (From Shipboard Scientific Party, 1988b.)

along with the computed density correction log, which gives an approximate measure of the error in the gamma-gamma density log. The laboratory and logging density data (in units of g/cm^3) are plotted using identical scales. The differences between the two data sets are minor, except where the logging density is systematically less than the laboratory density over a zone from about 260 to 370 mbsf. The density correction log tends to have the greatest (positive) values in this zone, which indicates that the lithodensity tool was not in optimal contact with the formation.

The porosities are plotted using the same scales. If the porosities were plotted on different scales, then we would observe a general similarity in the curves, which suggests that the dynamic range of the logging porosity is inadequate for the correct estimation of the formation porosity. The porosity derived from the gamma-gamma density (not shown) is quite similar to the laboratory porosity, which is expected given the similarity of the density curves. There is a mismatch only in the interval from 260 to 370 mbsf.

The densities and porosities are compared by means of crossplots in Figure 4. The laboratory and logging densities (Fig. 4A) lie on or near the line of equality, except in the zone where the lithodensity tool was not in good contact with the borehole wall. The porosity derived from the gamma-gamma density exhibits a similar pattern in comparison to the laboratory porosity (Fig. 4B). The logging porosity approaches the laboratory porosity at lower values (about 40%), but the logging porosity response flattens out at higher porosities (Fig. 4C). The grain density, wet-bulk density, and laboratory porosity are self-consistent, indicating that the measurement errors are small, and the agreement between the gamma-gamma density and the laboratory wet-bulk density and between the porosity derived from the gamma-gamma density and the laboratory porosity suggests that it is the neutron porosity that is in error.

The discrepancy can be explained if the logging porosity systematically underestimates the formation porosity. A similar pattern can be seen in the analysis of Gealy and Gerard (1970), who compared the neutron log and GRAPE porosities. How can we explain this apparently systematic error? Ellis (1987) proposed two parameters called the "slowing-down length" and the "migration length" to explain the observed response of the neutron log to different formation porosities. The response saturates at high porosities, and thus the dynamic range of the neutron "porosity" is diminished, as we noted in our discussion of Figure 4C. The formation porosity appears to be accurately estimated for porosities less than about 40%. In other words, the neutron log does not yield a measure of porosity for unconsolidated marine oozes. At the other extreme, for very low porosities, the neutron log tends to yield porosities that are higher than the actual formation porosities (Pezard et al., 1988; Broglia and Ellis, 1988). Thus, the neutron log does not yield a true measure of the formation porosity except in a narrow range from about 20% to about 40% porosity.

DISCUSSION AND CONCLUSIONS

In our comparison of the downhole geophysical logging results with the laboratory data, the density data show no evidence for rebound. The porosity obtained from the neutron log is consistently lower than the laboratory value, but the response of the neutron log can be markedly nonlinear and does

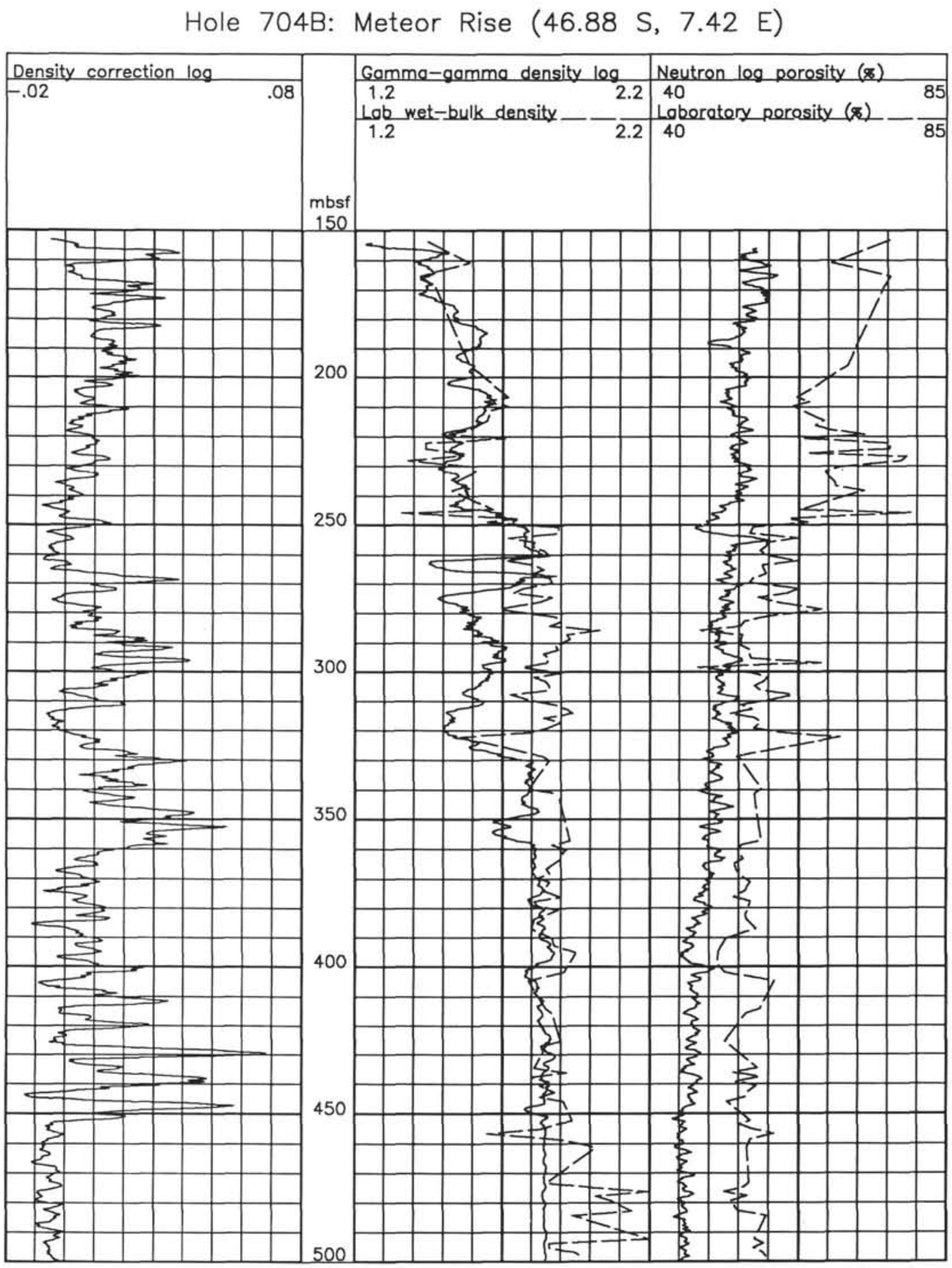

Figure 3. API-style presentation of the density correction and gamma-gamma density logs and laboratory wet-bulk density, in units of g/cm^3, and the neutron log porosity and laboratory porosity. The densities are plotted using a common scale, showing the strong similarity of the two curves. Also apparent is the anomalous zone between about 260 and 370 mbsf, where the logging density is less than the laboratory density. The neutron porosity is consistently lower than the laboratory porosity.

not yield accurate porosity estimates for high-porosity formations. Because the density and porosity are closely related, we conclude that there is no evidence for porosity rebound.

Comparative data are available only for a restricted depth range, from approximately 155 to 500 mbsf. However, previous corrections applied to laboratory data to account for porosity rebound had maximum values of about 8% at about 300 mbsf, well within the depth range under consideration. Throughout the whole comparative depth range, the logging density and the laboratory wet-bulk density were essentially equal, with little sign of any systematic differences, except where the lithodensity tool was not in contact with the borehole wall. The porosity derived from the gamma-gamma density similarly agrees with the laboratory porosity. We thus conclude that as long as

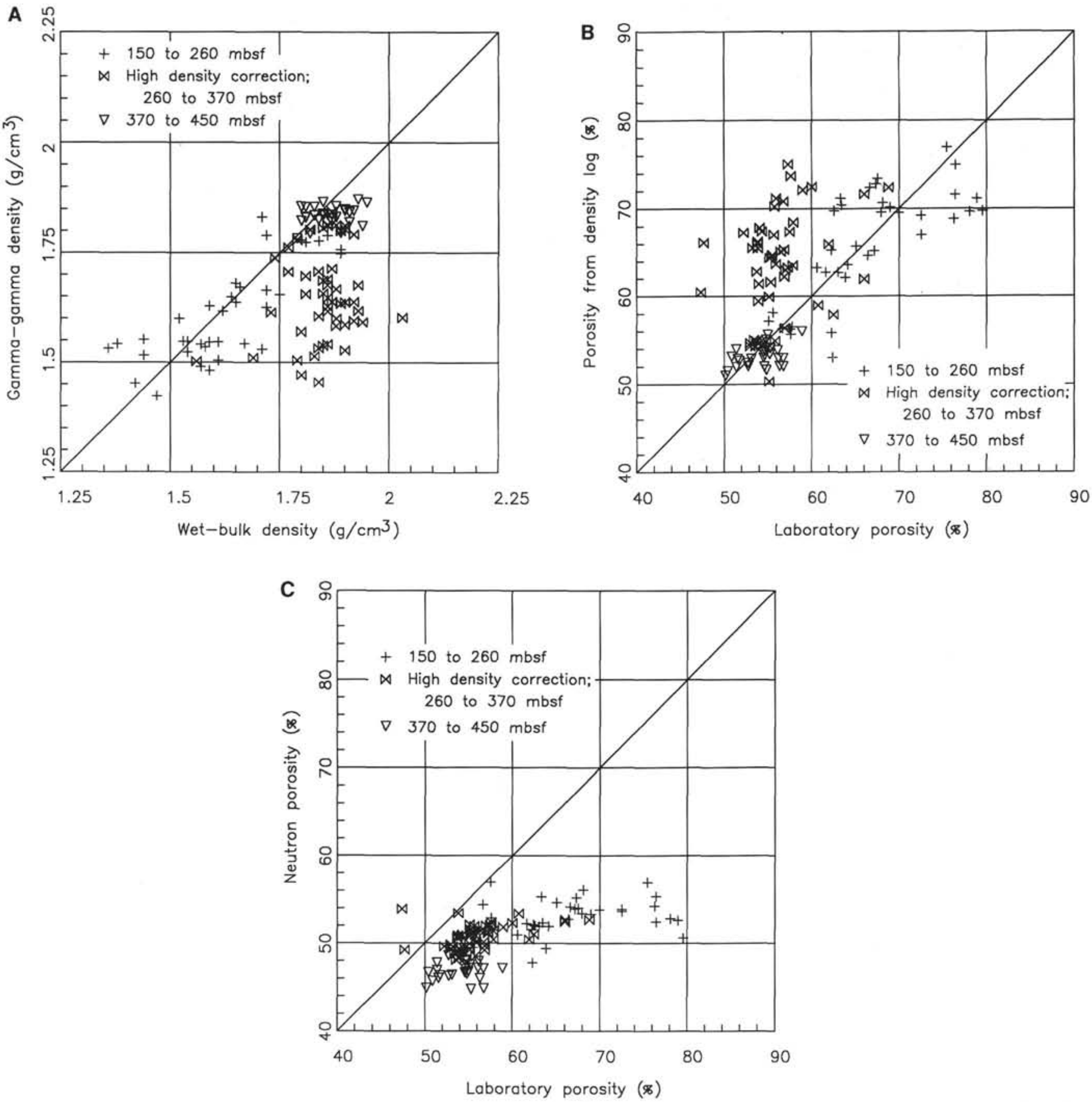

Figure 4. Crossplots of (A) the gamma-gamma density vs. the laboratory wet-bulk density, (B) the porosity derived from the gamma-gamma density vs. the laboratory porosity, and (C) the neutron porosity vs. the laboratory porosity. The density and density-derived porosity data form a cluster about the 1:1 diagonal line, except for the data for the zone from 260 to 270 mbsf where the density correction is high, which indicates that the lithodensity tool was not in proper contact with the formation. The neutron and laboratory porosities start to converge at the lower porosity range. The neutron porosity response flattens out at higher porosities.

relatively undisturbed samples are selected, laboratory physical-properties measurements for carbonate-rich sediments are representative of *in-situ* properties.

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