# 27. PHYSICAL PROPERTIES OF DEFORMED SEDIMENTS FROM SITE 181[1]

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## INTRODUCTION

It has been proposed that the Pacific plate is thrust against Alaska and that the Aleutian Trench marks the site of plate convergence. As a consequence, sediments of the Aleutian Trench should be deformed as they pile up against the continental slope or are lost down the zone of subduction. To test these ideas the zone of proposed deformation was cored at Site 181. Deformed and dewatered sediment was recovered from below a 170-meter thick sequence of undeformed deposits. Bands of light-colored silt mark small irregular open folds, fractures, and faults that must have formed after substantial consolidation. The center of some cores was hard and dry. In order to preserve these unusual physical properties for onshore laboratory measurements, four samples from the catchers of Cores 27 to 30 were sealed in cans within 15 minutes after the core barrel was on deck. By this time other parts of the core that were exposed longer to drilling fluid had already absorbed considerable moisture.

Bulk density, porosity, and consolidation as a function of pressure were measured. Consolidation measurements have been used to quantitatively estimate the lithostatic pressures to which the cored samples have been subjected. These measurements confirm conclusions from visual observations that sediment deformation in Core 181 was mainly tectonic, rather than the result of drilling, because although consolidation test pressures were more than six times as great as drill bit pressures, no additional deformation occurred.

## MEASUREMENTS

Physical properties were measured on Core 28 at the U.S. Geological Survey (USGS) laboratory and on the remaining four cores at the Naval Civil Engineering Laboratory (NCEL). Water content, grain density, and bulk density were measured first and are given in Table 1. The consolidation measurements were made with a ring system (fabricated at the USGS) and the loading systems at each laboratory. Cylindrical samples 1 inch in diameter and about 0.5 inch in height were trimmed and inserted into the ring. The measurements were conducted by first applying a vertical stress of 2000 to 7500 psf. The vertical stress was then progressively doubled until stresses of 200,000 psf (NCEL) and 925,000 psf (USGS) were reached. One of the samples (Core 27) was then rebounded to 12,000 psf, reloaded to 260,000 psf, and rebounded again to 0 psf. The other four samples were rebounded directly. Each stress was applied until it was certain that primary consolidation was completed. The time of load application ranged from 4 hours to several days. As the rate of secondary compression was low, any time-dependent characteristics are probably insignificant. The data are in the form of changes in sample

**TABLE 1**
**Sample Characteristics**

| | Core 27 | Core 28 | Core 29 | Core 30 | Core 15 |
|---|---|---|---|---|---|
| Depth of sample (m) | 281 | 322 | 340.5 | 369 | 142 |
| Density of sample before test (g/cc) | 2.132 | 2.12 | 2.141 | 2.136 | 1.858 |
| Void ratio of sample before test | 0.478 | 0.396 | 0.466 | 0.499 | 1.12 |
| Density of sample assuming 100% saturation (g/cc). | 2.226 | 2.33 | 2.324 | 2.194 | 1.86 |
| Void ratio of sample assuming 100% saturation | 0.435 | 0.269 | 0.375 | 0.474 | 1.12 |
| Assumed in situ vertical stress (psf) | 32,338 | – | 48,086 | 53,010 | – |
| Grain density (gr/cc) | 2.76 | 2.69 | 2.82 | 2.76 | 2.76 (assumed) |
| Degree of saturation of sample | 90.0% | 67.5% | 75.8% | 94.8% | 100.0% |
| Porosity of sample before test | 0.323 | 0.284 | 0.318 | 0.333 | 0.522 |

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thickness corresponding to each load increment and they were plotted as void ratio versus the log of vertical stress, a common means of presenting consolidation test information (Casagrande, 1936; Schmertmann, 1955). The complete void ratio-log stress curves for the five samples are given in Figures 1 to 5. A compilation of the loading portions of the curves for all of the samples is given in Figure 6. It should be noted that the measurement on the sample from Core 30 had to be conducted by loading perpendicular to the core axis, owing to the shape of the sample. The measurements are of value because they yield information about the horizontal stresses in the ground. The other three samples were loaded in the usual vertical fashion. The difference between the USGS and NCEL curves probably arises from different laboratory procedures as well as differences in void ratio and saturation.

## ANALYSIS OF DATA

These measurements were made so that the maximum pressure to which the samples have been subjected could be estimated Two standard techniques have been developed for estimating the "maximum past pressure" (Casagrande, 1936; Schmertmann, 1955), but both are inapplicable to the results from Cores 27 to 30. The methods rely upon a downward break in the void ratio/pressure curves that occurs as the maximum past pressure is exceeded, and no such break could be found. Severe sample disturbance is one common explanation for this response, but a more likely explanation is that the samples were not loaded beyond their maximum past pressure. In other words, the maximum past pressure is greater than the applied 250,000 and 925,000 psf. To explore this possibility further, a sample from Core 15 (142 m) was obtained and consolidated. This sample is undeformed and, although considerably less dense, has similar mineralogical and physical characteristics as the three lower samples. Sample 15 appeared to be normally consolidated, and it seems likely that its maximum past pressure would be less than the maximum pressure obtainable with the test equipment. The consolidation curve (Figure 4) appears indeed to bear this out. A break in the curve occurs around 50,000 psf. Using standard techniques, a maximum past pressure somewhat less than this (20,000 to 40,000 psf) is estimated. This would indicate a maximum past burial depth of about the depth from which Core 15 was recovered, i.e., 142 meters.

The portion of the Core 15 consolidation curve for pressures greater than 50,000 psf then appears to be a virgin compression curve—that is, a representation of how the sediment would respond to loading beyond its maximum past pressure and, to a certain extent, a model of the sediment compaction process. Assuming that it is a virgin compression curve and that the sediments of Cores 15, 27, 28, 29, and 30 behave identically, then the curve for Core 15 may also approximate the virgin compression curve for the four lower cores. If so, it models the response of these lower samples as they were loaded to a high maximum past pressure during sedimentation and tectonism. Extrapolating the lower curves into zones of high pressures gives a point of intersection that approximately represents the maximum past pressure of Cores 27 to 30 (given all of the previous assumptions). This point has a vertical stress between 1.1

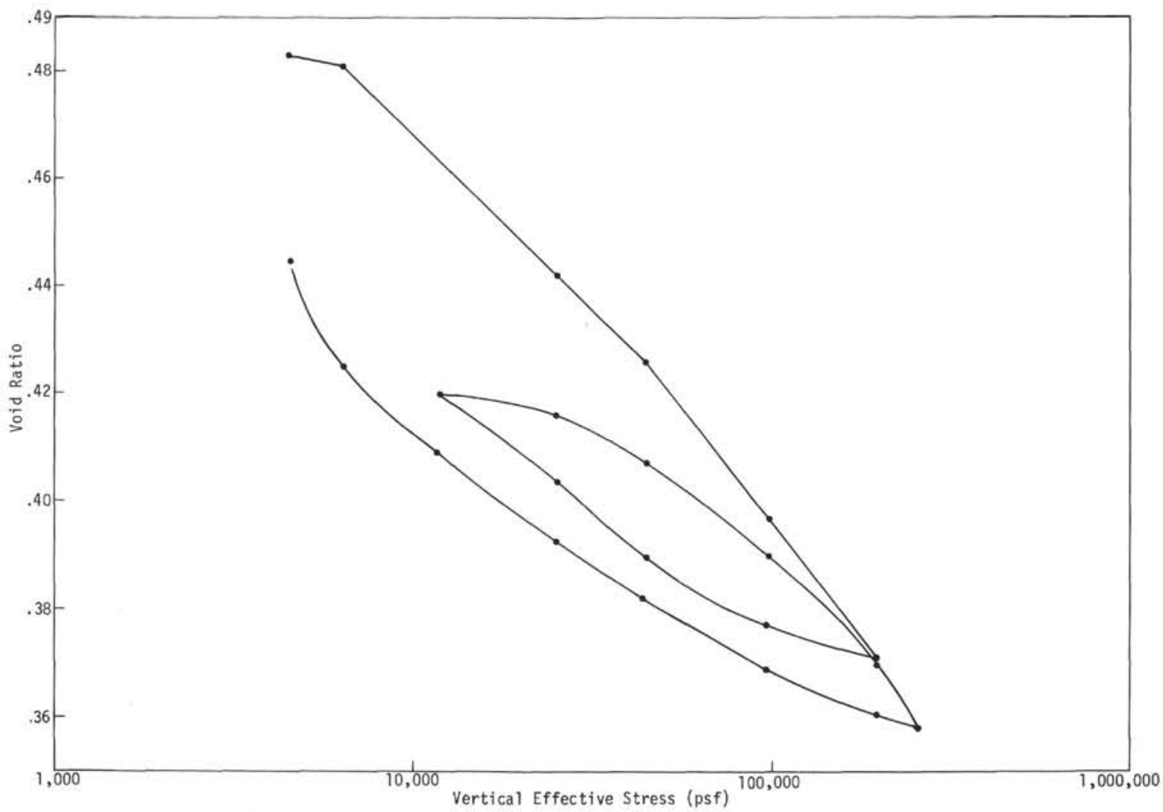


Figure 1. *Void ratio-log stress curve, Core 27 (CC).*

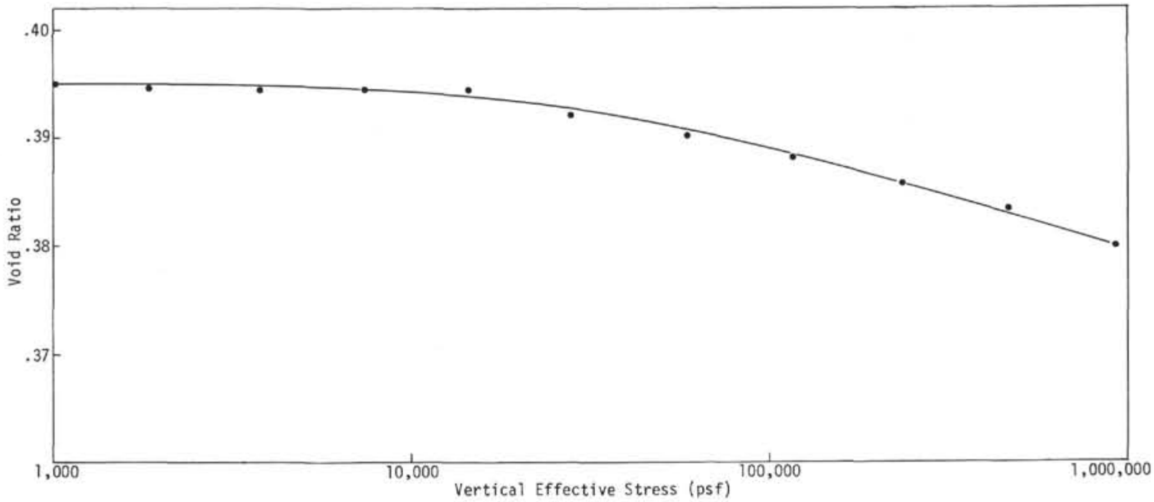


Figure 2. *Void ratio-log stress curve, Core 28 (CC).*

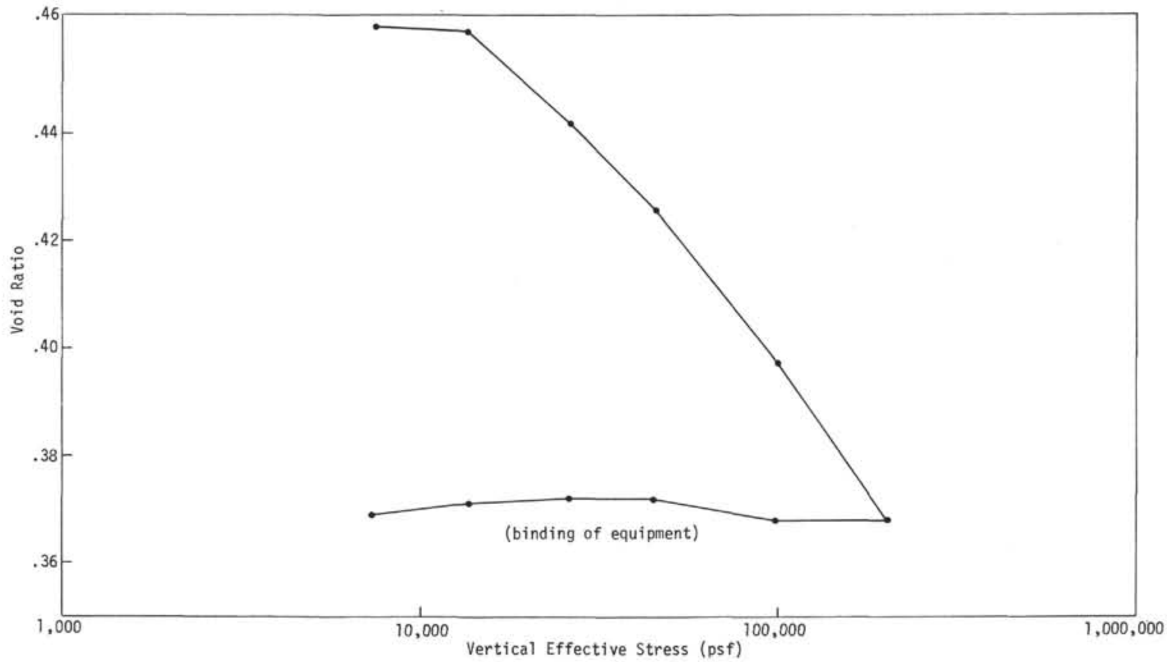


Figure 3. *Void ratio-log stress curve, Core 29 (CC).*

and $1.8 \times 10^6$ psf or a lithostatic load equivalent to burial at 3 to 5 km. The intersection point is quite sensitive to slight errors and irregularities and should be considered very approximate. Also, since the slope of the virgin compression curve for Core 15 appears very low in comparison with tests performed on other North Pacific sediments (Lee, in press) it is probable that errors have caused the estimated maximum past pressure to be a little too high. These results lead to the conclusion that the maximum past pressure of the Core 27, 28, 29, and 30 samples is between 250,000 psf and 925,000 (equipment limit), and 1,800,000 psf.

## GEOLOGIC SIGNIFICANCE OF PAST PRESSURES

These past-pressure data would usually be interpreted to indicate previous burial between 1.5 km and 3 km with a possible maximum of 5 km but this interpretation should be accepted with considerable caution. For sediment that has been subjected to static in situ loading, the consolidation test past pressures agree well with lithostatic pressures for the sample recovery depth. This is seen, for instance, in the test of Core 15 and in the data from Leg 19 (Lee, in press). However, tectonism has probably broken down much of the original sedimentary structure achieved

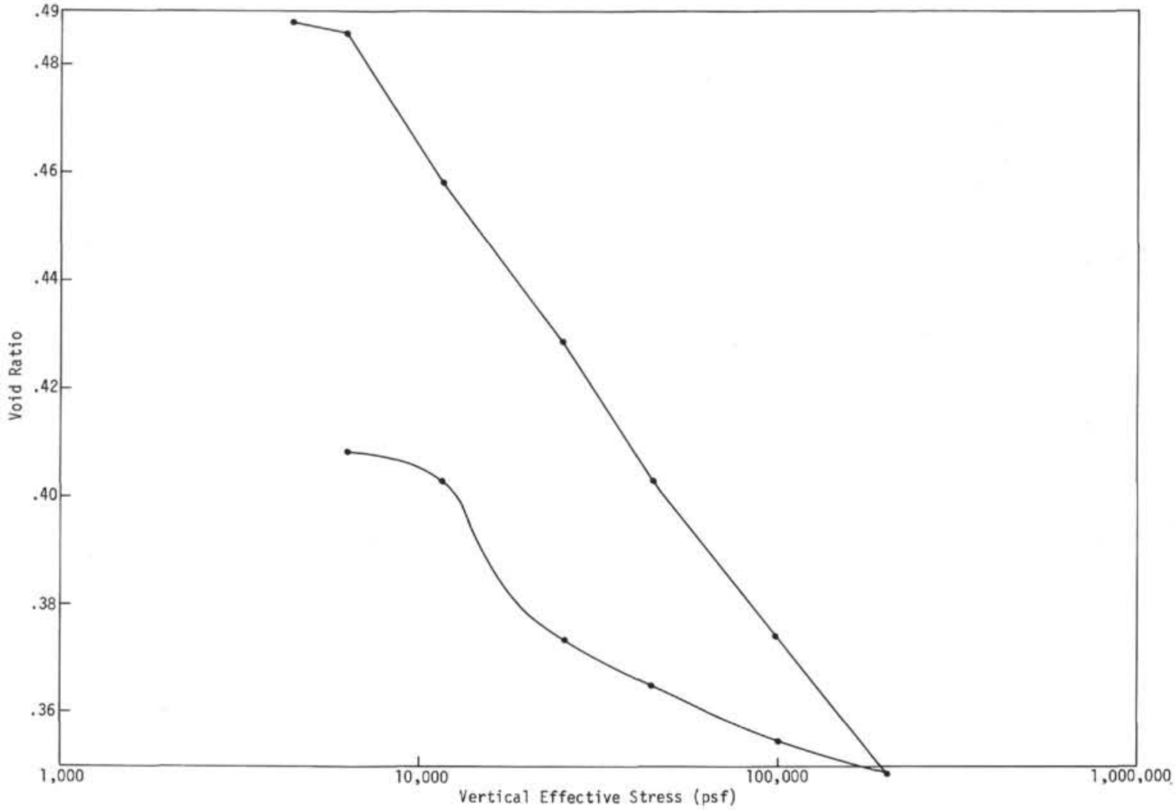


Figure 4. *Void ratio-log stress curve, Core 30 (CC).*

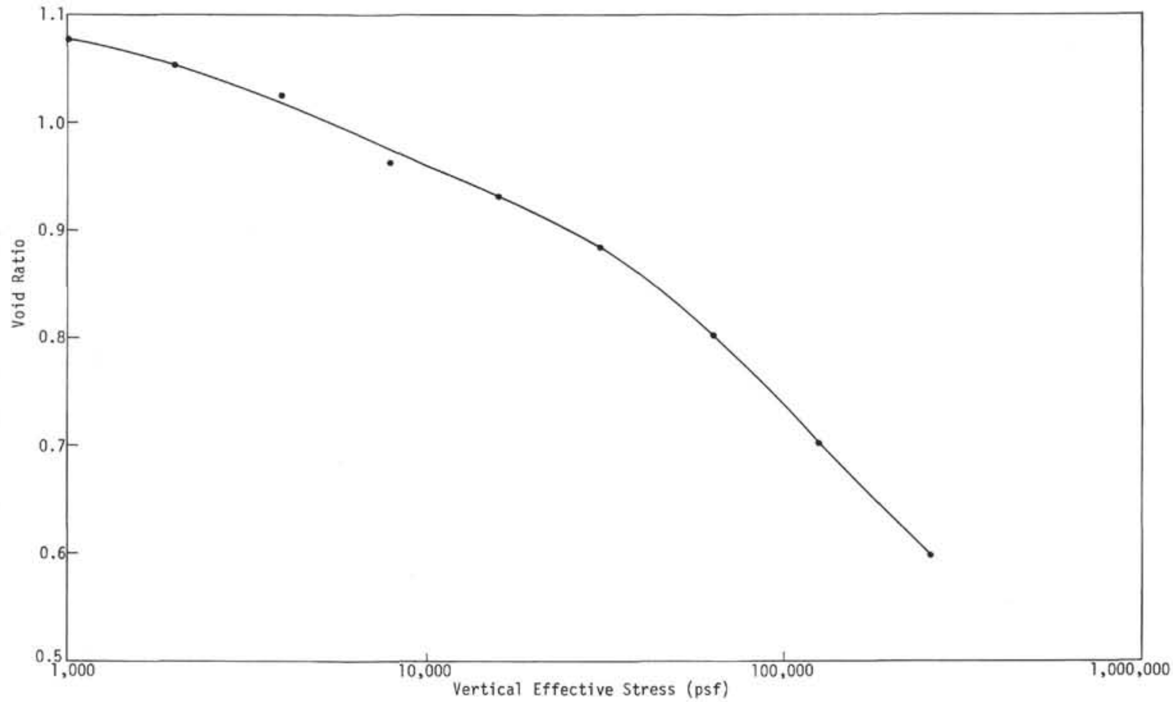


Figure 5. *Void ratio-log stress curve, Core 15 (2, 54-56 cm).*

by static consolidation, and the structure of the deformed samples could have been produced by tectonic overpressures superimposed on the previous structures. The past pressures indicated by the consolidation tests are exceedingly high, but not unreasonable, because the stresses have been sufficient to deform and smear quartz grains (Krinsley, this volume). The strength of sediments from Site 181 is not due to diagenesis because the clay minerals

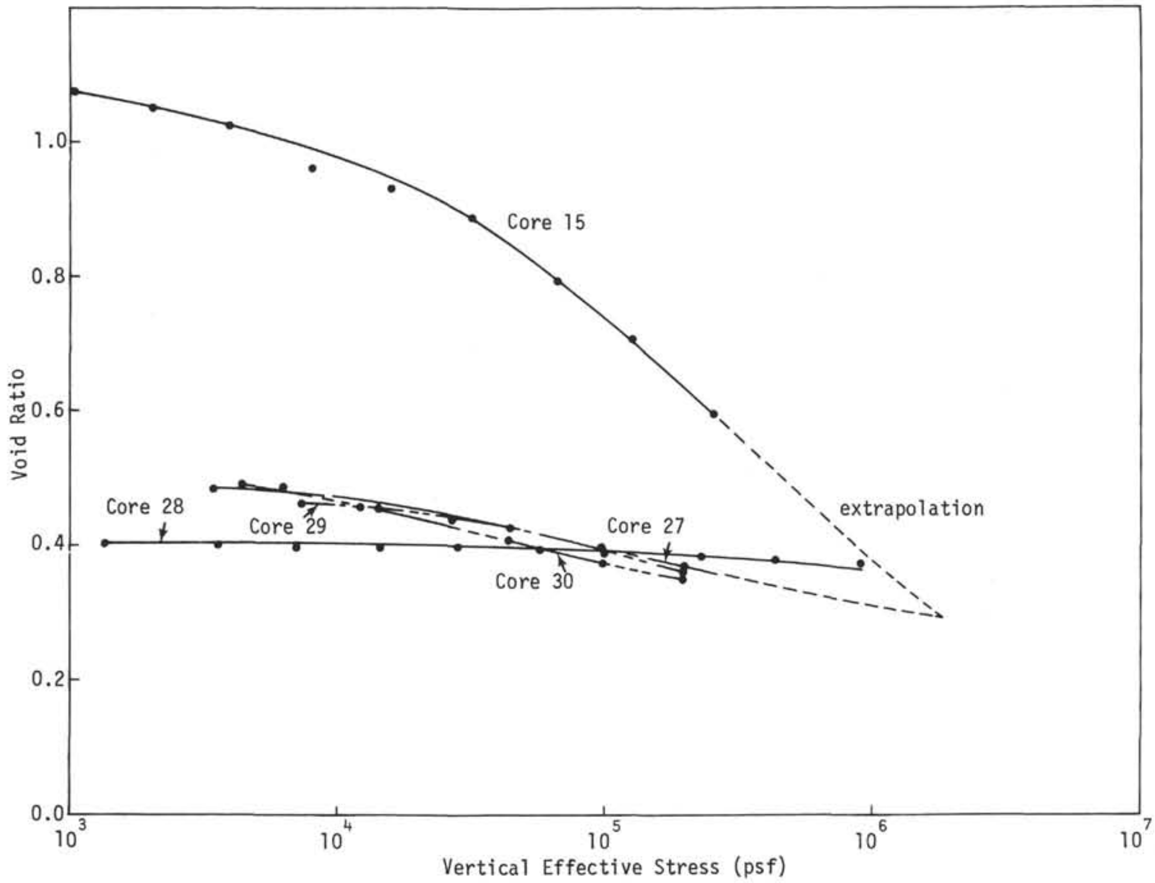


Figure 6. *Compilation of void ratio-log stress curves for Site 181.*

are unaltered (Hayes, Chapter 20, this volume). No carbonate cementation was observed, and, during washing for microfossils, the material broke up in water more readily than the fissile clays that are commonly retrieved.

Another rough estimate of previous burial depth can be obtained from the Leg 18 porosity curve (Chapter 26, this volume). Extended beyond the deepest data points (600 m), the curve crosses the median porosity value of Cores 27 to 30 at about 1.5 km. However, the numerous porosity measurements of on-land samples taken from basins that have continually subsided and filled (McCulloh, 1967) suggest that the porosities found in Cores 27 to 30 fall just within the statistical scatter of porosities for rocks buried at these depths.

Also, Pliocene and Miocene sediments recovered below a suspected diagenetic boundary at Sites 184, 189, and 192 (Lee, in press) are similar in bulk density (and probably porosity) to the sediments from Site 181.

From study of clay mineralogy (Chapter 28, this volume), Hayes concludes that the cores from Site 181 were not buried deeper than 3000 meters to 5000 meters because they did not undergo the lowest temperature diagenetic clay reaction that he could detect. This reaction is reported to occur between 1500 meters and 5000 meters in the Gulf of Mexico region.

Although the quantitative interpretation of consolidation measurements is somewhat inconclusive in the presence of these uncertainties, there is little doubt that the sediments from below 170 meters at Site 181 are overconsolidated for their present depth of burial. Their bulk density and porosity differ significantly from any Pliocene or Pleistocene sediments drilled during Leg 18, and they are the only undersaturated rocks found. Their present environment is not the environment in which they were deformed. Because the effects of severe tectonic deformation cannot be evaluated, a quantitative determination of past depth of burial is not possible. Since the overlying sediments did not have the high degree of strength to allow high-tectonic overpressures, the prior depth of burial probably exceeded the depth from which the samples were recovered. An estimated previous depth of 1.0 to 1.5 km does not seem unreasonable.

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