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Microstructure of Sediments: Investigation with Ultrathin Sections

Abstract. *Examination of ultrathin sections of "undisturbed" marine sediments from the Gulf of Mexico indicates that they are characterized by a loose, open, random arrangement of particles. The microstructures do not appear to conform entirely to either cardhouse or honeycomb structures.*

The microstructure ("fabric") of marine sediments has received little attention from geological oceanographers. Two popular theories prevail as to the nature of the particle arrangement in the sediments. Terzaghi (*1*) suggested a "honeycomb" structure, with adhesive forces causing the particles of clay mineral to stick together on contact; each cell of the structure consists of many adhering particles (Fig. 1A). Later was suggested (*2*, *3*) a somewhat different structure in which the clay-mineral aggregates, having a platy morphology, were arranged generally in an edge-to-face fashion forming a "cardhouse" structure (Fig. 1B). Tan (*4*) presented a three-dimensional idealization of cardhouse structure (Fig. 1C).

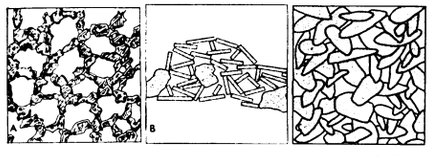

Fig. 1. (A) Honeycomb structure [after Terzaghi (*1*)]. (B) Cardhouse structure [after Lambe (*3*)]. (C) Cardhouse structure [after Tan (*4*)].

While some orientation studies, using polarized light and x-ray diffraction techniques (*5*), can reveal gross trends toward preferred or random orientation of particles, they do not reveal details of the microstructure. Most information has come from the electron microscope. Rosenquist (*6*) used the electron microscope and the replication technique to obtain stereomicrographs showing the microstructure of undisturbed marine clays; he concluded that the microstructure of such clays "corresponds to the cardhouse structure suggested by Goldschmidt and later by Lambe, and in fact exactly corresponds to the imaginative drawing of Tan." Use of the same technique for studying illitic Pleistocene clays led to a similar conclusion (*7*).

Whereas the electron microscope offers the best means available for study of sediment microstructure in detail, the replication technique does not provide easily interpretable results. My purpose is to illustrate the microstructure in samples of sediment from the Gulf of Mexico as revealed by ultrathin sections of the sediment, and to point out that this technique provides more easily interpretable results.

The samples (Table 1) came from cores taken by R.V. *Alaminos* (*8*). Only cores were selected that had been properly sealed and stored to preserve as well as possible the natural state of the sediment. From each core a cubic sample of 2 to 5 cm was carefully cut with a thin-bladed knife or spatula. A larger portion was cut initially in order to retain an undisturbed portion in the center of the sample; likewise, the sample itself was taken from the center of each core. From each sample, smaller samples (1 to 2 cm by 2 to 3 mm^2) were cut with a taut, very thin wire; the outer, disturbed portion of each large sample was first trimmed with the wire to expose the inner, undisturbed portion. The small samples were freeze-dried; this technique is recommended (*6*, *9*) because it entails less particle disturbance due to effects of surface tension than do standard oven- or air-drying techniques.

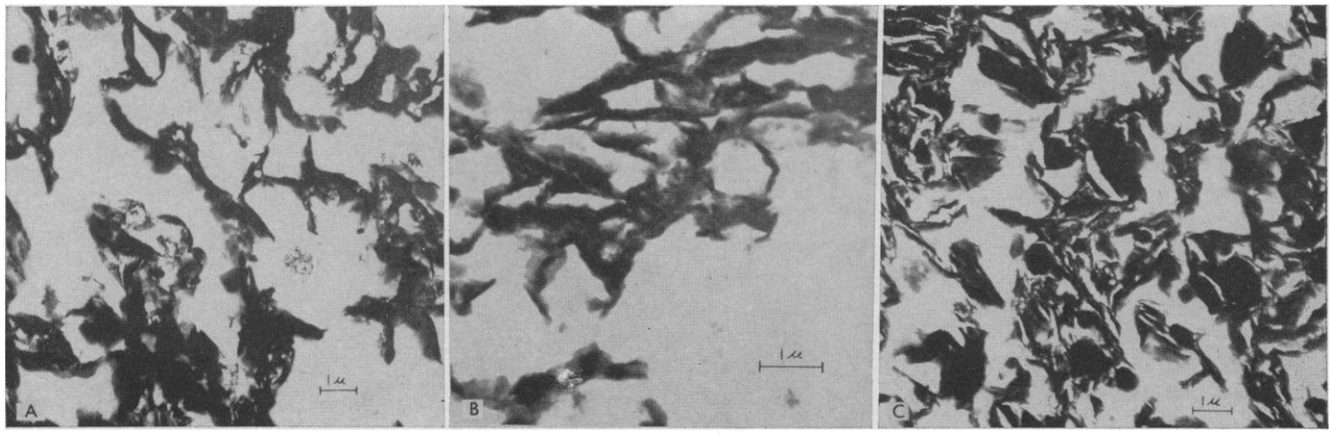

Fig. 2. Ultrathin sections showing the microstructures of undisturbed sediments from an abyssal plane (A), a continental slope (B), and a continental shelf (C).

Table 1. Sources and physiographic provinces of cores sampled.

Province	Core Type	Core Coordinates (N, W)	Depth Water (m)	Depth Sample (cm)
Abyssal plain	Box	23° 51′, 92° 27′	3358	32
Continental slope	Hydroplastic	27° 37′, 94° 47′	549	100
Continental shelf	Phleger	28° 42′, 90° 11′	36	4

The samples were quick-frozen by immersion in liquid nitrogen for several seconds and rapidly placed in a desiccator that was evacuated with a standard ⅓-hp pump; a gauge on the vacuum line showed a constant pressure of 5×10^{-2} mm-Hg. The samples were dried for 2 days at −23°C.

With a sharp razor blade and binoculars, each dried sample was cut into several smaller samples (5 mm by 1.0 to 0.5 mm²); the smaller the final size, the more complete is impregnation of the pore space. The impregnating medium was Maraglas, an epoxy resin, thinned with propylene oxide, in which the samples soaked for 24 hours; the containers were sealed to prevent evaporation of the propylene oxide. The samples were then placed for 24 hours in beakers containing only Maraglas before they were placed in Beem capsules filled with Maraglas for curing in an oven at 60°C. Ultrathin sections of the samples were cut with a Porter-Blum MT-1 microtome using a diamond knife.

Figure 2A (*10*) shows the microstructure of an abyssal-plain sediment; the most striking feature is the loose, open, random arrangement of the particles. Figure 2B shows a continental-slope sediment at somewhat higher magnification; again the open nature of the microstructure is readily apparent. Clayey sediments commonly have porosities as great as 70 percent or greater, and this fact is well illustrated by the micrographs. Figure 2C shows the microstructure of a continental-shelf core; it too reveals an open, random arrangement of particles, but the particles appear more closely packed than in Fig. 2, A and B, showing dense clusters separated by considerably smaller areas of voids.

Many of the particles shown (Fig. 2) do not appear to be in contact with other particles, but seem to be "floating in space." One must remember that the microstructure is being viewed in only two dimensions and that in some plane, either above or below (or above and below) the plane of the ultrathin section, these "floating" particles certainly contact other particles.

Like all idealized representations, Fig. 1, A–C, unavoidably oversimplifies the true picture. Rather than being regular, well-defined plates or rods, the clay minerals shown have very irregular morphologies. Much of the material appears fluffy and diffuse and is probably montmorillonitic or illitic (*11*); there are indications (*12*) that sediments of the Gulf of Mexico are rich in montmorillonite and illite.

It is difficult (usually impossible) to tell where a single particle begins or ends. Thus it seems unreasonable to state flatly that the microstructure of undisturbed marine sediments resembles only a cardhouse structure or only a honeycomb structure. However, on the basis of only Fig. 2 the microstructure appears to resemble more closely Terzaghi's honeycomb idealization. It may be more accurate to say that the microstructure is characterized by a loose, open framework of randomly oriented particles.

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Radiolarian Skeletons: Solution at Depths

Abstract. *Radiolarian skeletons were placed at several depths on the taut mooring wire of a buoy in the central Pacific for 4 months. Recent radiolarian sediment dissolved at appreciable rates at depths shallower than 2000 meters; solution was greatest near the surface and decreased with depth. This pattern correlates with bathymetric distributions of dissolved silicon and of temperature. Siliceous Radiolaria from planktonic samples appeared to dissolve about eight times faster than those from sediment. Tripyleans seemed to be less resistant than polycystins. Acantharia dissolved completely at all depths.*

Radiolaria are small shelled protozoans that live in the plankton of the open ocean. They comprise the groups Tripylea (Phaeodaria), Spumellaria and Nasselaria (polycystins), and Acantharia. Of these, the polycystins are important for reconstruction of the history of the oceans; they are the only ones preserved in the sediment over large areas of the present deep sea. The processes leading from shelled planktonic populations to sediment assemblages on the ocean floor are poorly understood. Recently the importance of solution of tests after death of the planktonic organisms has been stressed for Foraminifera (*1*). There is some circumstantial evidence that solution may also play an important part in the shaping of radiolarian assemblages. This evidence comes mainly from two kinds of observations: (i) undersaturation of the ocean water with respect to silicon (*2*), and (ii) differences between the amounts and kinds of shells observed in the plankton and on the ocean floor (*3*).

I now report direct evidence bearing on the solution of Radiolaria. Samples consisting entirely of polycystin skeletons were attached at various depths to the taut mooring wire of a buoy in the central Pacific close to Horizon Guyot (*4*). The samples were portions from Recent deep-sea sediment that had been acidified and washed in hydrogen peroxide solution; each weighed about 0.015 g. They were enclosed in small plastic tubes that were sealed with fine (openings smaller than 62 μ) nylon gauze and placed within heavy pieces of plastic tubing, one at each depth selected. They were exposed for 4 months. Experimental procedure is given in the report on solution of Foraminifera (*1*).