Reports

Microstructure of Agglomerated Suspended Sediments in Northern Chesapeake Bay Estuary

Abstract. *Suspended sediments in the turbidity maximum of Chesapeake Bay include composite particles which contain platy mineral grains, arranged both in pellets (attributable to fecal pelletization) and in networks of angular configuration (attributable to electrochemical flocculation and coagulation).*

The weathering of rock produces individual clay- and silt-sized mineral grains which become agglomerated into composite sedimentary particles during transport and deposition in lakes, rivers, estuaries, and oceans. Agglomerated sediments exhibit modes of grain attachment that are identified here for the first time in suspended sediments (Fig. 1) from the turbidity maximum of northern Chesapeake Bay (Fig. 2). These modes of grain attachment are attributable to fecal pelletization and to inorganic mechanisms of agglomeration, including electrochemical flocculation.

Electrochemical flocculation, a chemical phenomenon, is the agglomeration produced when salt is added to a freshwater suspension of clay minerals (*1*). Flocculation of suspended sediments occurs principally in estuaries, which are semi-enclosed coastal bodies of water having free connections with the open sea and within which seawater is measurably diluted by freshwater derived from land drainage (*2*). Flocculation of suspended sediments has been described and measured in controlled laboratory experiments (*1, 3*) and is widely mentioned as an important mechanism controlling the transport and deposition of fine-grained sediments in estuaries (*4–6*). Flocculation of suspended sediments has been associated with the formation of both estuarine "fluid muds" (*7*) and estuarine turbidity maxima (*4, 8*), which are zones where concentrations of suspended sediment are higher than those in either the inflowing rivers or the waters farther seaward in an estuarine basin (*9, 10*).

Unfortunately, the field evidence for the flocculation of suspended sediments in either estuarine fluid muds or in zones of turbidity maxima has been less than conclusive (*11, 12*). Fluid muds [a turbid underlayer or fluff mud (*11*) containing a concentration of suspended sediment greater than 10 g/liter (*6, 13*)] can theoretically be maintained solely by hydrodynamic processes (*14*), and fluid mud in the Delaware River estuary disappeared when dredge spoil began to be stored in diked areas (*15*). Thus, flocculation of suspended sediments may not be principally responsible for the natural formation of fluid mud in estuaries.

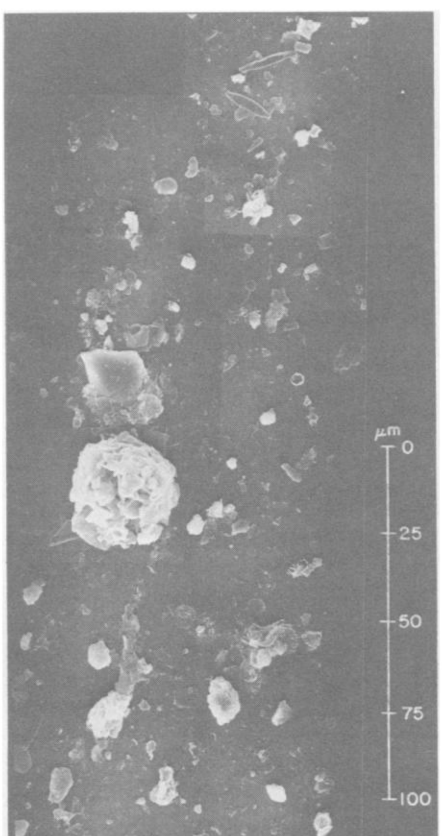

Fig. 1. Collage of scanning electron microphotographs of individual and agglomerated suspended sediments collected in the turbidity maximum of northern Chesapeake Bay (39°13′N, 76°16′W) near the time of slack water on 4 February 1975, at 2 m off the bottom. Sediments were filtered from suspension onto a 0.22-μm Nuclepore filter and desiccated. Microstructures of agglomerated sediments contain platy mineral grains arranged both in pellets, formed by fecal pelletization, and in networks of angular configuration, formed by electrochemical flocculation and coagulation.

Furthermore, flocculation is not principally responsible for the formation of zones of turbidity maxima in estuaries (*11*). Schubel (*12, 16*) studied the formation of the turbidity maximum in northern Chesapeake Bay and showed that it is maintained both by the net, nontidal estuarine circulation and by the periodic resuspension of bottom sediments by tidal currents. The available evidence shows that the dynamic processes that are responsible for the circulation of estuarine waters are probably the most important influences on the transport and deposition of fine-grained sediments in estuaries (*11*). Still, some composite sedimentary particles suspended in the Chesapeake Bay turbidity maximum exhibit floc modes of grain attachment (Fig. 1), and electrochemical flocculation, together with other mechanisms of sediment agglomeration, is important in the trapping of sediments that are introduced into the estuary.

In addition to true electrochemical flocculation, several other mechanisms can agglomerate suspended sediments in situ in estuaries. One mechanism is the pelletization of fine-grained sediments by filter-feeding planktonic and benthonic organisms (*17–20*). A second mechanism is coagulation (*21*) or sediment agglomeration by dissolved molecules which are sorbed onto immersed mineral surfaces (*10, 22*). A third is the growth of microbes on suspended sediments and the associated secretion of sticky mucal substances which bind suspended sediments together (*23*). Diatoms have also been observed to agglomerate suspended sediments in two South Carolina estuaries (*24*).

Pelletization, flocculation, and coagulation produce characteristic modes of grain attachment that can be recognized in the in situ arrangements of grains, or microstructures (*25*), or agglomerated sediments from northern Chesapeake Bay. To observe these microstructures, sediments are filtered from suspension, desiccated, coated with gold-palladium, and then observed through the scanning electron microscope (SEM). When a sample of water (less than 5 ml) is filtered through a 0.22-μm Nuclepore filter (shiny side up), it yields a sample of sus-

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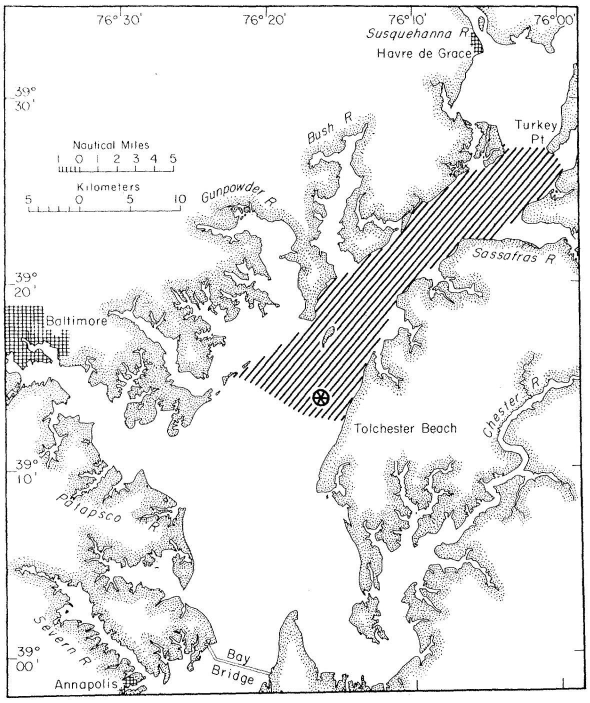


Fig. 2. Zone of turbidity maximum in northern Chesapeake Bay estuary. Samples in Figs. 1, 3, and 4 were collected at the station location off Tolchester Beach.

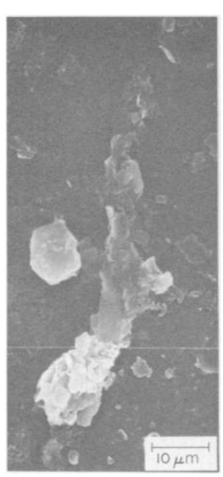
pended sediment that is distributed in a monoparticulate layer on the filter, with few particles touching each other (Fig. 1). Although some distortion of the particles takes place as they settle onto the filter, they do not exhibit excessive breakage if the sample is filtered under low vacuum.

Microbial structures and their associated secretions, which are attached to immersed mineral surfaces in situ, are destroyed by the desiccation of filtered suspended sediments, but they may be preserved by a process in which liquid Freon is substituted for water before the samples are filtered, and then the filtered samples are dried at the critical point of Freon (*26*).

In Chesapeake Bay, inorganic agglomeration of suspended sediments by flocculation and coagulation produces composite particles which contain angular networks of mineral grains arranged in face-to-face, edge-to-face, and edge-to-edge modes of grain contact (*1*, *27*). These modes resemble published descriptions of flocculated sediments (*1*, *3*, *28*); they are apparent in samples of Chesapeake Bay bottom sediments which were viewed through the SEM after artificial flocculation in the laboratory (*29*).

The microstructure attributable to inorganic agglomeration is different from that of the feces produced by filter-feeding organisms. These feces are generally pelleted (*17–20*), although some species of sediment-ingesting organisms do void feces that are poorly compacted (*30*). Those agglomerated particles from Chesapeake Bay that possess a pelleted microstructure bear some resemblance to fecal pellets identified by Schubel (*12*), Schubel and Kana (*31*), and Lal (*19*). The pelleted sediments in Fig. 1 are less than 50 μm in maximum projected diameter, and some are less than 10 μm. These pellets are probably feces produced by large populations of estuarine zooplankton (*31*), and they have yet to be rigorously identified and classified.

Agglomerated sediments in suspension in northern Chesapeake Bay estuary contain pelleted microstructures to which platy mineral grains are attached in a floc mode (Fig. 3). Sediments are also present which contain platy mineral grains attached only in a floc mode (Fig. 4).



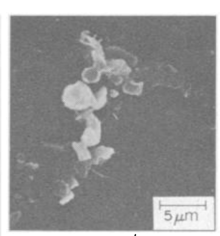


Fig. 3 (left). The microstructure of the suspended agglomerate contains a pellet to which platy mineral grains are attached in a network of angular configuration. Fig. 4 (right). The microstructure of the suspended agglomerate contains platy mineral grains attached in a network of angular configuration, which is attributable to electrochemical flocculation and coagulation.

Microbial structures—forms of algae, fungi, and bacteria—are attached to the microstructures of sediments in situ (*23*, *32*, *33*). As these organisms grow, they secrete mucal slime webbing which drapes over the sediment microstructures and stabilizes the arrangements of mineral grains (*23*, *29*, *33*). The secretion of one film-forming bacterium, *Pseudomonas atlanticus*, is composed of a polysaccharide that is sticky to the touch (*34*). A veil of this substance on suspended sediments probably traps isolated mineral grains which collide with agglomerated sediments in situ. Studies of suspended sediments in Lake Tahoe (*23*) show that the products of the growth of microbes increase the rate of sediment agglomeration over the rate due solely to flocculation and sorption.

Schubel (*12*) has suggested a classification of the composite sedimentary particles that are present in suspension in the Chesapeake Bay turbidity maximum. Those composite particles whose cohesive forces can be broken apart by ordinary laboratory dispersion techniques of peptization and ultrasonication (*35*) are called agglomerates (*12*). Those composite particles that are unaffected by ordinary dispersion techniques are called aggregates (*12*), a term that has been used to describe other types of composite particles for many different reasons (*1*, *3–5*, *17*, *24*, *28*, *36*). The composite particles in northern Chesapeake Bay suspended and bottom sediments are all agglomerates, since none survive laboratory dispersion (*29*).

Different mechanisms of sediment agglomeration operate in the transport and deposition of suspended sediments in natural aqueous environments. Pelletization produces agglomerates whose settling velocities exceed those of the individual mineral grains in the pellet (*18*, *20*), whereas inorganic agglomeration produces agglomerates whose in situ settling velocities are nearly equal to those of the individual mineral grains in the floc (*10*, *37*). In the Chesapeake Bay turbidity maximum, agglomerated sediments in the background population of suspended sediments contain few constituent mineral grains, which are arranged in microstructures attributable to flocculation and coagulation. Those agglomerated sediments in the resuspended bottom sediment population contain relatively large numbers of mineral grains arranged in pelleted microstructures to which additional grains are attached in a floc mode. Thus pelletization is crucial for the deposition of suspended sediments whose settling velocities are exceeded by the upward vertical velocities of water in northern Chesapeake Bay estuary (*16*), but flocculation is still an important depositional mechanism which agglomerates individual clay- and silt-sized mineral grains to pelleted sediments in situ (*29*).

These findings fill a gap in an area where very little is known about either the arrangements of grains in agglomerated sediments or the environmental significance of these features (*38*). Although this information will be useful in the modeling of sediment transport processes in estuaries, it will be of little use in the study of fine-grained sedimentary rocks because the effects of compaction and postdepositional diagenetic changes make it almost impossible to recognize the original texture in ancient sediments.

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39. I thank J. R. Schubel, R. H. Meade, M. O. Hayes, and O. P. Bricker for reviewing this manuscript; N. Watabe and the staff of the SEM Laboratory, University of South Carolina, for their assistance; and P. van Slyck and D. Pendleton for their assistance with graphics. This work was supported by the Maryland Department of Natural Resources, through a grant to Westinghouse Corporation, Chesapeake Bay Institute, and the University of Maryland, to study chlorinated hydrocarbon pesticides and polychlorinated biphenyl contaminants in upper Chesapeake Bay. Additional support came from the Department of Geology and the SEM Laboratory, University of South Carolina.
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Larval Bivalve Shell Morphometry: A New Paleoclimatic Tool?

Abstract. *The shells of the pelagic larvae of bivalve mollusks may be useful as paleoclimatic indicators. An inverse relationship between temperature and maximum size of larval shells within a particular population is reported for a number of Recent species. Changes in the dimensions of the prodissoconch-dissoconch boundary on juvenile specimens may reflect changes in the ambient temperature of marine environments.*

Paleoclimatic investigations in marine sediments are based primarily on the fossil record of holoplanktic microorganisms: Foraminifera, Radiolaria, calcareous nannofossils, diatoms, and silicoflagellates. Established techniques rely heavily on interpretation of oscillations of cold- and warm-water assemblages. In this report, we present evidence for an inverse relationship between temperature and maximum size in another group of minute shelled organisms, larval bivalves, which may provide an additional interpretive tool in paleoclimatic studies.

The larvae of marine benthic invertebrates are an important constituent of both the coastal and the oceanic plankton. Such meroplanktic stages often serve as a means of long-range dispersal and population recruitment for organisms of otherwise low migratory capability (*1*). Of all pelagic larval forms, members of the class Bivalvia are by far the most dominant, comprising more than 57 percent of the total invertebrate meroplankton in certain marine waters (*2*). In addition, the calcareous skeletons of these mollusks render such organisms useful in paleontological studies (*3*). During the past decade, various workers have alluded to the usefulness of such larval shells in paleoecological studies for defining population dispersal patterns (*1, 3*), in biostratigraphic studies for evaluating the potential of certain benthic species as index fossils (*1*), and in systematic studies for assessing evolutionary relationships (*3*). Here we discuss an additional paleontological application by illustrating how changes in the dimensions of shell features associated with larval metamorphosis may reflect changes in the ambient temperature of marine environments.

In mollusks, the term metamorphosis has often been used to describe the immediate changes that occur when the lar-

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