RECENT AND ANCIENT SEDIMENTATION; TWO ASPECTS OF ONE SUBJECT

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Geology has thrived on the application of the maxim, the present is the key to the past. Investigation of the phenomena and active processes of the surrounding world has proved to supply the most trustworthy foundation for interpreting the features of ancient rocks and unravelling the geological history of the earth's crust. But one chapter of geology has formed an exception, that of ancient marine sediments. Considering the extent as well as the economic and paleontologic importance of these rocks, it is a huge chapter. In this domain geologists have attempted the opposite procedure, namely to deduce the submarine processes from the features of their consolidated rocks.

Deep-sea deposits, it is true, have received a certain amount of attention, but they are too scarce in the geological column to be of much use in the study of ancient sediments. In themselves they are of fundamental importance to the earth sciences, being closely tied up not only with geophysics, paleoclimatology, and geoeconomy but no less with dynamic, chemical and biological oceanography. But this is not the subject of the present paper, although there will be occasion to return to consideration of deep-sea deposits later on. The following remarks, it should be realized, apply mainly to the sea floor at depths less than 100 fathoms.

During the last two decades, and more especially since World War II, a change has come about. Many have begun to realize not only the painful void in our understanding of what is going on on the sea floor but our inability to interpret the mode of origin of the rocks that enclose the bulk of our fossils, sedimentary ores, and oil, deposits used as fertilizers, building stone, raw materials for chemical industries, etc. F. P. Shepard has been particularly active in showing how hopelessly inadequate are our ideas on the distribution, nature and origin of recent marine sediments, especially those present in shallow water.

Several institutions are now embarked on investigations of the shallow sea floor; oil companies, navies, and universities are providing funds, with the result that knowledge is expanding rapidly. Just how rapidly will be realized by noting the increasing number of papers appearing on topics in the broad field of marine sedimentology. Almost all geological journals frequently contain papers of this kind.

It is not generally appreciated that there are two entirely different approaches to the study of shallow sea floors. The main objective can be a knowledge of the laws of sedimentation by ascertaining the properties of the sediments and of the environment. This kind of work will gradually teach us how to determine the type of environment that existed when ancient marine sediments were formed, and geologists will thus learn to unravel the paleogeography of the continents. In fact, the present sea floor will be used as a key to the past.

The opposite objective is to extend the geological map beyond the shore line out to the continental shelf. Thus data are sought which will tell us the history of a local area of the crust that happens to be covered by water at the present time. Whether the formations encountered are of marine origin or not is of no particular concern.

It is of some importance to realize this dual aspect of submarine geology, because techniques, teamwork, and suitable areas vary with the objective. For the study of sedimentation, areas of deposition must be sought. Physical, chemical, and biological oceanography of the environment has to be taken into account. Transport by waves and currents, source of mineral and biological components, solution and precipitation, diagenesis on the sea floor are of fundamental significance in these matters. Hence, a staff of specialists is required, and only a large oceanographic institution can tackle these problems successfully. Of course an individual, working on his own, can, with ingenuity, advance our knowledge as to certain aspects of sedimentation, but by and large marine sedimentology is a subject for teamwork. For most purposes simple grab samples will suffice, because bulk properties are the most important. But bottom photography and the complicated apparatus needed by the other oceanographers render a large ship necessary and hence require backing by ample resources.

On the other hand, the regional geologist, when venturing beyond the shore, will prefer areas of nondeposition or of thin sedimentary cover so that he can find the older formations at the surface or only a short distance below the obscuring sediment. He will require little equipment other than some heavy coring device or dredge, or he may use a self-contained diving outfit instead. Once he has secured his samples they need less deep-going investigation as to grain size, organic content, chemical composition, water content, etc. so long as he can recognize the formation they come from.

Thus an oil company considering the lease of an area on the sea floor will conduct field work in the latter sense. But if the research department of the same company seeks to learn more about the general principles of deposition they will sponsor the former type of investigation.

It is obvious that the two approaches noted above are interrelated. Luckily they are by no means exclusive of one another, and in practice both will often be included at the same time. Nevertheless it is important to bear in mind the basic differences between the two aspects of sea-floor study and to lay particular emphasis on one of the two.

An illustration of the combination is found in the study of stratification in cores of recent sediment; change in material is linked with a change in conditions, and the sedimentologist will be practicing regional historical geology when investigating the deeper strata of his core. Thus both approaches are combined in one study.

An instance of geological mapping of the sea floor is seen in the examination of the English Channel by investigators from Cambridge, Britain (King, 1950; Hill and King, 1952). They have taken samples of Mesozoic rock with a heavy corer, often below a thin cover of recent sand.

An example of work that is aimed purely at learning more about sedimentology is furnished by Stetson's well known investigations of the New England shelf and Gulf of Mexico terrace sediments (Stetson, 1953). Other instances could be given, such as the American Petroleum Institute Project for Gulf Coast sedimentation.

I will restrict myself to the recent reconnaissance of the Orinoco shelf area by a Dutch group. This project, sponsored by Shell Oil of the Hague, was carried out in 1952 and 1953. That particular region was chosen because it embraces within a limited area not only the protected Gulf of Paria but a large delta and an open oceanic shelf in the South Atlantic as well as one in the quiet Caribbean.

The report on the results obtained in the Gulf of Paria, which has just appeared (van Andel and Postma, 1954), deals with the current system during the dry season, when the Orinoco has little influence on the water circulation, and during the wet season, when the surface waters of the Gulf become brackish. In the wet season a vast amount of sea water is carried along by the fresh water that escapes into the Caribbean. This loss is compensated by a powerful incoming bottom current which strongly counteracts the spread of sediment away from the river mouths. In addition, throughout the year a clockwise eddy occupies the eastern half of the Gulf and greatly reduces sedimentation in its centre. Thus hydrography is used to elucidate sedimentological data.

All of the sand carried out to sea by the river is now deposited within a few miles of the coast. Powerful currents sweep the mud into the Gulf of Paria, but a large portion escapes again on the far side to the Caribbean. Hence, much of the Atlantic shelf off the Orinoco and Trinidad is nondepositional, whereas the shelf north of the investigated area receives a great amount of fine deposit.

The land surface which formed in the Gulf of Paria during low sea levels of the Ice Age now lies buried under fine mud, as determined by echo-sounder. The rate of sedimentation deduced from the estimated time of postglacial transgression is variable, ranging from zero at some spots with high current velocities to one foot per century elsewhere. After consolidation, this would still amount to about 10 centimeters per century.

The large distributary of the Orinoco that debouches in the Gulf of Paria at Pedernales appears to be young because the levees are poorly developed. The time of breakthrough can be estimated in the following manner. At various spots in the Gulf, the large grab sampler revealed beds of decaying shells which had lost their colour and had become brittle. They appeared to be fixed in position of growth and were covered in most spots by a few inches of mud. At present the floor of the Gulf is practically devoid of living pelecipods. This implies that the breakthrough at Pedernales brought in such quantities of fresh water during rainy seasons as to kill off the shell beds. C^{14} measurements on a few samples have given ages of roughly 700 years for these shells. Since that event the rate of sedimentation appears to have increased, especially near Pedernales.

The organic matter of the Gulf mud varies in nature according to location. The carbon-nitrogen ratio is higher close to the river than it is farther away where planktonic life probably provides a more important contribution. Space does not allow me to dwell on the many other significant findings of this cruise.

The contention that a single individual is still able to carry out valuable sedimentological research can be illustrated by pointing to the work on the tidal flats of Holland and elsewhere by Dr. van Straaten (1954) of Groningen. Tidal flats form an entirely different environment from the open sea floor or deep bays, and such studies require other techniques of investigation. Dr. van Straaten has spent several seasons on this work and has achieved important results. His investigation of Devonian rocks in the Ardennes demonstrates the usefulness of the experience gained on recent sediments for interpretation of ancient rocks. In many respects the Psammites du Condroz are almost identical with the tidal sand and mud flats along the North Sea coast. In both areas similar sand and mud rocks were laid down; one finds the same current ripples and wind ripples, the same gullies, mud pebbles, worm tubes, and mud cracks; there are identical lamination structures due to tidal currents alternating with slack water and comparable distortion by burrowing organisms. Even the area covered is of the same order of magnitude. But in one respect there is a significant contrast in that current action in the present tidal flats is much more active than that in the Devonian environment. Tentatively van Straaten concluded that the Psammites du Condroz were laid down in lagoons similar to those boardering the Gulf Coast, but later he changed his opinion (personal communication).

As a final example of the close relation between the investigation of recent sedimentological phenomena and ancient rocks, I would like to choose the insight gradually gained in the action of turbidity currents. Twenty years ago Daly came out with his epoch-making hypothesis which suggested that the submarine canyons off the New England coast had been scoured out during the Ice Age by currents of turbid waters rendered heavy by a load of mud. The author's experiments were later duplicated by Bell, and the principle of turbidity flow was confirmed.

Soon after, Stetson emphasized the significance of this mechanism for transporting fine material to the deep sea. Again a few years later the writer used experimental approach to supply convincing evidence that such a current could carry vast quantities of not only mud but sand as well and that it should be able to roll pebbles for great distances, even out to the deep-sea floor.

Migliorini was the first to suggest that the emplacement of certain sands showing graded bedding might be attributed to the action of turbidity currents. In graded beds the grain size decreases from the bottom to the top of a granular deposit. Again by experiment the author was able to confirm this and ventured to suggest that deep-sea sands might owe their origin to the transporting power of turbidity currents. Shepard and Phleger, and more especially Ewing and his associates, demonstrated the graded bedding of many deep-sea sands, their shallow-water components, their wide extent, and the great individual thickness of some of these beds. The latter group of workers has brought together an imposing array of arguments to indicate the vast importance of turbidity flow for deep-sea transport and for smoothing the topography of the ocean floor in the Atlantic.

The next step was Heezen and Ewing's (1955) analysis of the cable breaks following two earthquakes. They contend that a turbidity current which was triggered off ran down the continental slope at a velocity of over 50 knots. This hypothesis fits the data so perfectly and the subsequent proof of a thick bed of graded silt on top of normal deep-sea sediment in that area is so suggestive that there is not much room left for doubt. However, so staggering are both size and velocity of the assumed currents that many may still feel inclined to ask for further proof.

To round off this picture of turbidity currents the author would like to draw attention to results on graded bedding in ancient rocks of the graywacke type (Kuenen, 1953). It has now been demonstrated in a dozen formations of graded rocks of all ages that the graded beds are associated with features which indicate that they have been deposited by currents. These currents had a constant direction through many successive beds and over wide areas. Traced up-current, these beds make place first for nongraded rocks and finally for shallow-water deposits. This forms strong supporting evidence for the great importance of turbidity flow as a transporting and depositing agent in the oceans, both past and present.

In conclusion I should like to emphasize on the one hand that further insight in the sedimentology of the present oceans is of vast importance to geology and the earth sciences in general and on the other hand that marine sedimentology is a field from which a rich crop of results with fundamental significance can still be gathered.

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