was first imprinted on a female model and subsequently on a male model. Fourteen of the 22 ducklings, when tested with both models present, preferred the model to which they first had been imprinted, showing primacy. Only five preferred the model to which they had been imprinted last, showing recency, and three showed no preference at all.

In addition, it has been found that the administration of punishment or painful stimulation increases the effectiveness of the imprinting experience, whereas such aversive stimulation results in avoidance of the associated stimulus in the case of visual discrimination learning.

Finally, chicks and ducklings under the influence of meprobamate are able to learn a color discrimination problem just as well as, or better than, they normally do, whereas the administration of this drug reduces imprintability to almost zero.

Imprinting, then, is an obviously interesting phenomenon, and the proper way to approach it is to make no assumptions. To find out its characteristics, to explore its occurrence in different organisms, and to follow its effects would seem a worth-while program of study.

What can we say in conclusion about the general nature of imprinting? Our best guess to date is that it is a rigid form of learning, differing in several ways from the usual association learning which comes into play immediately after the peak of imprintability. In other words, imprinting in our experiments results in the animal learning the rough, generalized characteristics of the imprinting object. Its detailed appreciation of the *specific* object comes as a result of normal conditioning—a process which in the case of these animals takes a much longer time and is possible days after the critical period for imprinting has passed. It is an exciting new field and is certainly worthy of study.

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CURRENT PROBLEMS IN RESEARCH

Marine Sediments

Recent sediments give important clues about conditions under which sedimentary rocks may have been formed.

Francis P. Shepard

Most sedimentary rocks are believed to have been deposited in the seas of the past. One of the primary purposes in geological investigations has been to interpret the conditions under which these ancient sediments were deposited. One of the obvious places to look for guidance in these interpretations is in the deposits of the present. It is, therefore, rather surprising to find how little attention geologists had paid to these recent marine sediments until very recent years. Up until World War II only a few individuals were interested in remedying the situation (*1*). Even the large-scale oceanographic investigations, which were initiated shortly before the war, had helped little in the interpretation of ancient sediments because they had been largely concerned with the deep-ocean floor, and most marine sedimentary rocks now on the continents were probably deposited in relatively shallow seas.

For many years some of the leaders in petroleum geological research had recognized the importance of carrying on investigations of the sediments of today, and finally, in 1950, they developed a project supported by the American Petroleum Institute which had as its aim the study of near-shore marine deposits as an aid in the interpretation of ancient sediments. To date, the field work of this project, which we have administered at the Scripps Institution of Oceanography, has been confined to the northwestern Gulf of Mexico (*2*), although plans are now under way to continue the studies in the Gulf of California. Meantime, a number of other projects, largely supported by petroleum companies, have been carried on elsewhere. Notable among these have been the studies of the Bataafsche Petroleum Maatschappii, of the Hague, around the Orinoco Delta, Trinidad, and the Gulf of Paria (*3*); of the U.S. Geological Survey among the coral reefs of the western Pacific Ocean (*4*); of the Hancock Foundation off the southern California coast (*5*); of the Soviet Union in the various seas that surround the U.S.S.R. (*6*); and of the Germans, especially in the Baltic (*7*).

As a result of these studies of recent sediments it is now easier to interpret

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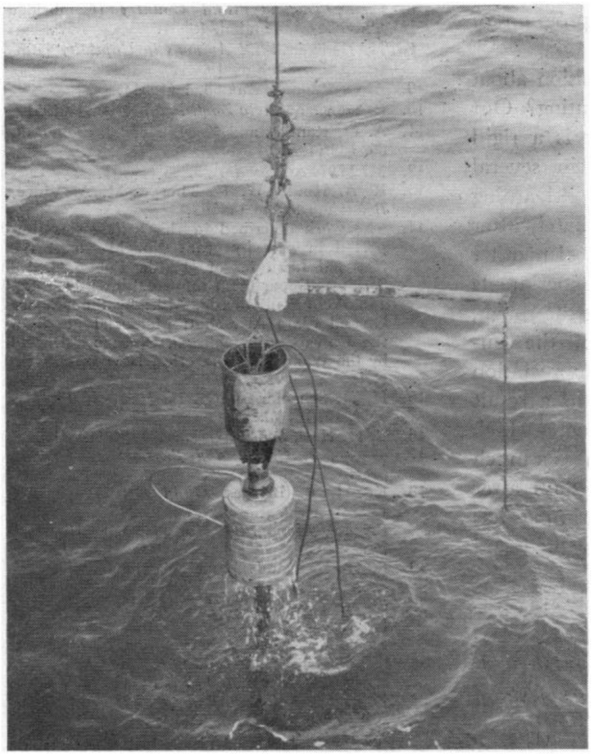

Fig. 1. A piston corer, modified from the Kullenberg type. A weight attached to the arm extends below the pipe and releases the core barrel and weights when it reaches bottom. The loop of wire allows the core barrel to fall free after release.

the environments in which many sedimentary rocks were deposited. The petroleum companies are making good use of this information in their search for oil.

Instruments

The instruments used in obtaining samples of recent sediments are for the most part quite simple in principle, in contrast to the amazing devices of the nuclear and space age. Cores of the ocean bottom are obtained partly by lowering heavily weighted pipes to the bottom and bringing up the core obtained when the pipe sticks into the soft sediments. A more complicated but much more successful method was devised by Börje Kullenberg (*8*), who placed a piston inside the pipe, which he attached to the winch cable. The heavily weighted pipe is allowed to fall free over the piston after a trigger weight has hit bottom (Fig. 1). The piston greatly reduces the friction of the mud entering the core barrel, so that much longer cores are obtained, and there is much less loss of length than is found in ordinary cores, where the sediment is pushed aside by the coring operation.

Various types of instruments which grab samples from the bottom are used. One of the most successful is the Van Veen grab (*9*), which obtains a sample of about 2 cubic feet. Orange-peel buckets of slightly smaller size are also used, but these are not very successful except in shallow water, whereas the Van Veen has been used at the greatest depths. Other samplers are used in shallow water from a vessel that is under way. These are shaped like a torpedo; they descend nose first, take a bite of the bottom, and return with the nose upward. The sediment is also held in by a lid, which closes after the sampler hits the bottom.

One of the most interesting developments in marine geology has come from the use by geologists of the Aqualung, made famous by its inventor Jacques Cousteau. The scuba (*10*) divers, as they are called, carry with them geological hammers, compasses, inclinometers, and cameras. They work at depths down to about 300 feet, and much exploration of the sea floor has been accomplished in this way. The bathyscaphe, invented by Auguste Piccard, has also been used to obtain data, but from considerably greater depths. Cameras which can take repeated photographs when lowered to the bottom have begun to provide us with much valuable information from great depths (*11*) (Fig. 2).

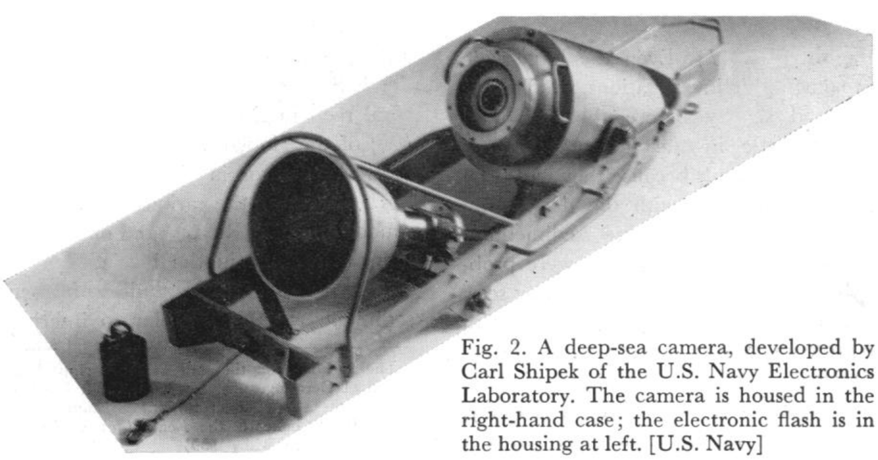

Fig. 2. A deep-sea camera, developed by Carl Shipek of the U.S. Navy Electronics Laboratory. The camera is housed in the right-hand case; the electronic flash is in the housing at left. [U.S. Navy]

Sandstones

In order to see how the characteristics of the recent sediments shed light on the conditions under which the sediments were deposited, let us consider some aspects of the origin of several of the most common types of rock.

Geologists usually define sandstones as rocks consisting of grains of detrital sediments which are predominantly within the size range of 1/16 millimeter to 2 millimeters in diameter. These rocks have been deposited either in the ocean or on the land, and many of them have been deposited along the border between the two, so they belong to some extent in each category. In general, sandstones are rather poor in fossils, and therefore the geologists need other criteria to interpret their origin.

Sheet sands. One common type of sandstone is characterized by its widespread continuity and is called a sheet sand. Some of these are formed by braided streams on a broad plain at the base of a mountain range. Although these fanlike deposits are well known to geologists, they are not easy to recognize in ancient rocks. Sheet sands containing marine fossils, and particularly those including forms of life characteristic of the open sea, have been even more difficult to interpret than the fans. Studies of the sea floor have shown that the continental shelves have many extensive areas of sand. The most puzzling thing about such sand areas is that the majority of them lie outside zones where the sediments are muddy—such as, for example, the broad sand belts along the outer continental shelf off the coasts of China. A similar outer-shelf sand has been studied off the Texas coast. The finding of shells that have been dated, by the carbon-14 method, as thousands of years old shows that, at least here, the sands may not have been deposited under present-day conditions. We know that the sea stood considerably lower during the ice ages, (because the water was locked up in glaciers), and it is believed that the rivers coming out onto this shelf carried more sand during glacial times than at present. As the sea rose, the rivers occupied estuaries and began depositing their sediments in these embayments, leaving many of the shelf sands uncovered. Furthermore, with the change in climate many rivers ceased transporting much sand to the sea and began introducing mud. This fine sediment could be deposited only where the currents of the sea floor were weak. Along many portions of the continental shelves the currents are strong enough to prevent mud deposition. These same currents move the sand back and forth on the outer shelf and may introduce the outer-shelf faunas into these former terrestrial or coastal sands.

Another type of marine sheet sand is found in shoal water where tides are very pronounced. Vast areas in the southern part of the North Sea are covered with sand which has been introduced in part from the English Channel by tides which run powerfully through the Straits of Dover. Another large area covered with sand occurs southeast of Cape Cod, in Nantucket Shoals, where the tides are constantly shifting the sand derived from the erosion of the cape. Farther to the east, on Georges Bank, there are equally extensive shoals. Here, much of the sand is remarkably pure quartz and well rounded, resembling the great glass-making sandstones of the Middle West, known as the St. Peter sandstone. Few fossils are found in the St. Peter sandstone, and a striking scarcity of shells characterizes the sands of Georges shoals. These, however, are only clues, and the two sands doubtless have quite different origins.

Shoestring sands. Other sandstones are characterized by their elongation and their lens shape in cross section. These sometimes form a reservoir in which oil accumulates, so their origin is a problem of much interest. Some of them show the characteristics of river sands, but others appear to be comparable to the great sand islands (Fig. 3) which form barriers along many of the lowland coasts of the world (*12*). By studying the characteristics of the recent sands in each of these environments, it is possible to identify the origin of many of the shoestring sandstones. Most of the sandy barrier islands have a straight or gently curving margin seaward and a scalloped margin facing the lagoon, whereas the river-channel sands have a slightly winding shape, with the two sides roughly parallel. In cross section the barrier islands are usually broader at the base than above but show asymmetry, whereas the river channel sands have a narrow concave base, are wider above, and have a rough bilateral symmetry.

The sediments are also quite different. The barrier sands are much better sorted, especially on the outside, where there are beaches and dunes. Some of the inner marshy flats developed by washovers from the ocean are somewhat muddy, especially where there are extensive ponds. The river sands are, in general, poorly sorted and have more lenses of gravel and of muddy sediments than the barriers. Unlike the sediment of the barriers, that in the river channels shows no contrast on the two sides. Studies of grain orientation show that in both cases the grains are elongated in the direction of flow (*13*). Therefore in the river channels the grains trend along the length of the channel whereas in the barrier islands, which receive their sediment from the outside, the grains are largely oriented across the sand body.

The faunas and floras are quite different. The river deposits contain an abundance of wood, which is rather scarce in the barriers. The ocean side of the barrier contains ocean shells, whereas the lagoon side has estuarine types. Shells are much scarcer in the river channels and consist largely of freshwater types.

Distinguishing between the beach and dune sands of ancient barrier-island deposits or of any coastal deposits has been somewhat difficult. Considerable study of the recent sands has provided some useful clues. Study of the type of bedding is often helpful, because the wind makes a special type of cross-bedding which is distinctive (*14*). When this cannot be found, other criteria are helpful. If the outcrops contain both dune and beach deposits side by side, the grains of the dune sands will almost always be more rounded (*15*) and the contrast will develop at the immediate point of contact, indicating that the wind has selected rounder grains, since there has not been enough transportation to produce rounding. The dunes almost always have more silt than the beach sands.

The idea long held by geologists that barrier islands are formed on coasts of emergence led to the thought that they were ephemeral features and, therefore, not likely to be preserved and to become reservoirs of oil. The work along the coast of the Gulf of Mexico, however, has shown that many or perhaps most of the barrier islands were built up by the waves as the sea level rose at the end of the glacial period, or after abandoned deltas sank beneath the sea. It seems likely that reexamination of shoestring sands will show that many of them are old barriers, as claimed many years ago by N. W. Bass (*12*).

Deep-sea sands. Geologists have long been puzzled by layers of coarse-grained sandstone interbedded with thick masses of shale, the former suggesting shallow-water conditions and the latter appearing to have been deposited in quiet deep water. They were at a loss to explain the sudden change of depositional conditions that was implied, particularly when it was found that the faunas of some of the shales were those representing deepwater conditions. These sandstones contain ripple marks and cross-bedding, both generally believed, in the past, to be a sure sign of shallow-water deposition. They even contain fragments of wood and shallow-water organisms. It was thought by some geologists that these sand and shale sequences indicated rapid, large-scale crustal movements so that deep-sea conditions alternate with those of shallow water or even of land.

The explanation of the phenomenon came when the Dutch geologist Kuenen (*16*) demonstrated with tank experiments that sand could be transported by currents resulting from a relatively heavy suspension of sediment and water. These currents can in turn be induced by slumping of the water-saturated sediments on a submarine slope, probably as the result of the development of spontaneous liquefaction (*17*). The extensive coring operations conducted by the Lamont Geological Observatory (*18*) did much to establish the great depth to which sand could be carried by this means. It can even be transported along a deep-ocean floor with little or no gradient. Almost all recent oceanographic cruises in various parts of the world have added to the record of these amazing currents. Many of them travel down submarine canyons, carrying the sands of the canyon head and the canyon walls out onto the deep fans which are found at the lower end.

The turbidity-current explanation for such sandstone layers has now been used widely, probably without enough caution in many cases. Actually there has been little study of the characteristics of deep-sea sands. Oceanographic institutions appear to have put too many of their resources into obtaining deep-sea cores and too little into studying the results. From preliminary investigations it has appeared that may of the deep-sea sands are graded—that is, the grains are coarse at the bottom and progressively finer above. This characteristic was also found in the experiments by Kuenen. Analyses of many of the deep-sea sands at Lamont and at Scripps, however, have shown that many of them are not perceptibly graded; others have alternating coarse and fine sediments in the same sand zone. Furthermore, graded bedding can be produced in several other ways, including the stirring up of sediment on the sea floor by great storm waves, so graded bedding by itself is not a safe criterion for assigning a turbidity-current origin to these sands (*19*).

Some study of the constituents of deep-sea sands indicates that there may be fewer organic constituents in them than in the sands of the slope from which they were derived. Admixture of deep- and shallow-water Foraminifera suggests that material has been picked up during the passage of the currents down the oceanic slopes. Much remains to be learned, however, before reliable interpretation of deepwater sand layers can be made.

Shales (Mudstones)

Various names have been applied to the sedimentary rocks which consist of grains of silt and clay (*20*), but the most common names are shale and mudstone or mud rock. Among the sedimentary rocks found on the continents, shale is generally considered to constitute more than 50 percent, whereas sandstone accounts for only about 20 percent. Just the opposite is found on the continental shelves, where sand covers more than half of the surface area and about 30 percent could be classified as mud—that is, silts and clays. This contrast constitutes something of an enigma, since so far as we know most sedimentary rocks were formed in shallow marine waters. The enigma is explained by the somewhat atypical nature of present-day shallow marine sediments. This, in turn, is due to the recent rise in sea level; many of the sands of the continental shelves are not yet covered by the muds derived from the continents. Furthermore, there were extensive shallow bays or epeiric seas in the past, and these are not well represented at present. If the continental glaciers of Antarctica and Greenland should melt, the rise in sea level would produce much larger embayments in which the protecting headlands would favor the deposition of fine-grained material to a greater degree than on the exposed continental shelves, where both waves and ocean currents interfere.

Continental shelf shales. To judge from available information, the chief areas of active deposition on the continental shelf have muddy sediments. Large areas on the continental shelf of the northwest Gulf Coast are mud-covered, and cores show that the muds are at least as thick as the length of penetration of the coring devices (10 or 20 feet). These deposits have little stratification, although they may develop fissility upon compaction. The chief fossils found in these shelf muds are Foraminifera. On the outer shelf, except near a delta, the Foraminifera are largely planktonic (the free-floating type of plankton). Nearer shore, on the other hand, the Foraminifera are largely benthonic—that is, bottom dwellers. Thus, these unicellular organisms often give a clue as to the part of the shelf on which they were deposited. Many of the benthonic Foraminifera dwell only at certain depths, and the range is limited. The sediments on the shelves off most of the large rivers are muddy, although the outer shelf, as explained previously, is usually covered with sand.

The coarse fraction of the shelf muds varies in composition from place to place, but it usually contains echinoid spines along with Foraminifera and small amounts of glauconite. Shell fragments are more common than in most other environments.

Muds of lagoons and estuaries. Most bays protected by sand islands receive mud deposits which are usually quite distinct from those of the open continental shelf. The echinoids and glauconite of the shelf muds are rare in the protected bays. Shells and Foraminifera are both found in typical bay deposits, but they differ considerably from those of the shelf. Among the shells, oyster shells are particularly common and often form reefs. In old bay deposits these reefs are frequently found cutting across the shales and mudstones. As for other shells, the bay deposits contain only a few species, in contrast to the diverse shell faunas of the shelf. In the Foraminifera found in bay deposits there are virtually no planktonic forms; as in the case of shells, the deposits usually contain only a few species.

The stratification is found to be poor wherever the bays support abundant burrowing organisms. The chief exceptions are bays where there are stagnant areas in the water mass, as in some bays with deep holes or in arid areas where there is little entering drainage. Stratification may also be preserved if the deposition is rapid. In arid bays the sand grains mixed with the mud are apt to have coatings of calcium carbonate, deposited as the result of evaporation.

Delta margin shales. The areas where mud deposition is going on most rapidly are at the margins of the large deltas (Fig. 4). At the mouths of the Mississippi, for example, mud is building up the slopes at rates of a foot or more per year (*21*) in contrast to typical shelf muds which have only accumulated a score of feet in the past 10,000 years or more since the sea came in over the outer shelf. This great contrast must have held also in the past. It is, therefore, somewhat puzzling that geologists have found so few shales to which they attribute a deltaic origin. Most of the old formations which are considered deltaic consist of sandstones, such as the Devonian Catskill sandstones of New York state that represent a great delta built into the sea from the old land of Appalachia.

Perhaps the scarcity of ancient mud deltas is explained by failure to recognize these deposits. Too much attention has been paid to the deltaic structure (Fig. 5), which geology textbooks show as a series of highly inclined foreset beds built over the horizontal bottomset beds and in turn covered by horizontal topset beds. The foreset beds represent a deposit formed on and conforming to an already existing slope, whereas the bottomset beds develop on the flat bottom of the body of water and the topset beds are deposited above the forward-building inclined series. This diagram applies to many small lake deltas built largely of sand, but it does not apply to the large muddy deltas built into the ocean. These latter have foreset beds with very gentle inclinations, rarely over one-half degree; hence, the discordance between the bottomset, foreset, and topset beds is very slight and could easily be overlooked in rock formations.

Studies of modern deltas have shown other characteristics which would be of more use than deltaic structure in identification of the old deltas. Among these is the good development of lamination in the topset beds. In most cases the laminae represent alternation between clayey and sandy or coarse silt layers. Such lamination is common among ancient shales, and it may be that much of it is deltaic but has not been so recognized. The deltaic deposits have an abundance of wood fibers, since most rivers transport great quantities of wood to the sea. In the swamps bordering some river channels future thin coal beds may be forming. Fossils other than wood are scarce in deltaic deposits. The rivers in general transport a great deal of mica; much of this is deposited at or near the river mouths, although it is also abundant in other environments. Small aggregated grains of orange or brown color are common in recent deltaic deposits and may be found as well in ancient ones.

Black shales. Geologists have been debating the origin of black shales for generations. The Chattanooga shale of the southern and midwestern states has been intensively investigated. In addition to being black, it is well laminated, although the laminae do not show the frequent alternation of fine and coarse sediment that is found in deltaic deposits. Presumably, few burrowing animals were present to disturb the layering. It is generally agreed that deposition conditions were those of stagnation. One group of geologists believes that the shale had a shallow-water origin and another group considers it a deepwater deposit. Among the findings which suggest that the water was shallow are the presence of ripple marks, the presence of occasional layers with cross-bedded sands, and the high degree of sorting. This, however, is not entirely convincing to marine geologists, since we have many photographs of ripples now forming in deep water and the

Fig. 3. A sandy barrier island along the coast of Alabama. Indications of overwashes into the lagoon are shown at several places, notably in the center. Underwater sand bars are indicated near the shore in clear water. [U.S. Coast and Geodetic Survey]

deepwater sediments include well-sorted and cross-bedded sands. A comparison with the deep floor of the Black Sea, where stagnant conditions exist at the bottom, is of interest, since the sediments include laminated black mud along with gray mud and calcareous deposits (*22*). On the other hand, the underlying unconformity and overlying shallow-water beds of the Chattanooga shale argue against deposition in such a deep basin. Black muds are also found in some of the fiord basins of Norway (*23*), where there is considerable depth of water. Here, however, we have a situ-

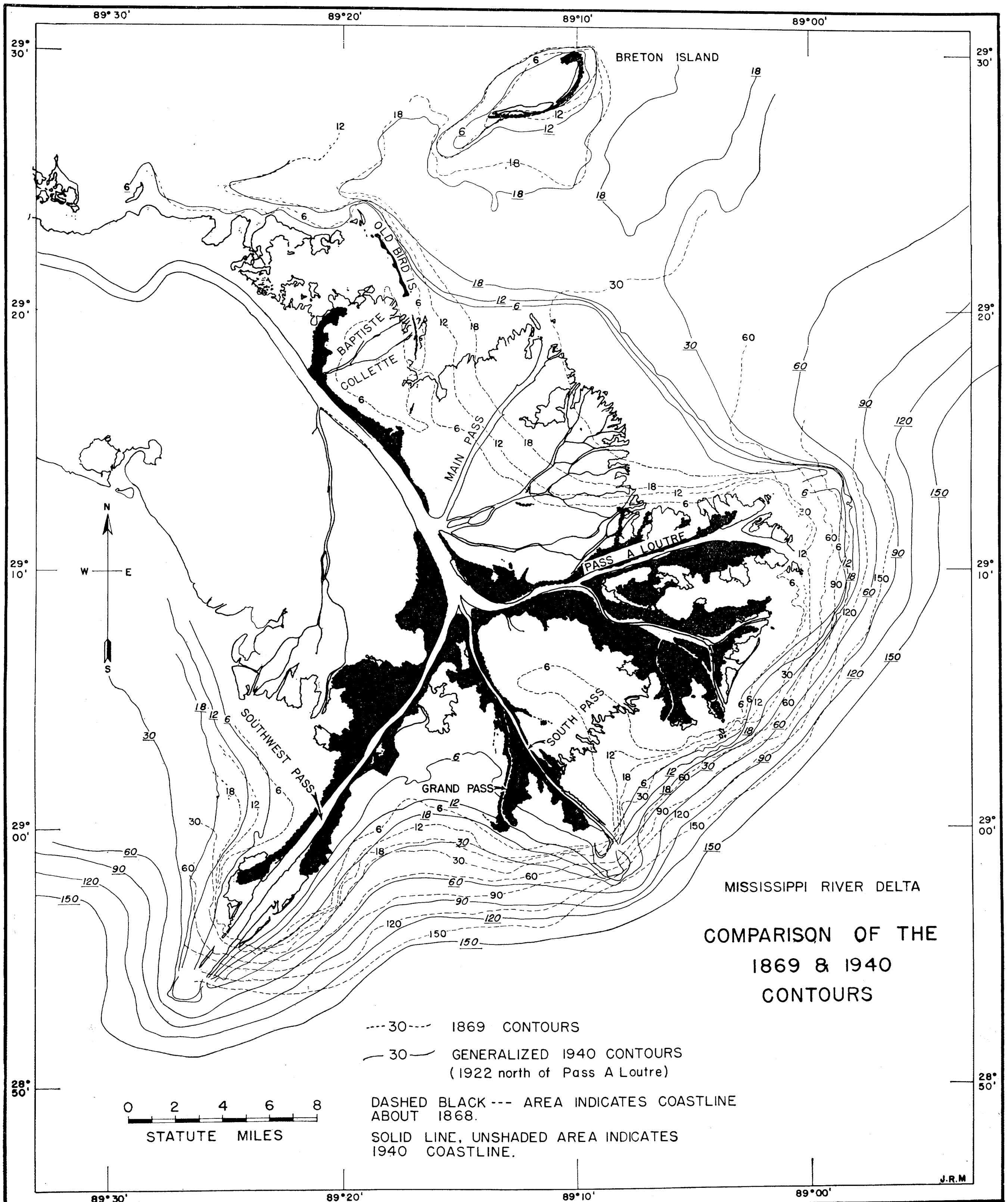

Fig. 4. Contour map showing the great forward building of the Mississippi delta that occurred between 1869 and 1940. Depths are in feet.

ation resulting from overdeepening of valleys by glaciation, and there is no sign of glaciation in the Devonian, when the Chattanooga shale was deposited. Furthermore, the Chattanooga shale forms a widespread blanket rather than a deposit formed in a narrow trough. The same objection applies to comparison with the laminated black muds of Kaoe Bay in Indonesia (*24*). Black color in sediments has been found in such bays as the Bay of Danzig and elsewhere in the Baltic Sea (*25*), but here the black color is due to excess of organic matter rather than to stagnation, and burrowing animals exist which churn up the bottom. In fact, it seems likely that we have not yet discovered a modern environment which contains all of the characteristics of that which produced the laminated black shales.

Deep basin shales. The deep basins and troughs bordering the southern California coast represent another environment in which mud is accumulating although it is interlayered with turbidity-current sands. The muds are dark green in color. Except for the sand layers, stratification is poor, and there is virtually no lamination except in the relatively stagnant Santa Barbara basin. In the Gulf of California, on the other hand, some of the basin muds are well laminated, having alternate layers rich in diatoms. Here, although there is some circulation, burrowing organisms have not destroyed the stratification; this is probably due to the annual overturn in the gulf in winter, which brings an abundance of nutrients into the surface waters and results in great blooms of plankton. The diatoms are the chief planktonic contributor to the sediments. Comparison with the diatomite shales of Miocene age in California seems justified. These were probably also of deepwater origin, to judge from fossil fish fauna (*26*).

Limestones and dolomites. The chief carbonate rocks are called limestone when calcite ($CaCO_3$) is the dominant mineral and dolomite or dolostone when the mineral dolomite ($CaMgCO_3$) is most common. Among recent calcareous sediments, only calcium carbonate is found; this suggests that dolomite is formed later. If the carbonate sediments are fine-grained and poorly consolidated, the limestone is referred to as a chalk. These carbonate rocks are comparable to sandstones in their abundance among marine sedimentary rock formations. The study of recent sediments has shown that almost all of the present-day carbonate deposits are developing in the tropics or subtropics. Ancient limestones and dolomites are found at all latitudes, and this has been considered (no doubt with good reason) an indication either that the climates of the past were warmer than those of the present or that the pole or the earth's crust has been migrating so that localities now at high latitudes were formerly near the equator.

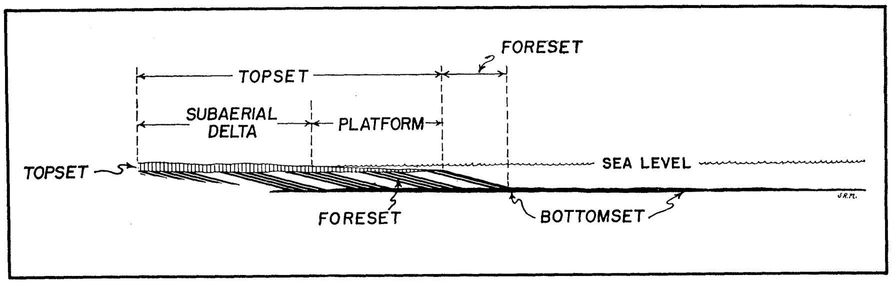

Fig. 5. Conventional diagram of a growing delta. Large marine deltas differ from this in having much lower foreset slopes.

The calcareous rocks include a variety of types. These can be conveniently subdivided into fragmental limestones, reef limestones (commonly called bioherms), chalk and other fine-grained calcareous rocks, and oölites. Each of these has its counterpart in the present seas. Much information concerning these environments has come from studies sponsored by the American Museum of Natural History (*27*) and by the U.S. Geological Survey (*28*).

Fragmental limestones. Probably there are more limestones consisting of fragments of shells, corals, and other calcareous organisms than any other type. Similarly, on the sea floor there appear to be more fragmental calcareous deposits than any other kind (*29*). For example, most of the wide shelf off the west coast of Florida has a cover of shell sands and fragments of calcareous algae. It is thought that the shelf off Yucatan has a similar cover. Most of the tropical islands of the Pacific are bordered by shelves with calcareous detritus. This material is transported by the waves and currents very much as the quartz sands and other land-derived minerals are transported across the shelves in cooler climates. Bars like those of Nantucket Shoals are developed out of the fragmental lime debris; hence, limestones often have the cross-bedding characteristic of sand bars.

Reef limestones. Geologists have long recognized that many limestones had their origin as ancient coral reefs. Much of the early exploration of the oceans, including that of Darwin, was concerned with the coral islands. Although the present-day corals are quite different from those of the Paleozoic, some of the reef characteristics are found in the ancient reefs. The steep reef margins are clearly recognized in many Paleozoic reefs with highly inclined flanking layers made up of coral talus broken from the reefs by the waves. Many of the ancient reefs consist dominantly of calcareous algae, and this is also true of many reefs of today. Another characteristic of the ancient reefs is the general absence of stratification. This is due to the upward growth of the reef which accompanied the subsidence of the bank on which it was growing. The interlacing of the corals allows little stratification. The dolomites in the eastern Alps, with their structureless appearance, are said to represent an example of these ancient reefs, although most of the coral structure has disappeared because of the ease with which carbonate minerals recrystallize.

Chalk and fine-grained limestones. Chalk, which used to be used universally for writing on blackboards, is found to consist of an abundance of planktonic organisms, of which Foraminifera are an important constituent. For a long time it was thought that chalk was a deepsea deposit comparable to the *Globigerina* oozes. More careful study, however, showed that its benthic organisms are primarily shallow-water types. The plankton can accumulate in shallow water as well as in deep, provided they are not masked by other material. Some of the chalks of the southeast United States have been shown to consist of coccoliths (*30*), parts of a small planktonic lime-secreting plant. These plant remains are easily altered under pressure, and therefore old formations are not likely to preserve them. Other fine-grained lime deposits appear to have been deposited as the result of chemical precipitation from supersaturated waters. This was probably the origin of the lime muds of the Bahamas (*31*). Still other fine-grained limestone may have been formed in the deep waters at some distance from reefs, where only the finest reef debris has been transported to the site of deposition. Such fine-grained calcareous muds are found at depth around some oceanic reefs, but elsewhere the Foraminifera are so common that the sediments are relatively coarse, even at depth.

Oölitic limestone. Many limestones consist of small rounded grains looking like fish roe; hence the name, derived from *oö*, a shortening of the Greek *oion*, meaning egg. In section the oölites show concentric layers and, in some cases, a nucleus. These oölitic limestones are particularly common in the Jurassic of Europe, and it was the English who first called the rocks of this period the oölite series. Modern oölites are particularly well represented in the extensive Bahama banks (*32*). The spectacular underwater dunes, which can be seen so well through the clear water when one is flying over these banks, consist largely of oölites. These will undoubtedly produce limestones with much cross-bedding. The Bahama oölites are generally attributed to chemical precipitation which occurs when cool waters rise from the depths onto the warm banks, and the warming causes supersaturation. Deposition is especially active at the edges of the shallow platforms or along the edges of the tidal channels. The roundness is due in part to concentric deposition and partly to the rolling of the grains by the waves and currents. The unstable dune area is not favorable for the growth of bottom-dwelling organisms, and fossils in such deposits are relatively rare. This is apparent in the elevated oölites found on various islands in the Bahamas. In some areas oölites occur on the continental shelves as relics of former shallow-water conditions. This is particularly well illustrated by the outer shelf off western Florida (*33*). Oölites are not all marine formations. In fact, they develop very commonly in dry basins around lakes, such as Great Salt Lake.

Marine Conglomerates and Breccias

The sedimentary rocks containing an abundance of pebbles, cobbles, or boulders in a matrix of finer material are called conglomerates if the fragments are somewhat rounded and breccias if they are largely angular. Most conglomerates are land deposits, developing especially in the fans at the base of mountain slopes. Rivers carry pebbles into the sea, and various types of rock fragments are broken from cliffs, landing in the shallow adjoining seas, but in neither case are extensive marine conglomerates likely to develop. This is partly because the waves in shallow water grind up the large fragments into sand or finer material and because the waves are not capable of carrying the pebbles out far from the shore. In fact, waves tend to work the coarser material in towards shore, building it up as rampart beaches.

There are, however, many conglomerates and breccias which lie interbedded between formations that have marine shells and, in some cases, deepwater assemblages. The Flysch formation in the Alps is notable for such an alternation between conglomerates or breccias and deepwater mudstones. Their origin is not quite certain. Some of the conglomerates grade upward into fine material and hence their presence has been attributed to turbidity currents (*34*). Others include boulders, some of them as big as a house, and do not appear to be due to turbidity currents, since they lack all signs of graded bedding. These Alpine breccias, and probably also many of the ungraded conglomerates, can be explained by a type of submarine slope failure which has allowed the rocks from the upper slope or even from the adjacent mountain walls to catapult down the sides of a deep basin and come to rest on top of the fine-grained basin sediments. The fine sediment in the interstices between the large fragments may consist of deep-sea deposits introduced after the slides occurred. Such conglomerates have been found at the base of the cliffs outside the Yucatan shelf (*35*). They are also well illustrated in the Pliocene formations of Ventura County, California (*36*), and in western Venezuela (*37*).

The study of submarine slopes has shown that many of them are very unstable (*38*). They are particularly likely to slide at the time of an earthquake. Many cable breaks have resulted either from these slides or from turbidity currents (*39*).

Other kinds of marine conglomerates and breccias may be formed through the rafting of rock fragments, although the "plums" in this type of "puddingstone" are apt to be few and far apart. The most important means of floating rocks out into the sea is by icebergs or drift ice. In the areas where there are many icebergs, as around Antarctica, the sea floor is littered with pebbles. This produces what is called a glacial marine sediment. Such sediments are found beneath the most recent sediments in the cores of the North Atlantic (*40*), representing the glacial stages of the Pleistocene, when icebergs were more common. On a smaller scale pebbles are rafted out by vegetation, especially beyond the mouths of tropical rivers. Also kelp, when broken off by the waves, often carries rock fragments in its rootlike holdfasts, and enough may be accumulated this way to make a local conglomerate.

Concluding Remarks

The foregoing suggestions regarding the origin of marine sedimentary rocks must be considered as partly speculative because they are based largely on investigations that are far from complete, and vast areas of the sea floor have not been explored at all by marine geologists. The introductory studies, however, seem to have shown that many of the old ideas about marine sedimentation are outmoded. Thus, sandstones and even conglomerates are not confined to shallow water, as was formerly supposed, but can form in deep water provided there are relatively steep slopes down which slides and turbidity currents may transport the material to the deeps. Similarly, the ripple marks and cross-bedding, formerly supposed to indicate shallow-water origin, have now been found also in deepwater sediments. We are still looking for the most reliable criteria for distinguishing between the deepwater and shallow-water sands, although graded bedding has already proved somewhat helpful when related to the occurrence of deepwater organisms in the underlying and overlying beds.

On the continental shelf so many exceptions have been found to the old concept that fine sediments are deposited outside of, and in deeper water than, coarse sediments that determination of grain size as a means of "finding the shoreline"—a method used so much by geologists—seems open to reexamination. On the continental shelves many of the sand zones outside deposits of mud appear to be relics of a period of lower sea level, but currents of sufficient strength to transport sand are found on the outer shelves in many places. Therefore, sand formations may be deposited on the continental shelf contemporaneously with, and yet farther from shore than, mud formations, and the two may have different geographical sources.

The frequent occurrence of mud deposits around the advancing margins of modern deltas and the very infrequent occurrence of ancient shales considered to be deltaic suggests that some or many ancient deltas may not have been recognized. The characteristics found in the sediments around the margin of the Mississippi and other great deltas should prove helpful in recognizing such deposits among rock formations. Similarly, the various types of calcareous deposits found on the shelves and banks of the world are providing means for determining the conditions under which the limestones now on the continents were deposited.

In concluding, it should be emphasized that the study of recent sediments can at best provide some useful clues which help us to interpret the past. The thoroughgoing field examination of stratigraphic relationships will still be the most important method available to the geologist.

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News of Science

Commission To Study Proposed Department of Science Asked

Disregarding the recommendations of administration spokesmen, a Senate committee has called for a Hoover-type commission to study the problems connected with the establishment of a Department of Science and Technology. In its report, the Committee on Government Operations, chaired by Hubert Humphrey (D-Minn.), also pointed out that such a commission is an "essential first step" if the Congress is eventually to gain access to the information it needs to legislate on scientific matters. The committee report, which is unusually pointed in its criticism of administration practices, represents a new move in a growing conflict between Congress and the Executive over access to scientific information.

Behind the Senate move is the fact that the Congress has no legal access to information and individuals in such executive agencies as the Science Advisory Committee and the Federal Council for Science and Technology. These agencies, which are staffed by many of the leading scientists and engineers of the country, enjoy "executive privilege" and do not have to respond to congressional calls for testimony. On a number of occasions, officials of these executive agencies—for example, James Killian, former presidential science adviser—have refused to testify. This practice has so angered many members of Congress that they have seized on the Department of Science bill as a means of solving their problem. If a Department of Science is created, its officials, like those of the other federal departments, will have ample reason, because of the legal and fiscal set-up, to be responsive to Congress, which controls the purse strings.

The idea of establishing a commission to study proposals for a Department of Science came up early in congressional hearings on a bill (S. 676) to create such a department. The suggestion was first advanced by spokesmen for the Engineers Joint Council and was later summed up by Wallace Brode, Science Advisor to the Secretary of State and retiring president of the AAAS Brode said, "Two major decisions are required, one as to whether a Department of Science should be formed, and,