

RESEARCHES ON SEDIMENTATION¹

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PURPOSE OF THIS SYMPOSIUM

The purpose of this symposium is not to give an inventory of present information on sedimentation, nor is it to lay before you the definite solution of specific problems; but it is rather to discuss certain needs in the light of what we now know, and to consider ways and means of filling those needs. Instead of "symposium," perhaps "conference" would be a more appropriate name, for geologists should confer regarding this matter, and it is hoped that discussion will be full, and that those here will give others the benefit of many suggestions.

OBJECT OF RESEARCHES ON SEDIMENTS

Since geologists generally will admit that one of the objects of the investigations of sedimentary rocks and processes of sedimentation is to aid in understanding the history of the earth, it is pertinent to ask how such researches can help in the solution of problems of that kind, and the inquiry may begin by asking about any sedimentary rock certain questions:

1. What is the rock, what are its constituents, and what are their

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physical characteristics? The answer to this question would include information on the chemical and mineralogic composition of the rock, the sizes and the percentage of the different sizes of the particles composing it, the shapes of the particles, the percentage of pore space, and the percentage of particles of different kinds.

2. What were the sources of the constituents of the rock? The answer to this question would tell whether the constituents are clastic, organic, or chemical in origin; or, if the constituents have been derived from more than one source, as usually is the case in sedimentary rocks, what the proportion of each kind is according to its source. In the case of clastic constituents, information would be given on nature of the parent rock, where it was, its topographic features and relations, and by what processes it was disintegrated. In the case of constituents of organic origin, the kinds of organisms, the relative importance of each kind, and the relative importance of the total organic constituents would be ascertained. In the case of chemically deposited constituents, the relative importance of the different constituents and the processes by which they were formed would be made known.

3. How were the constituents brought to the place of their deposition? The answer to this question would let us know whether the transporting agent was wind, flowing water, ice, or gravity without the help of these agents, or whether two or more agents acted jointly. We should also know the velocity of the transporting agents and their capacity for moving material.

4. What were the factors that caused deposition; what were the agencies that caused the particular arrangement in beds, laminæ, etcetera, exhibited by the deposit? Deposition may be caused by checking the velocity of a transporting agent, by the flocculation of particles, or by crystallization from a supersaturated solution. If this question were answered, we should know not only the part played by each of these processes, but should also know how currents were checked, the processes involved in the flocculation of the particles, and the nature of the solutions from which crystallization took place. Information would also be given on rates of deposition.

5. Under what conditions not necessarily factors in origin, transportation, and cause of deposition did deposition take place? The answer to this question would comprise information on the chemical composition of the water, in the case of aqueous sediments; the depth of the water; the relations to land areas—distance from the land, the topographic features of the land, and the climate of the land; and whether the deposit was made on a stationary, rising, or sinking basement.

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6. What changes has the sediment undergone after its deposition and what are the causes of those changes?

If all these questions regarding any one geologic formation could be answered fully, we should have made a considerable advance in interpreting the history of the earth, for such information could be applied in interpreting other formations; but it is safe to say that very few of the questions can be answered for any formation; it is also safe to say that some of the questions can not now be answered for any geologic formation, because the answers depend on deductions from premises that must be, but have not yet been, inductively established. In the investigation of such subjects as sediments the general method of modern science must be followed—that is, we must first build premises inductively, and then by deduction from those premises interpret phenomena that can not now be observed.

MODERN SEDIMENTS

In order to understand sediments, both modern and ancient must be studied, but a reliable basis for interpreting ancient sediments can be obtained only through a study of sediments now in process of formation.

Researches on modern sediments should cover the following kinds:

1. Continental deposits. These embrace (*a*) colluvial, fluvial, lacustrine, spring, and progradation deposits in cold, temperate, and torrid climates of humid regions; (*b*) eolian, talus slope, and water-laid deposits in desert plain and mountainous regions and in desert basins; clastic, organic, and chemical deposits in inclosed lakes; (*c*) glacial deposits.

2. Great lake deposits.

3. Marine deposits. (*a*) Deposits, mostly detrital, formed under diverse conditions, at the edges of coastal plains and off steep shores, as follows: In protuberant deltas, in bays, and in areas between embayments, in each major climatic zone; (*b*) deposits, mostly organic and chemical, on submarine plateaus, in lagoons, and on reefs, in tropical and subtropical waters; (*c*) the origin and distribution of the deeper-water marine sediments. A few subjects of importance in the study of marine sediments are the relations between certain abyssal deposits in the ocean (particularly red clay and manganese nodules) and the physico-chemical condition of ocean water; changes in outline and position of shorelines; direction of the movement of littoral drift; influence of depth, distance from shore, etcetera, in determining the character and continuity or lack of continuity of deposits; the effect of different degrees of salinity of the

water; the ratio of wave amplitude to symmetrical ripple-mark amplitude; the bathymetric and thermometric ranges of marine organisms.

This statement regarding modern sediments is not intended to be exhaustive; its purpose is to indicate what the scope of researches on such deposits should be. The aim of these researches is not only to understand present processes, it is also to discover and to make available for use criteria to be applied in the interpretation of ancient sediments.

ANCIENT SEDIMENTS

Researches on ancient sediments should include, besides seeking the general information needed for all sediments, studies of the lateral variations of geologic formations, the causes of cementation, the formation of concretions, the development of secondary stratification planes, replacements, vein-fillings, salt domes, etcetera—in fact all diagenetic changes of sedimentary rocks should be studied. The origin of dolomite is an important problem. Among important economic geologic resources that offer fields for further research are deposits or accumulations of coal, oil, gas, phosphate, potash, nitrate of soda, iron ores, manganese, etcetera. No attempt should be made to distinguish between researches into products of ascertained economic value and researches into products that are not commercially important, because knowledge of both kinds of products is necessary for understanding geologic history.

From the brief statements that have been made, it is obvious that an adequate knowledge of sediments requires diversity of research in the fields of physical, chemical, physico-chemical, and biologic sciences.

INADEQUACY OF SOME EARLIER INVESTIGATIONS OF SEDIMENTS

Although many valuable researches have been made on sediments, the statement that no sedimentary deposit is adequately understood will probably not be contradicted. The reason of this is that the results of an insufficient number of lines of research have been brought to bear on the problem of the origin of any particular sedimentary formation. The inadequacy of several researches will be briefly considered.

Certain deposits are practically 100 per cent organic remains, as, for instance, those on the coral reef of Murray Island, Australia. Knowledge of the chemical composition of the deposits, of what groups of organisms contributed material to them, and of the proportion contributed by each group of organisms is valuable; but this information alone is not adequate, for the material has been subjected to sorting by moving water,

with the result that very nearly all particles below a certain size have been removed. Knowledge of the transporting power of water of a certain density at certain rates of motion is necessary for understanding the sizing of the deposit. The part played by other factors, physical and physico-chemical, also needs to be known.

Mechanical analyses of deposits are indispensable in the study of sediments, but they alone will not supply all the information needed for the interpretation of the history of any deposit. The same may be said of other physical features of sediments, such as shapes of particles, relative amount of pore space, size of pores, and total surface of particles per unit volume, all of which is necessary information. These physical determinations do not take into consideration other factors, chemical and biologic, that have played rôles in the origin of most sediments.

Very valuable researches have been conducted on the chemistry and physical chemistry of sediments and sedimentary processes, but they do not solve the problem of the origin of any sedimentary formation. Clarke and Wheeler have shown that the difference in the chemical composition of the skeletons of marine invertebrates and calcareous algae is the determining factor of the difference in the chemical composition of certain marine sediments, but Professor Clarke himself emphasizes, in conversation, the inadequacy of such analyses alone to solve problems of sedimentation. With reference to investigations in physical chemistry: Should we know precisely the relations of CO_2 in sea-water to depth, temperature, and other physical factors in the ocean, and to the CO_2 content of the air above the ocean, we should not solve the problems presented by any sediment, but without such knowledge the origin of certain deposits can not be understood. The reason of the failure of this information to solve the problem is because it concerns only one of a number of factors involved in producing any particular sediment.

In order to understand the history of certain sedimentary rocks, it is necessary to know the causes, in many instances of physico-chemical nature, that have produced changes in the sediments. Among such changes are silicification, phosphatization, and dolomitization. But a complete knowledge of the processes whereby such changes were brought about will not suffice, because the origin of the unchanged sediment needs to be explained, and it may have undergone other changes than one of those mentioned.

Other instances of valuable chemical and physico-chemical researches might be given and the reason of their inadequacy for the interpretation of sediments indicated, but those mentioned seem sufficient to illustrate the point in mind.

Researches such as those enumerated, and the number might be greatly increased, have given insight into some of the factors and principles involved in the origin and subsequent changes of sedimentary rocks. One important result of these investigations is to make clear the complexity of the phenomena; another important result is to make it clear that an adequate basis for interpreting sediments will not be established until all the needed lines of research have been brought to bear in proper coordination on the different classes of sedimentary deposits.

SUGGESTIONS AS TO THE MEANS OF FURTHERING RESEARCHES ON SEDIMENTATION

The discussion so far has presented the object of researches on sedimentation in their geologic bearing; it has indicated the range of phenomena that should be covered; and it has pointed out that certain valuable researches have not been completely satisfying in their results. An attempt will now be made to bring forward some suggestions for increasing activity in this field of scientific endeavor and for providing additional agencies. The factors entering into the origin and the deposition of sediments and into the changes that take place in them after their deposition are so diverse and are so widely distributed that it is impracticable for any one man, any small group of men, or any organization of moderate size, especially one whose activities are areally limited, to cover the field. All possible activity needs to be encouraged and all possible agencies should be utilized.

According to the opportunities of individuals and organizations, three categories of researches may be recognized, as follows: (1) Researches on specific phenomena; for instance, Gilbert's "Transportation of debris by running water" and Harder's "Iron-depositing bacteria and their geologic relations"; (2) researches covering particular areas, such as Thoulet's study of the deposits in the Gulf of Lyons, Kindle's studies of the Great Lakes, and the work being done in San Francisco Bay by the geologists of the University of California; (3) complex investigations, requiring the cooperative and coordinate researches of physicists, analytical chemists, physical chemists, and biologists (including bacteriologists). There is no good instance of such an investigation, for there has been no institution established for conducting such researches. I attempted a piece of work of this kind in the study of the marine bottom deposits of Florida and the Bahamas, but, although valuable data were procured, the results obtained are inadequate. Sir John Murray had a similar ideal in mind in investigations conducted at the Granton Marine Laboratory, and

he assuredly accomplished important results, but he did not attain the desired goal.

According to agencies already existing whereby researches on sediments might be conducted, the following categories can be recognized: (1) National institutions; (2) State institutions; (3) privately endowed institutions; (4) universities.

Of the national institutions of the United States those that should be mentioned are the Geological Survey, the Bureau of Fisheries, the Coast and Geodetic Survey, certain bureaus in the Department of Agriculture, and the National Museum. The Geological Survey should cover a wide range of phenomena, and that a subsection on sediments has been established in it is at least promising. The Bureau of Fisheries is systematically collecting bottom samples, and as part of its oceanographic work it has inaugurated a survey of the hydrogen-ion concentration in the sea, in addition to acquiring data on the temperature and salinity of the water. The Coast and Geodetic Survey collects bottom samples. In the Department of Agriculture the Bureau of Soils has made for me alone hundreds of mechanical analyses of sediments, and the Bureau of Plant Industry has greatly helped, particularly through the work of Kellerman on calcium-carbonate-precipitating bacteria. The United States National Museum receives the samples of modern sediments collected by the different governmental agencies, but it has no staff for the study of them. Although the Federal Government has done and is doing much to further knowledge of sediments, it is not doing so much as might reasonably be expected of it. The Geological Survey of Canada, through Doctor Kindle, is making valuable contributions to knowledge of sediments in the Great Lakes and in some of the marine waters of Canada. This work should be encouraged and extended. If practicable, the help of others of the Canadian institutions should be enlisted in the prosecution of such investigations.

Of the State institutions the State geological surveys would naturally be expected to render much service. They have made important contributions and it is hoped others will follow. State surveys should be able to conduct researches on specific phenomena and on particular areas, such as a more accurate analysis of the physical characteristics of formations and the variations of formations in all three dimensions. It may also be practicable for them to conduct researches on special types of deposits that are well exemplified within the State boundaries, such as eolian, fluviatile, lacustrine, embayment, and beach deposits. Other kinds of deposits might be mentioned, but those named will serve as samples. It

is suggested that it might be well for each State survey to take into consideration the kinds of researches it could profitably undertake and make arrangements for the prosecution of at least some of them.

Of the privately endowed institutions, the possibilities of certain departments of the Carnegie Institution of Washington come immediately to mind. The Geophysical Laboratory has already put students of sediments under obligations to it through the researches of John Johnston, H. E. Merwin, and E. D. Williamson. Perhaps further researches into problems in sedimentation may be done by it. The Department of Botanical Research has issued a volume of much geologic value in its monograph on Salton Sea. Further researches of this kind are needed, and Doctor MacDougal should be urged to do all he can toward making known the geologic history of the inclosed lakes of the West, including the part plants play in the deposits forming there. Much work has been done on sediments in connection with the Department of Marine Biology, largely in cooperation with the United States Geological Survey and other national institutions, and other work of value is in progress. The work that is being done should be encouraged. Mention should also be made of the studies on diatoms by Dr. Albert Mann, who is now an associate of the Carnegie Institution of Washington.

Besides the researches conducted by at least three departments of the Carnegie Institution, it may be possible to arrange for more work on sediments at some of the marine laboratories. There are, for instance, the Scripps Laboratory of the University of California and the laboratory to be established in connection with the Bishop Pauahi Museum of Honolulu.

There are many problems in sedimentation that can be advantageously attacked in the universities; there are both problems dealing with specific phenomena and those dealing with particular areas. The University of California has set a good example by its studies of San Francisco Bay. At Harvard Professor Sayles has published an important memoir on seasonal deposition in aqueo-glacial sediments, but Harvard might do more and attempt work on Boston Bay and the Gulf of Maine. There are other aqueous sediments in this part of the country deserving critical study, and the sand-dunes of Cape Cod are worthy of monographic treatment. There are accessible to every university opportunities for research that will not soon be exhausted. Some universities are favorably situated for the study of the physical characteristics of geologic formations, and as instances of such work Goldman's paper on the Upper Cretaceous sediments of Maryland and a research by Prof. Leonard P. Dove, of the

University of North Dakota, on the Upper Cretaceous shales of that State may be mentioned. The studies of Prof. J. Claude Jones on the lakes of Nevada constitute an instance of another kind of research.

I will mention a special research of particular importance now in progress. Prof. Shiro Tashiro, of the University of Cincinnati, is trying to ascertain the physico-chemical factors controlling the formation and determining the chemical and mineralogic composition of the skeletons of marine organisms. This is really carrying one step farther the researches of Clarke and Wheeler, of the United States Geological Survey, and already there is promise that we shall soon have a more accurate basis for deducing the physical and chemical conditions under which certain deposits containing marine organisms were formed. Broadly synthetic work, such as that of Barrell, is of value and more of it is needed. The speakers who will follow me will make other suggestions regarding researches in universities. The possibilities are great. May our universities see fit to put a certain amount of their energy into studies of problems of sedimentation.

AN INSTITUTION FOR THE STUDY OF SEDIMENTATION

I think it will be admitted that all the kinds of researches indicated for the different existing agencies that might be utilized are really needed, and as much as possible should be done to accomplish the desired ends, but I will recall that, under a category described as "complex investigations requiring the cooperative and coordinate researches of physicists, analytical chemists, physical chemists, and biologists (including bacteriologists)," it was stated that no example of a satisfactory piece of work of this kind could be given. The reason for this is that there has been until now no institution in which a comprehensive, coordinated study of sediments and processes of sedimentation could be made. Valuable, more or less incoherent work, considered from the viewpoint of the interpretation of sediments, has been done by field geologists, oceanographers, engineers, students of soils, analytical chemists, physical chemists, and biologists, but the attempts of investigators to bring to bear on particular problems the results of researches along many lines are few indeed. The reasons of the paucity of such attempts are twofold: The first is that the object of the individual investigator usually has been to solve specific problems and not to consider sediments in a comprehensive way. The second is that there has been no institution or place wherein all the lines of research needed for the solution of problems offered by any sediment could be prosecuted. Without the existence of a definitely organized in-

stitution, the only way the results of multiple-lined research can be directed to the solution of a particular problem is either by the compilation of the results of dissociated studies or by enlisting the cooperation—as a rule, the voluntary cooperation—of specialists. Under a system of voluntary, mostly unremunerated, cooperation, it is usually—in fact, nearly always—impracticable to hold a group of specialists together until the desired result is assured. The fundamental basis of continuity of work, which is definite association with an established institution, is lacking. Under present circumstances, the desirability of the establishment of an institution for the coordinated study of sediments and sedimentary processes in the broadest practicable way is obvious.

An attempt is now being made to bring about the realization of this aim, and the members of the committee that I have the honor to represent trust that we shall have the support of the geologists of the country.

CONCLUSION

In conclusion, I wish to emphasize the purpose of the investigation of sediments as a part of the history of the earth. Such work does more than supply the foundation for stratigraphic geology—it includes stratigraphic geology. It tries to reconstruct the geography of the earth for each of the successive periods of the earth's history since sedimentation began; to ascertain the boundaries of land and sea; to trace the rises and the sinkings of the continents, the growth and the destruction of mountains, and the waxings and the wanings of the seas; to reconstruct the climates and the physical features of the lands of the past and to populate their surfaces with the life that then existed; to bring before our vision the seas of the ages gone by, so that we shall see what was happening in them and know the old oceans, with their currents, their temperatures, their depths, the composition of their waters, and the organisms that inhabited them. It tries to bring back the reality of what was long ago and follow the changes that have taken place on earth.

These investigations are the counterpart of researches into the physical constitution of the earth and into the forces that express themselves in the raising and lowering of continents, the building of mountains, and in the intrusion and extrusion of certain parts of the earth's crust as molten matter. If we would know the earth, the two kinds of research must advance hand in hand.