CHAPTER I

INTRODUCTION: CHRONOLOGY AND PHYSICAL CONDITIONS

PHYSICAL Geography is the geology of the present day, and conversely geology is the sum of the physical geographies of the past and present.

In attempting to restore the history of the Earth it is therefore necessary to establish a chronology, and having done so, to make a study of the rocks of each of the periods so established, in order to discover what events were happening at each particular period, with a view to elucidating the physical geography of that period. This is mainly, though not exclusively, done by a study of the sediments formed during the period: not exclusively, for the igneous rocks then formed must also be taken into account, and the various changes generally included under the head of tectonics. As a matter of fact the establishment of chronology and the study of the evidence for the conditions of deposit have to a great extent been carried on simultaneously.

A study of the sediments then is of prime importance to the geologist, and great progress has been made in it, but much still remains to be done. Not only must the petrographical characters of the sediments be taken into consideration, but other matters, especially their areal distribution and their organic contents.

A good deal of information has been acquired on all these points, but particular attention has been paid to the petrology. Even here the progress has not been so great as is desirable. The attention of geologists has it is true, during the last half century, been devoted in an exceptional degree to petrology, but the fascinating problems connected with the igneous and metamorphic rocks have to some extent diverted attention from sedimentary petrography, though this study has by no means been ignored; Sorby himself made most valuable contributions to it, especially in his two Presidential Addresses to the Geological Society in 1879 and 1880.

While much attention has been devoted to ancient sediments, those now being formed have been by no means neglected. Great impetus was given to this branch when the careful examination of the sea-floor, as the result of deep soundings, was instituted, and we now possess an extensive literature bearing upon the matter, prominent in which is the description of the sediments, by Sir John Murray and the Abbé Renard in the *Challenger* Reports[1].

Even here, however, the fascination of the deposits of the abyssal portions of the oceans tended to check interest in the more prosaic deposits of the shallows, which are nevertheless of particular importance to the geologist.

It behoves us then to make further study of ancient and modern sediments alike, to a much greater extent

[1] Report of the Scientific Results of the Voyage of H.M.S. *Challenger*: Deep Sea Deposits, 1891.

than has hitherto been done. That the present is the key to the past is in the main true, but there are cases when the past is the key to the present, as has been illustrated on many occasions during the history of geology, and notably so in this particular research into the nature and causes of formation of the sediments.

The student of ancient sediments has two important advantages over the oceanographer examining those now being formed. In the first place, whereas the last named, save between tide-marks, is dependent upon soundings, often made at considerable distances apart, the former can observe continuous sections often over wide tracts of country. Secondly, whereas the oceanographer can only regard the superficies, the geologist is able to deal with his material in three dimensions. On the other hand, when dealing with modern deposits we know the exact type of area in which they are formed; as estuary, bay, gulf and so forth, whereas in the case of the ancient deposits, this is a matter of inference. Only by continued study of ancient and modern deposits are we likely to make much progress.

The establishment of a chronology was begun when geology was in its infancy. Without such a time-scale it is obvious that little progress could be made in the prosecution of the science. In establishing a time-scale two main tests have been applied, namely that of superposition and that of the sequence of organisms. The former necessarily came first, for the sequence of organisms could only be primarily established in the case of a known upward succession of undisturbed

strata. That such regular superposition does occur was realised among others by John Woodward, as set forth by him in his *Essay toward a Natural History of the Earth*, published in 1695, though the cause was incorrectly explained and the time taken for the accumulation of the sediments was greatly underestimated.

The importance of the included organisms was first clearly set forth by William Smith in several publications, especially in his *Strata Identified by their Organized Fossils*. As the result of the recognition of such a sequence, not only could the order of the strata be detected in any given area, but a correlation of the rocks of widely distant regions could also be made. This is a subject which has been much debated, and will be considered more fully in a later chapter. Though the utility of these organisms as aids to chronology is now fully recognised, lithological character must not be altogether ignored in this connection, being distinctly useful as a subsidiary aid.

In the second part of the enquiry, which deals with the conditions that prevailed during the formation of the deposits of any particular period, the lithology of the sediments is obviously of primary importance, though very valuable information is also afforded by a study of the included organisms. From this point of view the organisms have not been studied to anything like the extent which is evidently required. In the great task of ascertaining chronological sequences attention has naturally been devoted mainly to similarities of the faunas and floras in deposits of the

same age, with the object of correlation, and this has often been done without paying much attention to the differences, save in a general way. The importance of the last named is obvious, and now that we have established a time-scale successfully applicable over wide areas, it is time that attention should be directed more particularly to differences in the distribution of the organisms when traced laterally.

The study of the sediments and of their organic contents, with a view to the establishment of chronologies and to the elucidation of the physical conditions prevalent at the different geological periods, will be pursued in the following chapters, taking the evidence of lithology and included organisms on, first, chronology, and second, conditions of deposition.

It may be well to devote a few words to the use of the term *sediment*. The classification of rocks now in use is to some extent arbitrary. We are accustomed to speak of two great classes, the Igneous, and the Aqueous, Stratified or Sedimentary. There is some objection to the use of each one of the three latter terms. To the term sediment it may be objected that some of the accumulations placed in this group are not sediments, as for instance surface soils: the objection is valid, but as the term has got into general use it may well be retained, as no other has been proposed which is not open to objection. The terms stratified and aqueous are also not sufficiently comprehensive. The word epiclastic has a more definite meaning than sedimentary, but unfortunately does not include all the rocks with which we are concerned, for volcanic ashes

belonging to the pyroclastic group directly concern us, forming, as they do sometimes, definite marine sediments with organisms, differing in no way from non-volcanic sediments with which they are associated save in the source of supply of their material.

The word sediment then will be used hereafter in its usual and generally understood sense, to include the various accumulations, whether terrestrial or sub-aqueous in origin, other than lava-flows and intrusive igneous rocks, which constitute the geological column.

CHAPTER II

CHRONOLOGY

When establishing the succession of strata it is necessary to make subdivisions, for without these no correlation of deposits of the same age in different areas can be attempted. Such a classification might be purely arbitrary, as by division of strata into groups of equal thickness, but this would obviously be of little practical value, and it is necessary to attempt a classification which is so far as possible natural.

A classification supposedly natural, into Primary, Secondary and Tertiary, was long ago suggested. It was founded on insufficient data and is known to be faulty; but the present admittedly imperfect classification has gradually been evolved from it. When the sediments were first divided into Primary, Secondary and Tertiary it was believed that violent changes occurred in the intervals between these periods, causing physical catastrophes and complete extinction of life, new floras and faunas being created at the beginning of the ensuing period. Similar changes on a smaller scale were believed to have occurred also in the intervals between the principal divisions, or systems, into which these three periods were further split up. Such a classification was then held to be natural, and in most cases world-wide.

In the present state of our knowledge it is recognised that even the larger divisions established in

this way by the occurrence of breaks cannot be of world-wide application, for it is obvious that the whole earth cannot be covered by land (or by sea) at the same time, and it has been abundantly proved that continuous sedimentation was proceeding in some areas while the breaks were being produced in others. Nevertheless the divisions founded on breaks are far from arbitrary, and such breaks have evidently occurred frequently and over wide areas.

As the oceans are mainly areas of deposition and the lands of erosion, the greater part of the sediments preserved are marine. A cycle of occupation of any region by the sea between two terrestrial periods will include three phases. Beginning with submergence of a pre-existing land, the early stage of a marine cycle will be marked by shallow-water deposits: the middle period by more open-water beds; and the final stage by the recurrence of shallow-water deposits. Each of these will be marked by certain characteristic features of the sediments, and the whole will usually be complicated by epicycles of minor emergences and submergences during the main cycle.

Towards and at the close of the cycle the sediments then formed will gradually emerge to become part of the succeeding land, and consequently will undergo erosion. It results from this that although the deposits formed during the lower and middle phases will probably escape, those of the upper will be partly if not entirely removed, and the earliest deposits of the succeeding marine period will be laid unconformably upon them. An important discontinuity thus pro-

duced will probably be accompanied by a marked palæontological break, due to more than one cause.

Fig. 1 *A* represents a section of a series of conformable strata *a–k*, the vertical lines being intended to represent the ranges in time of a number of fossils. In Fig. 1 *B* an attempt is made to show what happens

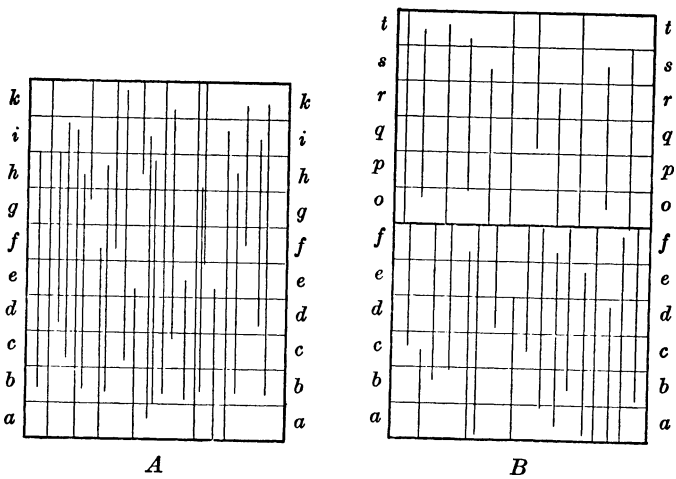

Fig. 1

when there has been a physical break, resulting in the denudation of the beds *ghik*, and the deposition of another set *op*... unconformably upon those deposits of the earlier set which remain. As the result of this we note, first, that the relics of organisms which existed in the area during the deposition of *ghik*, and were entombed in those strata, are destroyed by the processes of denudation, and a large number of

organisms which lived long after the deposition of *f*, and disappeared not simultaneously but at different times during the period when denudation was in operation, seem to become extinct simultaneously at the top of *f*, though if we could visit an area which was receiving sediment during the period of denudation, we should find them dying out in the rocks of that region at different levels. Furthermore, whilst denudation is going on, a longer or shorter period of time elapses, during which the upheaved area receives no deposit, and accordingly no organisms which lived during that period are preserved in the upheaved area. During this time a set of deposits *lmn* may have been laid down elsewhere, and besides the gradual disappearance of some of the organisms *ab*...*k*, there will have been a gradual appearance of new species. When the upheaved area is once more submerged, a new set of deposits *op*... is accumulated in it, and the species which gradually appeared in adjoining regions will now migrate to it, and will seem to come in simultaneously at the bottom of *o*; accordingly we may find that there is not a single species which passes through from *f* to *o*, and the palæontological break in this area is complete, though it is clear that it only implies local change, and that we may and indeed must find intermediate forms in other regions.

Owing to the occurrence of these breaks separating deposits formed during periods intervening between those during which the breaks were produced, we have a means of making a chronological classification,