THE DEFINITION OF GEOLOGY

by

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Introduction

The definition of geology - the delimitation, content, and meaning of the science - seems to be very largely left to take care of itself. Statements, in the preliminary pages of the textbooks for instance, are apt to be vague and various. Surely, however, an examination and analysis of this most elementary of all geological considerations is of some importance. In offering the following view of the matter I shall all the time be recalling those basic facts and principles which are very well known to everybody.

The material content of geology

What is Geology essentially, as one whole coherent science separate from the other sciences? It will, of course, make use of the findings of other sciences that it does not include as part of its own special content.

The word Geology is derived from the Greek *gē*, the earth, and *logos*, science; thus, on this basis, it means the science of the earth. The science of the earth, however, would include many subjects not in fact forming part of geology. First taking the earth in its widest sense, let us then restrict it until we find exactly with what part of the earth geology does deal.

The widest sense of the earth is the earth considered as a whole planet - Planet Earth. The first distinction that strikes the mind is that between the atmosphere and the rest of the planet. Of this rest of the planet (for which there is no single name) we can distinguish between the hydrosphere and what is sometimes called the 'solid earth' but better, perhaps, called the 'earth-body'. The hydrosphere, in the widest sense, includes all the water and ice (1) on the surface of the earth, (2) in the atmosphere and (3) within the earth. Neither the atmosphere nor parts 1 and 2 of the hydrosphere are themselves to be included within the matter of geology.

We are now left with the earth-body or whatever it may be called, everywhere underlying the atmosphere and about two-thirds of it underlying the main part of the hydrosphere as well.

Over most of the land there are thin veneers of materials which we must further discard. These are (1) vegetation and (2) the constructive works of man. There is also animal life. Plant and animal life are, of course, very much present in the hydrosphere and some kinds of animal life are active in the atmosphere. Plant and animal life constitute the biosphere.

Beneath all these overlying materials we come to the essential substance of the earth-body and it is this that constitutes the subject matter of geology. Again, there is no single term for it though *gee* suggests itself. We may say, however, that it is made up of mineral matter, extending for our purpose the primary definition of mineral matter: 'any substance obtained by mining' (with which operation can be associated drilling for oil and sinking wells for water). Geology thus deals with the Mineral Kingdom.

The mineral earth-body has been found by physical methods of detection, particularly by the recording and interpretation of earthquake vibrations, to consist of several concentric parts. In the first place there are two; the earth's crust or *lithosphere* and the underlying interior

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main mass of the earth, the *endosphere*, a term not much in use at present. The former occupies in average thickness only about 1/200 of the earth's radius; it is thicker under the continents than under the oceans.

The earth's crust consists essentially of various kinds of rocks and rock-materials. The endosphere comprises the *core*, extending outwards from the centre to about half the earth's radius, and the *mantle*, between the core and the crust. It is thought that the core is composed mainly of iron and nickel and that it is solid in its inner part, of radius about one-third of the whole, and fluid for the rest. The mantle is thought to be composed chiefly of silica, iron, and magnesium; it is solid but probably flows, particularly the upper part of it, given time, like pitch.

In practice, geology deals almost entirely with the earth's crust, the lithosphere. This is not merely because it is the only part to be seen or probed, or of which the structure can be directly inferred, but also because it is, in any case, the part in which nearly all the variety, activity, and interest lie.

We must now see more particularly what the earth's crust contains. In the first place, what does the geologist mean by the term rock? Although rock in the ordinary sense is a hard, compact, resistant substance, all the materials of the earth's crust that are in the solid state (as distinct from being liquid or gaseous), whether firm or loose, are included in what the geologist calls 'rock'.

We have used, above, the term 'mineral' as an adjective, defining it on the basis of occurrence; but 'mineral' as a noun is more restricted, being defined purely on the basis of its constitution. A short definition of a mineral is 'a solid of definite chemical composition formed by the inorganic processes of nature'. The vast majority of rocks are aggregates of particles of minerals, but a few are, wholly or in part, in the form of natural glass. Some important kinds of rock are composed of organic carbonaceous matter (e.g. coal), the remains of plants.

There are also certain fluid substances entering into parts of the earth's crust. We can call molten matter (*magma*) and also petroleum rock material, and with them must be classed the respective gaseous emanations - magmatic gases and the gaseous hydrocarbons (natural gas). The water in the earth's crust derived from the atmosphere (meteoric water) is a part of the hydrosphere, but it must also be regarded as an integral part of the earth's crust and be placed within our mineral kingdom.

The materials of the sea floor can be sampled, and drilling at particular spots can probe deeply. Modern quantitative physical methods allow a degree of inference about composition and structure over wide areas. Geology is, however, ordinarily practised on land.

We can in a general way make a preliminary convenient sorting of all the rocks entering into the substance of the land areas into two groups according to their manner of occurrence: (1) the superficial deposits (soils, gravels, sands, muds, etc.) and (2) the underlying 'solid masses', everywhere present but usually covered by superficial deposits. The superficial deposits may be loose but are often coherent and may be hardened in places. The solid masses are usually more or less hard, but some may be quite friable.

Under the waters of the oceans there are also two groups of rocks: the marine deposits and the underlying solid rock.

We are, here again, at a loss for a suitable term: for what we are calling the solid masses or solid rock as opposed to the superficial. *Bedrock* is a term sometimes used for this.

The accompanying table summarizes the foregoing analysis.

Table 1: The material content of geology

- Planet Earth
  - Atmosphere
  - The rest of the planet
    - Hydrosphere (the part on the earth's surface)
    - Earth - body
      - Veneers (on land) of vegetation and man's works.
      - Mineral earth-body (Mineral kingdom, *Gee*)
        - Lithosphere (see below)
        - Endosphere
          - Mantle
          - Core

- Lithosphere
  - Rocks
    - Aggregates of minerals (including glass)
    - Organic (coal, peat, etc.)
      - Superficial
      - 'Solid'
  - Liquid and gaseous 'rock material'
    - Magma and associated emanations
    - Petroleum and natural gas
  - Meteoric water (also a part of the hydrosphere)

Geological processes

The essential elements of the science of geology are to be found in a study of the solid rocks. These rocks are exposed, naturally or artificially, from beneath the veneers and superficial deposits, in places such as sea-cliffs, stream beds, mountain sides, and in quarries and cuttings.

The first fact to be observed about the solid rocks is that they are of different kinds in different places. This difference lies chiefly in (1) the particular constituent minerals, (2) the kind of texture, and (3) the inherent structure of the rocks as seen in the field.

Observation, record, mapping, and description lead to reasoning. How were the various kinds formed? The generalization emerges that there are two sharply contrasted kinds of (solid) rock, the *sedimentary* and the *igneous*. The former rocks are, clearly, hardened ordinary sediments (e.g. sandstone, mudstone, limestone). Of the latter some are as clearly the products of old volcanoes (e.g. basalt, fragmented pyroclastic rocks), while others, typically formed of a mosaic of crystals, can only have been produced by the more or less slow cooling of molten rock material within the earth's crust (e.g. granite, dolerite). A third kind of rock gives proof of having been profoundly altered - the *metamorphic* kind (e.g. gneiss, schist).

The sedimentary rocks usually show stratification; they are disposed in *strata*. Most of them contain *fossils* (sparsely or abundantly), the remains of the hard parts of organisms. By far the commonest fossils are those of invertebrate shelled marine animals. The inference is, therefore, that for the most part these rocks, now perhaps far and high inland, were laid down as sediments, layer on layer, in the sea. The sedimentary rock-masses (in particular) nearly always show that they have been to some degree deformed, bent into *folds* and broken by *faults*.

What can be seen happening at the present day of significance to our reasoning? We can see the rivers carrying down mud and we realize that this (or most of it) must finally come to rest on the sea floor. We can see volcanoes in action. Changes, comparatively recent, in the relative levels of land and sea, and earthquakes, give some evidence of crustal instability. But the occurrence and cooling of molten matter within the earth's crust, the potentiality of severe forces deforming the rock masses, and conditions of heat and pressure causing metamorphism - these can only be imagined, but they are certainly to be inferred.

All these operations constitute the geological processes, which can be grouped as follows:

(1) Erosion and transport of rock material, on and from the land, chiefly by running water, and also by the action of waves along the coast; all this resulting in a wearing away and a lowering of the land.

(2) Deposition of rock material on the sea floor.

(3) Deformation of rock-masses, with movements of parts of the earth's crust and uppermost mantle, producing interchange of land and sea areas. (Such recent conceptions as continental drift, sea-floor spreading, and plate tectonics find their place here).

(4) Igneous action.

(5) Metamorphism.

The first two of these processes are complementary. The atmosphere has a large concern in weathering, the preliminary stage of erosion, particularly if we include atmospheric moisture: and the wind can transport weathered material, with consequent abrasion of exposed rock. The paramount importance of the hydrosphere in effecting erosion, transport, and deposition is obvious. Thus the atmosphere and the main parts of the hydrosphere, while not in themselves part of the domain of geology, are media within, and by means of which, these two geological processes operate.

Geological time

The geological processes, certainly those of erosion and deposition, demand a very long time to operate in order to produce results on a large scale.

The concept of time enters into geology to a much greater degree than into any other science. Although the present day is just one day in the continuing passage of time, in practice we inevitably come to distinguish roughly between geologically recent conditions and happenings, covering the last few thousand (or few ten-thousand) years or so, and the conditions and happenings of past geological ages which stretch back, according to present calculations, through four or five thousand million years. On the present land surface the superficial deposits have been laid down more or less recently, while the underlying solid masses were formed in past geological ages and, with few exceptions, under conditions totally different from those now prevailing where we now find them.

It was not until towards the end of the eighteenth century that it began to be realized that there was such a thing as geological time. It was this realization, more than anything else, that caused geology to become established, rather late, as a rational major science and, indeed, it was at this time that the word 'geology' first came into general use.

A crucial question now arises: does the passage of time reveal itself in the rocks as we now see them and, if so, to what extent? Can we put the rocks in a time-order?

From what has been said as to the manner of formation of rocks there emerge two possible criteria of relative age among the rocks of a limited region: (1) in a normal stratal sequence of sedimentary rocks the upper are the newer, and (2) if an igneous rock A is found to have intruded into another rock-mass B, then A must be younger (to some degree) than B. Of these two criteria it is (1) that is much the more important.

How can local relative ages be extended and combined to give general relative ages and ultimately produce a time-classification of all rocks? Can we recognize a rock in one place as being of the same age as a rock in a separated, perhaps far distant, place? We cannot do this by means of the mineralogical and textural character (the lithological character) of the rocks themselves because a mudstone (say) in one region may be of the same age as a sandstone (say) in another, and similar rocks may be of any age. The character of an igneous rock in itself does not signify any particular age. It is by means of the fossils contained in the sedimentary rocks that a relative chronology of all rocks can be made out.

The principle, reduced to its simplest terms, is this: rocks can be identified and correlated, as regards age, by means of the particular kinds of their contained fossils. This was at first, during the early part of the nineteenth century, a purely empirical hypothesis, but it was found on application to produce order out of chaos. No biological considerations were involved, but it was soon seen to be in accordance with an independent and rational theory of more or less gradual change (evolution) in the kinds of life inhabiting the earth during the course of geological time.

The rocks of the world could then be classified into a stratigraphical table, into which the igneous and metamorphic rocks could to a large extent be fitted.

It was still impossible to make anything but guesses as to the actual periods of time involved, because the various kinds of evidence were all extremely unreliable. During the early part of the present century, however, the radioactive decay of certain isotopes of certain elements, at an unchangeable measureable rate in each case, was discovered, with the result that the absolute age, in years, of certain minerals, and thus of the rocks first containing them, could be determined. The stratigraphical table can now be placed alongside a standard scale of millions of years.

Group (era)	System (period)	Approximate age of the base in millions of years
Cainozoic		70
Mesozoic	Cretaceous	135
	Jurassic	180
	Triassic	225
Upper Palaeozoic	Permian	275
	Carboniferous	350
	Devonian	400
Lower Palaeozoic	Silurian	435
	Ordovician	500
	Cambrian	600
	Precambrian (undivided)	4,500

Geological History

Obviously the mere passage of time cannot produce or change anything. The course of events and the transformation of conditions within, and on the surface of, the earth's crust result from the geological processes working through time. Though the facts of geological structure, in the widest sense, are in themselves of the greatest interest and, incidentally, of the greatest economic importance, and though the inferences as to process are eminently scientific, it is the revelation of the history of the earth that sets geology among the few great departments of Natural Philosophy.

The superposition, correlation, and lateral extent of strata of different kinds, the structural discordance (*unconformity*) between one stratigraphical formation and an underlying one, the deformation undergone by the several formations, the occurrence of igneous rocks, extrusive and intrusive - these are the main things to be observed throughout a whole region, such as northern England for example, and which allow the geological history of that region to be reconstructed.

It must be mentioned that the lowest rocks contain practically no fossils useful in correlation so that any detailed world-wide history of those earliest times, some six or seven times as long as all the rest, is at present impossible.

A generalization that emerges from the reading of regional geological histories is that of the *geological cycle*. This, in essence, is as follows (omitting igneous activity, which occurs less regularly): (a) deposition and, at least partial, consolidation of sediments, most abundantly in a sinking part of the sea floor, a *geosyncline*, not very far from land, (b) pressure within the earth's crust squeezing the deposited rocks as in a vice, causing deformation within them and at the same time raising them to form land, (c) erosion of the land, providing material for the deposition of sediments in a neighbouring sea on the eroded surface of rocks formed in a previous cycle.

This kind of outline of the geological history of a region can be filled in according to the local details.

The study of the more or less recent superficial deposits of all kinds, and of the visible geological processes, provides a direct view of geological history in progress. We seem, however, to be by chance now living under rather peculiar, though doubtless not unique, conditions; that is, in an interglacial, possibly a truly post-glacial, period. Boulders, gravels, sands, and clays laid down by ice and associated streams in regions, such as Britain, now enjoying a temperate climate are conspicuous among the superficial deposits. The study of this Glacial Period (Ice Age), stretching back through a million years or more, is thus a specially apparent and interesting episode in geological history.

The principle that underlies all our ideas of time, process, and history is that of Uniformitarianism. This is the principle of the continuity of the action of the various forces and the continuity of the resulting changing conditions, in contrast to the idea of world-wide violent catastrophes interrupting the orderly course of nature.

We have now arrived at the final definition of geology: the Science of the Mineral Kingdom of the Earth; its composition, structure, processes, and history.

But there is still a note to be added. Recent exploration of outer space has suggested such titles as Lunar Geology, Martian Geology, Planetary Geology.

Concerning the divisions of geology

There are certain subordinate sciences which either definitely form part of geology or whose status in that respect is to be considered. The following are the chief of these.

Stratigraphy The study of strata. This in the first place requires a description of their occurrence, lithology, succession, and mutual relations, and their fossil content. The study of the manner of their original deposition is sedimentology. The study of the fossil content of strata from the points of view of (1) their identification and correlation, and (2) indication of conditions prevailing where they were deposited, is biostratigraphy. From all these studies we can infer something, at least, of the distribution of land and sea and of the variation in space of marine conditions at any one time - that is, we can study palaeogeography. We know much more about the palaeogeography of the marine areas than we do of the land areas, the evidence concerning these latter having been destroyed to provide the more lasting evidence of the former.

Structural geology. This is the study of the architecture of the earth's crust; the disposition and mutual relations of all kinds of rocks (sedimentary, igneous, metamorphic) on every scale, from the world-wide to the microscopic. Structures are primary, resulting from the manner of the original formation of the rocks, and secondary, deformations due to subsequent forces applied to them. It is the secondary deformations that demand the more intensive and detailed study. Structural geology is also called tectonic geology, the latter term being used particularly for the secondary deformations.

Mineralogy. Minerals have already been defined and have been seen to be the ultimate visible particles of the vast majority of rocks, so that the study of them is obviously of fundamental importance in geology. However, there are a great many minerals and geology is mainly concerned only with certain of them, the rock-forming minerals and the ores and their associates occurring in pockets and veins. The geologist is also mainly concerned with certain physical properties, such as colour and hardness, and with optical properties, particularly those seen under the microscope. Chemical composition is given to him from the chemical side of the subject. Crystallography is something of an exercise in solid geometry; atomic structure can be examined by x-ray analysis. Thus the science of mineralogy is one that can be studied in detail in several directions, beyond the more immediate requirements of the ordinary geologist.

Petrology. The science of the rocks in themselves. The descriptive part of it, petrography, is the study of the mineral composition and texture of rocks of all kinds. Their origin and mode of formation is petrogenesis, a term applied particularly to the igneous, and also metamorphic, rocks. Volcanism here finds a place. While many broad facts of petrology can be observed in the field, and more can be seen in hand-specimens, the details, which provide the most important information, can be studied only in thin sections (slices) under the microscope.

Palaeontology. This is the science of the life of past ages; it is a department of biology, not one of geology in the strictest sense - a sense we are trying to define. The evidence concerning palaeontology lies in the fossils; but the fossils are at the same time geological material. They are ingredients of the sedimentary rocks and are thus a part of the mineral kingdom as well as being parts of the animal and plant kingdoms. They may determine the lithological character of a rock, for example coral limestone, shelly sandstone. The geologist, finding the fossils, has for his own particular purposes to discriminate carefully between the different kinds. But when he attempts to infer the character of the soft parts from the mineralized remains, to establish biological relationships, and to reconstruct the life and habits of the animals and plants themselves, he is doing work of a biological kind, as he is also when he tries to trace evolutionary lines from the time-succession of the fossils in the rocks. Geologists are often led to do this, particularly with fossils of invertebrate animals, as an extension of their work into another domain of science. They will also, purely as geologists, make use of what is known about the distribution of life at the present day to throw light on the environment in which certain rocks were originally deposited.

Geomorphology. The science of the earth's surface features: their distribution, character, origin, and evolution. The description and cartographical delineation of these features constitute the most important part of physical geography. The earth's surface features are, however, entirely due to geological processes and geological structure, and include the superficial deposits. The form of the surface of the earth's crust, in addition to its internal structure, may be said to be in itself a geological, as well as a geographical matter. Thus geomorphology as a whole lies within the domain of geology, the descriptive aspects of it being at the same time geographical.

Geophysics and Geochemistry. These sections of geology result from the application of physical and chemical principles and methods to geological problems.

Finally, geology has many applications in the service of man: thus Agricultural Geology, Engineering Geology, Geology of Water Supply (Hydrogeology), Petroleum Geology, Mining Geology.

While geology remains firmly as a clearly defined individualized science, its investigation expands ever more widely and penetrates ever more deeply. As studies proceed it seems that there is a limitless amount and variety of things to record and from which to derive geological thought. Is there any region, in any part of the world, that has been fully explored? New techniques, such as that of the scanning electron microscope, enable minute but significant details to be examined, and wide-ranging, even revolutionary, conceptions such as that of plate tectonics emerge from generalizations based on new knowledge of the earth's crust and its behaviour. The riches of the Mineral Kingdom are indeed inexhaustible!

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