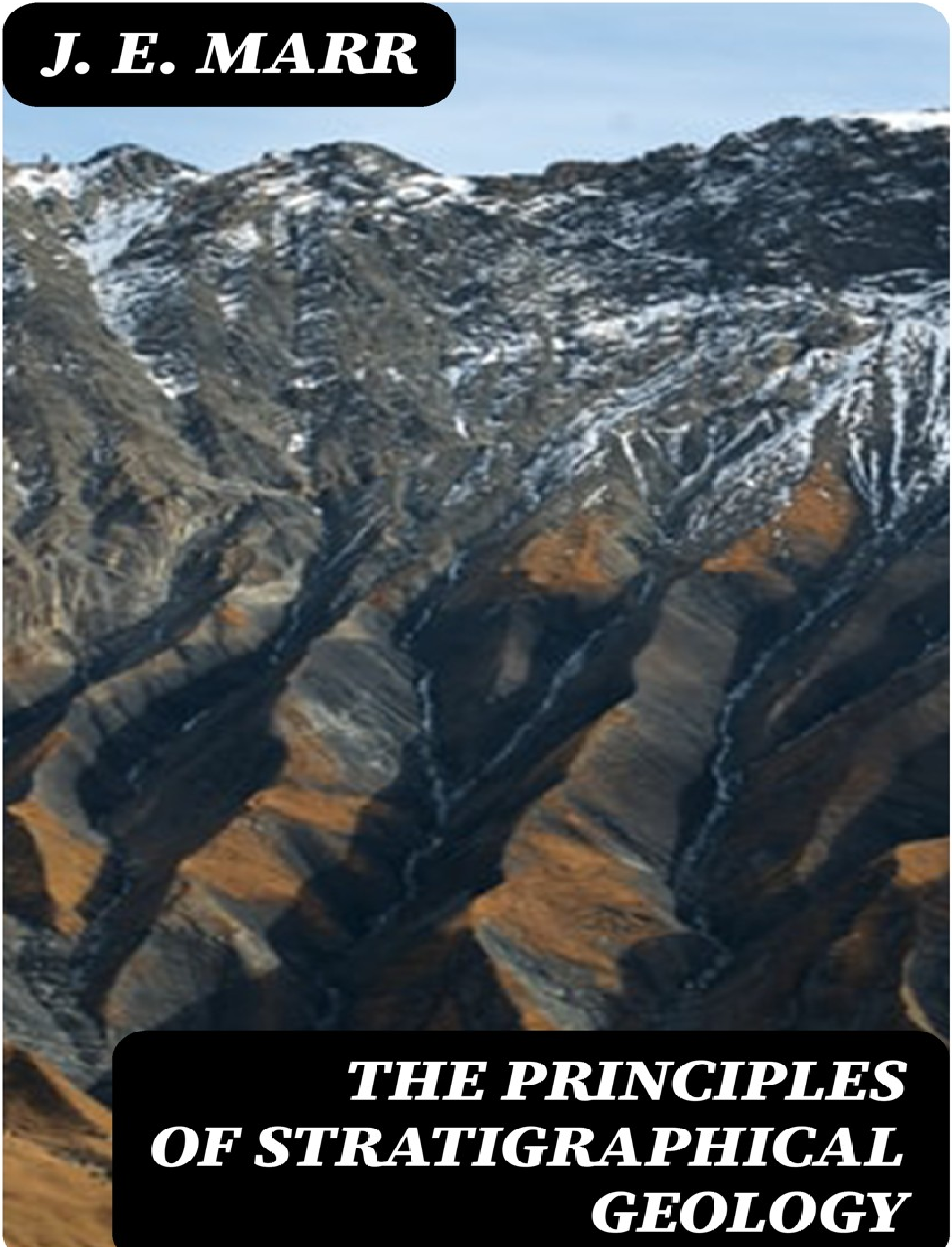
J. E. MARR



THE PRINCIPLES OF STRATIGRAPHICAL GEOLOGY

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CHAPTER I.

INTRODUCTION.

It is the aim of the Stratigraphical Geologist to record the events which have occurred during the existence of the earth in the order in which they have taken place. He tries to restore the physical geography of each period of the past, and in this way to write a connected history of the earth. His methods are in a general way similar to those of the ethnologist, the archæologist, and the historian, and he is confronted with difficulties resembling those which attend the researches of the students of human history. Foremost amongst these difficulties is that due to the imperfection of the geological record, but similar difficulty is felt by those who pursue the study of other uncertain sciences, and whilst this imperfection is very patent to the geologist, it is perhaps unduly exaggerated by those who have only a general knowledge of the principles and aims of geology.

The history of the earth, like other histories, is a connected one, in which one period is linked on to the next. This was not always supposed to be the case; the catastrophic geologist of bygone times believed that after each great geological period a convulsion of nature left the earth's crust as a *tabula rasa* on which a new set of records was engraved, having no connexion with those which had been destroyed. Careful study of the records of the rocks has proved that the conclusions of the catastrophists were erroneous, and that the events of one period produce their impression upon the history of the next. Every event which occurs, however insignificant, introduces a new complication into the conditions of the earth, and accordingly those conditions are never quite the same. Although the changes were no doubt very slow, so that the same general conditions may be traced as existent during two successive periods, minor complications occurred in the inorganic and organic worlds, and we never get an exact recurrence of events. Vegetable deposits may now be in process of accumulation which in ages to come may be converted into coal, but the general conditions which were prevalent during that Carboniferous period when most of our workable coal was deposited do not now exist, and will never exist again. The changes which have taken place and which are taking place show an advance from the simple to the more complex, and the stratigraphical geologist is confronted with a problem to which the key is development, and it is his task to trace the development of the earth from the primitive state to the complex condition in which we find it at the present day.

Our general ignorance of the events of the earliest periods of the history of the earth will be emphasised in the sequel, and it will be found that the complexity which marks the inorganic and organic conditions which existed during the deposition of the earliest rocks of which we have detailed knowledge points to the lapse of enormous periods of time subsequent to the formation of the earth, and previous to the deposition of those rocks. The imperfection of the record is most pronounced for that long period of time, but in this respect the geologist is in the same condition as the student of human history, for the relics of the early stone age prove that man in that age had attained a fairly high state of civilisation, and the gap which separates palæolithic man from the first of our race is relatively speaking as great as that which divides the Cambrian period from the commencement of earth-history.

Nevertheless, human history is a science which has made gigantic strides towards the solution of many problems connected with the development of man and civilisation, and similarly geology has advanced some way in its task of elucidating the history of our globe.

The task of the stratigraphical geologist is two-fold. In the first place, he must establish the order of succession of the strata, for a correct chronology is of paramount importance to the student of earth-lore. The precautions which must be taken in making out the order of deposition of the rocks of any area, and correlating those of one area with those of another will be considered in the body of the work. When this task is completed, there yet remains the careful examination of all the information supplied by a study of the rocks of the crust, in order to ascertain the actual conditions which existed during the deposition of any stratum or group of strata. In practice, it is generally very difficult to separate these two departments of the labour of the stratigraphical geologist, and the two kinds of work are often done to a large extent simultaneously, or sometimes alternately. Frequently the general succession of the deposits comprising an important group is ascertained, and at the same time observations made concerning the physical characters of the deposits and the nature of their included organisms, which are sufficient to afford some insight into the general history of the period when these deposits were laid down; a more detailed classification of the same set of deposits may be subsequently made, and as the result of this, more minute observations as to the variations in the physical and biological conditions of the period are possible, which permit us to write a much more concise history of the period. So great has been the tendency to carry on work in a more and more detailed manner, that it is very difficult if not impossible to tell when any approach to finality is reached in the study of a group of strata in any area. Roughly speaking, we may state that our knowledge of a group of strata is obtained by three processes, or rather modifications of one process. The general order of succession is established by the pioneer, frequently as the result of work carried on through one or two seasons. Subsequently to this, a more minute subdivision of the rocks is possible as the result of labours conducted by one or more workers who are enabled to avail themselves of the work of the pioneer, and our knowledge of the rocks is largely increased thereby. But the minutiæ, often of prime importance, are supplied by workers who must spend a large portion of their time in the area where the work lies, and it is only in districts where work of this character has been performed, that our knowledge of the strata approaches completion. The strata of the Arctic regions, for example, have in many places been examined by pioneers, but a great deal remains to be done in those regions; the main subdivisions only have been defined in many cases, and our information concerning the physical history of Arctic regions in past times is comparatively meagre. To come nearer home—a few miles north of Cambridge lies the little patch of Corallian rock at Upware; it has been frequently visited, and a large suite of organic remains extracted from it, but no one has devoted the time to the collection of remains from this deposit which has been devoted to that of some other formations presently to be mentioned, and accordingly our knowledge of the fauna of that deposit is far from complete. Contrast with this the information we possess of the little seam known as the Cambridge Greensand, from which organic remains have been sedulously collected during the extensive operations which have been carried on for the extraction of the phosphatic nodules which occur in the seam. The suite of relics of the organisms of that period is accordingly far more perfect than in the case of many other beds, and indeed the large and varied collection of relics of the vertebrata of the period which furnish much information of value to the palæontologist would not have been gathered together, had not this seam been so carefully worked, and an important paragraph in the chapter bearing on the history of this period would have remained unknown to us. Again, two little patches of limestone of the same age, one in central England and the other in the island of Gothland, have been the objects of sedulous inquiry by local observers, and we find again that our knowledge of the physical history of the period, as regards these two regions, is exceptionally perfect. Special stress is laid upon this point, for in these days, when every county possesses its learned societies whose members are desirous of advancing in every possible way the progress of science, it is well to insist upon the importance of this detailed work which can only be done by those who have a large amount of time to devote to the rigorous examination of the rocks of a limited area.

CHAPTER II.

ACCOUNT OF THE GROWTH AND PROGRESS OF STRATIGRAPHICAL GEOLOGY.

The history of the growth of a science is not always treated as an essential part of our knowledge of that science, and many text-books barely allude to the past progress of the science with which they deal. The importance of a review of past progress has, however, attracted the attention of many geologists, and Sir Charles Lyell, in his *Principles of Geology*, gave prominence to an historical sketch of the rise and progress of the science.

Historical studies of this nature have more than an academic value; the very errors made by men in past times are useful as warnings to prevent those of the present day from going astray; the lines along which a science has progressed in the past may often be used as guides to indicate how work is to be conducted in the future; but perhaps the greatest lesson which is taught by a careful consideration of the rise and progress of a study is one which has a moral value, for he who pays attention to the growth of his science in past times, gains a reverence for the old masters, and at the same time learns that a slavish regard for authority is a dangerous thing. This is a lesson which is of the utmost importance to the student who wishes to advance his science, and will prevent him from paying too little attention to the work of those who have gone before him, whilst it will enable him to perceive that as great men have fallen into error through not having sufficient data at their disposal, he need not be unduly troubled should he find that conclusions which he has lawfully attained after consideration of evidence unknown to his predecessors clash with those which they adopted. Want of this historic knowledge has no doubt caused many workers to waste their time on work which has already been performed, but it has also led others to withhold important conclusions from their fellow-workers because they were supposed to be heterodox. In an uncertain science like geology one of the great difficulties is to keep an even balance between contempt and undue respect for authority, and assuredly a scientific study of the past history of a science will do much to enable a student to attain this end. It will be useful, therefore, at this point to give a brief account of the rise and progress of the study of stratigraphical geology, so far as that can be done without entering into technical details, at the same time recommending the student to survey the progress of this branch of our science for himself, after he has mastered the principles of the subject, and such details as are the property of all who have studied the science from the various text-books written for advanced students.

William Smith, the 'Father of English Geology,' is rightly regarded as the founder of stratigraphical geology on a true scientific basis, but like all great discoverers, his work was foreshadowed by others, though so dimly, that this does not and cannot detract from his fame. It is desirable, however, to begin our historical review at a time somewhat further back than that at which Smith gave to the world his epoch-making map and memoirs.

Before the eighteenth century, stratigraphical geology cannot be said to have existed as a branch of science—the way had not been prepared for it. Data had been accumulated which would have been invaluable if at the disposal of open-minded philosophers, but with few exceptions prejudice prevented the truth from becoming known. There were two great stumbling-blocks to the establishment of a definite system of stratigraphical geology by the writers of the Middle Ages, firstly, the contention that fossils were not the relics of organisms, and, secondly, when it was conceded that they represented portions of organisms which had once existed, the assertion that they had reached their present positions out of reach of the sea during the Noachian Deluge. For full details concerning the mischievous effects of these tenets upon the science the reader is referred to the luminous sketch of the growth of geology in the first four chapters of Sir Charles Lyell's *Principles of Geology*.

The disposition of rocks in strata, and the occurrence of different fossils in different strata, was known to Woodward when he published his *Essay toward a Natural History of the Earth* in 1695, and the valuable collections made by Woodward and now deposited in the Woodwardian Museum at Cambridge, show how fully he appreciated the importance of these facts, though he formed very erroneous conclusions from them, owing to the manner in which he drew upon his imagination when facts failed him, maintaining that fossils were deposited in the strata according to their gravity, the heaviest sinking first, and the lightest last, during the time of the universal deluge. The following extracts from Part II. of Woodward's book, show the position in which our knowledge of the strata stood at the end of the seventeenth century: "The Matter, subsiding…, formed the *Strata* of Stone, of Marble, of Cole, of Earth, and the rest; of which Strata, lying one upon another, the Terrestrial Globe, or at least as much of it as is ever displayed to view, doth mainly consist.… The Shells of those Cockles, Escalops, Perewinkles, and the rest, which have a greater degree of Gravity, were enclosed and lodged in the *Strata* of Stone, Marble, and the heavier kinds of Terrestrial Matter: the lighter Shells not sinking down till afterwards, and so falling amongst the lighter Matter, such as Chalk, and the like… accordingly we now find the lighter kinds of Shells, such as those of the *Echini*, and the like, very plentifully in Chalk.… Humane Bodies, the Bodies of Quadrupeds, and other Land-Animals, of Birds, of Fishes, both of the Cartilaginous, the Squamose, and Crustaceous kinds; the Bones, Teeth, Horns, and other parts of Beasts, and of Fishes: the Shells of Land-Snails: and the Shells of those River and Sea Shell-Fish that were lighter than Chalk &c. Trees, Shrubs, and all other Vegetables, and the Seeds of them: and that peculiar Terrestrial Matter whereof these consist, and out of which they are all formed,… were not precipitated till the last, and so lay above all the former, constituting the supreme or outmost *Stratum* of the Globe.… The said *Strata*, whether of Stone, of Chalk, of Cole, of Earth, or whatever other Matter they consisted of, lying thus each upon other, were all originally parallel:… they were plain, eaven, and regular.… After some time the

Strata were broken, on all sides of the Globe:... they were dislocated, and their Situation varied, being elevated in some places, and depressed in others... the Agent, or force, which effected this Disruption and Dislocation of the *Strata*, was seated *within* the Earth."

Woodward's writings no doubt exercised a direct influence on the growth of our subject, but the indirect effects of his munificent bequest to the University of Cambridge and his foundation of the Chair of Geology in that University were even greater, for as will be pointed out in its proper place, two of the occupants of that chair played a considerable part in raising stratigraphical geology to the position which it now occupies.

The discoveries which were made after the publication of Woodward's book and before the appearance of the map and writings of William Smith are given in the memoir of the latter author, written by his nephew, who formerly occupied the Chair of Geology at Oxford[1]. It would appear that the fact that "the strata, considered as definitely extended masses, were arranged one upon another in a certain *settled order* or *series*" was first published by John Strachey in the *Philosophical Transactions* for 1719 and 1725. "In a section he represents, in their true order, chalk, oolites, lias, red marls and coal, and the metalliferous rocks" of Somersetshire, but confines his attention to the rocks of a limited district.

[1] *Memoirs of William Smith, LL.D.* By J. Phillips, F.R.S., F.G.S. 1844.

The Rev. John Michell published in the *Philosophical Transactions* for 1760 an "Essay on the Cause and Phænomena of Earthquakes," but Prof. Phillips gives proofs that Michell, who in 1762 became Woodwardian Professor, had before 1788 discovered (what he never published) the first approximate succession of the Mesozoic rocks, in the district extending from Yorkshire to the country about Cambridge. Michell's account was discovered written by Smeaton on the back of a letter dated 1788. The following is the succession as quoted in Phillips' memoir (p. 136):

	Yards of thickness.
"Chalk	120
Golt	50
Sand of Bedfordshire	10 to 20
Northamptonshire lime and Portland lime, lying in several strata	100
Lyas strata	78 to 100
Sand of Newark	about 30
Red Clay of Tuxford, and several	100
Sherwood Forest pebbles and gravel	50 unequal
Very fine white sand	uncertain
Roche Abbey and Brotherton limes	100
Coal strata of Yorkshire	—"

The order of succession of the Cretaceous, Jurassic, Triassic and Permian beds will be readily recognised as indicated in this section, though the discovery of the detailed succession of the Jurassic rocks was reserved for Smith.

In the year 1778, John Whitehurst published *An Inquiry into the Original State and Formation of the Earth*, containing an Appendix in which the general succession of the strata of Derbyshire is noted. The main points of interest are that the author clearly recognised the 'toad-stones' of Derbyshire as igneous rocks, "as much a *lava* as that which flows from Hecla, Vesuvius, or Ætna," though he believed that they were intrusive and not contemporaneous, and he also foreshadows the distinction between the solid strata and the superficial deposits—"we may conclude," he says, "that all beds of sand and gravel are assemblages of adventitious bodies and not original *strata*: therefore wherever sand or gravel form the surface of the earth, they conceal the original *strata* from our observation, and deprive us of the advantages of judging, whether coal or limestone are contained in the lower regions of the earth, and more especially in flat countries where the *strata* do not basset."

Werner, who was born in 1750, exercised more influence by his teaching than by his writings. His ideas of stratigraphical geology were somewhat vitiated by his theoretical views concerning the deposition of sediment from a universal ocean, in a definite order, beginning with granite, followed by gneiss, schists, serpentines, porphyries and traps, and lastly ordinary sediments. He recognised and taught that these rocks had a definite order "in which the remains of living bodies are successively accumulated, in an order not less determinate than that of the rocks which contain them[2]." The limited value of Werner's stratigraphical teaching is accounted for by Lyell, who remarks that "Werner had not travelled to distant countries; he had merely explored a small portion of Germany, and conceived and persuaded others to believe that the whole surface of our planet, and all the mountain-chains in the world, were made after the model of his own province," and the author of the *Principles* justly calls attention to the great importance of travel to the geologist. Those who cannot travel extensively should at any rate pay special attention to the works published upon districts other than their own, and even at the present time, the writings of some British workers are apt to be marked by some of that 'insularity' which our neighbours regard as a national characteristic.

[2] Cuvier's *Eloge*.

It is now time to turn directly to the work of William Smith, who, of all men, exercised the most profound influence upon the study of stratigraphical geology and may indeed be regarded as the true founder of that branch of the science. The memoir of his life which was before mentioned is all too short to illustrate the methods of work which he followed, but in it we can trace his success to three things:—firstly, his 'eye for a country,' to use a phrase which is thoroughly understood by practical geologists, though it is hard to explain to others, inasmuch as it epitomises a number of qualifications of which the most important are, a ready recognition of the main geological features from some coign of vantage, an intuitive perception of what to note and what to neglect, and the power of storing up acquired information in the mind rather than the note-book, so that one may use it almost unconsciously for future work; secondly, ability to draw conclusions from his observations, and thirdly, and perhaps most important of all in its ultimate results, a facility for checking these conclusions by means of further observations, and dropping those which were clearly erroneous, whilst extracting the truth from those which contained a germ of truth mixed with error.

Besides writers referred to above "some foreign writers, in particular Scilla and Rouelle, appear to have made very just comparisons of the natural associations of fossil shells, corals, &c. in the earth, with the groups of similar objects as they are found in the sea, and thus to have produced new proofs of the organic origin of these fossil bodies; but they give no sign of any knowledge of the *limitation of particular tribes of organic remains to particular strata*, of the *successive existence of different groups of organization*, on *successive beds of the antient sea*. Mr. Smith's claim to this happy and fertile induction is clear and unquestionable[3]." We get a clue to the manner in which he arrived at his view in the following passage[4]:—"Accustomed to view the surfaces of the several strata which are met with near Bath uncovered in large breadths at once, Mr. Smith saw with the distinctness of certainty, that 'each stratum had been in succession the bed of the sea'; finding in several of these strata abundance of the exuviae of marine animals, he concluded that these animals had lived and died during the period of time which elapsed between the formation of the stratum below and the stratum above, at or near the places where now they are imbedded; and observing that in the successively-deposited strata the organic remains were of different forms and structures—Gryphites in the lias, Trigoniæ in the inferior oolite, hooked oysters in the fuller's earth—and finding these facts repeated in other districts, he inferred that each of the separate periods occupied in the formation of the strata was accompanied by a peculiar series of the forms of organic life, that these forms characterized those periods, and that the different strata could be identified in different localities and otherwise doubtful cases by peculiar imbedded organic remains[5]."

[3] *Memoir of William Smith*, p. 142.

[4] *Ibid.* p. 141.

[5] The work of Smith which directly bears upon the establishment of the law of identification of strata by included organisms is published in two treatises, entitled:—

(i) *Strata identified by Organized Fossils*, 4to. (intended to comprise seven parts, of which four only were published), commenced in 1816.

(ii) *A Stratigraphical System of Organized Fossils*, compiled from the original Geological Collection deposited in the British Museum. 4to. 1817.

William Smith seems to have recognised intuitively the truth of a law which was but dimly understood before his time—the law of superposition, which may be thus stated: "of any two strata, the one which was originally the lower, is the older." This may appear self-evident but it was certainly not so. As the result of this recognition he established the second great stratigraphical law, with which his name will ever be linked, that strata are identifiable by their included organisms.

Before Smith's time, geological maps were lithological rather than stratigraphical, they represented the different kinds of rocks seen upon the surface without regard to their age; since Smith revolutionised geology, the maps of a country composed largely of stratified rocks are essentially stratigraphical, but partly no doubt on account of adherence to old custom, partly on economic grounds, the majority of our stratigraphical maps are lithological rather than palæontological, that is the subdivisions of the strata represented upon the map are chosen rather on account of lithological peculiarities than because of the variations in their enclosed organisms. It is hardly likely that Government surveys will be allowed to publish palæontological maps, which will be almost exclusively of theoretical interest, and it remains for zealous private individuals to accomplish the production of such maps. When they are produced, a comparison of stratigraphical maps founded on lithological and palæontological considerations will furnish results of extreme scientific interest.

Turning now from Smith's contributions to the science as a whole, we may now consider what he did for British geology. His geological map was published in 1815 and was described as follows:—"A Geological Map of England and Wales, with part of Scotland; exhibiting the Collieries, Mines, and Canals, the Marshes and Fen Lands originally overflowed by the Sea, and the varieties of Soil, according to the variations of the Substrata; illustrated by the most descriptive Names of Places and of Local Districts; showing also the Rivers, Sites of Parks, and principal Seats of the Nobility and Gentry, and the opposite Coast of France. By William Smith, Mineral Surveyor." The map was originally on the scale of five miles to an inch. In 1819 a reduced map was published, and in later years a series of county maps. He also published several geological sections, including one (in 1819) showing the strata from London to Snowdon.

The student should compare Smith's map of the strata with one published in modern times in order to see how accurate was Smith's delineation of the outcrop of the later deposits of our island.

The following table, taken from Phillips' memoir, p. 146, is also of interest as showing the development of Smith's work and the completeness of his classification in his later years, and as illustrating how much we are indebted to Smith for our present nomenclature, so much so that as Prof. Sedgwick remarked when presenting the first Wollaston Medal of the Geological Society to Smith, "If in the pride of our present strength, we were disposed to forget our origin, our very speech would bewray us: for we use the language which he taught us in the infancy of our science. If we, by our united efforts, are chiselling the ornaments and slowly raising up the pinnacles of one of the temples of nature, it was he who gave the plan, and laid the foundations, and erected a portion of the solid walls by the unassisted labour of his hands."[6]

[6] The reader may consult an interesting paper by Professor Judd, on "William Smith's Manuscript Maps," *Geological Magazine*, Decade IV. vol. IV. (1897) p. 439.

Comparative View of the Names and Succession of the Strata.

Table drawn up in 1799.	Table accompanying the map, drawn up in 1812.		Improved table drawn up in 1815 and 1816 after the first copies of the map had been issued.
	London Clay	1	London Clay

		Clay or Brick-earth	2	Sand
			3	Crag
		Sand or light loam	4	Sand
1	Chalk	Chalk	5	Chalk { Upper Lower
2	Sand	Green Sand	6	Green Sand
		Blue Marl	7	Brick Earth
		Purbeck Stone, Kentish Rag and Limestone of the vales of Pickering and Aylesbury, Iron Sand and Carstone	8	Sand
			9	Portland Rock
			10	Sand
			11	Oaktree Clay
			12	Coral Rag and Pisolite
			13	Sand
3	Clay	Dark Blue Shale	14	Clunch Clay and Shale
			15	Kelloway's Stone
		Cornbrash	16	Cornbrash
4	Sand and Stone		17	Sand and Sandstone
5	Clay			
6	Forest Marble	Forest Marble Rock	18	Forest Marble
			19	Clay over Upper Oolite
7	Freestone	Great Oolite Rock	20	Upper Oolite
8	Blue Clay			
9	Yellow Clay			
10	Fuller's Earth		21	Fuller's Earth and Rock

11	Bastard ditto and Sundries			
12	Freestone	Under Oolite	22	Under Oolite
13	Sand		23	Sand
			24	Marlstone
14	Marl Blue	Blue Marl	25	Blue Marl
15	Blue Lias	Blue Lias	26	Blue Lias
16	White Lias	White Lias	27	White Lias
17	Marlstone, Indigo and Black Marls			
18	Red Ground	Red Marl and Gypsum	28	Red Marl
19	Millstone	Magnesian Limestone	29	Redland Limestone
		Soft Sandstone		
20	Pennant Street			
21	Grays	Coal Districts	30	Coal Measures
22	Cliff			
23	Coal			
		Derbyshire Limestone	31	Mountain Limestone
		Red and Dunstone	32	Red Rhab and Dunstone
		Killas or Slate	33	Killas
		Granite, Sienite and Gneiss	34	Granite, Sienite and Gneiss

The above table contains a very complete classification of the British Mesozoic rocks, one of the Tertiary strata which is less complete, and a preliminary division of the Palæozoic rocks into Permian (Redland Limestone), Carboniferous (Coal Measures and Mountain Limestone), Devonian (Red Rhab and Dunstone) and Lower Palæozoic (Killas).

Since Smith's time the main work which has been done in classification is a fuller elucidation of the sequence of the Tertiary and Palæozoic Rocks, and this we may now consider.

The Mesozoic rocks are developed in Britain under circumstances which render the application of the test of superposition comparatively simple, for the various subdivisions crop out on the surface over long distances, and the stratification is not greatly disturbed. With the Tertiary and Palæozoic Rocks it is otherwise, for some members of the former are found in isolated patches, whilst the latter have usually been much disturbed after their formation.

Commencing with the Tertiary deposits we may note that "the first deposits of this class, of which the characters were accurately determined, were those occurring in the neighbourhood of Paris, described in 1810 by MM. Cuvier and Brongniart.... Strata were soon afterwards brought to light in the vicinity of London, and in Hampshire, which although dissimilar in mineral composition were justly inferred by Mr. T. Webster to be of the same age as those of Paris, because the greater number of fossil shells were specifically identical[7]." It is to Lyell that we owe the establishment of a satisfactory classification of the Tertiary deposits which is the basis of later classifications. Recognising the difficulty of applying the ordinary test of superposition to deposits so scattered as are those of Tertiary age in north-west Europe, he in 1830, assisted by G. P. Deshayes, proposed a classification based on the percentage of recent mollusca in the various deposits. It may be noted, that although this method was sufficient for the purpose, it has been practically superseded, as the result of increase of our knowledge of the Tertiary faunas, by the more general method of identifying the various divisions by their actual fossils without reference to the number of living forms contained amongst them. The further study of the British Tertiary rocks was largely carried on by Joseph Prestwich, formerly Professor of Geology in the University of Oxford.

[7] Lyell, *Students' Elements of Geology*. 2nd Edition, p. 118.

Amongst the Palæozoic rocks, it has been seen that the Permian, Carboniferous and some of the Devonian beds were recognised as distinct by Smith, though a large number of deposits now known to belong to the last named were thrown in with other rocks as 'killas.' The Devonian system was established and the name given to it in 1838 by Sedgwick and Murchison, largely owing to the palæontological researches of Lonsdale. An attempt was subsequently made to abolish the system, but the detailed palæontological studies of R. Etheridge finally placed it upon a secure basis. The establishment of the Devonian system cleared the way for the right understanding of the Lower Palæozoic rocks, which Sedgwick and Murchison had commenced to study before the actual establishment of the Devonian system, and to these workers belongs the credit of practically completing what was begun by William Smith, namely, the establishment of the Geological Sequence of the British strata. The controversy which unfortunately marked the early years of the study of the British Lower Palæozoic Rocks is well-nigh forgotten, and in the future the names of Sedgwick and Murchison will be handed down together, in the manner which is most fitting.

Our account of the growth of British Stratigraphical Geology is not yet complete. In 1854, Sir William Logan applied the term Laurentian to a group of rocks discovered in Canada, which occurred beneath the Lower Palæozoic Rocks. Murchison shortly afterwards claimed certain rocks in N.W. Scotland as being of generally similar age, and since then a number of geologists, most of whom are still living, have proved the occurrence of several large subdivisions of rocks in Britain, each of which is of pre-Palæozoic age.

The above is a brief description of the growth of our knowledge of the order of succession of the strata which is the foundation of Stratigraphical Geology. A sketch of the manner in which the knowledge which has been obtained has been applied to the elucidation of the earth's history of different times would require far more space than can be devoted to it in a work like the present, but some idea of it may be gained from a study of the later chapters of the book. It will suffice here to remark, that to Godwin-Austen we owe the foundation of what may be termed the physical branch of Palæo-physiography, which is concerned with the restoration of the physical conditions of past ages, while Cuvier and Darwin have exerted the most influence on the study of Stratigraphical Palæontology.

CHAPTER III.

NATURE OF THE STRATIFIED ROCKS.

The present constituents of the earth which are accessible for direct study are divisible into three parts. The inner portion, consisting of *rocks*, is known as the *lithosphere*; outside this, with portions of the lithosphere projecting through into the outermost part, is the *hydrosphere*, comprising the ocean, lakes, rivers, and all masses of water which rest upon the lithosphere in a liquid condition. The outermost envelope, which is continuous and unbroken is the *atmosphere*, in a gaseous condition. It is well known that some of the constituents of any one of these parts may be abstracted from it, and become a component of either of the others; thus the atmosphere abstracts aqueous vapour from the hydrosphere, and the lithosphere takes up water from the hydrosphere, and carbonic anhydride from the atmosphere.

The nebular hypothesis of Kant and Laplace necessitates the former existence of the present solid portions of the lithosphere in a molten condition, and accordingly the first formed solid covering of the lithosphere, if this hypothesis be true, must have been formed from molten material, or in the language of Geology, it was an *igneous rock*. Consequently, the earliest *sedimentary rock* was necessarily derived directly from an igneous rock, with possible addition of material from the early hydrosphere and atmosphere, and all subsequently formed sedimentary rocks have therefore been derived from igneous rocks (with the additions above stated) either directly, or indirectly through the breaking up of other sedimentary rocks which were themselves derived directly or indirectly from igneous rocks. The observations of geologists show that this supposition that the materials of sediments have been directly or indirectly obtained for the most part from once-molten rocks is in accordance with the observed facts, and so far their observations testify to the truth of the nebular hypothesis. This being the case, the study of the petrology of the igneous rocks is necessary, in order to arrive at a true understanding of the composition of the sedimentary ones. The igneous rocks are largely composed of four groups of minerals, viz.—quartz, felspars, ferro-magnesian minerals, and ores. Of these the quartz (composed of silica) yields particles of silica for the formation of sedimentary rocks; the felspars, which are double silicates of alumina and an alkali or alkaline earth, being prone to decomposition furnish silicate of alumina and compounds of soda, potash, lime, &c. The ferro-magnesian minerals (such as augite, hornblende and mica) may undergo a certain amount of decomposition, and yield compounds of iron, lime, &c. We may also have fragments of any of these minerals, and of the ore group in an unaltered condition. The composition of a sedimentary rock which has undergone no alteration after its formation will therefore depend upon the character of the rock from which it was derived, the chemical changes which take place in the materials which compose it, before they enter into its mass, and the mechanical sorting which they undergo prior to their deposition.

In the above passage the terms igneous rock and sedimentary rock have been used, and it is necessary to give some account of the sense in which they were used.

An *igneous* rock is one which has been *consolidated* from a state of *fusion*. It is not necessary to discuss here the exact significance of the word fusion, and whether certain rocks which are included in the igneous division were formed rather from solution at high temperature than from actual fusion. This point is of importance to the petrologist, but to the student of stratigraphical geology the term igneous rock may be used in its most comprehensive sense. These igneous rocks were consolidated either upon the surface of the lithosphere or in its interior.

The other great group of rocks is one to which it is difficult to apply a satisfactory name. They have been termed by different writers, *sedimentary*, *stratified*, *derivative*, *aqueous*, and *clastic*, but no one of these terms is strictly accurate. The term *sedimentary* implies that they have settled down, at the bottom of a sheet of water for instance. It can hardly be maintained that limestones formed by organic agency, like the limestones of coral reefs, are sedimentary in the strict sense of the term, and an accumulation like surface-soil can only be called a sediment by straining the term. *Stratified* rocks are those which are formed in strata or layers, but many of the rocks which we are considering do not show layers on a small scale, and igneous rocks (such as lava-flows) are also found in layers, though such layers are not true strata in the sense in which the term is used by geologists; the term *stratified* is perhaps the least open to objection of any of those named above. *Derivative* implies that the fragments have been derived from some pre-existing rock, but as there are many ways in which fragments of one rock may be derived from another, the term is too comprehensive. *Aqueous* rocks should be formed in water, and most of the class of rocks which we are considering have been so formed, but others such as sand-dunes and surface-soil have not. (The term Aerial or Æolian has been suggested to include these rocks which are thus separated from the Aqueous rocks proper; the objection to this is that the origin of these rocks is closely connected with that of the true Aqueous rocks, and moreover the group is too small to be raised to the dignity of a separate subdivision.) Lastly, the name *clastic* has been given, because the rocks so called are formed by the *breaking up* of pre-existing rocks. There are two objections to this name. In the first place, some rocks included under the head clastic are formed by solution of material and its consolidation from a state of solution by chemical or organic agency, though we may perhaps speak of rocks being broken up by chemical as well as by mechanical action. The most important objection is that many clastic rocks are formed by the breaking up of rocks subsequently to their formation, and it has been proposed that rocks of this nature should be termed *cataclastic*, while those which are formed by the breaking up of pre-existing rocks upon the earth's surface should be termed *epiclastic*; another group formed of materials broken up within the earth, and accumulated upon its surface as the result of ejection of fragmental material from volcanic vents being termed *pyroclastic*. This classification is scientific, and under special circumstances is extremely useful, but the older terms have been used so generally, and with this explanation their use is so unobjectionable, that they may be retained, and the term *stratified* will be generally used to indicate all rocks which are not of igneous origin or formed as mineral veins in the earth's interior.

The division of rocks into *three* great groups, the Igneous, Stratified and Metamorphic (the latter name being applied to those rocks which have undergone considerable alteration since their formation), is objectionable, since we have metamorphic igneous rocks as well as metamorphic stratified ones. The most convenient classification is as follows:—

A. Igneous	1.	Unaltered.
	2.	Metamorphic.
B. Stratified	1.	Unaltered.
	2.	Metamorphic.

It must be distinctly understood that all geological phenomena must be taken into account by the stratigraphical geologist. The upheaval of strata, the production of jointing and cleavage in them, their intrusion by igneous material, their metamorphism, give indications of former physical conditions equally with the lithological characters of the strata, and their fossil contents. Nevertheless it is not proposed to give a full account of the various phenomena displayed by rocks; the student is referred to Text-books of General Geology for this information. It will be as well here, however, to point out in a few words the exact significance of the existence of strata in the lithosphere.

The formation of strata and their subsequent destruction to supply material for fresh strata are due to three great classes of changes. Beginning with a portion of lithosphere composed of rock, it is found that rock is broken up by agents of denudation, as wind, rain, frost, rivers and sea. These agents perform their function mainly upon the portion of the lithosphere which projects through the hydrosphere to form *land*, and the land is the main area of denudation. The materials furnished by denudation are carried away, and owing to gravitation, naturally proceed from a higher to a lower level, often resting on the way, but if nothing else occurs, ultimately finding their way to the *sea*, where they are deposited as strata. The sea is the principal area for the reception of this material, and it is there accordingly that the bulk of stratified rock is formed. If nothing else occurred, in time the whole of the land would be destroyed, and the wreckage of the land deposited beneath the sea as stratified rock. As it is there is a third class of change, underground change, causing movements of the earth's crust (to use a term which can hardly be defined in few words but which is generally understood), and as the result of the relative uplift of portions of the earth's crust, the stratified rocks formed beneath the oceans are raised above its level, giving rise to new masses of land, which are once more ready for destruction by the agents of denudation. This cycle of change (all parts of which are ever proceeding simultaneously) is one of the utmost importance to the stratigraphical geologist.

Stratification is the rock-structure of prime importance in stratigraphical geology, and a few words must here be devoted to its consideration, leaving further details to be dealt with hereafter. The surface of the ocean-floor is, when viewed on a large scale, so level, that it may be considered practically horizontal, and accordingly in most places the materials which are laid down on the ocean-floor give rise to accumulations which at all times have a general horizontal surface (when the ocean-slopes depart markedly from horizontality the deposits tend to abut against these slopes rather than to lie with their upper surfaces parallel to their original angle). A practically horizontal surface of this character may give rise to a *plane of stratification* (or *bedding-plane*) in more than one way. A pause may occur during which there is a cessation of the supply of material, so that the material which has already been accumulated has sufficient time to become partially consolidated before the deposition of fresh material upon it. In this way a want of coherence between the two masses is produced, along the plane of junction, which after consolidation of the deposits causes an actual divisional plane along which the two deposits may be separated. This is a plane of stratification. The pause may be produced in various ways, sometimes between successive high tides, at others as the result of physical changes which may have taken ages to happen. Again, after material of one kind has been deposited, say sand, some other substance such as clay may be accumulated on its upper surface, giving rise to a plane of stratification between two deposits of different lithological characters. If this occurs alone, there may be actual coherence between the two strata, so that it is erroneous to speak of a plane of stratification as if it were always one along which one deposit could be readily split from the other, though as a general though by no means universal rule, change from one kind of deposit to another is also marked by want of coherence between the two. The material between two planes of stratification forms a *stratum* or *bed*, though if the deposit be very thin it is known as a *lamina*, and the planes are spoken of as *planes of lamination* (no hard and fast line can be drawn between strata and laminæ; several of the latter usually occur in the space of an inch).

A *stratum* will have its upper and lower surface apparently parallel, though not really so, for no stratum