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Science Primers.

GEOLOGY.

BY

ARCHIBALD GEIKIE, LL.D., F.R.S.,

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WITH ILLUSTRATIONS.

THIRD EDITION.

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NOTE.

The following Lessons having been designed to be based on practical instruction, teachers and learners will find it of great advantage to obtain and use a small collection of specimens. In a favourable locality the teacher may make his own collection; otherwise, he will do well to procure one of those described on pages 129, 130, *and accustom his pupils from the very beginning to familiarise their eyes with the specimens described in the Lessons.*

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SCIENCE PRIMERS.

GEOLOGY.

INTRODUCTORY.

1. An ordinary dwelling-house, such as those in which most of us live, is built of various materials, and one of these is always **stone.** In the walls, the hearths, the chimney-pieces, and the roofs, stone is used. But in each of these cases the kind of stone usually differs from that employed in the rest of the building. Thus the walls may be made of freestone, or limestone, or brick, the hearths of flagstone, the roofs of slate or tiles, the chimney-pieces of marble, while still another sort of stone called coal is burnt in the fireplaces. Go out into the streets and you find a still greater diversity. The causeway-stones are of one kind, those of the foot-pavement of another. Many different ornamental varieties are made use of in the shops and buildings. So that merely by looking at houses and streets you may readily perceive that **there are many different kinds of stone.**

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2. If you examine them a little more narrowly you will see that they receive various treatment before they become part of a building. The stones of the walls have been chipped and dressed with chisels and hammers; the marble of the chimney-pieces has been smoothed and polished; the slates have been split into thin plates. But some of these building materials have undergone much greater changes. The bricks, for instance, were originally soft clay which has been hardened by being baked in ovens. The mortar by which the stones or bricks of the walls are held together has been obtained by burning limestone in kilns. The iron used in the house was first of all in the state of a dull red or brown stone, which had to be roasted and melted before the clear bright metal came out of it.

3. But although these various stones differ so much from each other, they agree in one point—**they come from underneath the surface of the ground.** If you could trace back each of them to the place from which it came you would find that the freestone and limestone were taken out of quarries, perhaps not very far away, that the slates were cut out of the side of some hill, probably in Wales, that the marble was quarried out of some distant mountain, possibly in Italy, that the coal was dug out of mines, sunk deep into the earth in some part of Britain, and that the bricks were made from clay dug out of pits on some low ground in your neighbourhood.

4. In this country the greater part of the surface has a green grassy covering even over the sides of the hills—cornfields, meadows, woods, and orchards spread over it, concealing what lies beneath them, as a

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carpet conceals a floor. But this mantle of vegetation with the soil on which it grows is only a thin coating. You can easily dig through the grass and soil, or, better still, you can watch their removal in quarries, pits, or excavations of any kind. You find them to form a mere outer layer only a few feet thick at the most. Underneath them there always lies some kind of stone. So that just as in pulling up the carpet of a room you lay bare a wooden floor, so in peeling off the outer skin of vegetation and soil from any part of the land you expose a stone floor.

5. On this floor of stone we are walking every day of our lives. It stretches all over the globe, forming the bottom of the sea and the surface of the land. Unlike the floors of our houses it is very uneven, as you well know. In some places it spreads out into wide flat plains, elsewhere it shoots up into high and rugged mountains.

6. Again, this vast world-wide floor differs from our little wooden floors in the wonderful variety of its materials. You see only a small part of this variety in the various stones we use in building. There is an almost endless number of other stones. A builder is content if he can get his floors made of one uniform sort of wood which will last. But the great stone floor on which we are living has no such uniformity. Its varied materials are grouped together in the most irregular and changing manner, insomuch that if you made a map of them all, it would be like the intricate pattern of some costly carpet.

7. It is this stone floor of which I wish to speak to you in the following Lessons—what it is made of and

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how its different parts were put together. At first sight, perhaps, it may seem to you that there can be nothing very interesting or attractive about such a subject. Let me show you how it is related to you by the following illustration.

8. Take a map of the British Islands and draw across it two pencilled lines. Let one of these lines begin at Liverpool and stretch across England, touching Stafford, Birmingham, and Cambridge, to the sea at Harwich. Let the other run across the breadth of Scotland from the island of Skye to Montrose.*

9. Suppose that two foreigners who had never been in this country were to land on the west coast, and after crossing the island, each along one of the lines you have drawn, were afterwards to meet again on the Continent and compare notes as to what they had seen. The traveller who journeyed along the line from Liverpool to Harwich might report in some such words as these :—"I am astonished at the flatness of Britain. I went across the whole breadth of the island and did not see a single undulation of the ground worthy of the name of a hill. Most of the land is wonderfully fertile, being in one part covered with corn-fields, in another with orchards or woods, while wide tracts are given up to pasture. The houses are built of brick. I saw some large cities crowded with people and alive with all kinds of industry. I noticed, too, that in some parts of the country a great deal of the wealth of the inhabitants came from underground. In Cheshire they bring up large quantities of salt from mines. In Staffordshire

* A similar illustration has been used by Buckland, in his Bridgewater Treatise.

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they extract coal and iron from numerous deep pits. But on the whole Britain seems to me given up chiefly to the growing of corn and the feeding of cattle."

10. The other traveller would have a very different story to tell. "I cannot understand," he might say, "how you can talk of Britain as in any sense a flat country. I too crossed the island from sea to sea, landing on the coast of Inverness-shire and sailing from the port of Montrose. But I could see very little low or level land the whole way. It is one interminable succession of rough high mountains and deep rocky valleys. I could see no towns, hardly any villages, until I came to the eastern coast. The people live in houses of stone; I could not see a single brick anywhere. They have no coals except what are brought from a distance, and most of the poorer people cut the peat on the hills and use it for fuel. I saw no mines in my journey, and no manufactures of any kind. The population is but scanty, and seems to be occupied chiefly with sheep-farming. If I might judge of the whole of Britain from what I have seen with my own eyes I would describe it as a rough, mountainous, barren island, without commerce or industry, and fit only for pasture-land or grouse-shooting, and here and there for tillage."

11. Now each of these supposed travellers would have given a true enough account of this country so far as his own personal experience of it went. And yet both of them would have been quite wrong in supposing that what he had seen to be true of one part of the country was true in like manner of the whole.

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12. But why is it that there should be this great difference between different portions of Britain? What makes one region mountainous, another level, one fertile, another barren, one crowded with people and the scene of all manner of industry, another thinly peopled and given up to the rearing of sheep and the shooting of game?

13. **These great differences of the surface of the country depend upon differences between the stones or rocks.**

14. Now you can easily understand that if so much of the character of a country and of its inhabitants depends upon the nature of the stones underneath, it is very desirable that we should know something about these stones, how they came to be formed, what they consist of, and how it is that they should form plains or low grounds in one place, and single hills or lofty mountains in another. This kind of knowledge belongs to the science of **Geology.**

DIFFERENT KINDS OF STONES.

15. If I were to ask you how many different kinds of books you have seen in the course of your lifetime, you would perhaps say that it was quite impossible to count them. You have seen many that were new, some that were old; big books and little books; some with boards, others merely wrapped up in paper; some beautifully bound in cloth of red, green, blue, or other colours, others cased in leather and covered with rich gilding; some printed in large, others in small letters; some plentifully supplied with pictures,

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others without any at all. In short, you might go on for a long time trying to count up all these differences among the books which you have met with. But now if you think a moment you will see that, after all, these are only outside differences. The really important part of the book is not the binding, or the paper, or the printing, but the words which the book has to make known to you. You might print these words in very small type and make them up into a little book, or in very large and widely spaced type and make a big book; you might put in pictures or leave them out; you might bind the book in cloth or in leather, or give it no binding at all; but still it would be in reality the same book all the time.

16. When you pass, then, from such mere unimportant external resemblances or differences to what the books properly are in themselves, you soon discover that after all there are not so many kinds as you had imagined. You can pick them out and sort them into groups according to the subjects of which they treat. Thus in your little libraries you find that some are Books of Grammar, others Books of History, others Books of Geography, with Books of Poetry, Books of Travels, Books of Tales, and so on. Under each of these names you could put, if you had them, hundreds of books, resembling each other in treating about the same things, whether they were old books or new, large or small, bound or unbound.

17. In arranging your books in this way, not according to their mere superficial accidental resemblances, but according to the subjects which they treat of in common, that is, their real resemblances, you would follow what is called a **Principle of Classifica-**

tion. It would not matter how many different books came into your hands; they might be written, too, in English, French, German, Latin, Greek, or in any language. Still, following your principle of classification, you would be able to arrange them all in their proper places, all the books on the same subject being put together, so that at any moment you could lay your hands on any particular book which might be wanted.

18. Suppose that instead of books you are asked to arrange stones according to their several kinds. You think over the names of all the different stones you know and try to recollect their characters. Perhaps you begin by arranging them according to colour, as for instance, Black Stones, such as Coal; White Stones, such as Chalk. But in a little time you find that the same stone, marble for instance, is sometimes black and sometimes white. Plainly, therefore, colour will not do for your principle of classification among stones, any more than it would do for books. Then you might go on to see how a grouping into Hard Stones and Soft Stones would do. But as soon as you begin this kind of classification, you find that you need to put side by side stones which are so utterly unlike each other that you feel sure that mere hardness or softness is one of those accidental or outside characters, like the paper or printing of a book.

19. You must find out then what are the real and essential characters of stones. Now how did you do this in the case of books? You examined their contents and placed those together which on reading them you found to be devoted to the same subject. You must follow the same course with stones.

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20. But you may ask, "How are we to read the contents of stones? Surely this must be very difficult, for is there not an infinitely greater number of kinds of stones than of books?" By no means. You will soon learn that it is not so difficult as you might suppose to read the contents of stones, and that in reality the chief groups of stones are very much fewer in number than the chief groups of books. Let us see.

21. Here are three pieces of stone:—

1. A piece of Sandstone.
2. A piece of Granite.
3. A piece of Chalk.

22. You are quite familiar with each of these kinds of stone. Sandstone is a common material for walls, lintels, hearths, and flagstones. Granite may now be

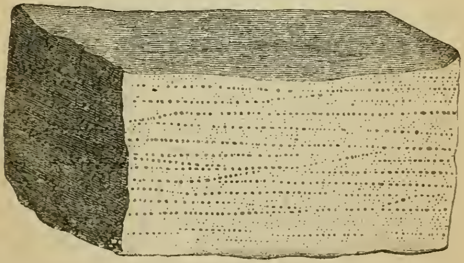

FIG. 1.—Piece of Sandstone.

frequently seen in polished columns and slabs in public buildings, shops, and in tombstones; and the streets in many of our large cities and towns are now paved with it. Common white Chalk is well known to everybody.

23. Take the piece of sandstone in your hands and

examine it carefully, using even a magnifying glass if the grains are minute. Then write down each of the characters you observe one after another. You will of course pay little heed to the colour, for sandstones, like books, may be red or white, green or yellow, or indeed of almost any colour. Nor will you give much weight to the hardness or softness as an essential character, for you may find even in a small piece of the stone that one part is quite hard while a neighbouring place is soft and crumbling.

24. If your piece of sandstone has been well chosen for you, you will be able to write down the following characters :—

(1.) The stone is made up of small grains.

(2.) The grains are all more or less rounded or worn.

(3.) By scraping the surface of the stone these rounded grains can be separated from the stone, and when they lie in this loose state they are seen to be mere grains of sand.

(4.) More careful examination of the stone shows that the grains tend to lie in lines, and that these lines run in a general way parallel with each other.

(5.) The grains differ from each other in size and in the material of which they are made. Most of them consist of a very hard white or colourless substance like glass, some are perhaps small spangles of a material which glistens like silver, others are scfter and of various colours. They lie touching each other in some sandstones; in others they are separated by a hard kind of cement which binds them all into a solid stone. It is this cement which usually colours the sandstone, since it is often red or yellow, and sometimes green, brown, purple, and even black.

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25. Summing up these characters in a short definition, you might describe your sandstone as a **stone composed of worn, rounded grains of various other stones arranged in layers.**

26. Proceed now in the same way with the piece of Granite. You find at once a very different set of appearances, but after a little time you will be able to make out and to write down the following :—

FIG. 2.—Piece of Granite.

(1.) The stone contains no rounded grains.

(2.) It is composed of three different substances, each of which has a peculiar crystalline form (see Chemistry Primer, Art. 23). Thus, one of these, called Felspar, lies in long smooth-faced, sharply defined crystals of a pale flesh colour, or dull white, which you can with some difficulty scratch with the point of a knife. These are the long white sharp-edged objects shown in the drawing (Fig 2). Another, termed Mica, lies in bright glistening plates which you can easily scratch and split up into thin transparent leaves. If you compare these shining plates with the little silvery spangles in the sandstone you will see that they are the same material. The third, named Quartz, is a very hard, clear, glassy substance on which your knife makes no impression, but which you may recognize as the same material out of which most of the grains of the sandstone are made.

(3.) The crystals in granite do not occur in any definite order, but are scattered at random through the whole of the stone.

27. Here are characters strikingly different from those of the sandstone. You might make out of them such a short definition as this—Granite is a **stone composed of distinct crystals not laid down in layers but irregularly interlaced with each other.**

28. Lastly go through the same process of examination with your piece of Chalk. At first sight this stone seems to have no distinct characters at all. It is a soft, white, crumbling substance, soils your fingers when you touch it, and seems neither to have grains like the sandstone nor crystals like the granite. You will need to use a magnifying glass, or even perhaps a microscope, to see what the real nature of chalk is. Take a fine brush and rub off a little chalk into a glass of clear water; then shake the water gently and let it stand for a while until you see a layer of sediment on the bottom. Pour off the water and place a little of this sediment upon a piece of glass, and look at it under the microscope or magnifying-glass. You will find it to have strongly marked characters, which might be set down thus :—

(1.) The stone, though it seems to the eye much more uniform in its texture than either sandstone or granite, is made up of particles resembling each other in colour and composition, but presenting a variety of forms.

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(2.) It consists of minute shells, pieces of coral, fragments of sponges, and white particles, which are evidently the broken-down remains of shells. In Fig. 3 you see some of these chalk grains as they appear when you place them under a microscope which

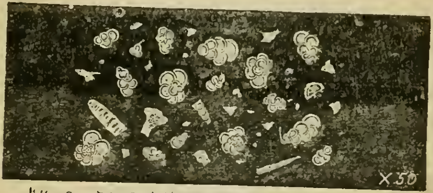

Fig. 3.—Some of the Grains of a piece of Chalk.

magnifies them fifty times. Larger and well-preserved shells, sea-urchins, and remains of other sea-creatures occur imbedded in the chalk. (See Fig. 23.)

29. As a brief description of chalk you might say that it is a **stone formed out of the remains of once-living animals.**

30. You should repeat this kind of examination again and again until you get quite familiar with the characters which have been written down here. And you will see why it is important for you to do so when you come afterwards to find out that these three stones are examples of the three great groups into which most of the rocks of the world may be arranged. So that when you master the composition of a piece of sandstone, or chalk, or granite, and learn how each stone was formed, you not only do that, but lay a foundation of knowledge which will enable you to understand how by far the greater part of the stones of our mountains, valleys, and sea-shores came into existence.

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31. In spite then of the apparently infinite diversity of the stones of which the globe is built up, you see that by a little study they may be grouped into very few classes. You have to follow a simple principle of classification, and each stone you may meet with falls naturally into its own proper group. You do not concern yourselves much with mere outer shape and hue, but try to find out what the stone is made of, and ask whether it should be placed in the Sandstone group, or in the Granite group, or in the Chalk group.

WHAT STONES HAVE TO TELL US.

32. But if you went no further than merely being able to arrange stones under their proper divisions it would be hardly worth your while to study them at all. You would be like people who could put a library into such excellent order that every volume should stand on its proper shelf and compartment, ready for easy reference at any moment, but who should rest content with this mere systematic arrangement and never open any of the books to make themselves acquainted with the contents as well as with the boards. The classification of stones, or flowers, or birds, or fishes, or any other objects in nature, is in itself of no more service than such an arranging of a library, unless you use it in helping you to understand better what is the nature of the things you classify and how they are related to each other.

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33. This habit of classifying what we discover lies at the base of all true science. Without it we could not make progress ; we should always be in a maze, and would never know what to make of each new thing we might find out. We should be like people turned into a great hall and required to educate themselves there, with the floors and galleries strewed all over with piles of books in all languages and on every subject, but utterly and hopelessly in confusion.

34. Let us now try what this habit can do for us among the seemingly endless variety of stones with which the world is stored.

35. We take again our three pieces of stone—sandstone, chalk, and granite—and compare other stones with them. We get out of town to the nearest pit or quarry or ravine, to any opening in fact, either natural or artificial, which will enable us to see down beneath the grass and the soil of the surface. In one place we may find a clay-pit, in another a sandstone-quarry, in another a railway cutting through chalk or limestone, in another a deep ravine in hard rocks with a stream flowing at its bottom. It does not matter for our present purpose what the nature of the opening be, provided it shows us what lies beneath the soil. In all such places we meet with stone of some kind, or of many different kinds. By a little practice we learn that these various sorts of stones may be usually arranged under one or other of the three divisions of which mention was made in last Lesson. For example, a large number of stones will be found answering to the general description which you found to be true of

Sandstone. These will of course be placed together with our piece of sandstone. Another considerable quantity of stones will be met with made up wholly or almost wholly of the remains of plants or of animals. These we arrange in the same division with our piece of chalk. Lastly, a good many stones may be met with built up of crystals of different kinds, and these, for the present, we class together with our piece of granite.

36. In this way you would advance from the mere pieces of stone which you can hold in your hand, up to the masses of stone lying under a whole parish or a county or even the entire kingdom. You would learn that a long range of hills, stretching completely across England from the coasts of Dorsetshire to those of Yorkshire, is formed of chalk, and that other parts of the country lie upon kinds of stone in many respects resembling chalk. You would soon discover that a great part of Britain is made of stone like your piece of sandstone, for example the hills and dales of most of Wales, Lancashire, and the south of Scotland. And if you climbed up to the tops of some of our highest mountains, such as Ben Nevis, you would see them to be built up of solid masses of granite, quite similar to your little specimen, or of other sorts of stones belonging to the same division as granite.

37. You would begin to perceive that the different kinds of stone are not scattered at random over the country, but have each their own places, with their own kinds of hills or valleys.

38. But a little further attention to these matters would bring before you a far more wonderful thing. In

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questioning the stones about how they were made, you would learn by degrees that each of them can give you a more or less distinct answer. In fact they may be compared to books each of which has a little piece of history to tell.

39. You do not grudge to read books of history. You find much interest in following the changes which happened in old times in your country, how battles were fought and laws were made, and old customs gradually passed away. You have no doubt found that the more you know about these events of former times the better do you understand how the laws and customs of the present day came to be what they are.

40. Well, the solid earth under your feet has a history as well as the people who have lived on its surface. Take Britain for example. You will learn that once a great part of this country as well as of Europe and North America was buried under ice like Greenland. Earlier still it had jungles of palms and other tropical plants; yet further back it lay beneath a wide deep ocean; and beyond that time can be traced many still more remote periods, when it was forest-covered land or wide marshy plains, or again buried under the great sea. Step by step you may follow this strange history backwards, and with as much certainty as you trace the doings of Julius Cæsar, or William the Conqueror.

41. Now the records of all these old revolutions of the earth's surface are contained in the stones beneath your feet. In learning what these stones are, how they were made and how they came to be as you now see them, you are really unravelling a part of the

history of the earth. Even the commonest bit of stone has its own part of the story to tell you. If you are sure that it was well worth your while to go through the trouble of learning to read for the sake of all the knowledge which you can gain from books, you will discover, too, that you will be fully repaid for any pains you take in acquiring a knowledge of how to read the meaning of the stones. This earth-history is written in clear and legible language which with a little patience you will easily master. And when you have once acquired it you will not be content with what you can learn from books. It will then be a constant and increasing source of delight to you to get away to the quarries and brooks, and sea-shores and hill-sides, to any place in short where the rocks stick out to the surface, that you may question them and learn what they have to tell about the ancient revolutions of the earth.

42. The object of this little book is to set you in the way of putting such questions to every stone and rock you may meet with. We shall begin with the very simplest lessons and appeal at every step to things which are already familiar to you. In this way you will feel how sure and steady your progress is, and in the end you will be able to carry on the questioning yourselves without much help from book or friend. By watching what takes place from day to day, as in a brook or by the shore of the sea, you will understand the events which have happened in long past times, and be able to decipher among the rocks that wonderful earth-history which it is the business of Geology to study and record.

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SEDIMENTARY ROCKS.

I. What Sediment is.

43. We have now advanced some way in the attempt to understand what stones are. We have learned that they are full of a history of old revolutions of the earth, and that we may find out what this history is, but that in order to make any progress we must arrange into distinct groups the various stones which we mean to study. We have found, too, that they may be divided into three great groups or classes, each having a set of well-marked characters.

44. To each of these groups names must be given. We might call them the Sandstone group, the Chalk group, and the Granite group. But it happens that other names have been already in use, which will be more convenient. Accordingly we shall refer all stones having characters like those of sandstone to the **Sedimentary Rocks**; those formed of the remains of plants or animals, as chalk is, to the **Organic Rocks**; and those having a crystalline character, like our granite group, to the **Igneous Rocks.** The meaning of these names will be seen as we proceed.

45. The word "**rock**" is applied to any kind of natural stone, whatever may be its hardness or softness. In this sense, sand, mud, clay, peat, and coal are rocks, as much as sandstone, limestone, or granite.

46. Now it is evident at the very outset that each of these groups, since it is so well defined from the others, must have a history peculiar to itself, that is, its various kinds of stone or rock must have been formed

differently from those of the other groups, in order to be so unlike them. Let us then take up each of the groups in succession, beginning with the Sedimentary Rocks, that is, with those which have a more or less close resemblance to sandstone.

47. But first we must understand the meaning of this word, **sedimentary**, and why it is applied. We take a glass of water and put some gravel into it. The gravel at once sinks to the bottom and remains there even though we stir the water briskly. We close the mouth of the glass and shake it up and down so as to mix the water and gravel thoroughly together; but as soon as we cease to do so and place the glass on the table again, we see that the gravel has sunk and formed a layer at the bottom. This layer is a **sediment of gravel.**

48. Instead of gravel we put sand into the water and shake them up as before. We mix them so completely that for a moment or two after we cease the water seems quite dirty. But in a few minutes the sand will have all sunk to the bottom as a layer below the water. This layer is a **sediment of sand.**

49. We take a little mud or clay, instead of either the gravel or sand, and shake it up in the water until the two are thoroughly mixed. When the glass is replaced on the table this time the water continues quite dirty. Even after some hours it remains still discoloured, but we see a layer beginning to appear at the bottom. If the glass is allowed to stand long enough undisturbed that layer will go on growing until the water has again become clear. In this case the layer is a **sediment of mud.**

50. Sediment, therefore, is something which after

having been suspended in, or moved along by, water has settled down upon the bottom. The coarser and heavier the sediment the quicker will it sink, while when it is very fine it may remain in suspension in the water for a long time.

51. Sedimentary Rocks must thus be those which have been formed out of sediments. And just as sediments differ from each other in coarseness or fineness, so will the sedimentary rocks formed out of them.

52. Here are pieces of three sedimentary rocks:—

(1.) A piece of **Conglomerate** or pudding-stone (Fig. 4).

(2.) The piece of **Sandstone** you have already looked at (Fig. 1); and

(3.) A piece of **Shale** (Fig. 5).

53. Examine the first of these three specimens. You find it to be made of rounded little stones, firmly cemented together. Were these round stones

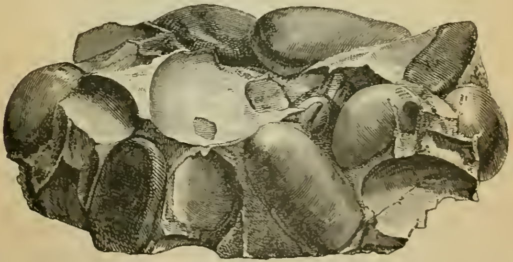

FIG. 4.—Piece of Conglomerate or Pudding-stone.

to be separated from each other, and gathered into a loose heap, you would call it a heap of gravel. The stone is evidently nothing more than a hardened gravel, such as you might pick up on the sea-shore, or in the channel of a stream. It is sometimes called pudding-stone, because the stones lie together somewhat like the fruit in a plum-pudding.

54. Take up the piece of sandstone again, and make a further examination of it. Did you ever see anything like the grains of which it is made up? You reply that they are mere grains of sand such as might be met with anywhere. And you are quite correct. The sandstone consists of nothing else but sand firmly held together so as to form a stone. If you went down to the sea-shore, or to the bed of a brook or river, you could gather sand of very much the same kind, and by hardening such sand into a compact mass, you might make sandstone.

55. In the third specimen you cannot so easily make out what the grains of the stone are, since their size is so small. But take a knife and scrape a little of

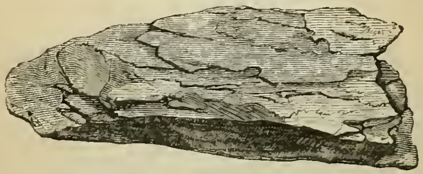

FIG. 5.—Piece of Shale.

the end of the stone and work it up with some drops of water. You will make a kind of paste in this way. Then put this paste into a tumbler of water and stir it well round. Immediately the water gets dirty-looking, and remains so even for some time afterwards. But put the tumbler aside for some hours and

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you will find that the water becomes clear again; that what you put in as a dirty paste has sunk to the bottom of the glass as a layer of sediment, and that it is simply mud. The shale, therefore, is nothing more than a stone formed of fine muddy sediment, just as the conglomerate is formed out of coarse gravelly sediment.

56. Thus you see that the term Sedimentary Rocks is a very expressive one, for it includes stones formed of all kinds of sediment whether coarse or fine.

Look again at any one of our three specimens, and you will understand that we have two things to find out about them. First of all, how was the sediment made out of which they have been formed? and secondly, how did the sediment come to be gathered and hardened into solid stone?

II. How Gravel, Sand, and Mud are made.

57. You have taken the first step in the study of the Sedimentary Rocks,—you now know that they are made of sediment such as gravel, sand, and mud. The next step must be to find out where this sediment came from and how it was formed. If you can settle this matter you will evidently know a good deal more about the history of these rocks. And here, as in all such matters, you will find it well to ask yourselves at the very outset:—Is there anything going on now-a-days which will explain what we are in search of? By starting fresh from the observation of what takes place at the present time, you will be far better able to understand what has been done long ago. How then are gravel, sand, and mud made at the present day?

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58. A little attention will show you that the difference between gravel and sand is only one of degree of coarseness. In gravel the stones are large, in sand they are mere grains. To make this clear, place a little sand under a strong magnifying glass, which will make the grains appear much larger than they really are, so large, indeed, as to give them the look of gravel-stones rather than grains of sand. You can then see that each grain is a worn, rounded stone, sometimes with little chips and hollows on its sides, just like those on the sides of any pebble we may pick out of a heap of gravel. The longer you look at the sand in this way the more sure do you become that, after all, sand and gravel are just different states of the same thing, the one being merely coarser than the other.

59. If you were to search on the shore of the sea, or on the banks of a river, you could, without much difficulty, prove in another way that sand and gravel only differ from each other in the size of their grains. You might gather handfuls of fine sand, then of sand a little coarser in the grain, and so on by degrees until the material became a true gravel, with rounded pieces of stone of all sizes, from mere little pebbles up to blocks as big as your head. How did all these fragments, whether small or large, come to be broken off and ground so round and smooth, and heaped up where we now find them?

60. Let us get away up among the hills, and watch what goes on where the brooks first begin to flow. Where the rocks are hard and tough, they rise out of the hill-sides as prominent crags and cliffs, down which the little streamlets dance from ledge to ledge

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before they unite into larger streams in the bottoms of the valleys. Now look at those crags. See how they are split up and wasted by the rains and frosts. You have learnt already something about how this is done (Physical Geography Primer, Arts. 126—142). But you have now to consider some of the results of the waste.

61. Suppose, for the sake of distinctness, that we single out one special crag where the rock is of some bright colour, say red, and differs in that respect from the rest of the crags round about it. It rises out boldly from a steep hill-side, and looks down a long slope to the little stream which in the distance seems a thread of silver winding through the green meadows far below us. Our crag has been sorely wasted in the long course of time. The rains and frosts of many centuries have carved its sides into deep clefts and gullies (Physical Geography Primer, Art. 142). These, when wet weather sets in, become each the channel of a foaming torrent, which pours headlong down the slope and sweeps away every loose bit of stone or earth within its reach.

62. We climb cautiously along the face of the crag to look into some of these frost-splintered, torrent-swept gullies, and then we descend to the base. All the slope below is strewn with pieces of the crag. Some of these are huge blocks, but most of the material forms a kind of mere rough rubbish, which slides down the slope with us as we descend with long strides to the bottom.

63. Each of the deep clefts which have been scooped out of the crag has a long slope of this kind of rubbish lying below it. You cannot for a moment doubt that

all this broken-up material on the slope actually formed at one time part of the crag itself, that in fact it is simply the material which has been removed by the slow wasting away of the sides and bottoms of the clefts, and that if you could gather it all up again so as to put it back where it formerly stood you would really fill the clefts up.

64. The slope leads us down to a little brook, the bed of which is strewn with pieces from our crag. Now let us descend the brook and look at its channel carefully as we go. The red fragments from that crag will be easily distinguishable from the other dull grey stones, which have been detached from the rest of the crags on either side. If you look narrowly at the bits of stone which are strewed about upon the slope you will notice that they are all more or less angular in shape, that is to say, they have sharp edges. But those in the brook are not quite so rough nor so sharp-edged as those on the bare hill-side above. Follow the brook down the valley for some way and then take another look at the stones in the bed of the stream. You do not now find so many big blocks of the red stone, and those you do meet with are more rounded and worn than they were near the crag. They have grown smooth and polished, their edges have been worn off, and many of them are well rounded. Once more you make a further examination still lower down the valley, and here and there where the stream has thrown up a bank of gravel, you find that the pieces of our red crag have been so well ground away that they now form part of an ordinary water-worn gravel.

65. In the same way by descending the stream still

further you could trace the gravel becoming finer and passing at last into sand. And if you were to place some of this sand under a magnifying glass you would find it partly made up of more or less rounded grains of the same red stone which you detected in the gravel, and which you knew to have come from our crag far up in the hills.

66. Now how is it that the stones get worn down in this way? Why should lying in the bottom of a stream make them smaller?

67. If you watch the stream only in fine weather, when the water is low and the current feeble, you can hardly judge as to the real power of the water. Come back when heavy rains have filled every gully in the hills with a foaming torrent, and when every streamlet rushes headlong down its valley, filling its bed to the brim and even rising high on either side. You cannot now see the stones on the bottom of the channel, but listen and you can hear them. That sharp rattle which every now and then comes out of the water is caused by the stones thumping against each other, as they are hurried along by the rushing water. They are kept grinding against each other as in a mill. Of course, they must needs have their edges worn off, and their sides smoothed, while at the same time they smooth and polish the rocks of the channel over which they are driven.

68. When the stones first fall or are swept from the hill-side into the brook, they are, as you saw, mere angular chips (Fig. 6). But by the time they have travelled down the brook a little way, and have suffered from the grinding of a few floods, they lose their sharpness. The smoothing and polishing process goes

on till they become more or less rounded, and at last appear as well-worn gravel (Fig. 7). A rounded stone will travel farther and faster than an angular one, but in the end gets worn down into mere sand (Fig. 8).

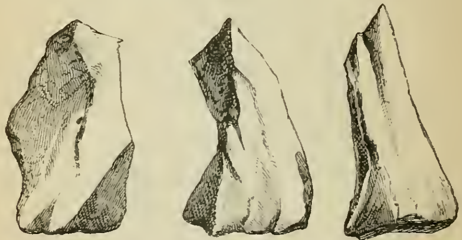

FIG. 6.—Stones detached from a cliff by rains, frosts, &c., and launched into a brook.

69. Thus we see that as the stones grow rounder they at the same time become smaller. And not only do they wear away each other, they also grind out the sides and bottom of the channel of the brook.

FIG. 7.—Stones from same cliff after having been rolled about in the bed of the brook.

A good deal of stone must be consequently rubbed down (see Physical Geography Primer, Art. 175). Now it is this worn material which makes gravel, sand, and mud. In the bed of every stream you will never fail to find plenty of this worn material, derived from the rubbing away of stones by water.

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70. The finer particles, being more easily moved, travel much farther than the coarser fragments. Hence, while the gravel and coarse sand are pushed

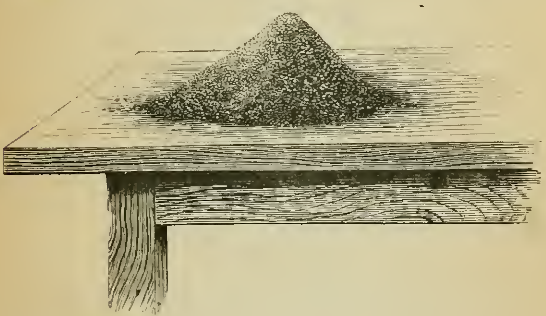

FIG. 8.—A small heap of sand consisting of pieces of stone from the same cliff which have been still further worn away in the bed of the brook.

along the bottom, the fine sand and mud are suspended in the moving water and may be carried by it for many miles before they slowly sink to the

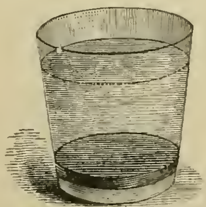

FIG. 9.—A glass of water taken from the same brook when in flood, to show how the finer particles worn from the same stones settle down on the bottom as a layer of mud.

bottom to form there a deposit of silt or clay (Fig. 9). Digitized by Microsoft ®

71. You will see from this, that while the brooks in

the higher parts of a country may have their channels encumbered with big blocks of rock, and quantities of coarse, sharp, angular rock-rubbish, all this material is worn down by degrees, and reaches the lowlands or the sea only as fine sand and mud. As the brooks are always flowing, so are they always transporting the worn materials of the hills. But as fast as they do so, the hills are crumbling down and supplying fresh materials to the brooks. So that the amount of gravel and sand ground up every year even by the comparatively small streams of this country must be enormously great. (See Physical Geography Primer, Arts. 170—182.)

72. We can now return to our crag of red rock with freshened interest. Every cleft and gully which has been worn into its sides, bears witness to the general crumbling which the surface of the land undergoes. We may follow its ruined blocks and rubbish into the brook below, watch how they are ground down there, and trace them onwards until in the form of fine silt and mud their remains find their way at last into the far distant plains and thence to the bottom of the great sea.

73. But it is not only in the beds of brooks and rivers that you can watch how the hardest rocks are ground away into gravel and sand. Look at any of the rocky parts of the coast line of this country and there mark the effects of the waves of the sea. If a cliff rises from the upper edge of the beach, you can at once tell which parts are exposed to, and which lie beyond the reach of the waves. Overhead the cliff is rough and splintered where merely rain, frost, or springs have acted on it (see Physical

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Geography Primer, Arts. 137, 138). But towards its base the rocks have been ground smooth and polished like those in the bed of a mountain-brook. What has smoothed the bottom of the cliff and left all the higher parts rough and crumbling? The waves have done it.

74. Huge slices of the weather-roughened cliff have been detached and have fallen down on the beach below. Others are ready to tumble off. Examine the fallen blocks and you will see that usually only those lying at the base of the cliff, and which have not yet been moved by the waves, have still their sharp edges. A little lower down the blocks show signs of having been ground together, while the greater part of the beach is strewn with stones of all sizes, well rounded and polished.

75. On a calm day when only little wavelets curl on the shore you cannot easily judge what the sea really does in the way of grinding down the beach and the bottom of the cliffs, just as you could not form a proper notion of the work of a brook merely by seeing it lazily creeping along its bed in a season of drought. But place yourselves near a cliff during a storm, and you will not need any further explanation as to the power of the waves to grind down even the hardest rocks. Each huge breaker as it comes tossing and foaming up the beach lifts up the stones lying there and dashes them against the base of the cliff where it bursts into spray. As the green seething water rushes back again to make way for the next wave, you can hear, even perhaps miles away, the harsh roar of the gravel as the stones grate and grind on each other while they are dragged down the

beach, only to be anew caught up and swept once more towards the base of the cliff. You could not conceive of a more powerful mill for pounding down rocks and converting their fragments into well-worn gravel and sand (Physical Geography Primer, Arts. 230—232). Just as in the channel of every stream so along the shores of every sea you meet with the fragments of the rocks of the land in all stages of destruction, from the big angular block down to the finest sand and mud.

76. If, therefore, I now repeat the question, "How are Sand and Gravel made ?" you will at once answer —"Sand and Gravel are part of the material worn away from the surface of the land, and ground down in moving water." Materials which have been rubbed smooth in this way are said to be "water-worn." But you will now see that it is not the water which of itself wears them away. They are in fact worn away by themselves, and all that the water does is to keep them moving and grinding against each other.

III. How Gravel, Sand, and Mud become Sedimentary Rocks.

77. We have now got so far on our way as to understand whence the materials of which sedimentary rocks are made were derived. But the further question remains, how have these materials been gathered together and hardened into solid stone? As before, we must find the answer to such questions in what we can see going on around us. By turning back again to the brooks, rivers, and sea, we shall get this next matter very clearly explained.

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78. Water flows more quickly down a steep slope than over a gentle one. You know that when you raise one end of a tray, water poured on it runs down to the lower end, and does so the faster the steeper you make the inclination.

79. If you put crumbs or pebbles of different sizes on the tray you will notice that they are swept down more by the rapid than by the slower flow of water. A quickly flowing current of water is more powerful to move anything than one which flows slowly. Hence, as you will at once see, there must be great differences in the size and weight of materials which different streams or different parts of the same stream can move.

80. So long as a current of water is moving swiftly it keeps the gravel, sand, and mud from settling down on the bottom. You remember that when you put some of each of these materials into glasses, and kept the water in rapid motion, they continued suspended in the water, and only sank to the bottom as the water began to lose its motion, the gravel first, then the sand, and last of all the mud (Arts. 47—49). Now this is just what takes place in all the moving waters of the globe. A rapid current will hurry along, not only mud and sand, but even gravel. As its rapidity flags, first the gravel will sink to the bottom as a sediment, the sand will sink more slowly and be carried further, while the mud will hang in the water for a long time, travel a much greater distance, and only fall with extreme slowness to the bottom.

81. You must test the truth of these statements the first time you have an opportunity of looking into the rocky channel of a brook as it escapes from the hills.

Get to some part where the water, shooting swiftly over ledges and rocks, has strength enough to sweep even big blocks of stone along with it. A little way further down you will find the channel less steep and the current less strong. Now look into the bottom of the stream. Is it covered with fine mud? Assuredly not. You meet only with big blocks of stone and coarse gravel. These have been dropped as soon as the water had its force checked by coming from a steep to a more level part of its course. But it still had power enough to transport the finer sorts of sediment. You need to go further down towards the low grounds before you see the bed of the stream covered with sand, and much further yet, even far into the plains, before you meet with layers of mud.

82. After seeing these things with your own eyes, you would be convinced that wherever you find masses of gravel they tell you of strong currents of water, that beds of sand point to less rapid currents, while sheets of mud show where the water has had either a very gentle motion or has been quite still so as to let the fine sediment settle down quietly on the bottom.

83. Now see how important this knowledge becomes when you begin to inquire how different stones were made. If you have ascertained clearly how various kinds of sediment are formed, you have got a long way towards understanding how Sedimentary Rocks came to be made. These rocks may be hard stone now, and may be used for paving streets or building houses. But you have learnt that mere hardness or softness goes for little, and that it is the materials of which the stone consists that you have to consider.

When you find these materials to be water-worn grains of mud, sand, or gravel, you confidently assert that no matter how hard the stone may be now, it was once in the state of mere loose sediment under water.

84. But you can tell more than this. By seeing the kind of sediment of which a rock is made up you know something about the nature of the water in which the materials of the rock were laid down. For instance, you recognize a rock of conglomerate to be only a mass of compact gravel, and you are sure that like ordinary gravel now-a-days it was rolled about in shallow water such as the bed of a lake or river or on the shore of the sea. Again, you see in a rock formed of fine mud, such as shale, proofs of deeper or stiller water into which only the finer particles worn away from the land were carried.

85. We have watched how the sediments are ground down by brooks, rivers, and waves; let us now follow them until they are gathered into places where they can accumulate without being constantly washed away.

86. Some account has already been given (Physical Geography Primer, Arts. 147 and 182) of what becomes of the materials worn away from the surface of the land. You have learned how they are washed down by rains into brooks and rivers, how they are there ground down, and how finally they are borne as fine sand and mud away out to the bottom of the sea.

87. Now these deposits of sediment over the sea bottom will by-and-by become hard sheets of stone, like the common sedimentary rocks we have been dealing with in these lessons. You cannot see what goes on under the sea, but you can form some notion

of it by watching what takes place in pools of water on the land.

88. Let us suppose that we know a muddy street or road which slopes down gently to a more level part, and that in wet weather the rain gathers in pools at the bottom of the slope. We choose a wet day, and after following the course of one of the gutters down the slope and noticing how the muddy water sweeps along sand, gravel, bits of cork, stick, paper, and whatever lies in its way, we halt at a large pool which has gathered on the road, and into which the current of muddy water is discharging itself. So long as the water flows quickly downward it sweeps away gravel and sand. But see what happens when it begins to flow more slowly over the flat at the bottom and enters the pool. By losing speed it loses carrying power, and must needs drop some of its burden of sediment. The heaviest particles fall to the bottom first, and this takes place just where the current is checked by meeting the level water of the pool. Now mark the result. That part of the pool where the current enters is gradually filled up, except the channel which the current keeps open for itself. You can see how this tongue of sediment is advancing upon the water, and that it will in the end, should the rain last long enough, fill the pool up entirely. It is only the coarse sand which collects there; the fine mud goes across the pool, and though part of it, as you will find, settles down on the bottom, much or most of it escapes at the further end of the pool, because the water has not had time, in its passage from the one side to the other, to drop its burden of mud.

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89. Let us suppose further that when the rain has ceased, no cart-wheel or other intruder comes to disturb our pool, but that the water is suffered quietly to soak into the ground and to evaporate, so that in a day or two the hollow is laid dry. You can now examine the bottom of the pool and see exactly what took place when the muddy water filled it. Here at the upper end is the tongue of sand pushed out from the shore by the streamlet. You recognize it as a true Delta (Physical Geography Primer, Art. 181). The bottom of the rest of the pool is covered with fine muddy silt or sand spread out over all the space on which the water lay.

90. With a knife we carefully cut a hole or trench through these deposits on the floor so as to learn what they consist of from top to bottom. A cutting of this kind is called a **Section**, and may be of any size. The steep side of a brook, the wall of a ravine, the side of a quarry or railway-cutting, a line of cliff, are all sections of the rocks. Let us see what our section has to tell.

91. In the centre of the little basin the sediment brought in by the rain has accumulated to a depth, let us say, of an inch, below which lies the ordinary surface of the roadway. Now what feature strikes you first about this deposit of sediment when you come to look at the section which we have cut through it? Are the materials arranged without any order? By no means. If you made a drawing of the section it might be something like the following woodcut (Fig. 10). The materials have been deposited in layers which have been laid down flat one above another. Some of these layers are finer, others coarser than

the rest. But whether coarse or fine they all show the same general arrangement in level lines.

92. In looking at these layers you can follow exactly how each of them was deposited. The coarse sediment is seen chiefly at the bottom, and marks where the stronger currents carried sand and bits of stone across the pool. But as the rain slackened, the runnels on the roadway grew less and the currents in the pool became feebler. Hence, instead of coarse sand, only fine silt was deposited, so that in the

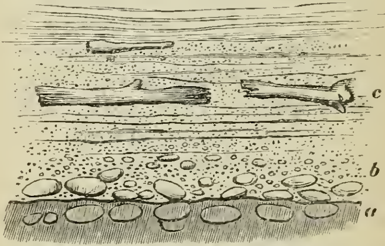

FIG. 10.—Section or cutting through the sediment brought by rain into a pool on a roadway. *a*. Surface of roadway. *b*. Layers of coarse sand with bits of coal and ash. *c*. Layer containing twigs, bits of straw, leaves, paper, &c.

upper half, the layers are finer than they are in the lower. Together with the sand, gravel and mud, you may notice chips of wood, leaves and twigs (*c* in Fig. 10) which have been laid down among the layers of sediment.

93. You may think perhaps that observations such as these are too trifling, and that surely it cannot matter what rain may do in a little pool on a roadway, since we are not to judge of the world at large by what goes on upon so small a scale. In reality, however,

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if you thoroughly understand what takes place over the bottom of such a pool, insignificant though it may seem, you lay a foundation from which it will be easy for you to understand how sedimentary rocks are and have been formed all over the world.

94. Instead of the pool imagine to yourselves a great lake such as that of Geneva, and in place of the mere tiny runnel on the road, formed by the sudden rain, and disappearing when the rain ceases, picture a great river like the Rhone, ever fed by the rains and snows and springs of a huge mountain chain. And yet though you make the scale on which the work goes on greater, the kind of work remains the same as in the pool. You look with wonderment on the river rushing so swiftly past, and tossing its muddy waters into wave and foam, from bank to bank. You watch it enter the lake, and mark how the waves one by one sink down, and how the river loses itself and its tumult in the quiet silent water of the deep blue lake.

95. But climb one of the mountains which rise steeply from either side of the upper end of the Lake of Geneva. When you get up a few hundred feet, turn and look down upon the river and lake, and see if they do not strongly remind you of our runnel and pool on the road. The bottom of the valley lies spread out as in a map before you. The windings of the river, the flat green meadows on either side running as a long tongue into the lake, the little cottages and hamlets, and the lines of road—all so dwindled down in the distance that you can see at a glance how they lie. That green tongue of meadows filling up the upper end of the lake and stealing along each side

of the river is the Delta. It has been formed in the same kind of way as the little delta in our pool, only instead of hours it has needed thousands of years for its formation. About a mile and a half from the edge of the lake, a little hamlet, standing among the level fields, was actually at the margin of the water some eighteen hundred years ago, and is still called Port Vallais. The river has thus pushed out its delta and filled up the lake for a mile and a half since Roman times.

96. From the high ground overlooking the head of the lake you can see moreover another curious fact about the way in which the sediment gathers over the bottom. The Rhone is very muddy, and as the mud has a white colour here, the milky look which it gives to the water enables you to follow the course of the river into the clear blue lake. Looking down upon it from the heights you can trace the pale muddy current for some way out from the shore until it gradually gets mixed with the lake-water and disappears.

97. Go now to the lower end of the lake, and watch where the water escapes. Do you see any mud now? No, your eyes never looked on clearer, brighter, bluer, water than that which comes rushing and leaping between the banks and beneath the bridges of Geneva. What has come of that cloud of pale mud which you saw carried by the river into the upper end? It has all settled down upon the bottom. Day by day, year by year, and century after century, the cloud of mud is there, always sinking through the water to the bottom, and always renewed by the restless river.

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98. Could you drain off all the water of the lake you would find the floor covered with deposits of sediment stretching, not over a few square feet, as in our little wayside pool, but over many square miles. The coarser sediments—shingles and gravels—would be met with at the upper end where the strong current flowed, while the finer sediments—sand and mud—would cover the main part of the bottom.

99. If you were to bore through these deposits, you would find them in some places to be perhaps more than a hundred feet thick, and digging down anywhere among them you would see the same arrangement into flat layers which you observed in the rain-pool. Sand, mud, and gravel might follow each other from top to bottom, but always in beds or layers lying one above another.

100. The Lake of Geneva is many thousand times larger than our little pool; and yet it is itself only a pool, and a very small one, when compared with the great sea. Go to the margin of the sea where a large river enters, and you will see that mere size does not alter the kind of work which the river and the sea are doing, and that in their case too you have the same process to study which you have watched already. You perceive how the river is continually carrying vast quantities of sand and mud into the sea. You can follow the muddy river-water to a distance from the shore until, as its mud slowly sinks to the bottom, it loses itself in the waters of the ocean. You know that by this means the bottom of the sea for a long way from the coast is constantly receiving fresh deposits of sand and mud which have been washed off the land. The upper edge of these deposits is un-

covered when the tide goes out. You can dig into them where they form the beach, and when you do so you recognize the same arrangement into layers as you found to be the case elsewhere.

101. In this way you gradually would come to be convinced that one grand leading feature of the sedimentary deposits laid down under water is that they

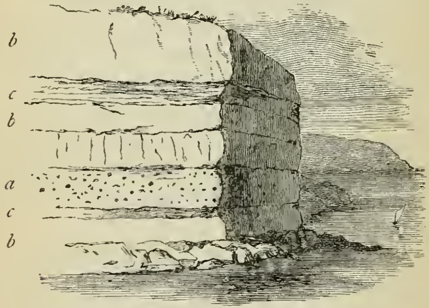

FIG. 11.—Stratification of Sedimentary Rocks. *a*. Conglomerate. *b*. Sandstone. *c*. Shale.

are not mere random heaps of rubbish, but that they are assorted and spread over each other in regular layers. This kind of arrangement is called **Stratification**, and the sediments so arranged are said to be **stratified**. So characteristic is this mode of arrangement among the sedimentary rocks that they are often called also the **Stratified Rocks**.

102. The sheets of sand, gravel, or mud which can be seen on the sea-shore, or at any lake or pool on land, are **soft** or **loose** materials. Sandstone, conglomerate, shale, or any other sedimentary rock, is usually more or less **hard** or **compact**.

How is this difference to be accounted for? You are quite sure that, in spite of their firmness, these rocks were once mere loose sediment formed under water in the same way as sediment is made everywhere at the present day. But what has turned them into hard stone?

103. If you take a quantity of mud, and place it under a weight which will squeeze the water out of it, you will find that it gets firmer. You can thus harden it by **pressure.** Again, if you place some sand under water which has been saturated with lime (that is, the material of which chalk and limestone are made) or with iron, or with some other mineral which can be dissolved in water, you will notice that as the water slowly evaporates it deposits its dissolved material round the grains of sand and binds them together. Were you to continue this process long enough, adding more of the same kind of water as evaporation went on, you would convert the loose sand into a solid stone. In this case the hardening of the sediment into stone would be done by the process called **infiltration.**

104. In one or other or both of these ways most of the sedimentary rocks have been hardened into the state in which we now find them. When sand and mud are piled up over each other in wide sheets or layers, to a depth of hundreds or thousands of feet, the layers at the bottom, lying under such an enormous weight, must be squeezed into a much firmer condition than those at the top. But besides this, water is always filtering through pores and cracks of the rocks, sometimes removing, sometimes depositing, mineral matter (in the way explained in the Physical Geo-

graphy Primer, Arts. 117—125), and helping to cement the grains of many rocks more firmly to each other.

105. If I were now to ask you what an ordinary sedimentary rock is, you would readily give me, and clearly understand, such a definition as this—"A sedimentary rock is one formed from sediment which was derived from the waste of older rocks, and deposited in water. It usually shows the stratified arrangement characteristic of water-formed deposits. Since its original formation it has usually been hardened into stone by pressure or infiltration."

IV. How the Remains of Plants and Animals come to be found in Sedimentary Rocks.

106. Although sedimentary rocks consist of such materials as gravel, sand, or mud, they often contain other things quite as interesting and important. For example, here are two additional pieces of Shale (Figs. 12 and 13), in which you will see certain objects very different from the ordinary sediment of which the stone is made. Let us first satisfy ourselves as to what these objects are, and then as to how they came to be imbedded in the stone.

107. We begin with the specimen which is drawn in Fig. 12. In the stone itself you would recognize merely a fragment of common shale, formed of the same materials, and arranged in the same stratified way as in your former specimen of that rock.

108. But what is this black object lying on the upper surface of the stone? You see at once that it has the

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form of a plant and resembles some of the fern tribe. Examine it more closely, and, tracing the delicate veining of the fronds, you cannot doubt that, although no longer soft and green, it was once a living fern. It has been changed into a black substance which,

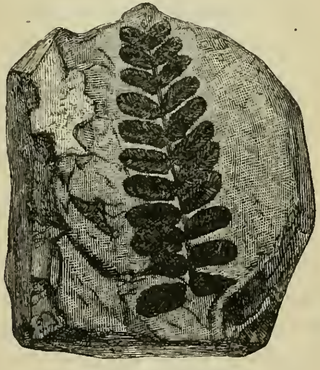

FIG. 12.—Piece of Shale containing portion of a fossil fern.

when you look carefully at it, proves to be a kind of coal. Little fragments and layers of the same black coaly substance may occur throughout the piece of shale. If you scrape a little off and put it upon the point of a knife, you find you can burn away the black material while the grains of sand or clay remain behind. These fragments and layers are evidently only leaves and bits of different plants imbedded at the same time as the larger and better preserved fern. Now how did plants find their way into the heart of a piece of stone?

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109. To understand how this happened we must

again go back to what nature is doing at the present time. You remember that when you were watching the runnel coursing down the sloping roadway (Art. 88), you noticed that it sometimes swept along bits of straw, wood, paper, or other loose objects which it managed to reach. Some of these floated away into the nearest drain and were soon lost sight of. But others sank to the bottom of our little pool. Look again at the section we cut open there (Fig. 10), and you will find little chips of wood or straw or leaves and blades of grass among the fine sand and mud left by the rain. These objects lie flat between the thin layers of sediment. And if you think of it you will understand how that should be the position they would naturally take as they sank to the bottom. Rain therefore can wash away leaves and other pieces of plants, and allow them to drop in a pool, where they become **interstratified** with the silt, that is, are deposited between its layers and covered over by it.

110. Again : watch what takes place along the banks or at the mouth of a river, and you will soon observe that the leaves, branches, and other floating objects carried down by the current in the end sink to the bottom, there to be imbedded in and gradually covered up by the growing accumulation of sand and mud. If you dig into any of the deposits along the banks you meet sometimes with layers of leaves and twigs, grouped in the same stratified way as the sediment above and below them. Such deposits of drifted vegetation often form a conspicuous part of the accumulations of which the delta of a river consists. (Physical Geography Primer, Art. 180.)

111. But it must happen continually that before the

leaves or branches or the trunks of trees have become so saturated or water-logged as to sink to the bottom they are borne onward into the sea. In such cases they may float a long way from shore ere they fall to the bottom and become buried in the silt and sand there. Hence, whether in the beds of rivers, or at the bottom of lakes or of the sea, the remains of land plants must be constantly dropping among the sedimentary deposits which are gathering there.

112. You can now see therefore how it is that pieces of ferns or any other kind of land plants should be found in the heart of such a solid stone as our bit of shale. The stone was once merely so much sediment laid down below water, and the fragmentary plants were drifted away from the place where they grew until at last they were buried among that sediment. As the mud hardened into shale the plant became more and more altered until its substance passed into coal. You will find in a later lesson that coal was formerly vegetation which, buried under great masses of sediment, has been slowly changed into the black glossy substance so familiar to us.

113. It is not only plants, however, which occur imbedded in sedimentary rocks. Here for example (Fig. 13) is a drawing of a piece of shale in which you notice a number of shells and other animal remains, chiefly *trilobites*, that is, little sea-creatures belonging to the same great tribe with our common crab and lobster. You do not need now to be told how they came there. You have learnt that anything lying at the bottom of the sea or of a lake will be buried in sediment. The remains of shells, corals, fishes, or any other animals which live in the water,

must gather on the bottom when these animals die, and become imbedded in the silt or other deposit which is there forming. It was clearly in this way

FIG. 13.—Piece of Shale with animal remains.

that the shells and corals in our piece of shale were preserved.

114. Did you ever look into the little pools of sea-water left upon a rocky beach when the tide has gone back? How full of life they are! Tufts of sea-weed sprout up in one place, groups of brightly tinted sea-anemones appear in another, periwinkles and limpets cling to the sides, and down at the bottom you may see tiny crabs cautiously creeping out of your sight, with many other kinds of sea-creatures moving to and fro of which you do not know the names. If you look a little more narrowly you can observe that some of the shells at the bottom are empty, the animals which once lived in them having died, and that broken pieces of other dead creatures lie there also.

115. You are not to suppose of course that the whole

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of the bottom of the sea is like the bottom of one of these pools on the beach. The plants and animals in the pools are those which live along the shore or shallow parts of the sea, while the deeper parts have other plants and animals peculiar to them. But although these living things differ greatly in different portions of the ocean floor, and though here and there they may be absent from bare patches of gravel, stones or sand, the floor of the great sea resembles the floor of the little pool on the beach in this respect that it swarms with many kinds of living creatures, and with the remains of dead ones. So that the deposits of sand and mud which gather upon the sea-bottom must contain abundant relics of these creatures.

116. If then the remains of plants and of animals are very generally buried in the accumulations of sediment which now increase from day to day at the bottom of lakes or of the sea, we may be sure that the same must have been the case in past times, and that sedimentary rocks, which are only so much hardened sediment of the bottom of old lakes or seas, should also contain remains of plants and animals. And so they do abundantly—you will meet with sandstones, shales, and other sedimentary rocks, as full of such remains as any part of the modern sea-bottom is now crowded with life.

117. Any relic of a plant or animal imbedded in rock is called a **Fossil.** The fern in Fig. 12 for example, and the shells and trilobites in Fig. 13 are fossils. Some of the questions which fossils enable us to answer will be pointed out in the next Lesson.

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V. A Quarry and its Lessons.

118. In the foregoing lessons you have learnt what sediment is, how different kinds of sediment, arranged under water, have become sedimentary rocks, and how they may contain the remains of plants or animals. Let us now try to put some questions to these rocks, and see how they tell their own story.

119. If you go into the quarries which abound in many parts of this country you may learn a great deal on this subject. Let us suppose ourselves to be in such an one as that represented in Fig. 14.

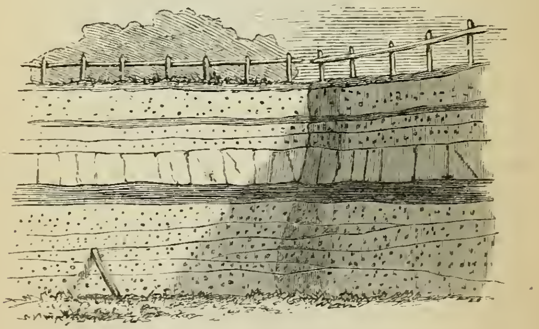

FIG. 14.—Quarry in Sedimentary Rocks.

120. In the first place what feature about the quarry strikes you most forcibly when you enter? You answer readily, the **Stratification** of the rocks. They are arranged in layers or beds, one above another, in that stratified arrangement which you have found to be so characteristic of rocks laid down as sediment under water. (Arts. 90—101.)

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121. In the second place, you observe that they do not all consist of the same materials. Some are of fine conglomerate (marked with little circles and dots in the drawing), others of various kinds of sandstone (marked with finer dots), and some of different sorts of shales or clays (marked with horizontal lines). These **beds**, or **strata** as they are called, alternate irregularly with each other, just as gravel, sand, and mud might be found alternating in the delta of a river or under the sea.

122. In the third place, let me ask you to point out which are the oldest of the beds. You answer without hesitation that those at the bottom of the quarry must be the oldest because they certainly were deposited before those lying above them. The lowest bed may be of exactly the same materials and thickness as one or more of the others, and may so precisely resemble them that you might not be able to see any difference between them if you looked at them each by itself. Yet their occurrence one above another would prove them not to be the same bed, but to have been formed at different times one after the other. In all such cases the beds at the bottom are the oldest, and those at the top the newest. This arrangement of one bed or stratum above another is called the **Order of Superposition.**

123. In such a quarry as that drawn in the woodcut, this order is no doubt very simple and self-evident, but you will learn afterwards that it is not usually so clear, for in many cases the rocks are concealed from you in part by soil or otherwise, and much care and patience may be needed before their true order of superposition is ascertained. But when, in spite of all difficulties,

you succeed in showing which are the bottom rocks and which the uppermost, you at the same time determine which are oldest and which newest.

124. In the fourth place, let us see if the rocks of this quarry have preserved any evidence as to where they were deposited. We split open some of the lower beds of sandstone and find that their surfaces are often covered with such markings as are shown in the following drawing (Fig. 15). Did you ever see anything

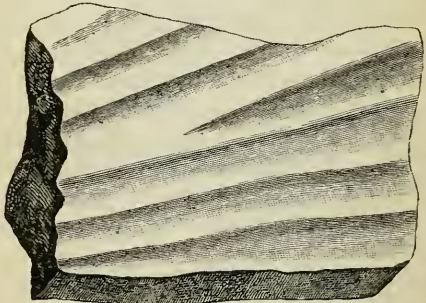

FIG. 15.—Ripple-marks in Sandstone.

resembling these impressions elsewhere? If you have ever walked along a flat sandy beach you must have noticed the ripple-marks which the shallow rippling water leaves on the soft sand. They are precisely like those on the sandstone. You may see them too along the shelving margin of a lake, indeed wherever water has been thrown by the wind into little wavelets over a sandy bottom. They betoken shallow water. Hence we have learnt one important fact from our quarry, as to the origin of these rocks: viz. that they were not deposited in a deep sea, but in shallow water.

125. We look still further among these strata, and notice at last that some of them are curiously covered with little round pits, about the size of peas or less. The general appearance of these pitted surfaces is shown in Fig. 16. How did these markings come there? Like the ripple-marks they must of course have been impressed upon the sand when it was soft, and before it had been hardened into sandstone. Again, you must seek for an explanation of them by watching what takes place at the present time. You know that when drops of rain fall upon a smooth surface

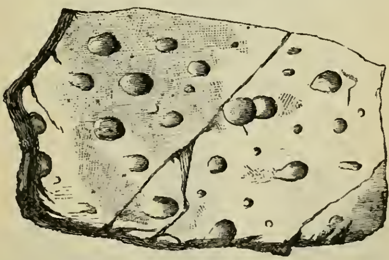

FIG. 16.—Rain-prints on Sandstone.

of moist sand, such as that of a beach, they each make a little dent on it. You have learnt something about these rain-prints, and if you compare the present drawing with the picture of the rain-prints in the Physical Geography Primer, Fig. 9, you will see that they are essentially the same, and that they have both been made by the fall of rain-drops upon soft moist sand.

126. Here then is another fact which throws still more light on the history of these rocks. The ripple-marks show that the water must have been shallow; the

rain-prints prove that it must have risen along a beach liable, now and then, to be laid dry to the air and rain. Now can we tell whether the water was salt or fresh? in other words, was this beach the shore of a lake, or of the sea?

127. Again we turn to the rocks themselves, and from some of the layers of shale we pick out a number of **fossils**, which enable us to answer the question. If you were to fish in a lake, would you catch only the same fish which you find in the sea? Certainly not; you would soon learn that not only the fishes but the other animals and the plants living in fresh water, differ from those living in salt water. Star-fishes, limpets, oysters, and flounders, for example, are inhabitants of the sea, while your old friends the perch, the minnow, and the stickleback are natives of rivers

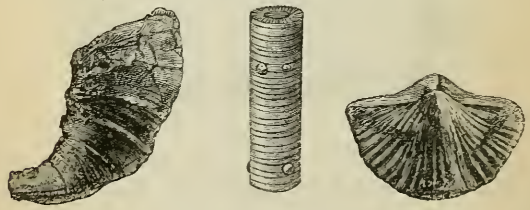

FIG. 17.—Fossils. *a*, Coral; *b*, part of Encrinite; *c*, *Spirifer*, a marine shell.

and lakes. You can understand, therefore, that the remains of animals and plants preserved in the deposits of the sea-bottom must differ from those preserved on the bottoms of lakes.

128. Some of the fossils which we have picked out are represented in the woodcut (Fig. 17). Of these

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a is a coral; *b* is part of the jointed stem of the Encrinite or stone-lily—an animal related to the common star-fish; and *c* is a shell belonging to a family the members of which are all dwellers in the sea. Now these are all unmistakably marine animals, and when we find them associated in this way in a bed of stone, we feel certain that the materials of the stone must have been laid down under the sea; they were possibly cast ashore on the old sea beach, as shells are to this day.

129. Here, again, is a third fact about the history of our rocks. The ripple-marks and rain-prints made it certain that they were formed in the shallow water close to shore, and along a beach; and now the fossils prove that those waters were part of the great sea.

130. In this quarry then you have found clear proofs that land and sea have here changed places. Though the quarry may be in the very heart of the country, far away from the sea, yet you cannot be more sure of anything than that the sea was once upon its site. But if you search among other quarries you will find the same kinds of proofs of the former presence of the sea. In fact, were you to start from the south of England, and go north to the far end of Scotland, by much the largest number of quarries you would meet with would be in rocks which were originally formed under the sea. In such a journey you would learn that almost the whole of our country is made up of such rocks. Down at the bottom of deep mines, and away up at the summits of high mountains, you would come upon them. Nor is Great Britain singular in this respect. Suppose you

were to cross Europe and look carefully at all the rocks on your way, you would still find the sea-formed ones to be the great majority. From Europe into Asia, and from Asia through Africa on the one hand, down the whole length of America on the other, you would encounter far more rocks which had been formed under the sea, than of any other kind. The very highest mountains in the world consist of sea-made rocks.

131. Now is this not a very singular fact? How is it that the solid land has been chiefly made under the sea? The rocks must have been raised up out of the sea by some means, and since the land is so uneven they would seem to have been raised much more in some places than in others. How this raising of the sea-bed has taken place, will be spoken of in a later lesson. But first we must trace the history of certain other rocks, many of which have also been formed under the sea.

ORGANIC ROCKS, OR ROCKS FORMED OF THE REMAINS OF PLANTS AND ANIMALS.

I. Rocks formed of the Remains of Plants.

132. Since the leaves, branches, and stems of plants, and the shells or other remains of animals, are sometimes scattered so abundantly through ordinary sedimentary rocks, it is easy to see that sometimes they may occur in such quantity as to form great deposits of themselves. You could hardly call such deposits sedimentary, in the same sense in which common shale and sandstone are so named. We may term them **Organic Rocks**, or, **Organically derived**

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Rocks, because they owe their origin to the accumulation of what are called **organic remains**, or fossils, that is, the remains of plants or animals. A plant or animal lives, moves, and grows by means of what are called **organs**. For instance, we walk by using our legs, which are our *organs of locomotion;* we speak with our mouth, which contains our *organs of speech;* we see by means of eyes, which are our *organs of sight;* and so on. Every object, therefore, which possesses ogans is said to be organized or to be an **organism**. So that when you see this word organism you will remember that it means either a plant or an animal, for it is only plants and animals which are really organized.

133. We begin with those rocks which have been formed out of the remains of plants. As an illustration let me ask you to examine carefully a **piece of coal**. If you master all that it has to tell you, you will not have much difficulty in tracing out the history of other rocks belonging to this series.

134. You know well the general appearance of coal. Did you ever notice that though brought to the fireplace in rough, irregular lumps, it has nevertheless an arrangement in layers like the sedimentary rocks? Try to break a big solid piece of coal, and you find that it usually splits more easily in one direction than in any other. This direction is that of the thin layers of which the coal consists. If you want large pieces of coal to burn up quickly and make a good fire, you will take care so to put them in the grate that those layers shall be more or less upright. In that position the heat splits them up.

135. Now look at one end of a lump of coal, where the edges of the layers are exposed. You

cannot follow them with the same ease as in the case of a piece of shale, for they seem to blend into one another. But you may notice that among the layers of hard, bright, glossy substance, there occur others of a soft material like charcoal. A mere general look at such a piece of coal would show you that it is stratified.

136. You know that coal can be burnt away so as to leave only ashes behind, and that in this respect it resembles wood and peat (see Art. 145). Chemists have analysed coal and found that it consists of the same materials as wood or peat, and that in reality it is only so much vegetation which has been pressed together, and gradually changed into the black substance now used as fuel.

137. Let us suppose ourselves at a coal-mine, with the object of seeing exactly how the coal lies before it is dug out of the earth and broken up into the small pieces which we burn in our grates (see Fig. 37). We descend in one of the cages by which the miners are let down into the pit. After our eyes have got a little used to the darkness at the bottom, we set out, lamp in hand, along one of the roadways, and reach at last a part of the pit where the miners are at work removing the coal. Now, first of all, you see that the coal occurs as a bed, having a thickness of a few feet. This bedded character agrees with what you have already noticed as to the internal layers in the stone, and confirms you in believing that coal is a stratified rock. Next observe that the pavement on which the coal rests, and the roof which covers it, are both made of very different materials from the coal itself. Were you to cut a trench or section (Art.

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90) through pavement, coal, and roof, you would find some such arrangement as in Fig. 18. You would prove beyond any doubt that the bed of coal lies among beds of common sedimentary rock.

138. But what is this layer marked *b*, forming the floor or pavement on which the coal lies? Examine it with attention and you recognize it to be a bed of dark clay, with abundance of black streaks and branching strings, like roots, spreading through it. You may trace these root-like strings into the bottom of the very

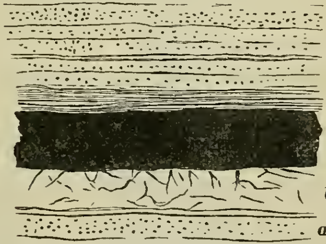

FIG. 18.—Section of a Coal-seam with its roof and pavement. *a*. Sandstones, Shales, &c. *b*. Under-clay forming pavement of Coal (*c*). *d*. Sandstones and Shales, forming roof of Coal

coal itself. If you visited other pits you would find each coal-seam to lie usually on such a bed as this. Now why should the coal rest rather on a bed of clay or shale than on one of sandstone or any other sort of rock? If you noticed that this peculiar pavement met you in every pit you visited, would you not begin to feel quite sure that the constant association of the coal and its under-clay could not be a mere accident but must have a meaning?

139. Now look at the under-clay again. Does it not remind you of a bed of soil with roots branching

through it? With this idea suggested to your mind, the more you examine the rock the clearer will this resemblance appear, until you are driven to conclude that in truth **the under-clay is an old soil, and the bed of coal represents the vegetation which grew upon it.** (See Fig. 38.)

140. Each coal-seam has been in truth at one time a dense mass of vegetation growing on a wide marshy flat, somewhat like the swampy jungles of tropical countries at the present day. These great marshy plains had a bottom of muddy soil on which the rank vegetation grew, and it is this very soil which you still see in the under-clay.

141. Can we tell anything about the kind of plants which flourished over these plains, and accumulated into the thick mass which formed the coal? Not much can usually be made out from the coal itself, for the vegetation has been so squeezed and altered as to destroy the leaves and branches of the plants; yet in many kinds of coal parts of the old plants have been changed into a sort of charcoal, which soils the finger, and shows traces of the vegetable fibre like any ordinary charcoal. If you cut slices from coal, fix these on glass, rub them down until they are so thin as to be transparent, and place them under a microscope, you may often find that the coal contains millions of little seed-vessels, or, as they are called, **sporangia.** These were shed by plants somewhat like the club-mosses of our own moors and hills, but much larger in size, and must have fallen so thickly over the flat grounds as to form a kind of mould or soil upon them.

142. But though the larger plants have not usually

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been preserved well in the coal itself, you may sometimes find them in great perfection and beauty in the beds of rock above or below the coal. Some of the common varieties are shown in Fig. 19. Now and then you may see these plants lying across each other

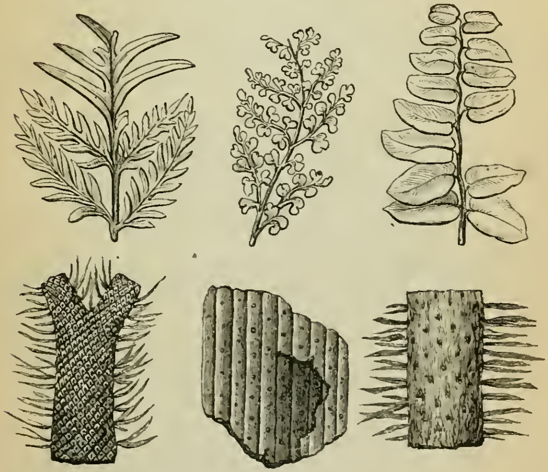

FIG. 19.—Plants out of which Coal has been formed.

and all squeezed flat, but still retaining much of their original gracefulness, upon the bottom of the bed of rock which forms the roof of the galleries as you go through the coal-mine.

143. Each coal-seam, once a luxuriant surface of vegetation, open to the sunlight, and stretching over many square miles, now lies buried deep within the earth, under huge masses of rock, which must be bored through before the coal can be reached. How

this burying has taken place we shall find out in a later lesson (Arts. 213—216). In the meantime you should learn a little about another kind of formation, where vegetation comes into play, and which you may examine not in a deep mine but in the open day.

144. You have no doubt read about, you may even have seen, the bogs and peat-mosses so abundant in Ireland, Scotland, and some parts of England. If you have not, you must imagine a wide, flat space of brown moor and green marsh, in many parts so soft and wet that you would sink deep into the black mire if you tried to walk on its treacherous surface; in other parts having a firmer crust, which shakes under your feet as you jump from one dry standing-place to another. Such a flat space is called a bog in Ireland, whilst in Scotland and England it is known as a moss, or peat-moss. Of the whole surface of Ireland nearly a seventh part is believed to be occupied with bogs, and in many parts of Scotland too they occur in great numbers.

145. Visiting one of these places you notice that round its edges it is usually quite firm. It may even have become so dry over the very centre as to be ploughed up and to furnish crops of turnips and potatoes. Wherever you can catch a sight of the substance of which the moss consists, you find it to be a black or dark brown sort of mould called Peat, formed of the remains of plants firmly matted together. Over the whole of the moss this peat extends as a bed, sometimes thirty or forty feet thick. It is simply a vegetable deposit, and in this and other respects resembles coal.

146. Such being its composition it may of course

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be readily burnt, so that at the mosses it is dug out in pieces, which are dried and used for fuel. Over great parts of Ireland and wide regions of Scotland the peasantry have no other fuel than this peat, which they cut every summer from the mosses.

147. In Fig. 20 a representation is given of one of these cuttings for peat. It is in such places that the mode of origin of the deposit can best be studied, and as the tracing out of the formation of a peat-moss

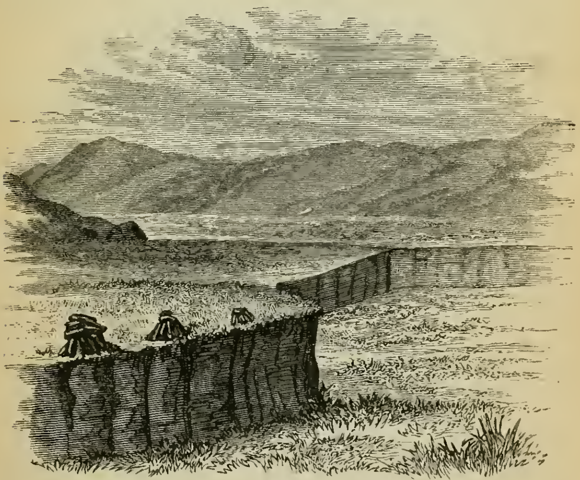

FIG. 20.—Section of a Peat-moss, where the peat is cut and piled into small stacks to dry for fuel.

furnishes a good example of the way in which geologists try to find out the past history of the earth, let me ask you to suppose yourselves looking into the opening which has been made in the peat-moss drawn in Fig. 20.

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148. Below the surface of coarse grass and heather lies the peat, a brown fibrous mass in the upper parts, but getting more and more compact towards the bottom, till it passes perhaps into a dark compact substance in which no trace of any fibres may be discernible. Down below the bottom of the peat there sometimes lies a layer of fine clay, containing the remains of shells which are only found living in fresh water. Now and then, too, a rude canoe, hollowed out of the trunk of an oak tree, is dug up from the bottom of a peat-moss—a relic of some of our uncivilized ancestors.

149. Here, then, is a little bit of geological history. Now put these separate facts together and make out the story of the peat-moss.

150. Beginning at the bottom, the oldest formation you meet with is the layer of clay just referred to. You have already learnt that such a layer must have been laid down under water. If it should happen to be thick it will suggest to you that probably this water was not a mere shallow pool or brook, but had some depth and extent. But the shells indicate further that the water must have been that of a lake, for they are such shells as you might find still living in the lakes of the neighbourhood. The first point you settle, therefore, is that before a peat-moss existed here, a lake occupied its site. You may even yet trace what the boundaries of this lake were, for the slopes which rise all round the flat peat-moss must in the same way have surrounded the old sheet of water, whereon our rude forefathers floated the canoes which are now and then dug up from the bottom of the mosses.

151. Above the layer of clay which marks the former

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lake-bottom, comes the bed of peat, made up wholly of vegetable materials. Evidently it has taken the place of the water. The plant-remains have filled the shallow lake up, and converted it into a peat-moss. In many places you may see. this process actually going on still. In such a peat-moss, for example, as that shown in Fig. 21, it is evident that the little patch of water in the centre is only a remnant of the lake, which once covered the whole hollow.

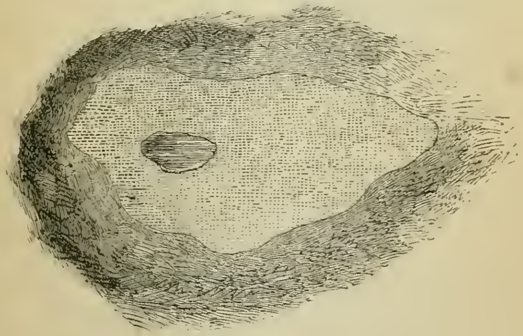

FIG. 21.—Ground-plan or map of a Peat-moss filling up a former lake, and with a portion of the lake still unfilled up.

At the edge of that remaining pool you find that the marshy vegetation out of which the peat has been formed is growing into the water on all sides. Put a pole down to the bottom and you will stir up the fine black or brown peat, formed out of decayed roots and fibres. Here there is still some water between the dead peaty matter at the bottom and the growing plants which form a sort of crust over the top. But in the end the plants will fill up the whole of

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this intermediate space, and then even the centre will be converted into a solid bed of peat, as all the outer parts of the moss have already been.

152. Peat-mosses have been formed in marshy grounds or shallow lakes by the growth and decay of plants, and the accumulation of their remains on the place where they lived and died. Like coal-seams they show how in certain circumstances the growth and decay of plants may give rise to thick and wide-spread deposits.

II. Rocks formed out of the Remains of Animals.

153. At first when you think of it, there seems not much chance of animal remains accumulating to such a depth as to form any well-marked deposit. Though the air may be filled with insects, though birds in abundance may be seen and heard as the summer slips away, though in our meadows and woodlands rabbits, hares, moles, and many other creatures live in great numbers, yet you nowhere see their remains forming a deposit on the surface. Nay, you comparatively seldom see a dead animal at all. They creep into holes and die there, and their bodies gradually crumble away and disappear. But if you look at the right places you will discover that the remains of animals as well as of plants, and indeed much more than plants, form great accumulations.

154. In the bed of clay under a peat-moss, as described in Art. 148, the shells which are sometimes

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to be seen mouldering away belong to certain kinds which live in lakes. In some parts of the country the bottoms of the lakes are covered with similar shells, so much so that if you were to take a boat and begin to dredge up some of the soft mud from the bottom of one of these sheets of water, you would find it to consist of a kind of white chalky substance, or marl as it is called, made up of shells in all stages of decay. The animals which live in these shells so abound in the water that as they die their shells form a layer over the floor of the lake. Now and then such a lake has been either gradually filled up by being choked with vegetation and silt (Art. 151), or has been drained artificially so as to be converted into dry land. Digging down on the site of that vanished lake you would come to the fresh-water marl, forming a bed or layer several feet, or even yards, in thickness. Perhaps you would meet with the skeleton of some deer, or wild ox, or other animal, which had somehow been drowned in the old lake; or you might disinter the canoe or stone-hammer or other relic of the early human races, which peopled the country before so many of its lakes and forests had disappeared. In some districts where limestone is scarce, the marl of the old lakes has been dug up in large quantities as a manure for the land. Hence you learn that even the frail shells which are to be seen on the stones and reeds along the margin of a lake may afford an illustration of how rocks are formed out of the remains of animals.

155. It is on the floor of the great sea, however, that the most wonderful examples occur of the way in which rocks are gradually built up from the remains

of animals to a depth of many hundreds or thousands of feet, and over distances of many hundreds of miles. Something has already been said on this subject in the Physical Geography Primer, Arts. 236 and 247; where the use of the dredge for the exploration of the bottom of the ocean was referred to, and allusion was made to the fine mud, formed of minute organic remains, and found over most of the bed of the Atlantic Ocean. Let us now consider this mud a little further.

156. To the west of Britain the Atlantic soon and suddenly deepens. Its floor then stretches away to Newfoundland as a vast plain, the lowest part of which is about 14,000 feet below the waves. It was over this wide sub-marine plain that the Telegraph-cables had to be laid, and hence numerous soundings were made all the way across from Ireland to the American coast (Physical Geography Primer, Art. 234). While in the shallower parts of the sea the

FIG. 22.—Some of the Ooze from the Atlantic bed, magnified 25 times.

bottom was found to be covered with sand, gravel, or mud, from the deeper parts there came up with the sounding-lead a peculiar grey sticky substance known as **ooze**, which must stretch over that wide

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deep-sea basin for many thousands of square miles. This ooze when dried looks like a dirty kind of chalk. You may purchase a minute quantity of it prepared on a glass slide for the microscope. Looking at such a slide with only your naked eyes, you might suppose that the little specks you see are merely so many grains of dust upon the glass. But place them under a strong magnifying glass or microscope, and you discover that they consist of minute shells called Foraminifera, some of them quite entire, others broken, and all most delicately sculptured and punctured (Fig. 22). As you look at these graceful forms, reflect that they are crowded together, millions upon millions, over the floor of the Atlantic, that as they die their shells gather there into a wide-spread deposit, and that as fresh generations spring up one after another this deposit is continually getting deeper. After the lapse of centuries, if the deposit were to remain undisturbed, and if we could set a watch to measure its growth, we should find it to have risen upward and to have enclosed the remains of any star-fishes or other sea-creatures which chanced to die and leave their remains upon the bottom. Hundreds of feet of such slow-formed deposit have no doubt already been laid down over the bottom of the ocean between Ireland and Newfoundland. Here then is a second and notable example of how a deep and far-spread mass of rock may be formed out of the remains of animals.

157. Now return once more to our piece of chalk (Art. 28) and compare it with the ooze of the Atlantic. At the first glance in many a piece of chalk you can see shells, corals, sea-urchins, and other marine

remains, either entire or in fragments (Fig. 23). These are enough to convince you that chalk must have been formed under the sea. But a little further examination will show that the chalk not merely contains animal remains, but is altogether made up of them. If you were fortunate in the piece of chalk, which you treated as recommended in a former Lesson (Art. 28), you found numerous little cases or shells (Fig. 3), quite like those in the Atlantic ooze (Fig. 22), along with fragments of larger broken shells and other remains. The whole

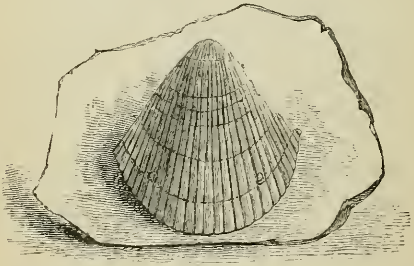

FIG. 23.—A piece of Chalk with shell in it.

of the chalk is evidently made of animal remains, some quite perfect, others so broken and crumbled that you cannot be sure to what kind of sea-creatures they belonged. You must not be disappointed if for a time none of the chalk which you brush off shows you any distinct organism (Art. 132), but only shapeless white grains. All these grains are only the mouldered fragments of organisms, and you must search among them until you find some still perfectly preserved and entire specimens. When successful you will meet with some such assemblage of minute organic

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remains as shown in Fig. 3, which represents some of the chalk of Gravesend.

158. But chalk is only one of many rocks composed altogether of the remains of animals. Most of the limestones have been formed out of these materials. Here, for instance, is a piece of limestone (Fig. 24) which has been lying exposed to the air for many

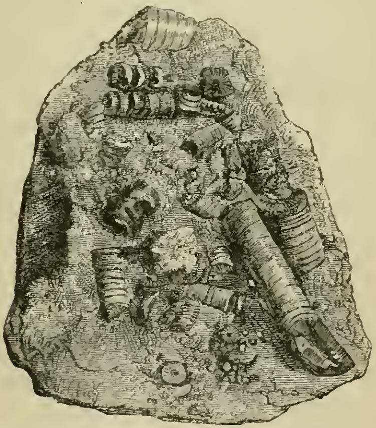

FIG. 24.—Piece of Limestone, showing how the stone is made up of animal remains.

years, and you see how its surface is crowded with bits of "stone-lilies," corals, shells, and other remains. The sight of such a piece of stone as this at once sets you thinking about some old sea-floor. You can picture to yourselves how all these delicately sculptured little fragments once formed parts of living creatures, which moved or grew beneath the clear waters of the sea. The bit of limestone becomes to

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you a kind of model of what a sea-floor must be, and reminds you of what you may even have seen with your own eyes at the bottoms of some of the rocky pools upon the beach. (Art. 114.)

159. If a little fragment of limestone might suggest these thoughts to you, what would you think if you were taken to places where all the hills are made up of such limestone—vast piles of rock two or three thousand feet thick, and stretching over the land for hundreds of square miles? And yet you may meet with such wonderful masses of limestone crowded with the remains of old sea-creatures, in almost every country of the world. In Britain, for example, the hills and dales of a great part of Derbyshire and Yorkshire are built up of limestone. Looking up one of these wonderful valleys you see the beds of limestone winding along either side and rising in broad terraces, one above the other as far as the eye can reach. In walking along the surface of one of these high hill-terraces, you are really walking on the bottom of an old sea, and if you stop anywhere to look at the rock under your feet, you will see that it is only a mass of the crowded remains of the little animals which peopled the waters of that sea. Somehow the sea-bed has become dry land, and the thick animal deposits of its bottom have hardened into limestone, out of which high hills and wide valleys have been formed.

160. Still thicker masses of similar limestone occur in Ireland. Some of the giant mountain chains of the world consist in great measure of limestone. Among the lofty crests of the Alps, for example, and in the chain of the Himalaya, limestone, made up of the remains of marine animals, is found to constitute great

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ranges of the high ground on which the eternal snows rest and from which the glaciers descend into the valleys.

161. **Summary.** Before advancing further you may now look back upon what you have learnt, and see exactly the point to which you have come. If I were to ask you to make a short abstract of the foregoing lessons you would probably jot down such a summary as the following :—

(1.) The surface of the land is worn away by rain and by streams, and a vast deal of mud, sand, and gravel is consequently formed.

(2.) This material worn from the land accumulates at the mouths of rivers, in lakes, and over the floor of the sea, so as to form great deposits, which will in the end harden into Sedimentary Rocks.

(3.) Leaves, twigs, trunks, and other parts of plants, together with the remains of animals, become imbedded and preserved as Fossils in these sedimentary accumulations.

(4.) Plants and animals of themselves sometimes form thick and extensive deposits upon the surface of the earth.

(5.) The rocks of which the dry land is made have been formed, for the most part, under the sea.

(6.) Old land-surfaces which, like the coal-seams, once spread out into luxuriant forests, are now buried deep beneath the present surface under masses of solid rock.

162. You have advanced step by step to these conclusions, and are quite sure of them, for you have tested everything on the way. Again and again you have met face to face with proofs that in some way

or other land and sea have often changed places. You have found old sea-bottoms even up among the crests of the mountains. You have found old forests buried in the form of coal-seams deep in the bowels of the earth. How can these wonderful changes have taken place? To be able to answer this question you must find out something about the history of the third of the three great groups into which we divided the stones of the earth—the Igneous Rocks.

IGNEOUS ROCKS.

I. What Igneous Rocks are.

163. Turning back to one of the early Lessons of this book (Art. 44), you find that we divided stones into three great classes, of which the third was named the Igneous class. This word igneous, means literally fiery. It does not very accurately describe the rocks to which it is applied, but it has long been in use to include all rocks which have been actually melted within the earth, or which have been thrown out at the surface by the action of volcanos. So that the Igneous Rocks owe their origin to some of the effects of the internal heat of the earth, about which you have already learnt something (Physical Geography Primer, Arts. 252—265), and must now learn more.

164. The first thing to occur to you when you begin to search for examples of igneous rocks, will probably be the fact that they are by no means so abundant as the other two great classes of rocks. Take Great Britain as an illustration. If you traversed the country from end to end, you would meet everywhere with rocks belonging to the Sedimentary, and the

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Organic series. But you would travel over considerable spaces without meeting with any of the Igneous class. The whole of that part of England, for example, which lies to the south-east of a line drawn from Lyme Regis, by Leicester, to Flamborough Head, contains not a single mass of igneous rock. And yet were you to cross over into North Wales, or Cumberland, or the midland valley of Scotland, you would find rocks of that kind in abundance, protruding through the surface, and forming many of the highest and most picturesque hills and crags in these parts of the island. So that though igneous rocks are not universally diffused, they occur abundantly enough in many places. Even in so small a space as Britain they are plentiful; they are likewise to be met with in most parts of the world. They have a very curious and important history, and hence it is desirable that you should know what they really are, and how you could recognize them.

165. In the account given of volcanos in the Physical Geography Primer (Art. 258) you will find that the solid materials cast up by volcanos were stated to be of two kinds—1st, streams of molten rock called **lava** poured down the sides of a volcanic mountain during an eruption; and 2nd, immense quantities of **dust, sand,** and **stones,** cast up into the air from the mouth of the volcano, and falling down upon the mountain, sometimes even all over the surrounding country for a distance of many miles.

166. Here then are two very dissimilar kinds of rock-material discharged from the interior of the globe. The lava cools and hardens into a solid rock. The loose ashes and stones, likewise, are in time pressed

and hardened into more or less firm beds of stone. So that two totally distinct kinds of rock are laid down upon the surface of the earth by the volcano. In the case of the lava, the rock, if you look at it with a magnifying glass, is seen to be made up of distinct **crystals** all matted together. The beds of ashes, on the other hand, no matter how compact they may have become, are found to be made up of irregular **fragments** of various kinds of stone, and of all sizes, from the finest dust up to big blocks. By attending to this very simple and intelligible difference you could arrange igneous rocks into two great

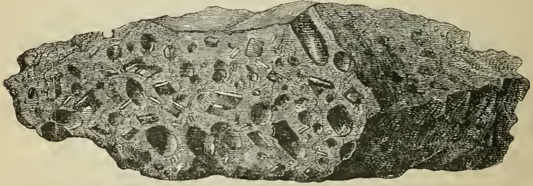

FIG. 25.—Piece of Lava, showing the crystals and the steam-holes.

groups—1st, **the Crystalline**, that is, those which are made up of crystals, and which have once been in a melted state; and 2nd, **the Fragmental**, that is, those which consist of the loose materials thrown out during volcanic explosions.

167. I. **Crystalline Igneous Rocks.** The piece of Granite which we have examined (Art. 26) is an example of one form of the rocks of this class. We have seen how greatly it differs from such rocks as sandstone or chalk. But there are many other varieties of crystalline igneous rock. In Fig. 25, for example, one of these varieties is drawn. It is a

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fragment broken from a current of lava which in a molten state ran down the side of a volcano. You observe the little angular crystals, some of them black and large, others mere white specks in the general mass of the stone. But besides the crystals

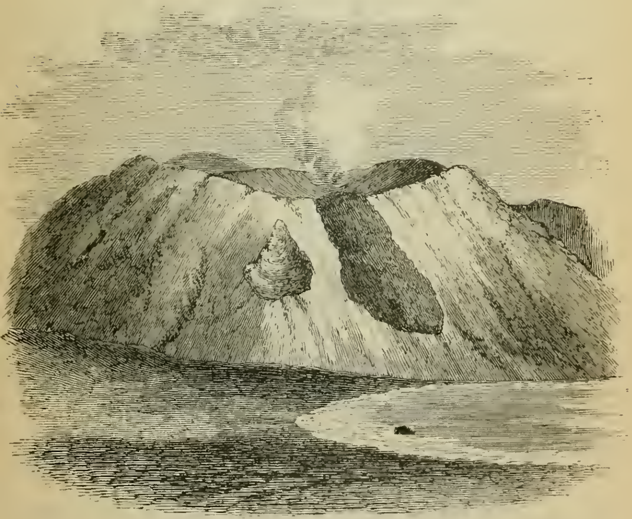

Fig. 26.—View of the north side of the volcanic cone of the Island of Volcano, showing a stream of black lava which has not flowed down to the bottom of the slope.

you notice a number of rounded holes or cavities, as if little water-worn pebbles had fallen out of the rock. When the rock was still melted it was full of imprisoned steam and gas which were constantly striving to escape to the surface. It was this steam which collected into little bubbles and formed the curious set of holes in the mass of the still molten rock. In the same way the holes which you often see in the heart of a loaf of bread were formed by the struggles of the steam to escape from the dough as it was heated in the oven.

168. All lava belongs to this class of rocks. One or two pictures may serve to show you some of the more simple and striking features of these lava

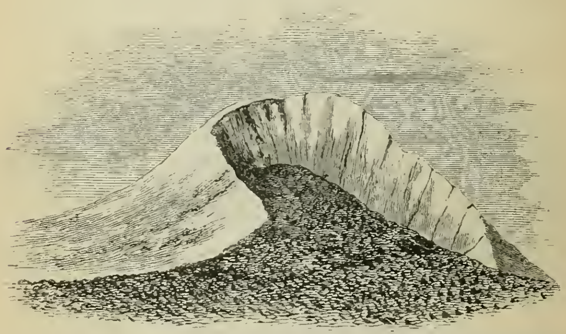

FIG. 27.—View of Lava-stream issuing from one of the extinct volcanic cones of Auvergne, in Central France. (Scrope.)

masses. In Fig. 26, a drawing is given of part of the Island of Volcano, in the Mediterranean, in which you will see how the lava has risen up the inside or throat of the volcanic hill to the edge of the crater (see Physical Geogeraphy Primer, Art. 256), and run down the outside of the slope. When that took place the lava was of course thoroughly molten like liquid iron, and hardened as it cooled in moving. You observe that it has not been able to reach the bottom of the hill. It was in truth a very small stream, cooling and hardening before it got even down to the foot of the slope. But look now at Fig. 27. You there perceive that a much more copious stream of lava has issued, that one side of the volcanic cone has been broken down so as actually to let you see into the crater, and that the lava has burst out, and poured down the sloping ground. Thus, each outburst of lava is the escape of a river of molten rock from the top or the side of a volcano. Like an ordinary river of water, it of course sweeps into the readiest hollow or valley it can reach, so that round an active volcano the valleys often get quite filled up and buried under the vast sheets of lava which are poured out. Like rivers, too, the streams of lava vary greatly in size. In Fig. 26, you see one which was too feeble to reach the base of the hill, but in the famous eruption of Skaptar Jokul, Iceland, in the year 1783, two enormous streams were poured out, one of them flowing to a distance of forty-five, and the other of forty miles. They ranged from less than seven to twelve or fifteen miles in breadth, with a thickness of a hundred, and sometimes in confined valleys even six hundred feet.

169. If you paid a visit to any ordinary stream of lava after it had come to rest and cooled, you would find its surface to be an irregular accumulation of rough black or dark brown fragments very like the "slags" or "clinkers" from a furnace. Down below this rough surface the rock is more compact, usually dark in colour, containing various crystals scattered through its mass, and often full of holes, as shown in Fig. 25. In some cases the lava as it grew solid has

assumed a curious and beautiful internal arrangement into columns. The pillars of Fingal's Cave in Staffa, and of the Giant's Causeway in Antrim, have been produced in this way. At both of these places the rock was once a molten lava. As it grew cold and solid it contracted, and in so doing became divided into these regular columns. You might imitate

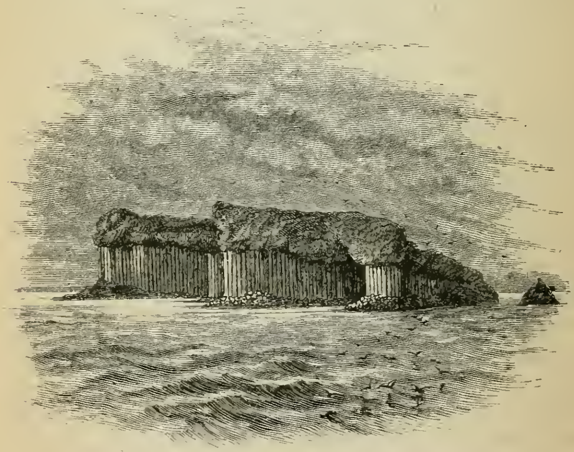

FIG. 28.—View of the Island of Staffa, with Fingal's Cave.

this arrangement by putting starch in warm water, stirring it well round, and then letting it stand. By degrees you would observe that as the starch grows solid it assumes an internal columnar arrangement, not unlike the basalt.

170. Next let us see where rocks of this kind are to be met with. Of course you would expect to find them

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round the flanks of an active volcano. And indeed, at most volcanos, as Vesuvius or Etna, or those of Iceland, they abound. But you would trace them too round volcanos no longer in activity, as for example in that part of Central France where the extinct volcanos occur of which one is drawn in Fig. 27. And as you travelled over the world, you would recognize them in hundreds of places where no volcanic eruption has ever been known since human history began. In fact they would be the witnesses to you of where old volcanos had once been at work. In this way by learning how to detect these forms of ancient lava, you would be able to prove that there had been volcanos in very far distant times in districts where there are now busy cities or fertile fields.

171. For example, though no active volcanos exist in Great Britain at the present day, they can be shown to have often broken out here in olden times, long before man appeared upon the earth. Some of the oldest traces of volcanic action are to be met with in North Wales, where not a few of the lava-beds form prominent features in the scenery of that rugged district. Much younger are the sheets of various ancient lavas which stretch across the middle of Scotland, and there compose most of the hills. But the latest of the British volcanos were those which ranged in a long line from Antrim in Ireland, through the Western Islands, and away north by the Faroe Islands into Iceland. The vast terraced mountains of Antrim, Mull, Skye, and Faroe have been built up of piles of lava-sheets.

172. But there are other crystalline igneous rocks besides those which come to the surface and flow out

there as molten lava. Granite, for example, which we have already examined (Art. 26), is an admirable illustration of the crystalline character. But instead of coming to the surface to cool there, granite appears to have crystallized and cooled deep down beneath great masses of other rocks. Yet it now forms bare, naked, lofty mountains. Many of the Scottish Highland hills for example, as Ben Nevis, Ben Macdui, and Cairn Gorm, consist of granite. It rises high, too, in the centre of the chain of the Alps. Granite often sends out veins into the rocks which lie above and around it. It could not have done this unless it had been in a fluid or pasty state.

173. But you may ask, if granite has not crystallized at the surface, but under masses of other rocks, how does it come to be at the surface now, and not there only, but even forming the crests of bare lofty mountains? This question is not quite so easy to dispose of, but you will probably be able to see how it is to be answered after you have come to that portion of these Lessons which treats of what is called the Crust of the Earth. (See Art. 239.)

174. 2. **Fragmental Igneous Rocks.** The piece of stone represented in Fig. 29 is a fragment from a bed of consolidated volcanic ashes. You notice that it is made up of irregular and angular fragments. These are little bits of lava and other rocks which have been blown into the air by the discharges of the volcano. You observe too that when they fell to the ground and accumulated above each other there they took a stratified form. That layer of coarse fragments at the bottom points to a shower of coarser volcanic ashes, while the layers of smaller fragments above

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show how showers of finer dust afterwards fell throu the air. Now this is the kind of material under which the old Roman city of Pompeii was buried (Physical Geography Primer, Art. 259). It fell upon the streets and houses and gradually covered them up as the eruption of the neighbouring volcano continued. And at this day when they excavate the ruins, the workmen find the streets and chambers all choked up with layers of coarser and finer volcanic ash and dust arranged just as you see in Fig. 29.

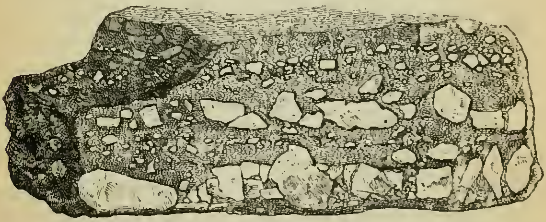

FIG. 29.—Piece of Volcanic Tuff – a rock formed of consolidated Volcanic ashes.

175. Of course if the volcanic ashes fell over the sea or a lake they would settle down beneath the water and form deposits there. They might cover up and preserve, too, the remains of any plants or animals which might be lying on the bottom at the time of the eruption. This has often happened in past times. In the mountain of Snowdon in Wales, for example, many hundreds of feet of such consolidated volcanic dust still exist, and on examining this material you may still pick out shells and other marine organisms which show that the volcanic materials fell into the sea. Again in Scotland many beds of

similar nature are found lying among seams of coal. These masses of consolidated volcanic dust and stones are known by the name of **Tuff.**

II. Where Igneous Rocks come from.

176. If I ask you from what source the Igneous Rocks have been derived, you will reply that they have come up from the intensely hot regions within the earth. In the Physical Geography Primer (Arts. 252—265) some account is given of the inside of the earth, and of the proofs that it has a high temperature. I need not remind you what a very little part of the outer portion of our planet we can actually see, even from the top of the highest mountain to the bottom of the deepest mine. Let us go over in this Lesson a little more in detail the evidence for the great heat of the earth's interior, and the connection between that heat and certain movements and changes at the surface.

177. **Deep Borings and Mines.** If you were taken down to the bottom of a deep mine in England you would find the temperature much warmer there than near the surface, and a similar increase of heat would meet you in the deep mines of every country in the world. You would soon discover, too, that on the whole the deeper the mine the greater the warmth would be. In the same way were you to bore a deep narrow hole into the earth for several hundreds of feet and let a thermometer down to the bottom, you would find that the mercury would rise in the tube.

178. Experiments of this kind have been made all over the globe, with the result of showing that after we get down for a short and variable distance below the surface, we reach a temperature which remains the

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same all the year, and that underneath that limit the temperature rises about 1° Fahrenheit for every fifty or sixty feet of descent. If this rate of increase continues we should get uncomfortably hot before having descended very far. For instance, at a depth of about two miles water would be at its boiling-point,

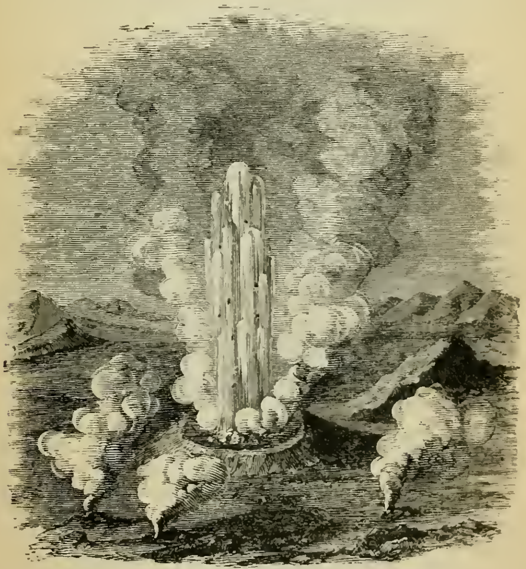

FIG. 30.—View of Hot Springs or Geysers, Iceland.

and at depths of twenty-five or thirty miles, the metals would have the same temperatures as those at which they respectively melt on the surface of the earth. It is clear from this kind of evidence that the inside of our planet must be in an intensely heated condition.

177. Proofs of another kind lead to the same conclusion. The city of Bath has long been famous for its wells. Now these come out of the earth at a temperature of 120° Fahr., that is, rather hotter than the water is usually made in a hot bath. And this warm water has been rising to the surface and flowing to the sea ever since the Romans were in this country, and probably long before that. In many other parts of

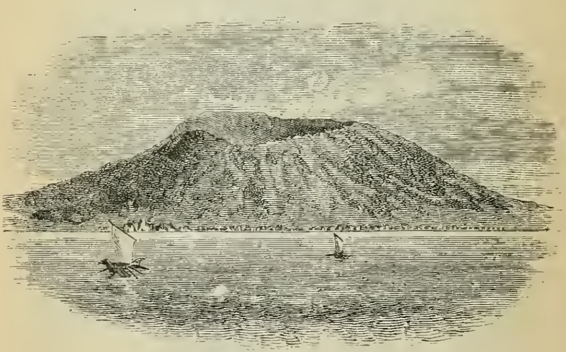

FIG. 31.—Vesuvius, as it appeared a. the beginning of the Christian Era, when it was a *dormant* volcano.

the world similar **Hot Springs** occur. Iceland, for example, furnishes some remarkable examples called Geysers, where at intervals the boiling water and steam rush out with a great noise, and rise high into the air (Fig. 30). To keep up such hot springs in every quarter of the globe there must assuredly be great stores of heat within the earth.

180. Neither the heat of deep mines nor of hot springs affords such an impressive lesson as to the

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earth's internal high temperature as is furnished by **Volcanos.** The hot vapours and steam which rise from the craters of volcanos, the torrents of hot water which sometimes issue from their sides, the streams of molten lava which break out and roll far down the slopes of a volcanic mountain, burning up and burying trees, fields, gardens, and villages—are all tokens of

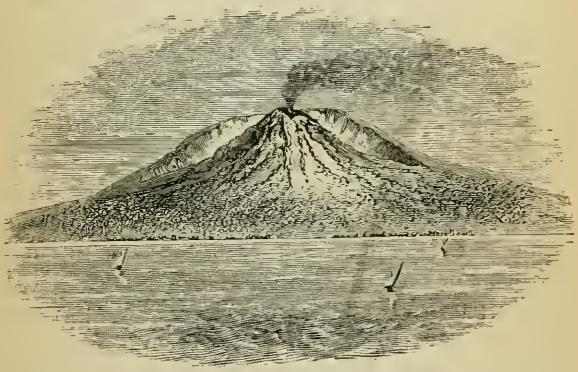

FIG. 32.—Vesuvius as it appears at the present time—an *active* volcano.

the intense heat of the inside of the earth from which they come.

181. At the present time there are, it is said, about 270 volcanos either constantly or at intervals throwing out steam, hot ashes, and lava, in different parts of the globe. You will comprehend how widely they are distributed if you again take a map of the world and note upon it the lines of active volcanos (see Physical Geography Primer, Art. 260). First of all, down the whole line of the mountains which range along the western margin of the American continent. vol-

canos are numerous, some of them of vast height like Cotopaxi (18,877 feet). From the northern extremity of America they extend, by way of the Aleutian Islands and Japan, to the Malay Archipelago, where in Java they greatly abound. From that point they may be traced at wide intervals into New Zealand on the one hand, and on the other through the centre of Asia by way of the Red Sea and the Mediterranean, up to Iceland and down to the Azores, and thence across to the West Indies and the centre of America. Even among the perpetual snows of the South Polar regions they have been met with, and also far within the Arctic Circle at the Island of Jan Mayen.

182. But besides these volcanos which are still active, many others occur from which no eruptions have ever been seen to take place, and which are therefore called **dormant** or **extinct** (see Figs. 27 and 31). If you were to put down upon a map the position of every volcano which either now or at some past time has given out hot gases, steam, ashes, or lava, you would probably find very few large areas of the earth's surface in which no trace of volcanic action can be found. Britain, for instance, is now wholly free from any volcanic disturbance, and yet, as already pointed out (Art. 171), you would need to mark many places on the map of this country as having once been the scene of long-continued volcanic eruptions. You would have to put some dots upon the map round Exeter to mark the position of some ancient volcanos; a good many in Wales, some in Derbyshire, and others in Cumberland. You would have to cover almost all the centre of Scotland with such dots, for that region

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is full of volcanic rocks, and in Ireland too there would be a good many scattered marks.

183. In this way you would come to see how universal volcanic action has been, on the whole, over the globe, and therefore how powerfully and generally the heat of the interior has manifested itself at the surface.

184. But in igneous rocks you do not see the only evidence of how the internal heat affects the surface of the earth. There can be little doubt that **Earthquakes** (Physical Geography Primer, Art. 262) must be mainly due to commotions which take their origin from the effects of this heat.

185. Perhaps you will ask, why, since the inside of the planet is so hot, does it not melt the outside, or at least why is the outside not warmer? There can be no doubt that, at one time many millions of years ago, the globe was immensely hotter than it is now. In fact it then resembled our burning sun, of which it once probably formed a part, and from which it and the other planets were one by one detached. During the vast interval which has passed away since then it has been gradually cooling, and thus the heat in the inside is only the remains of that fierce heat which once marked the whole planet. The outer parts have cooled and become solid, but they are bad conductors of heat, and allow the heat from the inside to pass away into space only with extreme slowness (Physics Primer, Arts. 64, 65). Hence, in spite of the high temperature of the interior, we are not sensible that it warms the outer surface of the earth.

186. To illustrate this point suppose that you could see a volcano in the very act of pouring a great

stream of molten lava down its slopes. At first the torrent would be at a white heat, glowing so fiercely that you could hardly keep your eyes upon it. But a few yards below the point from which it emerged it would begin to assume a reddish hue, which would get duller and darker, just as a live coal does when it falls from the grate upon the hearth, and the surface of the lava would at the same time get cool and solid so quickly that in a few days you might stand upon it, even though it was still red hot only a foot or two below. You might come back to it a dozen of years afterwards. Its surface would be perfectly cold—a mere rough sea of black bristling lumps of rock—and yet down in the depths of the mass the rock would be still hot, and you might even meet with cracks from which the heat escapes along with wreaths of steam, and where therefore you could not hold your hand without having it burnt. Now if a mere river of lava takes so long to cool down to its centre, you can realize perhaps why it is that the huge mass of our globe should still be intensely hot inside even though its outer portions have been solid and cool for long ages.

187. You are already familiar with the fact that bodies expand when they are heated, and contract as they cool (Physics Primer, Art. 49). When the earth was vastly hotter than now it must also have filled more space. While cooling it has been contracting. As it is still cooling it must be still contracting, but so slowly that on the whole we are not sensible of the process. But some of the effects are visible enough among the rocks. The contraction could not fail to cause an enormous pressure or strain on the outer

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parts, which, since they are made of such very various materials—Sedimentary, Organic, and Igneous Rocks —would yield to the stress more in some places than in others. And thus, somewhat like the skin of a dried and shrivelled apple, the surface of the globe would be ridged up in one region, or would sink down in another, besides being squeezed and broken. What evidence we have for all this will be told in the next Lessons.

THE CRUST OF THE EARTH.

I. Proofs that parts of the Crust have been pushed up.

188. We have now completed the first part of the task which was proposed in an earlier Lesson (Art. 7)—to find out what the materials are of which the great stone floor of the earth is made. We have learnt something about three great classes of rocks which form that floor—how they were made, and where they are to be seen. But while learning these facts about the earth, we have seen that the rocks are not a mere thin covering like a wooden floor below which we should come to something quite different. We cannot get down beneath the rocks. Deep as the deepest mine the same kind of rocks may be found which elsewhere exist at the surface. It is always through rock of some kind that we must descend as far as we can penetrate into the bowels of the earth.

189. This solid rocky outer part of the earth on which we live, into which men sink mines and out of which springs arise, is called **the Earth's Crust.** This

name came into use when people supposed that all the inside of the planet was an intensely hot liquid mass with a cool and comparatively thin crust outside. A great deal of dispute has arisen as to whether the main mass of the inside of the earth is liquid or solid, but those who dispute, whatever their view may be, agree to use this phrase the Earth's Crust as meaning that part of the earth which men can observe from the top of the highest mountain to as far below the deepest mine as they can reasonably infer what the rocks must be.

190. The rocks of which this crust consists belong mostly to the Sedimentary series, a large number to the Organic series, and a smaller, but still considerable proportion, to the Igneous series. In Britain, for example, if we could put all the different series of sedimentary and organic rocks together, one above another, in the order in which they were deposited, they would form a mass at least ten or twelve miles thick. Out of such materials the solid earth is built up as far down into its depths as man has been able to descend.

191. But from what has been stated in previous Lessons it is clear that many of these rocks are not now in their original positions. Our quarry, for example (Art. 119), told us how the rocks in which it lay had once formed a part of the sea-bottom. Then again the coal-seams, buried so deep in the earth, were once verdant forests or jungles at the surface (Art. 139). How could a sea-floor become dry land, and how could a forest on the surface of the land come to be covered by hundreds of feet of solid stone?

192. Let us begin by considering how it is that a

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portion of the floor of the sea can be changed into good dry land. And in order to follow the change as clearly as possible we shall choose one of the simplest examples, and one moreover which many of us may have the opportunity of verifying for ourselves.

193. Round the coast-line of some parts of the British Islands there runs a low flat terrace bounded by the sea on the one hand and by a cliff or inland slope

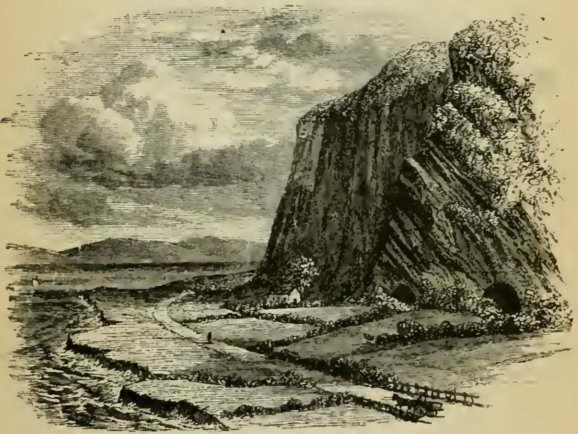

FIG. 33.—View of a Raised Beach.

on the other. Seaport towns have been built upon this terrace, such for instance as parts of Glasgow, Greenock, and Leith. It is so level that roads run along its surface for miles among cornfields, meadows, and villages. You may gather some notion of its general appearance from Fig. 33, which shows how flat it is and how little elevated above the sea at its outer edge. Along its inner margin there often rises a line of cliff pierced with caves, as represented in the drawing. If you were standing on some part of this terrace and looking along its level surface as it winds in and out against the cliffs and slopes of the land, would not the idea of an old coast-line at once suggest itself to your mind? You can without difficulty picture the sea covering that terrace and beating against the base of those cliffs and slopes.

194. Could you prove this fancy of yours to be anything more than a fancy? Let us see. Cross to the inner margin of the terrace and consider attentively the line of caves you find there. How did these excavations come to be drilled into the solid rock all along the same line and exactly at the same level, so that the floor of each of them should just open upon the flat terrace? Suppose that you visit one of these caves. Festoons of ivy and honeysuckle hang perhaps in tangled luxuriance about its mouth, and you may have to force your way through a brushwood of strong briars. But you gain at last the floor of the cave, which you find to be roughened with rounded, water-worn stones. The roof is partly hung with ferns, mosses, and liverworts, and the sides too have their drapery of green. But the bare rock appears abundantly, and you notice that it has been rubbed smooth, and has the same water-worn character as the stones under your feet. Now go outside and look at the bare rocks of the cliff above; you see how rough and sharp-edged they are, as from time to time they split up under the influence of the weather. The walls of the cave have been ground smooth from one cause, the face of the cliff has been made rough from another.

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195. The explanation of this difference will be apparent if you remember what takes place where a sea-cliff of hard rock has its base washed by the waves (Arts. 73—75). You have seen how the rocks, wherever the waves can reach them, are worn smooth by the ceaseless grinding of the gravel and stones to and fro. And every cave into and out of which the waves drive the gravel is ground down in the same way. A single forenoon spent on such a coast-line gives you a lesson you can never forget as to the way in which rocks have their surfaces smoothed by the waves. But all which lies above the reach of the breakers comes under the influence of other forces. Rain, frost, and springs com-

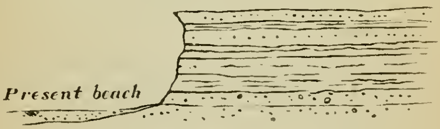

FIG. 34. - Section of a Raised Beach.

bine to make the cliff crumble down, and fragments to split off from its face so as to give that rough angular appearance which contrasts so well with the water-worn rocks below.

196. After having observed in this way what is taking place now along a sea-cliff, you can hardly doubt that the line of cliff which rises from the inner margin of our terrace was once a sea-cliff too, with the waves beating against its base and boring that line of caves there, as they are still doing elsewhere. The line of that cliff thus becomes in your mind the line of a former sea-shore.

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197. But further proofs of the former presence of the sea present themselves if you put questions to the terrace itself. Dig beneath the surface of that terrace anywhere, and what do you find it to consist of? Sand and gravel, sometimes with abundance of shells. Look at the outer margin of the terrace where the sea is gradually cutting it away, and you find there that the sand and gravel are laid down in layers, just as they are on the beach below, and that the shells belong to the common kinds which are washed up by every tide upon the sands. You discover that in truth the terrace is simply an old beach, and that the sea must have laid down the materials of the terrace when it was scooping out the caves at the foot of the cliff. Thus the terrace and the caves combine to prove a change in the coast-line.

198. By measuring the height of the floor of the caves and the height of the terrace above the present high-water mark, you would ascertain the difference of level between the present beach and the old one. Let us suppose that this difference is in the present case twenty feet; it is plain that the land must have risen, or the sea must have sunk, to the extent of twenty feet.

199. When you watch the restlessness of the sea, with its ebbing and flowing tides, its waves and currents, and then when you contrast with this ceaseless motion the calm steadfastness of the land, you may naturally suppose that, in any changes of the relative position of land and sea, it is much more likely that the sea should have shifted its place than that any alteration should have happened to the land. But reflect for a moment on what would be involved in a change in

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the sea-level at any place. If I deepen the bottom of one end of a pond, does the level of the water fall just over that part where I have been at work? Assuredly not: the level of the whole pond is lowered. In the same way, if I empty a quantity of stones and earth so as to make one part of the pond very much shallower, do I raise the level of the water only over that part? By no means: the influence of what I have been doing extends through every part of the pond, and the level of the water is uniformly raised over the whole.

200. Now instead of the pond, think of the great ocean, which is only an enormously large continuous sheet of water. You see that an alteration of its level in one region must necessarily extend over the whole globe, until the same general uniformity of level is restored. If the sea has sunk from our terrace (Figs. 33, 34) to the extent of twenty feet, there must have been at the same time a general lowering of the sea-level all over the world. But is it so? How would you set about to ascertain this point?

201. Plainly if the terrace has been left by a sinking down of the bed of the sea, you should meet with a corresponding terrace all over the globe. But you would not require to travel far before you ascertained that no such universal terrace is to be seen. Even around the coast of Britain you would find enough to show you that there has not been any general subsidence of the ocean. Throughout a great part of the margin of our island no terrace occurs at all. Only in certain districts is such a terrace to be met with, and its height is not always the same.

202. Sometimes a series of terraces may be seen rising

one over another, each marking a former coast-line. In the north of Norway they occur in great perfec tion (Fig. 35), up to heights of several hundred feet. They look perfectly horizontal to the eye, yet when they are measured accurately they are found sometimes to rise towards the upper end of the long inlets on the sides of which they run, so that a terrace which at the sea-ward end may stand at a height of 80 feet above the sea, is as much as 90 or 100

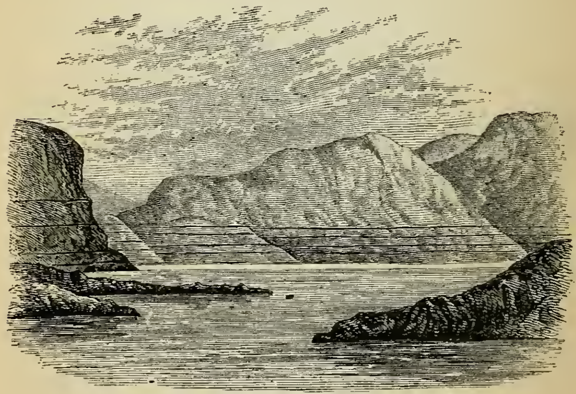

FIG. 35.—Terraces (Raised Beaches) of the Alten Fjord, Norway.

feet at the land-ward end. Now such a difference of level in a short distance proves that something else must have taken place than a mere subsidence of the sea, for had that been the cause of the terraces being left, they should all have been as horizontal as the surface of the sea itself, and at least traces of them should have been found at corresponding heights in our own country and all over the world.

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203. Strange as it may seem to you, it is nevertheless true, that **it is the land which rises**, not the sea which sinks. If that be the case, it is easy to see how there should be terraces in some countries and not in others, and how the same terrace should vary in height at different parts of its course. For the land may have been pushed up at one place and not in others, and more at one place than in another. The old sea-terrace (Fig. 33) is called a **Raised Beach**, because it consists of gravel, sand, and other beach deposits, which have been raised above the level of the sea. Every such raised beach points to a former sea-margin, and to an elevation of that sea-margin into dry land. Where a great many terraces occur one above another, as in Norway (Fig. 35), they show us how the land has been raised up at intervals for a long period, the time when the land was stationary between two upheavals being marked by a terrace or raised beach. Of course the highest terrace must needs be the oldest, and for that reason is often less perfect than the newer ones, having suffered more from the various forces such as rains, frosts, and streams, which are so busy in making the surface of the land crumble away. (Physical Geography Primer, Art. 126.)

204. In some parts of the world we can detect the ground in the very act of rising. In the south-east of Sweden, for example, rocks have been marked at the place where high-water reached them, and in the course of years have been found to be considerably above their former level. From observations of this kind it has been inferred that the land there is rising at the rate of about two or three feet in a century.

This appears to be but a very slow movement, too slow to be appreciated, except by careful measurement; and yet if it were to go on for another thousand years, what is now the beach would have risen to a height of twenty or thirty feet above the sea-level.

205. You see, then, that the upraising of the bottom of the sea, strange as it may seem to us, is not entirely a thing of the past. It is going on slowly at the present time in several parts of the globe. And just as the coast of Sweden is rising with no violence or shock, so in old times the upraising of the sea-bed into dry land may have been a gentle and quiet process.

206. The rocks of every country furnish abundant evidence that the sea-bottom has again and again been elevated into land. This evidence is furnished, as you now know, chiefly by the remains of corals, star-fishes, shells, and other sea-creatures, which may be traced imbedded in the rocks. The height at which these remains are found affords us some idea of the extent of the elevation. The shells of our raised beach (Art. 197) indicated a rise of only some twenty feet. But if you found such sea-shells at a height of twenty thousand feet they would prove that the bed of the sea had been elevated at least to that extent (Art. 128). By this kind of evidence it can be shown that by much the greater part of the dry land has been raised, piece by piece, out of the sea, and that the movements have been far from regular or uniform, seeing that some parts have been upheaved to a much greater height than others.

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II. Proofs that parts of the Crust have sunk down.

207. We have now traced out some facts which show that the surface of the globe has from time to time been pushed up, so that parts of the sea-bottom have become dry land. But other movements of exactly an opposite kind have turned parts of the land into the bed of the sea. Let us follow some of the evidence for these depressions, and take, as before, our illustrations from places which are easily visited, and in our own country.

208. Along some parts of the coast-line of Britain, as for example on the coasts of Devon and Cornwall, and on that of the Firth of Tay, a very curious and interesting feature occurs between high and low-water mark. From the flat sandy surface of the beach a number of dark stumps may be seen sticking up, which on closer examination prove to be the lower ends of

FIG. 36.—Section of a Submerged Forest.

trees. Scraping away the sand of the beach you meet with dark loam or earth, out of which the tree-stumps protrude, and from which you may pick up hazel nuts, leaves, twigs, and, now and then perhaps, the wing-case of a beetle, or the bone of some land animal. As you trace stump after stump along the beach, you see that they are all in the usual upright posture in which trees grow. The dark earth in which the tree-roots spread is clearly an ancient soil, in which to this day may be gathered the very leaves, twigs, and nuts which fell from the trees, and fragments of the insects which lived amid their decaying timber. These stumps on the beach are evidently parts of an old forest or wood.

209. But could the trees ever have grown where their remains are now to be seen? By no means. The hazel, birch, alder, and oak, of which the stumps mostly consist, would be killed if their roots and trunks were to be permanently submerged in the sea. You never see any of these trees growing below tide-mark now, and you cannot suppose that they ever did so. If the trees on the beach must have grown where their remains still exist, and if they could not have grown up in the sea, then, either the sea must have risen up so as to cover them, or the land must have sunk down so as to submerge them. But we have already learnt (Art. 203) that in all such cases of change of level we cannot believe that the sea alters its level to any appreciable extent, so that we must conclude that the submergence of the old trees has been due to a sinking down of the land. These **Submerged Forests**, therefore, are to be regarded as evidence of subsidence of the earth's surface, just as the raised beaches are taken as proofs of upheaval.

210. You can understand that it must be more difficult to trace evidence of ground having sunk than of its having risen in level. Because when any district has gone down below the sea, the waves gradually obliterate all trace of the former land surface, as they

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are now washing away the submerged forests; while, on the other hand, when the bed of the sea is turned into dry land such traces as raised beaches, and old sea-worn caves, remain to mark the space which the salt water once covered.

211. In different parts of the globe it has been observed that the sea appears to be gradually rising upon

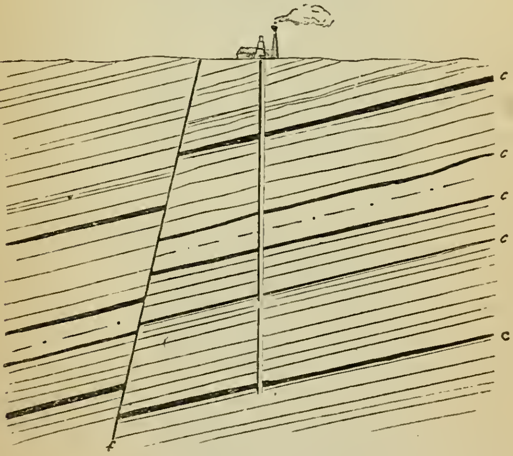

FIG. 37.—Section of the Strata in a Coal-pit. *c*, Coal-seams. *f*, a fault or fracture of the rocks.

the land. In reality it is the land which is there sinking below the sea. For example, the southern part of Greenland for several hundred miles has during the last few centuries been slowly subsiding, so that rocks which once lay above the limits of the tides are now submerged, and the dwelling-houses of the inhabitants have had to be shifted further and further inland.

212. Other proofs of the same fact have already been referred to in the foregoing Lessons. The beds of coal, for example, which once flourished as green forests at the surface are now found buried deep within the earth. By what process did they get there? Let us return for a while to the Coal-pit referred to in Art. 137.

213. In many parts of Britain the coal-pits are more than a thousand feet deep. And yet down at the bottom of each of these pits lies the coal-seam, which we have found to be a buried swamp or jungle. If you could look at all the rocks which have been cut through in making the long shaft of the pit, you would usually find among them other coal-seams than the one at the bottom. In fact, several seams are sometimes worked for coal at different levels in the same pit. You will understand their position from the section in Fig. 37, which shows how the rocks lie one above another in one of these pits. You notice that the seam down to which the shaft has been sunk is the fifth of the series, but it is chosen in the meantime, probably because it is a better kind of coal than the other four seams above it, and therefore brings more money in the market.

214. In such a section as that in Fig. 37, which shows only what may be met with in any coal-field, we see that the strange revolution whereby a green waving forest has been buried underground must have happened not once only, but many times; for every separate coal-seam was evidently at one time a verdant plain, open to the sun, and bright with many a graceful tree and fern. And still more, besides the evidence of the coal-seams, upright stems

of trees, now turned into stone, are sometimes found standing in the sandstones and shales, in the very position in which they grew with their roots even yet imbedded in the ancient soil. (Fig. 38).

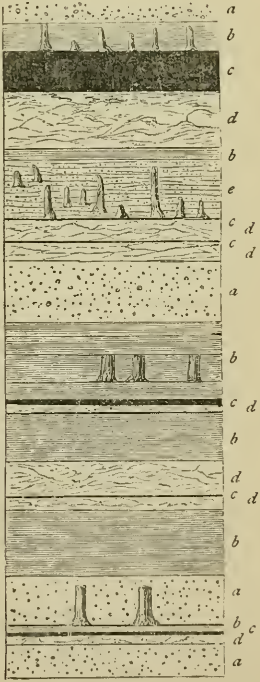

FIG. 38.—Section of a part of the Cape Breton Coal-field, showing seven ancient soils, with remains of as many forests. (R. Brown.) *a*, Sandstones. *b* and *e*, Shales; *c*, Coal-seams; *d*, Underclays, or Soils.

215. The lowest strata are of course the oldest (see Art. 122). Hence the undermost coal-seam must

have been buried before the later forests could spring up on its site. It grew probably in a wide, marshy plain, which when the ground sank down became a wide sheet of water. Sand and mud were carried into this water, and laid down upon the submerged forest. These sedimentary deposits may now be traced in the beds of sandstone and shale which overlie the coal-seam. The sand and mud brought into the wide and shallow sheet of water might in the end fill it up so that at length, as the muddy bottom rose to the surface, a new mass of vegetation would take root and form as luxuriant a growth as the buried forest had done. But after this had taken place the downward movement of the ground again showed itself, for this second forest was carried beneath the water and covered with renewed accumulations of sand and mud.

216. Hence we learn that our coal-fields were formed in regions which were sinking, and that the downward movement was not continuous, but went on at intervals. That it must have been prolonged through vast periods of time is apparent from the fact that the strata of the coal-fields are many thousands of feet thick, and must hence have needed long ages for their formation.

217. Two facts are now very clear to you about the crust of the earth—1st, it has often been pushed outwards, so as to rise above the level of the sea; and 2nd, it has also often sunk inwards so as to carry parts of the land deep beneath the sea-level. But it could not undergo these movements without suffering other changes, which will be considered in the next Lesson.

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III. Proofs that the Rocks of the Earth's Crust have been tilted, crumpled, and broken.

218. If you think about the movements described in the two previous Lessons, and consider how often the crust of the earth must have been pushed up or let down, you will not be surprised to find that the rocks have not only been shifted up or down, but have been crumpled up and broken across. Hence the crust of the earth, instead of being made of regular layers one above another, like the coats of an onion, has been so squeezed and fractured, that in many cases the bottom or oldest rocks have been pushed up far above the newest. Let us clearly understand how this statement can be made out; and for that purpose we shall begin as before with the simplest case.

219. Look back again for a moment at the view and section of the Raised Beach in Figs 33 and 34. The old sand and gravel beds have there unquestionably been raised up above their former level, but they have not otherwise been disturbed. They still lie out horizontally as they used to do. But would this be the case everywhere along that terrace? You remember that we ascertained that the terrace cannot be traced all round the country, that it dies out in certain directions, and consequently that the elevation which produced it was not universal but local. Now it is clear that though the upheaved tract rose so uniformly that the raised beach may retain the same level for many miles, still, between the horizontal strata which were upraised, and those which, lying outside of the

elevated district, remained unchanged in level, there must be an intervening space, longer or shorter, where the strata slope down from the raised to the stationary ground.

220. To make this clearer, suppose by way of illustration that we place upon a table a number of sheets of cloth to represent the different strata with which we are dealing. The cloths, like the strata, lie there horizontally. But if we push them up anywhere they will be found to slope away from the elevated to the unmoved part. Put a flat plate, for instance, underneath them, so as to raise a considerable surface. Over the flat surface of the plate the cloths are flat, as they are in our raised beach, but from that upraised area they slope down to the undisturbed parts around. So that you see how a local elevation, even though it may raise up strata over a wide district without disturbing their flatness, must yet give rise to an inclination of the strata round the outskirts of the movement.

221. Wherever, therefore, strata are pushed up or let down more at one place than at another, without being actually broken across, they must be thrown into an inclined position. Now this unequal and irregular kind of movement has taken place many times in every quarter of the globe. If you look at the stratified rocks, in most parts of this and other countries, you will seldom find them quite flat—usually they are inclined, sometimes gently, sometimes steeply, so that they have not only been upheaved out of the sea (Art. 206), but have been moved irregularly and unequally.

222. In the quarry which we formerly visited

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(Art. 119) the strata were horizontal. But in many quarries you would find them turned up as in Fig. 38, where the right-hand portion has gone up (or

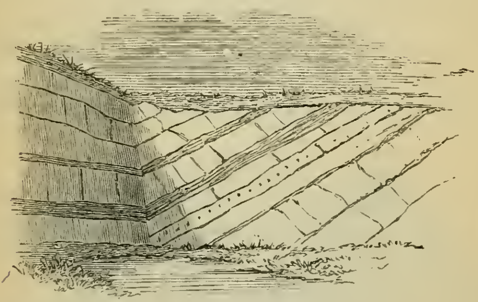

FIG. 38.—Inclined Strata.

the left-hand parts have gone down) more than the others. In some places, indeed, you will meet with

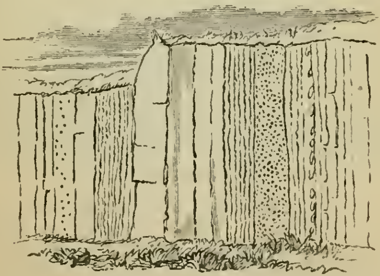

FIG. 39.—Vertical Strata.

the rocks so tilted up as to stand fairly on end (Fig. 39), like a row of books on a shelf. As they are made of sediment which gathered on a flat or

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gently sloping bottom, you see at once that they never could have been placed on end originally, but have been tilted into this position by underground changes.

223. But this is not all. If when the cloths were lying flat on the table (Art. 220) you had squeezed them from either end, they would have been thrown into crumplings (Fig. 40). In the same way during the

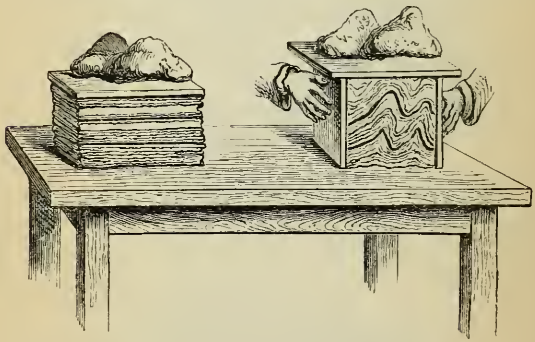

FIG. 40.—Cloths crumpled by pressure.

movements by which the strata have been raised up a great deal of similar crumpling has taken place. In Fig. 41, for instance, the hard rocks are shown to have been twisted and folded over as if they had been mere layers of cloth. How enormous must have been the pressure to which they were exposed before they were squeezed into these shapes!

224. One difference between the cloths and the strata will occur to you. The one are soft and pliable, the others hard and rigid. But we may make even the most unyielding rocks to bend a little, and if this

can be done even with the comparatively feeble force which man can employ, we may perceive how, under the enormous pressure which they underwent in the depths of the earth before they were upheaved, the rocks should have been crumpled up like mere pliable layers of cloth.

225. Still there must sometimes have been a point beyond which they would rather break than bend any

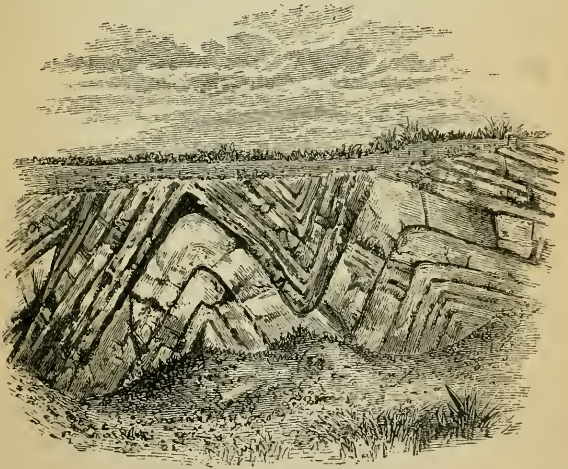

FIG. 41.—View of contorted strata.

further. Cracks would then be formed, and the strata would be thrust up or made to sink down. You see one of these cracks, or **faults**, as they are called, at *f*, in Fig. 37, where the coal-seams and the strata between them have been broken across—those on one side of the fracture being now found at a lower level than those on the other. Dislocations of this kind are of such frequent occurrence that the whole surface of the earth may be looked upon as a network of cracks. They greatly interfere with the working of coal-mines, as shown in Fig. 37, where the galleries which are driven along the coal-seams from the pit towards the left-hand will need to be altered where the coal is cut off by the dislocation *f*.

226. It has often happened that into the cracks thus formed masses of melted or igneous rocks from the

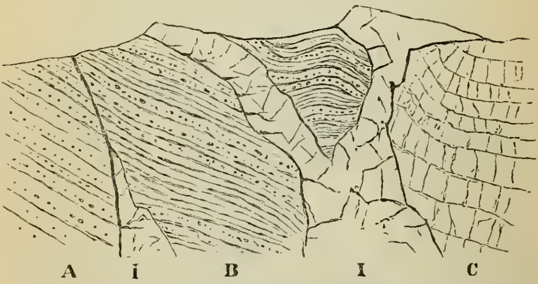

FIG. 42.—Section of Igneous Rock forced up into Cracks and Fissures of the Earth's Crust.

interior have been pressed, so as to rise up and intersect the other rocks. In the section in Fig. 42, for example, two such dislocations have occurred in a series of stratified rocks, so that three different groups, A, B, and C, have been displaced. Into one of these cracks a mass of igneous rock (I) has forced its way for some distance. But in the other, that to the right hand, a much larger body of melted rock has risen so as completely to separate the stratified rocks B and C, and not only so, but to break through the group B, ascending even to what is now the surface of the earth.

IV. The Origin of Mountains.

227. It is common to speak of the "eternal hills" as if they had existed from the very beginning of the world's history. And certainly few objects upon the surface of the globe convey to the mind such an impression of vast antiquity. As far back as history or tradition can go the mountains have remained without sensible change; and thus, because they have always appeared to man to be what they still are, he is apt to think of them as parts of the original architecture of the planet.

228. And yet from what has been learned in some of the foregoing Lessons, you will be prepared to find that old as the mountains undoubtedly are, they do not belong to the beginning of things. It is still possible to trace out their origin, and to get back to the records of earlier times before they existed at all. If I ask how this knowledge can he gained you will doubtless answer that it can only be by examining the rocks of which the mountains consist. You have already learnt how rocks tell their story. It is only a further stage of the same kind of reasoning to inquire what the rocks tell regarding the birth of the mountains.

229. First of all, then, when any chain of mountains is examined it is found to be made of rocks belonging to one or more of the three great classes—with which you are already acquainted. In particular, the great mass of most mountain chains consists of various kinds of stratified rocks—such as sandstones,

conglomerates, limestones, and others. Now you have found that these rocks have been laid down under water, most of them under the sea. They often contain the remains of shells, corals, sea-urchins, or other marine creatures, and these remains may be taken out of the rocks even at the summits of the mountains (Art. 160). No clearer proof than this could be required to show that mountains are not so old as "the beginning of things," for these fossils prove that where the mountains now stand wide seas once rolled.

230. Again, mountains which consist of rocks formed originally under the sea must owe their existence to some force which could raise up the bed of the sea into high land. That force has been already (Art. 187) alluded to. As a consequence of the slow cooling of our planet, its outer crust, under the enormous strain of contraction, has been forced up into ridges in different places, with wide, sunk spaces between. The ridges form mountain chains, while the sunk spaces are filled with the waters of the ocean. If you look at a map of the world you may trace out the principal **lines of elevation**, as they are called, over the globe. Perhaps the most remarkable of all the folds or puckerings into which the surface of the earth has been ridged up is the long line of mountains which runs down the whole of the continent of America. You observe that the various ridges of the Rocky Mountains, of Central America, and of the Cordilleras and Andes, are prolonged in one vast line of elevation. Other minor foldings are seen on the same continent, as, for instance, the chain of the Alleghanies, in the eastern part of the United States.

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In Europe we have a line of elevation stretching across the continent, and throwing off spurs in its course. It is seen in the Pyrenees, then in the Alps, whence, after sending southwards the ridges of the Apennines, it is carried eastward by the chain of the Carpathians, and then by the Caucasus to the Caspian Sea. The same line, however, reappears on the other side of that inland sea, and crosses the vast continent of Asia in two divergent lines; one of which turns south-eastward, to form the grand Himalayas, while the other trends eastward across the great Asiatic table-land to the shores of the Pacific Ocean. When you reflect upon these enormous mountain-chains as the results of the cooling and contraction of the mass of the globe, you begin to feel how enormous

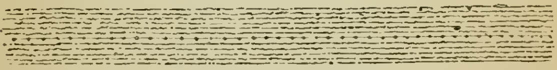

FIG. 43.—Section of a series of Sedimentary Rocks originally deposited horizontally on the sea-bottom.

must be the force which could crumple up solid rock into ridges many thousands of miles long and thousands of feet high.

231. But as the globe has been cooling and contracting since the very first, we may reasonably expect to find that mountains have been uplifted at various times, and, therefore, that they differ from each other in age. A little attention to the rocks is enough to show not only that mountains are not all of the same age, but that even the same mountain has not been formed entirely at one time, but that one part has been raised up long before another.

232. Suppose, for example, that a series of ordinary

sedimentary rocks, such as the sandstones, conglomerates, and shales, described in earlier Lessons, has been laid down upon the sea-bottom. These rocks would be formed one above another in flat beds (Fig. 43), until they had accumulated into a mass perhaps many thousands of feet in thickness. They might remain undisturbed for a long time. Let us further suppose,

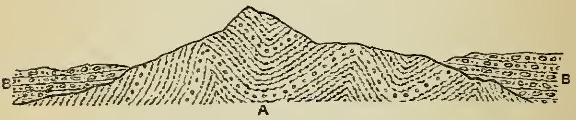

FIG. 44.—Section of a mountain formed of crumpled rocks, A, which have been contorted before the deposition of the flat rocks, B.

however, that they happen to lie in one of those weaker parts of the crust which, when the accumulated effects of the long-continued contraction of the earth's mass begin to make themselves felt, are pushed outward by the subsiding spaces on either side. Squeezed together by the pressure of these sinking areas the

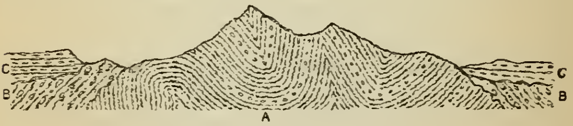

FIG. 45.—Section of a mountain in which the rocks A were upheaved before the series B, and the latter before series C.

formerly horizontal rocks will be crumpled up into folds (like our cloths in Fig. 40, when similarly squeezed), and be made to rise above the level of the surrounding tracts (Fig. 44). A ridge or mountain-chain would thus arise upon the surface of the earth.

233. Such a ridge or chain formed out of sedimentary rocks (A), once horizontal but now contorted, could not rise up into the atmosphere without becoming a prey to those various forces, which, as you have learnt (Physical Geography Primer, Arts: 126—142), are ceaselessly at work in wearing down the surface of the globe. The air, rain, springs, rivers, frosts, or the waves of the sea, would attack the newly formed mountain, and begin to waste its surface as soon as it raised its head above the level of the ocean. Deep furrows would in time be carved out of its sides, and all its decayed fragments would be washed down to the lower grounds. There these fragments would form new deposits, which would be laid down upon the edges of the older rocks, as in Fig. 44 the newer series B is seen to lie upon the older A.

234. Now such a section as this (Fig. 44) would enable you to fix, relatively at least, the date of the mountain. You could assert positively that, 1st, there was a time when the mountain did not exist, but when its place was occupied by a sea in which the sedimentary rocks A were deposited; 2nd, that the mountain was formed by the crumpling up of these rocks, and that this took place before any of the rocks of series B began to be formed; and 3rd, that after the formation of the strata marked B the whole mass was further uplifted so as to raise these strata out of water into dry land.

235. But suppose that in some other part of the chain we discover such an arrangement of rocks as that shown in Fig. 45. Here, as before, we see that the series A was upturned before the series B could be laid down on it. But in the present case series B

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has also been tilted up out of its original horizontal position. Such a mountain would indicate three successive periods of upheaval, the first older than the time of B, the second older than the time of C, while the third came after the formation of C, for it raised that series of strata into land.

236. It is in this kind of way that the relative ages of mountain-chains are determined. Wherever you meet with sedimentary rocks turned up on end or crumpled, you know that they have been disturbed, and whenever these disturbed rocks have their broken edges covered by others, you see that the uplifting must be older than the second set of rocks.

237. If now you could find out any means of recognizing the same series of rocks in different countries: if, for example, you could be sure that the groups A and B of Figs. 44 and 45 occurred both in England and Germany, you would be able to compare the relative ages of the mountains of the two countries. If in the one country a mountain shows the structure represented in Fig. 45, and if in the other country a mountain formed of the same series of rocks is built up in the way shown in Fig. 44, you would infer that the former mountain was newer than, or, rather, had received a push upward after, the latter.

238. In the next Lesson it will be shown how geologists identify the same series of rocks in different countries—viz. by Fossils. With this kind of evidence it becomes possible to decide which are the oldest and which the newest mountain-chains. In this way we learn that the giant Alps, towering so far above the plains of Europe, are less ancient than many a green hill in Wales and Scotland.

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239. But another singular and important fact about mountains is made plain by such sections as those in Figs. 44 and 45. The series of rocks marked A is the oldest part of the mountain in each case. You might naturally suppose that the oldest parts ought to be those which are buried deep under other portions. And yet on examination it is found that the most ancient parts are not always those which lie at the

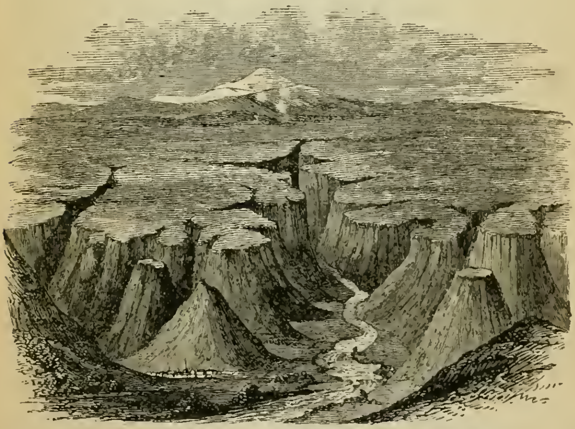

FIG. 46.—View of a table-land cut into ridges and valleys by the flow of its rivers.

lowest level, but that, as in the two cases we have supposed, they may have been pushed up so as now actually to form the loftiest peaks and ridges. But if you get away to the flanks of the mountain you find that the oldest rocks do really pass under the newer ones, as series A in the drawings passes under B.

240. The crumbling down of the surface of the

earth is so constant and so wide-spread, that in process of time every mountain-chain undergoes great and manifold changes. Its summits and sides are wasted and lowered. Its crests get splintered into peak and pinnacle, as the rains and frosts of ages do their work upon them. Crag and cliff are carved out of its sides ; ravine and gorge, wider glen and still wider valley, are excavated in its rocks by the never-ending flow of rill and river. Hence, though the original line of elevation remains, the upheaved tract is cut into innumerable ridges and valleys as the process of waste goes on. (See Physical Geography Primer, Art. 126.)

241. So enormous have been the effects of that process over the surface of the earth, that great table-lands or broad masses of high land have been cut down into mere ridges and detached hills. In Fig. 46 you may as it were watch how the excavation proceeds. That is a drawing of part of a table-land in Spain. You observe how the streams as they descend and become larger in size, dig wider and deeper trenches out of the rocks, how their ravines widen out into valleys, how the high ground between them is being cut into irregular ridges, and how these ridges, still further cut into separate hills or mounds, lose height as the rains and frosts attack their summits and sides. In every quarter of the globe illustrations of these changes may be found. In Britain, for example, our mountains are only fragments, like those in the drawing, which have been left after the excavation of the valleys that surround them. The great Ghauts of India, and the Table Mountain of the Cape, are likewise conspicuous instances of the same kind of origin.

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242. The same forces which have carved out valleys and left mountain-ridges standing out between them are still busy at their work. Every year adds to the waste. And thus, although when we gaze at a mountain-chain we know that first of all it was heaved up by movements from below, we nevertheless learn to recognize that all the familiar forms which it now assumes have since that early time of upheaval been carved upon it by the very same forces—rains, frosts, springs, glaciers, and the rest—which are busy sculpturing its surface still.

V.—How the Rocks of the Crust tell the History of the Earth.

243. When a historian betakes himself to write the history of a country, his first care is to make himself acquainted with all the scattered documents likely to throw light upon the transactions which he will have to describe. He ransacks the papers in the public archives and libraries, gleans what he can from printed books, and even it may be travels into foreign countries in search of contemporary writings which may explain what is dark or uncertain at home. Only after prolonged labour of this kind, is he able to gather up the sum of all he has learnt, and to weave it into a continuous narrative. In the course of his researches he will no doubt find some periods much better illustrated by contemporary documents than others, while of some he may possibly be hardly able to collect any satisfactory information, for in the course of time the papers which would have supplied him with the facts are

lost or destroyed. Hence his history is not all equally full and reliable. There may even be gaps in it which no amount of industry in his search for information has enabled him to fill up.

244. Now what is thus true of the historian of any country, is true also of the geologist. As already pointed out (Art. 38), and as must now be very clear to you, the earth has a history as well as the people who dwell upon its surface. A geologist may be called a historian of the earth. His great aim is to collect all the evidence which remains of the changes that have happened upon the earth's surface, and to arrange them in the order in which they have occurred, so as to show the grand march of events down to the present time.

245. What papers and inscriptions, coins and books are to the historian, the rocks of the earth's crust are to the geologist. They contain all the real evidence at his disposal. What he can gather from them at one place must be compared with what he collects from them at another. He must journey far and wide in search of facts which are not to be found at his own door. Gaps will certainly occur, which even the skill and industry of many years may never completely bridge over; for the rocks, as we have already seen, are subject to revolutions quite as destructive in their way, as those which have swept away the archives of cities and nations. The geologist, therefore, can only at the best produce an imperfect chronicle. But it is one which has a profound interest for all of us, for it is the story of our own globe—of its continents and oceans, its mountains and valleys, its rivers and lakes, of the tribes of plants and animals which people

its surface, and of the advent and progress of man himself.

246. Regarding the earliest stages of the earth's history no direct evidence is now to be obtained from the rocks. When the earth was detached from its parent sun, it must have been a fiercely hot mass as the sun is still. Not until long after that period could any such rocks as we now see have been formed. So that although the rocks carry us a vast way back into the past, they cannot bring us to the beginning of the earth's history as a separate planet. That early time can only be inferred from other and chiefly astronomical evidence.

247. In the foregoing pages you have learnt how the rocks may each be made to give up its little bit of earth-history. You succeeded in discovering, for example, from the rocks of a single quarry the site of an old sea-floor with some of the remains of the sea-creatures which lived upon it (Arts. 118—131). Again, you found how a peat-moss might enable you to trace out the limits of a long-vanished lake on which our rude forefathers launched their oak canoes (Arts. 144—152); and how the rocks of a coal-pit could furnish forth a record of forest after forest which had each flourished green and fair at the surface, but which had sunk down one after the other, and were now buried deep within the earth. (Arts. 137 and 212.)

248. In these and all such illustrations, while each series of rocks tells its own story, that story is only a part of the general history of the earth. The more carefully we can gather each separate narrative, the fuller will be that general chronicle of the earth's history which it is the object of geology to compile.

249. According to the law of superposition (Art. 122) the undermost stratified rocks are the oldest. We can reach but a little way down into the earth. The deepest mines descend but a very few thousand feet into the rocks. If, therefore, these rocks still lay flat as they were deposited, we should be able to make ourselves acquainted only with those near the surface. But in consequence of the way in which the rocks have been bent and broken, and pushed up and down (Arts. 188, 218—226), we not only see the topmost parts of the series, but even some of the oldest masses. Instead of lying flat, the rocks are very commonly found to slope into the earth more or less steeply, and we can walk over their upturned edges, like the backs of so many rows of books. (See Figs. 38 and 39.) So far therefore from the bottom rocks being still buried under the thousands of feet of solid rock beneath which they once lay, they are often found rising into the summits of lofty mountain ranges (Art. 239). And thus the geologist is saved the trouble of sinking deep bores and pits to find out the order of the rocks under his feet. By making careful sections from what can be observed at the surface (as in Figs. 44 and 45), he determines that order with certainty, and when he has done so he knows which are the oldest parts of his chronicle, and which are the newest.

250. The crust of the earth, so far at least as we can examine it, is chiefly made up of Sedimentary and Organic Rocks. In these rocks, therefore, must the chief sources of evidence for the history of the earth be sought. If we could pile them up, one above another, in the order of their formation, they would

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form a mass probably more than a dozen miles thick. This, then, is the library out of which geological history must be compiled.

251. Besides the order of superposition, however, the geologist has another clue to the relative age of rocks. By comparing the different series of rocks with each other he has discovered that the fossils, or remains of plants or animals (Art. 117), of one series differ from those of another. For example, to turn again to Fig. 45, it is ascertained that if fossils occur in the set of rocks marked A, they will be found to differ from those in the series B, and these again from those in C. If, starting from the plants and animals of to-day, we go back into older and yet older rocks, we learn that the fossil plants and animals become, on the whole, more and more unlike those which are still living. Each great division of rocks is found to have its own characteristic fossils. So that, over and above the test by Order of Superposition, we can discriminate between these divisions by means of Fossils.

252. By these methods of classification the vast complex mass of Stratified Rocks may be divided into a few great divisions, these into subdivisions, these again into minor compartments, and these into still smaller zones or bands, so that when a bed of rock is found it can be referred to its own particular part of the whole vast series. This method of arrangement is necessary for the sake of clearness, very much in the same way that a work on history requires to be divided into volumes, these into separate books, these again into chapters, and these into pages and lines.

253. Making use, therefore, of every kind of evidence which the rocks afford, the geologist endeavours

to weave together his narration of the history of the earth. He shows how land and sea have often changed places, how time after time volcanos have broken out in all quarters of the globe, how continents have, one by one, arisen, how mountain-chains have been successively formed, how valleys, and ravines, and lakes, have been excavated, how climates have slowly changed from tropic heat to arctic cold. Amid all these revolutions of the solid earth itself, he finds that there have been at the same time vast changes in the plants and animals which have peopled its surface. He can trace how Life, beginning in the remotest past with the simplest organisms, has advanced through long ages, in more and more highly organized forms (Art. 132), up to the present time. He can mark how group after group of shells, or fishes, or reptiles, has come into existence, and, after living for protracted periods, has slowly died out to make way for newer tribes, until towards the close of the history Man has appeared upon the scene.

254. Geological history brings before us, in this way, many facts well calculated to impress our minds with the great antiquity of our planet, and with the marvellous chain of changes by which the present order of things has been brought about. We learn from it that mountains and valleys have not come suddenly into existence, such as we now see them, but have been formed gradually, by a long series of processes similar to those which are even now slowly doing the same work. We discover that every part of the land under our feet can yield us up its story, if we only know how to question it. And, strangest of all, we find that the races of plants and animals which now tenant

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land and sea, are not the first or original races, but that they were preceded by others, these again by others still more remote. We see that there has been upon the earth a history of living things, as well as of dead matter. At the beginning of that wonderful history we detect traces merely of lowly forms, like the foraminifera of the Atlantic ooze. At the end we are brought face to face with Man—thinking, working, restless Man, battling steadily with the powers of Nature, and overcoming them one by one, by learning how to obey the laws which direct them.

CONCLUSION.

255. It is not the design of this little book to enter further into the history of the Earth. It has led you to the threshold whence you can see the kind of interest in store for you if you advance beyond. You have now learnt something of the general principles upon which the history is based. Looked at in the light of geological teaching, the very stones of the street and the pebbles of the shore have each a meaning for you now. You will no longer be content to gather minerals and rocks merely because they are pretty objects to look at. Apart from their beauty you will seek to discover what they are, and how they came to be where they are found.

256. A landscape will lose none of its beauty in your eyes though you seek to discover how the rocks of its hills were formed, how ridge and valley came into existence, why a crag should rise in one part and a wide plain stretch away for miles in another. When you stand by the brink of a foaming river there will

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be no lessening of your pleasure in its rush and roar, if you think of the river as one of nature's most powerful engines, busy day and night in digging out its channel in the rocks, and carrying the waste of the mountains down to the plains and to the depths of the ocean. The shores of the sea will wear a new charm when you trace along their cliffs and caves the progress of decay, and on their beaches of sand and shingle the counterpart of those sedimentary deposits out of which whole mountains are built up.

257. Every quarry and ravine where the naked rock comes to view, offers an attraction, if you seek to find there the remains of some of those lost forms of plants which covered the land, or of those long extinct tribes of animals which once tenanted the sea. These fossils will become, in your hands, not mere things to wonder at. You will try to learn, from friend or book, what they resemble most in the present living world. And you will not rest contented until you have seen all that you can discover of the light which they throw upon the former condition of the district in which you find them.

258. Geology will thus be no longer a task to be conned from books, but a delightful companion in every walk and ramble. You may never become geologists, but you will never regret the time you have spent in trying to master the principles on which geological science is based, and to trace out under their guidance the marvellous History of the Earth.

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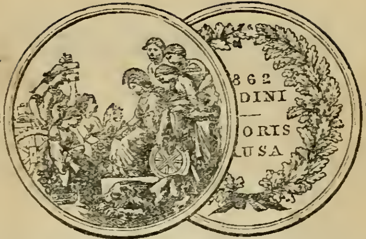

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