[S]cience Lectures

at South Kensington.

OUTLINES

OF

FIELD-GEOLOGY.

BY

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WITH ILLUSTRATIONS.

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LECTURES TO SCIENCE TEACHERS.

OUTLINES OF FIELD-GEOLOGY.

With an Account of the Use of Surveying Instruments and the Construction of Geological Maps.

BY PROFESSOR GEIKIE, LL.D., F.R.S., DIRECTOR OF THE GEOLOGICAL SURVEY OF SCOTLAND.

No questions are probably put so frequently to the field-geologist as these—"How do you know what lies beneath the surface soil? Do you dig or bore?" When he replies that he neither digs nor bores, yet can usually infer with considerable confidence what must be the nature of the rock underneath, his statement is received with a look of bewilderment or a half-incredulous smile. I propose in the two lectures to be given by me here to furnish such an answer to these popular queries as may enable you with a little practice to perform the geological operations which at first are supposed to be so occult. The term FIELD-GEOLOGY, which I would select as expressive of my subject to-day, points, as you will infer, to practical work in the open field, as distinguished from the researches which may be carried on in the library or laboratory. I wish to describe some of the methods by which a geologist obtains his information regarding the nature, position, arrangement and history of the rocks of a country. Such practical observation evidently underlies all solid research in geology. He who would pursue the theoretical parts of the science must either himself lay a foundation in good thorough field-work, or take advantage of the foundation which has, in this respect, been laid for him by others.

Field-geology may be pursued with various aims and in various ways. To some men it is little more than another name for holiday-making in the country—fresh air, healthy exercise, new or old charms of scenery, and a bag full of "specimens" to attest the scientific nature of the work. To others it is the solace and delight of busy lives, furnishing them not only with bright intervals of escape to the country, but with materials for much profitable thought and study when the ordinary duties and cares of life confine them to their work in town. To other men, again, it is itself the main occupation of life, whether they cultivate it for its own sake, or with a view to the economic applications of which it is susceptible.

There are few countries or districts where field-geology may not be cultivated, and where its healthful influence as an educational instrument may not be tested. A few days of intelligently guided observation in the field are worth far more to a pupil than many weeks of lectures and reading. But we seldom hear of such practical instruction, mainly because the teachers never received it, and have not had time, inclination, or opportunity to develop it for themselves.

1. Preliminary Considerations.—Necessity of a Map.

The results obtained by the geologist in the field from his investigation of the rocks may be set down either in writing, or in maps and sections. No one can follow the practical pursuit of the science without being conscious how much his work gains in precision when he is compelled to put it down upon a map. Not only is his information made more accurate when he requires to trace the exact lines of geological boundary, but he is led to search in nooks and corners of which he would not otherwise have suspected the existence, and thus he acquires a thoroughness of grasp which can be attained in no other way. The best field-geology is of that kind which careful and minute map-making requires. It is not, of course, imperative that an actual survey should be made by the geologist; but he must proceed in such a way that his observations, if tabulated and placed upon a map, would make that map a good geological one.

Since, then, the kind of work required in the preparation of geological maps illustrates most completely the nature and methods of field geology, I shall describe the construction of these maps as practised in this country. You will bear in mind that though you may never draw a geological boundary line, nor take any part in a geological survey, you cannot attain excellence in the practical pursuit of geology in the field without going through the training which, if need be, would qualify you for becoming professional geologists. How this should be the case will, I hope, become clear to you before we part company here.

Let us first consider what a "geological map" is. The meaning now attached to this term differs very much from that with which it was associated not very many years ago. In the early days of geology those who devoted themselves to this branch of science were mineralogists rather than what we should now call geologists. They termed their subject "geognosy," meaning thereby to indicate their object to be the increase of their knowledge of the minerals and rocks of the earth. They constructed what they called "geognostical maps," on which the positions of marked varieties of minerals and rocks were shown, but without any attempt at accurate, or even sometimes approximate, boundary lines, and with no hint whatever of geological structure, which we now regard as one of the chief objects of geological maps.

A perfect geological map should represent—1st. A full and accurate topography, with the form of the surface and heights in contour-lines, shading, or otherwise. The Ordnance Survey maps of Britain on the scale of six inches to a mile may be taken as an admirable example. 2nd. All geological deposits, from the most recent to the most ancient, which may occur in the district embraced by the map, with their boundary-lines accurately traced, and the relation of their distribution to the external form of the ground clearly depicted. 3rd. The geological structure of the region, that is, the relation of the rocks to each other, their inclination downwards from the surface, their curvatures and dislocations; in short, all particulars necessary to enable a geologist to apprehend the manner in which the rocks of the crust of the earth beneath the region in question have been built up. 4th. Information which may have special economic value, such as the nature and distribution of the soils, the position of available building materials, the direction, thickness, and extent of ores, coal-seams, or other useful minerals, the best sources of water supply, &c.

To fulfil these various requirements the map must evidently be not on too small a scale. If the scale is small, the attempt to crowd a great deal of information into the map may result in confusion of detail, and most of the beauty and usefulness of the work may be lost. In such cases it is better, where practicable, to subdivide the labour, putting the older geological formations on one copy of the map, the superficial accumulations and soils on another, the industrial information on a third, and so on. But without attempting to express all the detail possible, we may construct a correct and serviceable geological map of a district or country by generalising the information so as to give at a glance a broad and clear view of the distribution of the formations and the chief points of geological structure.

The Geological Survey of Great Britain and Ireland is constructed chiefly upon field-maps (Ordnance Survey), on the scale of six inches to the British statute mile, or $\frac{1}{10560}$ of nature, but some limited districts, where great detail is required, have been surveyed on the scale of twenty-five inches to the mile. The general geological map of the British Islands is published on the scale of one inch to the mile, or $\frac{1}{63360}$ of nature. A convenient scale for a generalised map of a country is ten miles to an inch. Of course the smaller the scale the less detail is possible, and the more care must be taken to select those geological features which are of prime consequence.

More important than the scale is the correctness of the topographical map which is to serve as the basis of the geological one. Unless the geography be accurately depicted, geological lines may be distorted, sometimes to an extent which seriously interferes with the value of the map. That you may see the importance of this point, let me draw your attention to two diagrams which represent the influence of correct and incorrect topography upon geological lines. You will observe that the same district is represented in both drawings; the streams and their tributaries are the same in both, but differ considerably in direction. A geologist trusting to the map A inserts the boundary lines between the formations 1, 2, 3, 4, and 5, guiding himself by the points of intersection of the different streams. If now he were to trace these same lines on a map with the correct topography, as shown in B, he would find them to present considerable

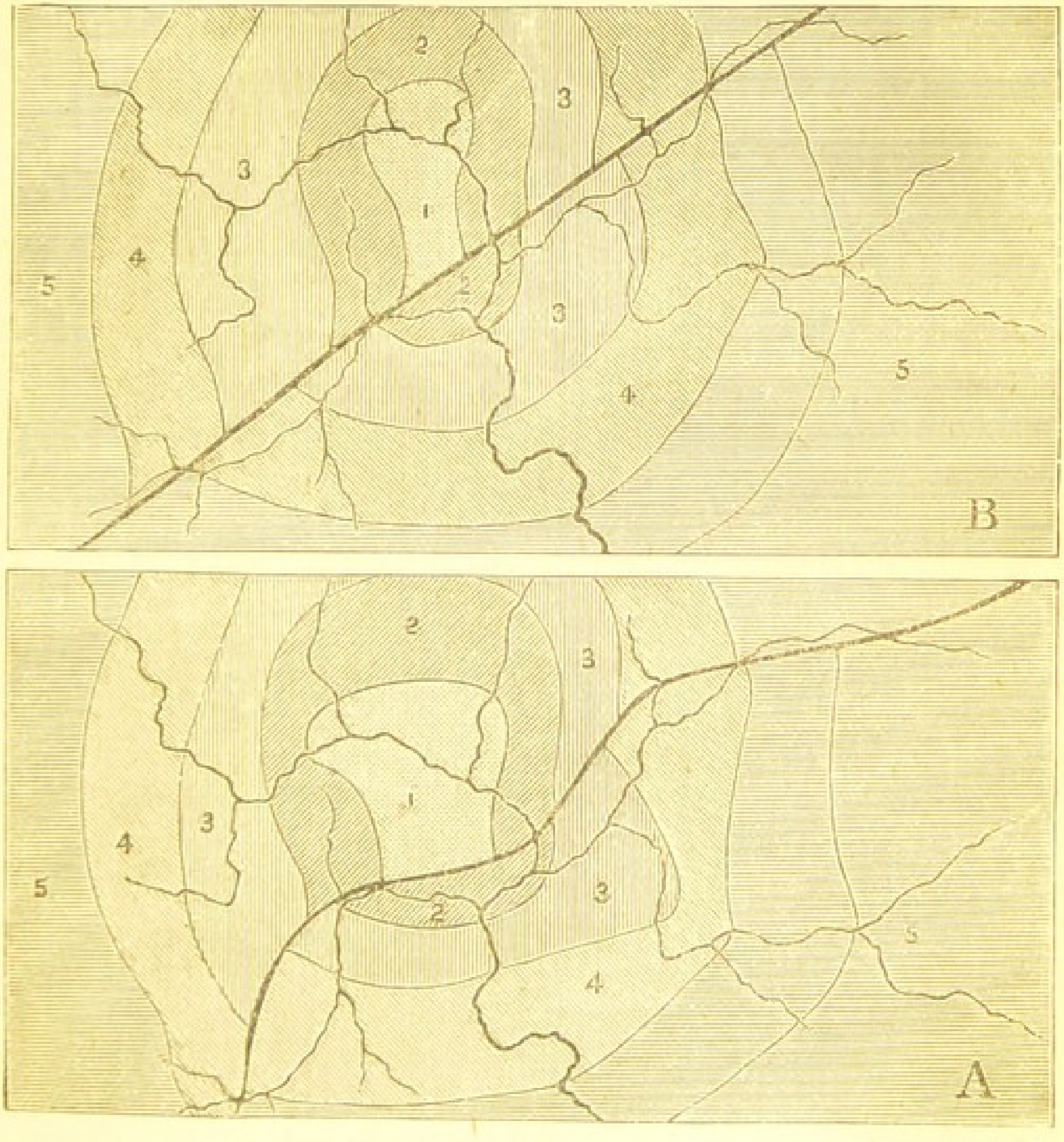


FIG. 1.—Maps showing the effect of incorrect topography in distorting geologica lines.

differences from those on A, although crossing each stream at the same points on each map. In A his thick black line is a winding one, in B it is nearly straight. Should this boundary be a line of dislocation, you will see that by the one map he might be led to speculate upon a curved dislocation, in the other on a straight one.

In this country we fortunately possess accurate Ordnance maps on various scales, so that except in those few and remote districts of which the Ordnance Survey has not yet been completed, we have a good topographical basis, and may reach any degree of finish and completeness in geological map-making. It is useful, however, to be able to construct our own rough field-map, or to correct a faulty one. For this purpose we avail ourselves of the ordinary methods of triangulation. We may measure, as accurately as practicable, a base-line along some level piece of ground, such as a river-meadow or a sea-shore. From each end of our measured line we take a bearing with an azimuth compass to some neighbouring object. The point of intersection of the lines of these two bearings gives the position of the object on the map. Having one or two triangles constructed in this way, we may continue triangulating the whole district and filling in the topography, so as in the end to produce a map which may not be quite accurate indeed, but which will probably serve our immediate purpose.

In those parts of the world where no good maps yet exist, geological and topographical surveying are sometimes conjoined. I may cite as admirable illustrations of this union the explorations of the river-courses of Canada by the late Sir William Logan, Director of the Canadian Geological Survey. He and his colleagues had to furnish themselves with canoes, attendant Indians, provisions, and hunting-gear, and push up unexplored rivers winding through the dense forests of the province. They explored, mapped, geologised, and hunted, laying down lines of traverse which served as the base for future more detailed topography, and did vast service in opening up the country. Still more elaborately topographical are the remarkable surveys at present carried out under Dr. Hayden, Geologist in charge of the Geological and Geographical Survey of the Western Territories of the United States. Year by year valuable reports, drawings, and photographs by that able observer and his associates make known the geography, geology, natural history, botany, meteorology, ethnology, and antiquities of thousands of square miles of previously unexplored or but partially explored land.

Having obtained or made as good a topographical map as may be attainable for his purpose, the observer is furnished with the first great requisite for geological surveying, and one of the most useful parts of the equipment of a field-geologist. Before he takes the field, however, let us consider the instruments or apparatus necessary for his work.

2. Accoutrement of a Field-Geologist.

Field-geology does not mean and need not include the collecting of specimens. Consequently a formidable series of hammers and chisels, a capacious wallet with stores of wrapping paper and pill-boxes are not absolutely and always required. Rock-specimens and fossils are best collected after the field-geologist has made some progress with his examination of a district. He can then begin to see what rocks really deserve to be illustrated by specimens, and in what strata the search for fossils may be most advantageously conducted. He may have to do the collecting himself, or he may be able to employ a trained assistant, and direct him to the localities whence specimens are to be taken. But in the first instance his own efforts must be directed to the investigation of the geological structure of the region. The specimens required for his purpose in the early stages of his work do not involve much trouble. He can detach them and carry them off as he goes, while he leaves the full collection to be made afterwards.

It is of paramount importance that the field-geologist should go to his work as lightly equipped as possible. His accoutrements should be sufficient for their purpose, and eminently portable. You may judge of the portability which may be secured when I tell you that I have on my person at this moment all the instruments necessary for carrying on a geological survey, even in the detailed manner adopted in the Geological Survey of this country. You observe, therefore, that a fully-equipped field-geologist need not betray his occupation by any visible implement. The want of such tokens of his craft often greatly perplexes rustic observers, to whom his movements are a fruitful source of speculation. I shall divest myself of my accoutrements one by one as I have occasion to refer to them, and describe their uses.

1. *The Hammer.*—This is the chief instrument of the field-geologist. He ought at first to use it constantly, and seldom trust himself to name a rock until he has broken a fragment from it and compared the fresh with the weathered

surface. Most rocks yield so much to the action of the weather as to acquire a decomposed, crumbling crust, by which the true colour, texture, and composition of the rock itself may be entirely concealed. Two rocks, of which the outer crusts are similar, may differ greatly from each other in essential characters. Again, two rocks may assume a very different aspect externally, and yet may show an identity of composition on a freshly-fractured internal surface. The hammer, therefore, is required to detach this outer deceptive crust. If heavy enough to do this it is sufficient for your purpose ; any additional weight is unnecessary and burdensome. A hammer, of which the head weighs one pound or a few ounces more is quite massive enough for all the ordinary requirements of the field-geologist. When he proceeds to collect specimens he needs a hammer of two or three pounds, or even more, in weight, and a small, light chipping hammer to trim the specimens and reduce them in bulk without running a too frequent risk of shattering them to pieces.

Hardly any two geologists agree as to the best shape of hammer; much evidently depending upon the individual style in which each observer wields his tool. This (Fig. 2) is the form which, after long experience, we have found in the Geological Survey to be on the whole the best. A hammer formed after this pattern combines, as you observe, the uses both of a hammer and a chisel. With the broad, heavy, or square end you can break off a fragment large enough to show the internal grain of a rock. With the thin, wedge-shaped, or chisel-like end you can split open shales, sandstones, schists, and other fissile rocks. This cutting or splitting edge should be at a right angle to the axis of the shaft. If placed upright or in the same line with the shaft, much of its efficiency is lost, especially in wedging off plates of shale or other fissile rocks.

A hammer shaped as I recommend serves at times for other than purely geological purposes. On steep grassy slopes, where the footing is precarious, and where there is no available hold for the hand, the wedge-like end of the hammer may be driven firmly into the turf, and the geologist may thereby let himself securely down or pull himself up.

The most generally convenient way of carrying the hammer is to have it in a leather sheath suspended from a waist-belt. The hammer hangs at the left side under the coat, the inside of which is kept from being cut or soiled by the protecting outer flap of the sheath. Some geologists prefer to carry the belt across the shoulders outside, and the hammer suspended at the back. Others provide themselves with strong canvas coat-pockets and carry the hammer there.

2. *The Lens.*—Even the most sharp-sighted observer is the better of the aid supplied to him by a good magnifying-glass. For field work a pocket lens with two powers is usually sufficient. One glass should have a large field for showing the general texture of a rock, its component grains or crystals,

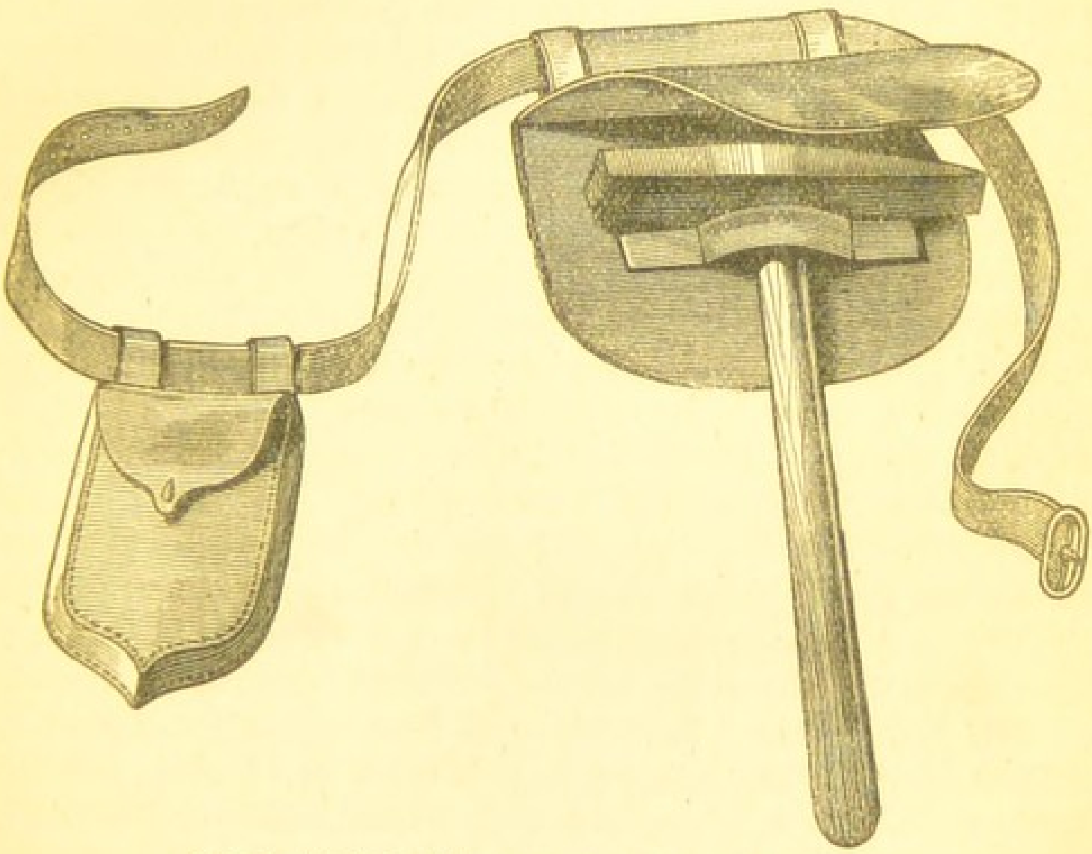


FIG. 2.—Geological hammer, compass-case, and belt.

and the manner of their arrangement; the other glass should be capable of making visible the fine striæ on a crystal, and the minuter ornament on the surface of a fish-scale or other fossil organism. Applied to the weathered crust of a rock, the lens often enables the observer to detect indications of composition and texture which the fresh fracture of the rock does not reveal. It sometimes suffices to decide whether a puzzling fine-grained rock should be referred to the igneous or the aqueous series, and consequently how that rock is to be coloured on the map.

3. *The Compass.*—Any ordinary pocket compass will suffice for most of the requirements of the field-geologist. Should he need to take accurate bearings, however, a small portable azimuth compass will be found useful. This is the instrument employed in the Geological Survey. It is carried in a leather case or pocket hung from the waist-belt on the side of the body, opposite to the hammer. (Fig. 2.) The directions of the dip and strike of rocks, the trend of dislocations and dykes, the line of boundaries, escarpments, and other geological features are observed accurately, and noted on the spot at the time of observation, either on the map or in the note-book. A convenient instrument for light and rapid surveys, or reconnaissances, combines the compass and the next instrument I have to describe—the clinometer. I shall refer to it again.

4. *The Clinometer*, or dip-measurer, is employed to find the angle at which strata are placed to the horizon—an important observation in the investigation of the geological structure of a country, and one having frequently a special economic value, as, for instance, when it points out the depth to which a well or mine must be sunk. Various patterns have been proposed and used for this instrument. Formerly a spirit-level was commonly employed. But apart from the difficulty of rapid adjustment for the requirements of the field, the spirit levels in the clinometers were apt to get broken. A much more portable and serviceable form of clinometer may be made by the geologist himself. It consists of two thin leaves of wood, each two inches broad and six inches long, neatly hinged together, so as to open out and form a foot rule when required. On the inside of one of these leaves a small brass pendulum is so fixed that when it swings freely and hangs vertically it forms an angle of 90° with the upper edge of the leaf to which it is attached. An arc, graduated to 90° on each side of the vertical, is drawn on the wood, or on paper or brass fastened to the wood, so that when the leaf is moved on either side, the exact number of degrees of inclination is shown by the pendulum on the graduated arc. The corresponding face of the opposite leaf is hollowed out just enough to let the two leaves fit closely, and keep the pendulum in its place when the instrument is not in use. This form of clinometer, made of boxwood and bound with brass, may be obtained of instrument

makers.[1] It is light and strong, and its durability may be understood from the appearance of the instrument which I hold in my hand, and which, though it has been in constant daily use for more than twenty years, is as true and serviceable as ever.

If at any time the geologist has occasion to lighten his equipment for some long mountain expedition, where every additional ounce of weight begins to tell by the end of the day, and where, therefore, for the sake of doing as much and holding out as long as possible, he should carry nothing that is not absolutely needful for his purpose, he may advantageously combine the pocket-compass and clinometer in the one instrument to which I have already alluded. This convenient instrument is about the size of an ordinary gold watch. It consists of a thin, round, flat metal case, shaped like that of a watch, and covered either with a common watch-glass or,

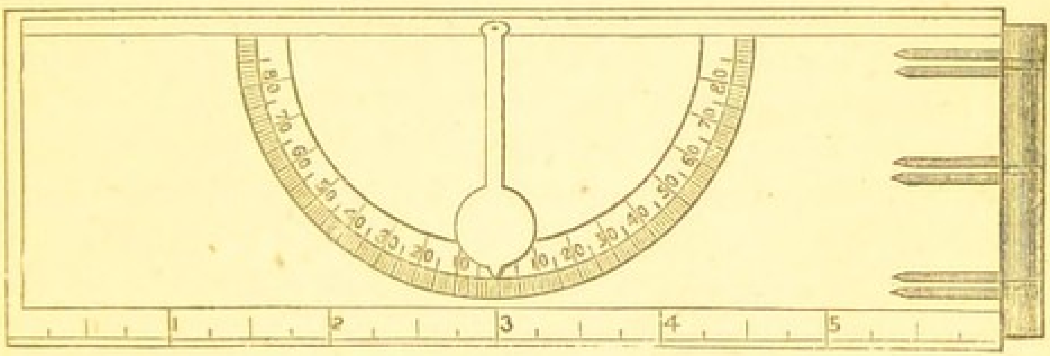


FIG. 3.—Clinometer.

still better, with a flat disc of strong glass. Instead of figures for the hours and minutes, the white enamelled face of this geological watch is that of a common pocket-compass. But the interval between each of the four cardinal points is divided into 90°. On the central pivot, just underneath the needle, a small brass pendulum is placed, and a straight-edge of metal is soldered on one side of the outer rim of the watch-case in such a position that the instrument will stand on it if need be, and the pendulum will then point to zero. A simple piece of mechanism passing through the handle enables the observer to throw the needle off the pivot, or let it down, as he may require.

[1] Messrs. Troughton and Simms, London, Mr. J. Bryson, Edinburgh, and Messrs. Spencer and Son, Dublin, supply this and the other instruments referred to in the text.

5. *The Note-Book and Pencils.*—As it is impossible for a field-geologist to remember the details of all the observations he makes on the ground, or to insert them on a map, he regards a good note-book as an essential part of his apparatus. From the nature of his work he has frequently occasion to make rough sections, or diagrams, and if possessed of the power of sketching, he has abundant opportunity of aiding the progress of his researches by jotting down the outlines of some cliff, mountain, or landscape. Hence his note-book should not be a mere pocket memorandum-book. A convenient size, uniting the uses of a common note-book and a sketch-book, is seven inches long by four-and-a-quarter inches broad. Let me remark in passing that perhaps no accomplishment will be found so useful by the field-geologist as a power of rapid and effective sketching from nature. If he has this power in any degree, he ought sedulously to cultivate it. Even though he may never produce a picture, he can catch and store up in his note-book impressions and outlines which no mere descriptions could recall, and which may be of the highest value in his subsequent field-work. This is true of ordinary detailed surveys, and still more of rapid reconnaissances which may have their ultimate usefulness enormously increased if the observer can seize with his pencil and carry away the forms of surface as well as the geological relations of the region through which his traverse lies.

As every device which saves labour and time in the field, or which adds to the clearness of the work, is deserving of attention, I would refer here to the use of variously-coloured pencils for expressing at once, upon map or note-book, the different rock-masses which may occur in a district. Water-colours are of course ultimately employed for representing the geological formations on the finished map. But a few bits of coloured pencils carried in his pocket save the geologist much needless writing in the field. To a red dot or line he attaches a particular meaning, and he places it on his map without further explanation than the local peculiarities of the place may require.

This leads me to remark also that he necessarily adopts a system of signs and contractions on his map, not only to save writing, but to prevent the map from being so over-crowded with notes as to become hopelessly confused. Every field-geologist insensibly adopts contractions of his own.

For the fundamental facts of geological structure, however, it is eminently desirable that the same signs and symbols should be used with the same meaning on all published geological maps. The subjoined diagram shows some of the signs used on the maps of the Geological Survey of Great Britain and Ireland.

Such are the few prime instruments required in field-geology. We may add others from time to time, according to the nature of the work, which in each region will naturally suggest the changes that may be most advantageously made. A small bottle of weak hydrochloric acid, carried in a protecting wooden box, or case, is sometimes of use in testing for carbonates, particularly in regions where rocks of different characters come to resemble each other on their weathered surfaces. When Sir William Logan was carrying on the survey of the Laurentian limestones of Canada, he received much help from what he called his "limestone spear." This was a sharp-pointed bit of iron fixed to the end of a pole or a walking-stick. He enlisted farmers and others in his operations, instructed them in the use of the spear, and obtained information which gave him a good general notion of the distribution of the limestone. The spear was thrust down through the soil until it struck the rock below. It was then pulled up, and the powder of stone adhering to the iron point was tested with acid. If, after trying a number of places all round, the observer uniformly obtained a brisk effervescence when the acid drop fell on the point of his spear, he inferred that the solid limestone existed below, and noted the fact on his map accordingly.

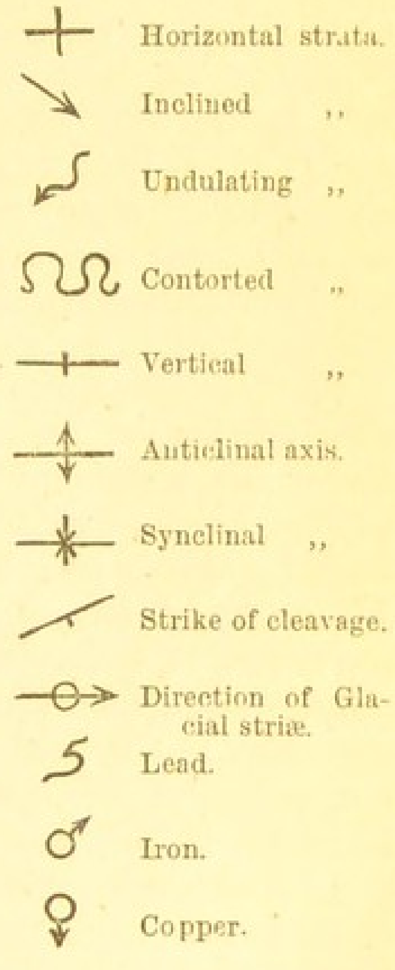


Fig. 4.—Some useful signs in geological surveying.

When the Geological Survey was busy with the great Wealden area of the south-east of England, my colleagues used what they nicknamed a "geological cheese-taster." It was indeed a kind of large cheese-taster, fixed to the end of a long stick. This implement was thrust down, and portions of the subsoil and of the clays or sands beneath were pulled up and examined. Similar devices must obviously suggest themselves, according to the nature of the work in different districts and countries.

In the course of his observations in the field the geologist will meet with rocks as to the true nature of which he may not be able to satisfy himself at the time. He should in such cases detach a fresh chip from some less weathered part of the mass and examine it further at home. The detailed methods of investigation, which may be pursued with all the conveniences of a laboratory in town, are not possible to him in the country. But he may subject his specimens to analysis in two ways, and obtain valuable, and perhaps sufficient, information as to their characters. He can easily fit up for himself a small and portable blowpipe box, a machine for slicing and preparing rocks, minerals, and fossils for examination under the microscope, and a microscope.

6. The *Blowpipe Box* should contain a common blow-pipe, platinum-tipped forceps, platinum wire, small bottles with the ordinary re-agents, and as many of the most useful parts of blowpipe apparatus as the space will admit, consistently with the whole box being easily packed into a portmanteau. By means of the blowpipe it is often possible to determine the nature of a doubtful rock or mineral, and to ascertain the proportion of metal in an ore. A young geologist should take with him to the field only the most essential apparatus and re-agents; he will gradually come to see by practice what additions he may best make to his equipment.

7. *Rock-slicing Machine.*—A convenient and portable form of this instrument is sold by Fuess, of Berlin. Where it cannot be obtained the field-geologist may succeed in preparing his slices by chipping thin splinters from the rock and reducing them upon a grindstone or whetstone. One side of the splinter is to be made as smooth and free from scratches as possible, which can be effected by polishing on a water-of-Ayr stone. This polished side is then cemented with Canada balsam to a piece of plate-glass. When quite firm, the upper side of the stone is ground down until the requisite degree of transparency is obtained. Considerable practice may be required, and many preparations may be spoiled before the observer becomes proficient. But the

labour is well bestowed, for in no other way can he obtain the same insight into the internal texture and arrangement of the rocks with which he is dealing. He sees what are the component minerals of a rock, and how they are built up to form the mass in which they occur. He likewise can detect many of the changes which these minerals have undergone, and he thus obtains a clue into some of the metamorphic processes by which the rocks of the earth's crust have been altered.

8. *Microscope.*—This instrument should be, like the rest, as portable as possible. For most geological purposes high powers are not required, consequently a small microscope is sufficient.

It is sometimes of service, when working in a district where microscopic rock-sections are required, to carry a small collection of microscopic slices of selected or typical rocks or minerals for purposes of comparison. A series of fifty or one hundred slices can be packed in a box a few inches square.[1]

3. Character of Field-work.—Preliminary Traverses.

Having now examined the various parts of the equipments of a field-geologist, let us proceed to notice what use he must make of them. At the outset I would remark that while the mere possession of good instruments cannot make a geologist, the want of them will not prevent a skilled geologist from doing good work. The training of years enables him to judge of rocks and angles, of dip and trends of boundary so nearly accurately as to make him often independent of hammer, compass, and clinometer. In like manner long experience quickens his eye to detect geological evidence where a less practised observer, though searching for information, would fail to find it. This difference of training tells greatly in all preliminary surveys, reconnaissances, or rapid traverses of a country. The geologist who has already had many years of campaigning carries with him a faculty of grasping the salient features of geological structure, and directing his attention on the march to every available source of information which will help him to fill in the details of his

[1] Typical series of this kind may be had from Fuess, of Berlin, or from Tennant or Gregory, London; or Bryson, Edinburgh.

section. If it were always practicable, the exploration of new regions, where the traveller is necessarily confined to his line of route, but where he has nevertheless to report on the geology of many thousands of square miles of territory, should be placed in the hands of men trained in geological surveying. That this arrangement would be of advantage you will, I think, admit when we have entered a little more into the details of field-work.

Though the geologist does not usually dig or bore, he avails himself of every artificial opening he can hear of as offering any information with regard to the rocks beneath the surface. Every natural exposure of rock comes under his notice. If there is a coast-line he makes a preliminary traverse of it to ascertain the general nature of the rocks. He ascends one or more of the stream-courses for the same purpose. If there is any commanding hill in his district, he makes an early excursion to its top, that he may gain some general idea of the form of the ground and the probable distribution of the geological formations, so far as may be indicated by the landscape. After such preliminary examination he has some notion of the probable character of the problems with which he will be called upon to deal. He then sets himself to examine the various natural and artificial sections in detail, carefully recording his observations at the time on his map and note-book.

The nature and conduct of these preliminary examinations not only vary with the character of the geology and physical features of the country, they differ according to the extent to which the country is settled and populous, or trackless and unexplored, according to the existence or absence of maps of the region to be examined, according to climate and other obvious causes. Such peculiarities as those which greatly affect the first general traverses of a country are apt to influence all the subsequent more detailed work.

As an illustration of the different conditions under which field-geology may be carried on, let me contrast the work of the Geological Survey of Great Britain and Ireland with that of the United States Geological and Geographical Survey of the Western Territories. In this long-settled and populous country we have abundant means of communication by road, railway, or steamboat between all or almost all districts. Villages and towns are scattered so numerously over the land that we seldom need be in any doubt as to obtaining good quarters and food. The penny-post and electric telegraph accompany us even into some of the most retired spots. Books, specimens, and instruments can be sent to us at a few days' notice. Of nearly every district in the British Islands we may procure detailed Ordnance maps by which to make our way over the ground, and on which to place the results of our geological observations. Besides, the main features and much of the detail of British geology are already known, and have been expressed with more or less precision upon published geological maps. We cannot, therefore, begin anywhere in this small country without some kind of general knowledge about the formations and structure of the district we may propose to examine.

There is still another element to be taken into account as determining the character and methods of field-geology in Britain — one which perhaps geologists themselves hardly sufficiently recognise—the climate of the country. I do not believe that any one who has not daily occasion to be out for many hours in the open air, and whose avocations make him to some extent dependent upon the weather, can have any proper notion of how good the average weather of this country is, and how few thoroughly bad days there are in the year, when he cannot secure even an hour or two of outdoor exercise. Our summers are seldom too hot to prevent the full use of a long July day. Our winters are so mild, and in many seasons bring so little snow, that if need be we may carry on field-work up to the end of December, and renew it at the beginning of January.

Such being the conditions under which field-geology may be prosecuted in Britain, it is evident that an observer may start for any district of the country alone and investigate its structure by himself. There is no occasion for combining a geological party, though that may be done if need be. In the organised field-work of the Geological Survey each officer has his own area assigned to him, and works out its geology himself, consulting, of course, from time to time his colleagues, who may be stationed in adjoining tracts, and arranging with them as to the joining-up of their various geological boundary lines.

The extent of ground which can be examined and mapped in a year by one of the geologists of the Survey varies, not only with the capacity of the surveyor, but with the nature of the ground, whether level, easily traversed, and with comparatively few geological sections, or rough and high, laborious to climb or cross, and abounding in streams and crags, all of which must be examined and mapped. A man might complete the survey of half a county lying upon the chalk of the south-east of England before another could get over more than a part of a single parish in such intricate geological and rough mountainous ground as that round Snowdon, or that in many districts of Scotland.

Let me place before you some statistics respecting the rate of work in the Geological Survey of Scotland—the branch of the Surveys of the United Kingdom with which I am more immediately connected. The average annual area of ground geologically examined and surveyed by each officer in the field is somewhere about 100 square miles. This amount is performed by an average daily walk of from ten to fifteen miles, exclusive of Sundays, holidays, wet days, and the time spent indoors in reducing the field-work and preparing it for publication. The part of the year devoted to actual surveying may be set down as about 200 days, or it may be perhaps rather more than that. We see, then, that one of the members of the Scottish Geological Survey walks about 2,000 or 2,500 miles in the course of the year. Every square mile of his completed map represents, therefore, on the average, about twenty or twenty-five miles of actual walking.

You can readily believe that with all the advantages for field-geology in Britain it should be possible here to construct the most elaborate geological maps. I would refer you to some of the published sheets of the Geological Survey of the United Kingdom for an illustration of what can be, and has been, done in this respect. I do not suppose that any such detailed geological work has been elsewhere attempted. The large maps on the scale of six inches to the mile, with which the field-work is now chiefly conducted, admit of almost unlimited detail. Every important or interesting stratum may be put down and traced on these maps; little dislocations of only a few feet in extent may be shown even when they are pretty closely crowded together; no feature of geological value need be omitted for want of space to express it. As illustrations of intricate and detailed geological mapping I may cite sheets 14, 15, 22, and 23 of the one-inch

Geological Survey Map of Scotland, and the corresponding six-inch coal-field maps belonging to the same tract of the country.

Now with field-geology and map-making as possible, and as actually accomplished, in Britain, let us contrast the conditions under which work of this kind must be carried on in an unexplored region like the Western Territories of the United States. The survey of these vast tracts of the North American continent has been entrusted to my friend Dr. Hayden—one of the most zealous, active, and efficient geologists who ever undertook the task of pioneering through a new country. But the utmost skill and experience cannot alter the natural features of a country and its climate. The American survey requires to be carried on in a very different manner from ours, and I cite it as an excellent example of how field-geology can be prosecuted in new and previously unmapped regions.

As the topographical map of the country requires to be made, Dr. Hayden's survey is at once geographical and geological. His staff contains more topographers than geologists. It requires division into separate working parties, to each of which a distinct tract of country is assigned. From the higher hill-tops triangulations are made and outline-sketches are taken, so that a general map is traced and filled in. In this work the geologists co-operate, indicating to their associates the salient geological features of each region, and inserting these upon sections or diagrams, which, for beauty and effectiveness, are among the most remarkable geological sketches which have yet been produced.

Besides the scientific staff, however, provision has to be made for a foraging department; and sometimes, also, an escort has been needed, where the work lay in or near the territories of hostile Indians.

As a sample of the equipment of Dr. Hayden's survey, let me cite a few particulars from his Report for 1874, just received. The staff in the field was divided into seven parties. Of the organisation of these, the first may be taken as a type. It consisted of one assistant geologist as director, two topographers, two meteorologists, one botanist and collector, one general assistant, two packers, cook, and hunter. It would seem that there was thus only one geologist in the party, though probably one or two of the other members were able to lend him some assistance. Starting on the 20th of July, the party continued the campaign till the 27th of November. During that time it surveyed 4,300 square miles of new ground, which is probably an average of somewhere about forty square miles a day. This working party, therefore, though probably not much more than one geologist strong, accomplished in three days as great an area of work as one of my colleagues finds it possible to complete in a year. Such rapid surveying can of course be regarded as furnishing merely a kind of rough preliminary sketch of the geology of the territories, to serve as the basis for future detailed surveys. It may be taken as an example of broad generalised field-work on the one hand, while the Geological Survey of Britain stands at the opposite extreme, as a model of patient and elaborate detail. Obviously, such detail is at present wholly out of the question in such regions as those where Dr. Hayden is at work. He must be content to sketch the main outlines, and leave the details to be filled in by his successors. The manner in which he is fulfilling his task may be usefully studied, not only by beginners in field-geology, but by practised surveyors, who will cheerfully recognise the masterly character of the work which their American brother of the hammer is conducting.

4. Determination of Rocks and Fossils.—Tracing of Boundaries.

Whether field-geology is to be carried on rapidly and in a generalised way, or slowly and in detail, the same methods must be followed. I have supposed the geologist to have selected and reached his ground, and to have made a few preliminary traverses to gain some notion of the chief rocks and their arrangement. Let us follow his subsequent operations.

The brooks, ravines, sea-coasts, hill-sides, valleys, and mountains, in short every natural section or exposure of the rocks, will be carefully examined, and the observations made will be registered in note-book or map at the time. In the course of these rambles two points will have to be settled by him: first, the lithology and distribution of the rocks; second, their probable or actual geological horizon or date. A third question, viz. the position of the rocks with regard to each other, that is, the geological structure of the district, will early claim his notice. I shall treat of the latter subject under the 4th head—Determination of Geological Structure.

1. The determination of the nature of the rocks is obviously the first question which must be dealt with. Are they derivative or stratified rocks, and if so, are they conglomerates, sandstones, shales, clays, limestones, ironstones, or other varieties of this great series? Are they, on the other hand, crystalline or igneous rocks, and if so, must they be classed as granite, syenite, diorite, basalt, gabbro, serpentine, tuff, or other species of this family? Or are they metamorphic rocks, such as gneiss, mica-schist, or hornblende-slate? To be able to answer these questions, the observer must have trained his eye by the examination of good typical specimens of rocks. This is a kind of knowledge not to be obtained from books; it can only be gathered from patient and intelligent handling of the rocks themselves. In the field, the observer who has had this training in petrography can usually recognise the rocks he encounters. A pocket-knife, lens, and acid-bottle will assist him if his eye does not readily detect the characters of the stone. Should there be any doubt about the rock, he ought to compare a weathered surface with a fresh fracture; the former often revealing the component grains of the rock, owing to the more rapid decay of some of the ingredients. Minute quartz particles may be readily detected in this way.

It may happen that he still finds himself at a loss how to name the rock. In such a case let him take one or two small chips in his pocket, wrapping them in paper with a label inside, to mark their proper locality. When he gets back to his quarters in the evening he may submit one or two minute splinters of the rock to blow-pipe tests, or if these be inapplicable, or give no satisfactory results, he may proceed, in the manner already described, to prepare a slice of the stone for mounting on glass and submit it when ready to examination under the microscope. If, even after all these trials the rock still puzzles him, he had better give it some provisional name, and lose no more time over its determination, but proceed with his field-work, laying aside, however, some good typical specimens of the doubtful rock for subsequent more careful analysis either by himself or some experienced petrographer.

It should be added that as the geologist gains experience he finds fewer and fewer of those puzzling rocks; his first rough or field determination becomes increasingly accurate, and he employs the blowpipe and microscope not so much to enable him to name the rocks as to solve interesting questions as to their composition and history.

A very short experience of geological work in the field suffices to show the observer that over wide spaces he cannot actually see what rock lies beneath him. He may get an admirable section laid bare in some ravine or brook, or by the shore of the sea; but beyond the limits of this section the ground may be deeply buried under vegetation, soil, sand, gravel, clay, or other superficial formation, and no other section may occur for an interval of, it may be, several miles. Yet he must form some conclusion as to the nature of the rocks between these places.

In cases of this kind information may often be obtained from an examination of the soil. What we call vegetable soil is merely the upper stratum of decayed rock mixed with vegetable and animal remains. It commonly betrays its origin by the still undecomposed fragments of stone mixed through its mass. In one tract, for instance, we may find it full of pieces of sandstone, to the exclusion perhaps of every other kind of rock. If the land has been under cultivation, the sandstone fragments may be of some size where they have been turned up by the plough. We should infer with some confidence that sandstone lay underneath *in situ*. If again the soil were a stiff red loam or clay, with few or no stones, it would indicate the existence of some red marl or clay immediately underneath. A sandy soil full of well-rounded, water-worn stones would show the presence below of some gravelly deposit. A stiff argillaceous soil, abounding in smoothed stones, many of them well-striated, would prove that a boulder-clay or till lay below. A profusion of fragments of some peculiar rock, a basalt, for example, or a diorite, or a porphyrite, extending in a definite band across a field or hill-side, would probably show us that a rock of that character existed *in situ*, somewhere in the immediate neighbourhood of the fragments. We require of course in all these cases to go carefully over the ground, and draw our conclusion only after we have exhausted all the evidence procurable.

But you may remark that except on freshly-ploughed land the soil is not bare and exposed to our scrutiny ; that, on the contrary, it is commonly just as much concealed by its coating of vegetation as the hard rocks are by their covering of soil. Even under the most unfavourable circumstances, however, the geologist may be able to learn not a little of the information he needs. Where the ground has a slope he will probably have no great trouble in finding some little rut or trench which has been cut, or at least deepened, by rain, and where he will obtain access to the underlying soil, or even, it may be, to the subsoil and the still undecomposed rock below it. Where on the other hand the ground is too flat to hope for assistance from rain-action, he will look for traces of burrowing animals, by which the soil may have been thrown up to the surface. In Britain the common earth-worm, the mole, and the rabbit are excellent coadjutors in his work. The fine castings of the earth-worm give him at least the colour and general constitution of the soil, whether sandy or clayey. The heaps of the mole include the smaller stones in the soil, and permit an inference to be drawn as to the probable nature of the materials from the decomposition of which the soil has been formed. The extensive excavations of the rabbit lay bare not only the constitution of the soil, but often also the angular debris which rests immediately upon the solid rock.

From vegetation also the field-geologist learns to draw many a shrewd inference as to the character of the soil and rock below. A spring or line of springs will reveal itself by marshy ground or by a brighter green along a hill slope. The course of a limestone band or a basalt-dyke may be followed by the peculiar verdure of its vegetable covering, across a moorland where little or no solid rock may be seen. A ridge of serpentine stands up bare and rough, affording at best but an unkindly soil for plant-growth. Trees, too, change with the varying character of the rocks on which they grow. Each country presents its own local illustrations of these relations which must be gradually learnt and made to give their assistance to the observer's progress.

In judging of the probable character of the rocks underneath from the nature of the overlying soil, the geologist will of course be guided by the local circumstances in every case. For example, if the surface of the ground should present many rounded pebbles and boulders, he will not at once conclude that these fragments have been derived from the rock *in situ* below. Their rounded forms will rather raise a suspicion that they have been transported, and should many of them plainly show the characteristic smoothed surface of water-worn stones, they will be set down as derived immediately from some adjacent bed of gravel or conglomerate. The mere fact of a great variety of rock-fragments occurring over the surface at any locality suggests a mass of transported material, rather than the decomposition of the solid rocks underneath.

On the other hand, the occurrence of abundant angular fragments of rock on the surface at once arrests attention, as indicative of the vicinity of that rock *in situ*. The observer traverses the ground in all directions in search of any projecting knob of the actual rock itself. Failing to find it, he notes the position of these angular chips, and tries whether they can be traced further, so as to indicate by their distribution at the surface the probable trend of the solid rock underneath. In ascending a hill-side so covered with trains of detritus or vegetation that no rock can be seen in place, the geologist may learn much regarding the concealed rocks by examining the debris. He knows that the fragments of stone have all rolled down, and not up. When therefore, in his ascent, he observes that the angular chips of some particular rock, abundant enough below, no longer appear, he surmises that he must have crossed the limits of the solid rock which furnished the fragments. If in the course of subsequent examination he discovers that those fragments disappear about the same line all along the hill, he may regard his first surmise as probably correct, and draw a boundary line accordingly, even although he may never have seen the actual rock itself *in situ*.

Again, in the ascent of streams similar close observation and sagacious inference will often go far to supply the place of actual sections of rock. The use of the evidence in these cases, however, requires still more caution than on the bare hill-side, because the tendency of running water is to round the rock fragments exposed to it, and hence in the channel of a brook or river, it may not be always possible to distinguish between the pebbles which came as angular fragments from neighbouring solid rocks, and have been rounded by the attrition of the brook or river itself, and those which, derived from some old gravel, were already rounded and water-worn before they tumbled into the channel. A great abundance of fragments of one particular variety of rock, however, would suggest that they had not been washed out of some gravel bed, but had been derived from the waste of a solid rock lying somewhere further up in the drainage-basin of the stream. In such a case, moreover, the proportion of these fragments in the channel would probably be found to increase as the stream was traced upwards. Perhaps they might be observed, too, to become larger in size and less water-worn, the further they were followed up the stream. If they should suddenly cease, the observer should at once note the fact, as possibly indicating that the rock did not occur higher up, but had its upper limit somewhere near the point where the fragments in the stream disappeared. While these particular rock-chips ceased, others of some different rock might be found to increase in number, and another zone of rock might be shown and traced in a similar way.

In nothing is the highest type of a field-geologist better displayed than in the exhaustiveness and sagacity with which, in the absence of all other evidence, these various little indications of the geology of a district are sought for, found, and marshalled in their proper places, so as to bear witness to the distribution and probable structure of the rocks. Such an observer would be able in many cases to trace lines, with a near approach to accuracy, over ground which a less skilled student would pronounce to be a blank.

2. The determination of the geological age of the formations is a point of prime importance, which, if he has the facts and the knowledge, should be settled by the field-geologist. For the purposes of such determination he avails himself chiefly of fossil evidence. Since each great stratified formation of the earth's crust is distinguished by its own characteristic fossils, a method is obtainable of recognising the relative geological date of fossiliferous rocks. To determine and name fossils is the task of the palæontologist. As a rule the field-geologist can do this only to a very limited extent, though the greater his power in this respect the more valuable his services in the field. Part of his training, however, should consist in the study of as good a series of typical fossils as he can consult. He ought to familiarise his

eye with the leading genera or more characteristic fossils of each geological system and formation. Knowledge of this kind, so portable when carried in the head ready for use, so bulky and difficult to transport and use when contained in many learned volumes, enables him to decide for himself as to the geological horizon of the formations. Should he be in doubt about the determination of his fossils, he must submit them to an expert in the subject.

For many purposes of field-geology it is not absolutely necessary, though it may be very desirable, that we should know the names and the zoological or botanical grade of the fossils. What we need to know in the field is that certain organic remains, whatever be their nature or names, occur in particular strata. We should be able to recognise them and use them as indices to mark out the strata, and thus to fix our geological horizon. William Smith, by whom this stratigraphical use of fossils was originally taught, knew little of the nomenclature or natural history of the fossils he dealt with. But he learnt to recognise them and to judge accurately of their position in the geological series, and he made as admirable use of them in tracing the outlines of the development of the Secondary rocks across England, as if he had been able to name and describe each species. Geology has made vast strides since his time. Though the field-geologist may use the fossils without any scientific knowledge of them, the sooner he obtains that knowledge the better for his work. The broad outlines of William Smith's days have to be filled in by more minute and exhaustive work now.

It is not merely in their bearing upon questions of stratigraphy that fossils claim the notice of the field-geologist. He treats them likewise as memorials of ancient conditions of physical geography. They show him at one place evidence of an old sea-bottom in the strata where marine remains are crowded together. At another locality they bring before him, in freshwater shells and other forms, the traces of long vanished lakes and rivers. At a third spot they reveal, by successive layers of compressed vegetation and hardened loam, the gradual depression and submergence of old forest-covered lands. In such cases they suggest the lines along which his further search should be prosecuted for additional corroborative testimony as to these ancient aspects of the district in which he is at work. The land-plants, for example, lead him to look for freshwater forms of life, for sun-cracked and rain-pitted surfaces among the clay-beds, while traces of former encroachments of the sea are indicated by layers of rock containing marine forms of life.

To be able to make the full use of fossils in the field it is not only desirable that the observer should know the species, as exhibited in good specimens in a museum and described in books. He must learn how they occur in nature, and discover after careful practice that it is not luck, but skill and good eyesight, which make the successful collector. Two observers may go over the same ground; one of them

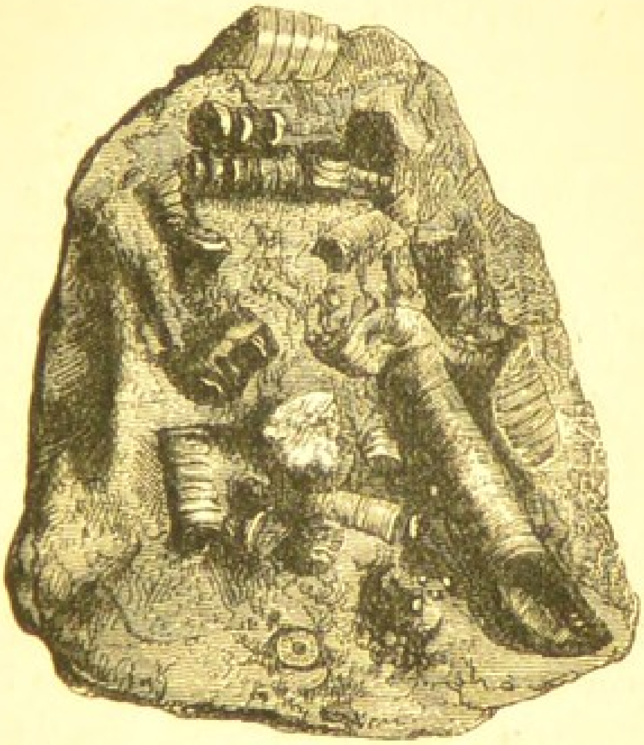


FIG. 5.—Fossils standing in relief on a weathered surface of limestone.

diligently applies his hammer, breaks up innumerable blocks of limestone, finds not a single recognizable trace of a fossil, and, pronouncing the rock to be unfossiliferous, passes on; the other, recognising the calcareous nature of the stone, and, therefore its possibly fossiliferous character, puts his hammer in his belt, and betakes himself at once to the *weathered blocks*. He knows, as everyone soon does who attends to the subject, that in many cases a rock which is really highly fossiliferous may not appear to be so on a fresh fracture, where the whole texture of the stone may be uniformly crystalline. But when exposed to the slow corrosive influence of the weather, the different molecular arrangement of the calcareous matter in the organic remains and in the surrounding matrix begins to appear. Shells, corals, and crinoids stand out in relief on the weathered stone, showing even some of their most delicate sculpturing, while the surrounding limestone has been slowly dissolved and removed. In this way a rock which may have been supposed to be unfossiliferous by one observer is shown by another of greater training to be full of fossils. Old walls and buildings, the refuse heaps of old quarries, the angular blocks strewn at the base of a cliff—in short all surfaces of rock which have been lying exposed for a long while to the gentle influences of the air, rain, and frosts, may be made to yield their evidence as to the fossils in the rocks of a district.

5. Determination of Geological Structure.

If we could only recognise the rocks, where actually seen, but form no satisfactory conclusion regarding their distribution under a concealing mantle of vegetation or superficial detritus; if we could tell the arrangement and measure the thickness of strata only at the surface, but offer no opinion as to the prolongation of these strata underground, we should never know much about the crust of the earth, and certainly could do comparatively little to advance geological inquiry. Fortunately it is not only possible but comparatively easy to pronounce upon the subterranean arrangement of rocks from indications obtainable at the surface. We do not need to bore or dig. It is enough if we can avail ourselves of this surface evidence. How this is done, and how the field-geologist, from the determination of his rocks, proceeds to work out the geological structure of his district, let us now consider.

Horizontal Strata.—Outcrop.—In a region where the rocks are all horizontal, only the uppermost stratum may be seen, in which case an example of extreme simplicity of structure would result. There would then be no outcrop or exposed edge of any stratum to be traced, unless the surface of the ground should be so uneven as to expose the edges of lower strata. Except in tracts of low alluvium, however, horizontal strata have usually been more or less trenched by valleys and ravines, so that sections are laid bare of the underlying beds, while the surface of the country seldom rigidly corresponds with the surface of a stratum, but has been worn across it, so as here and there to leave "outliers" or outstanding portions of this upper stratum, and to lay bare the strata below. Where this has taken place in

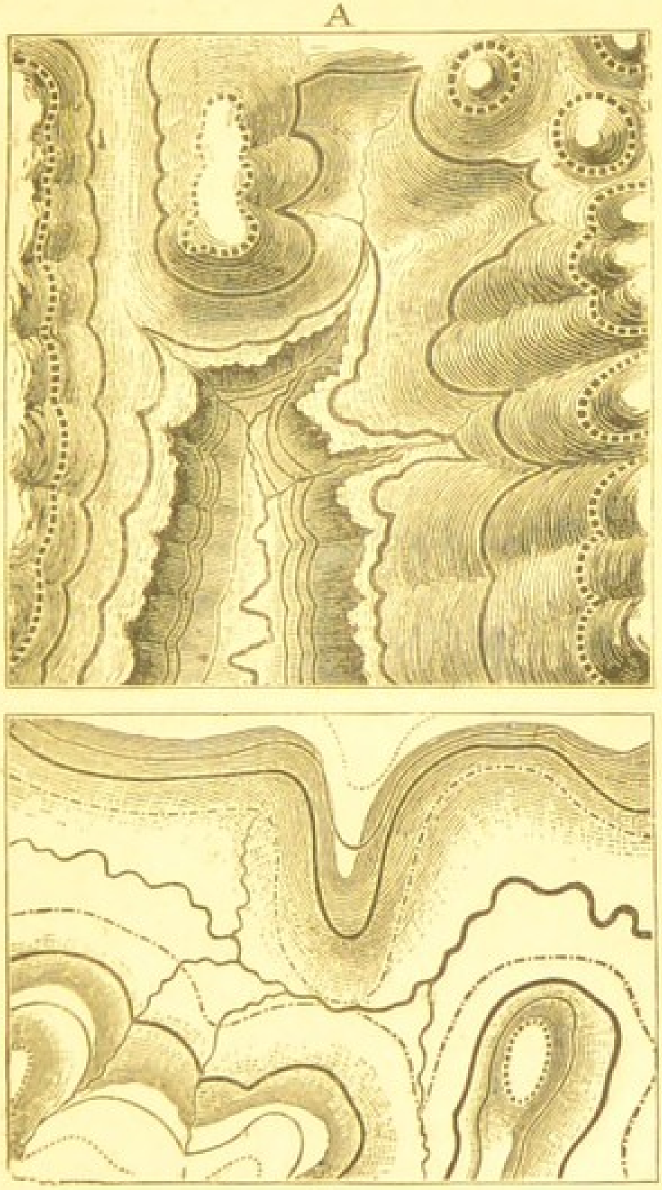


Fig. 6.—Sinuous outcrops of horizontal strata depending on inequalities of surface.

bare, hilly land, with abundance of exposures of the rocks, although the geological structure is still of the simplest possible kind, considerable practice and skill may be needed to follow the exposed edges or outcrops of the strata, and to delineate them accurately, and at the same time artistically upon a map. The accompanying drawings (Fig. 6) may serve to illustrate how very tortuous the outcrops of perfectly horizontal beds may be, should the ground be much varied in outline, and especially by the occurrence of wide and deep valleys. In the uppermost map (A) a representation is given of horizontal rocks deeply trenched by valleys and ravines. In the lower map (B) the inequalities of the ground are much less, yet even in such a gently undulating district the outcrops of horizontal strata may evidently run in remarkably sinuous lines.

I have used the word artistic with reference to the tracing of geological boundary-lines, and have done so advisedly. Where the rocks are all visible the observer has only to follow nature, and the more faithfully he does so, the more graceful will his lines probably be. The curves produced by denudation, though often complex, are never awkward and inharmonious. Where the rocks are not seen, and where, therefore, the position of the boundary-lines must be inferred, the surveyor will follow the analogies of his district and run his boundaries with the same kind of flowing lines which he sees them to possess where they can be actually examined. Two men may map the same piece of ground quite correctly as regards its general structure, but the map of the one will show by the complexity of its lines and the fidelity with which they follow the varieties of the surface configuration, how faithfully and skilfully the work has been done; while the map of the other will indicate that its author has contented himself with marking the general structure, and has failed to express the relations of that structure to external form. The former map will in most cases be a far more artistic as well as accurate production than the latter. Not only in such simple work as the tracing of horizontal strata, but in all the details of geological map-making, the artistic eye and hand have scope to show their presence: to the great advantage of the maps in which they are applied.

Inclined Strata.—Dip.—Instead of lying quite flat, however, stratified rocks are usually inclined to the horizon. This inclination, called their *dip*, is measured as to its direction by the compass, as to its angle by the clinometer. To be sure of the true angle and direction, we must not be content with one small face of rock, but should go round a section until we determine the point satisfactorily. A face of rock, for instance, seen from one side, as in Fig. 7, may appear to be made of horizontal strata, which from another point of view are found to be considerably inclined. The direction of dip will always be at a right angle to the line along which the edges of the inclined beds appear horizontal. Failing, therefore, to find any actual section along the true line of dip, we should so place ourselves as to have the exposed edges of the strata running in horizontal bars in front of us. We may then take the direction of dip with

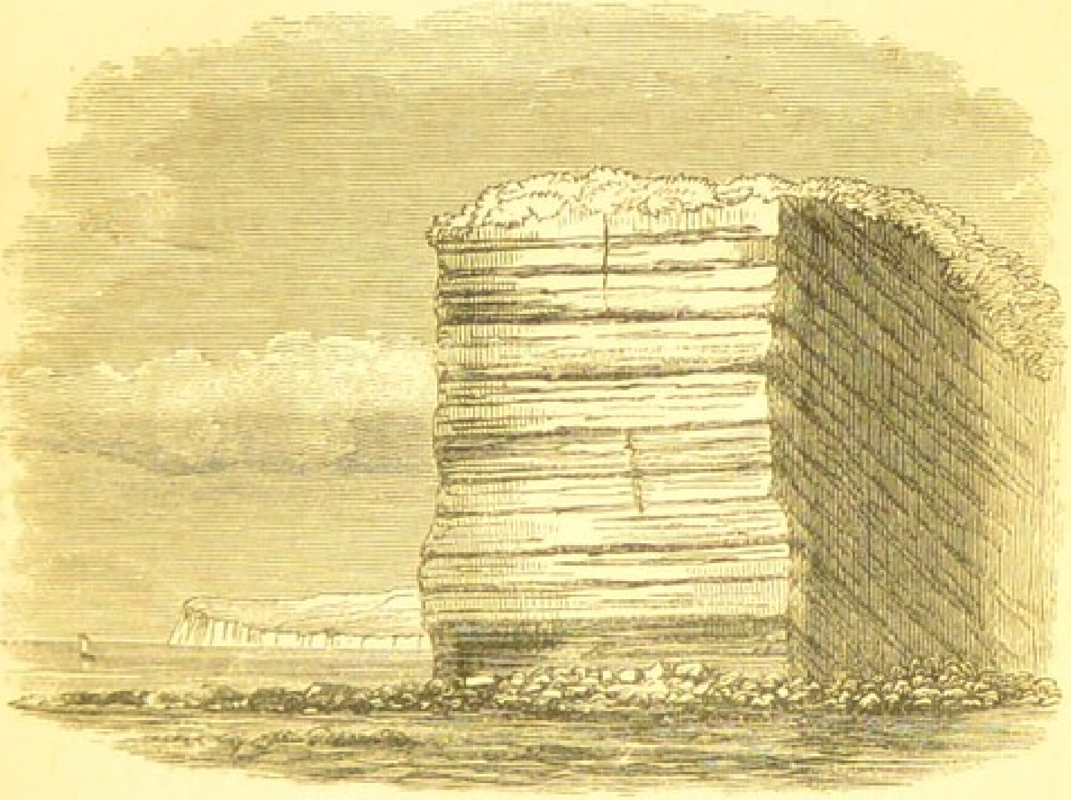


FIG 7.—Inclined strata appearing horizontal when exposed at a right angle to the dip.

the compass, and determine from the mean of a number of observations taken with the clinometer on projecting ledges what must be the general average angle of dip. The best measurements of the angle of dip are made when we can place ourselves some little distance in front of a face of rock which has been cut in the true direction of dip. We can then place the clinometer in front of our eye, and make its edge coincide with the line of a particular stratum many yards in extent. Thus in one single observation we obviate the risks of error where only small ledges of the inclined beds can be used. Where the true dip cannot be directly measured we may, by measuring the apparent dip of two faces of rock inclined at a considerable angle to each other, obtain the true dip by calculation.[1]

Having ascertained these particulars, we insert the information in our note-book or map. The use of a map for the registering of observations on geological structure requires an amount of precision which might not be thought needful for the pages of a note-book, and secures in consequence the most careful and exhaustive kind of field-work. I shall, therefore, suppose in what I have to say on this part of my subject that we are required not only to make observations on geological structure, but to formulate them on paper, and to construct the geological map of a region.

The usual sign used on geological maps to express the dip of strata is an arrow pointing in the direction of inclination (the direction being found on paper by help of an ordinary protractor), with the number of degrees of angle shown in figures at the side of it. (See Fig. 4.) We place, therefore, an arrow at each point on the map where we ascertain the dip of strata. A glance at the map (Fig. 8) will show how this is done. Each arrow marks the site of the observation, and with its accompanying figures records the result. Where possible we enter beside the arrow some symbols, or contracted writing, to describe the nature of the rock, or any other particulars which it seems desirable to record. Further detail, where required, finds its place in the note-book.

Selection of Horizons.—Mapping of Outcrop.—As it is impossible on any ordinary map to represent every bed of rock, the geologist must decide what beds should be selected to be traced out. This cannot always be done until considerable progress has been made with the work. The selection must depend not merely upon the geological or industrial importance of the beds, but also, and not less frequently, upon the extent to which they are exposed and capable of being followed across the district. A particular stratum of no special interest in itself may come to have a high importance as a geological horizon or platform if it is easily recognisable, and from its thickness, hardness, or other peculiarity, stands

[1] Elaborate rules are sometimes given for measuring or calculating the dip. For almost all practical purposes, however, a good field-geologist can get his angle with the clinometer in the field by selecting, as he learns how to do, his points of observation.

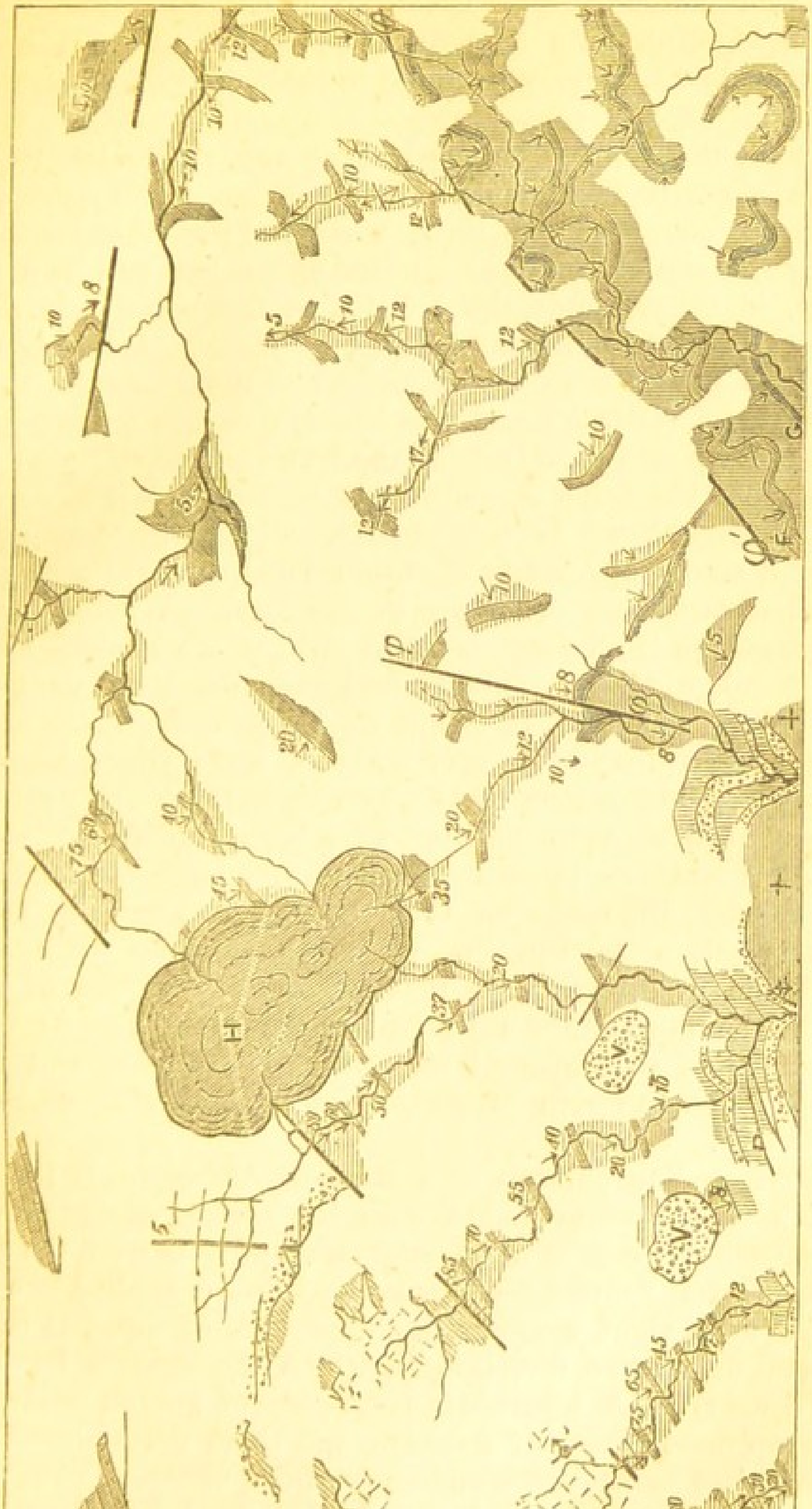


Fig. 8.—Map showing the data from which a completed geological map is made. (The top of the map is north.)

out so prominently that it can be satisfactorily traced from point to point for a long distance. Such stratigraphically serviceable bands may be found in most districts of stratified rocks.

The outcrop may be marked at any particular locality by a short line beside the dip-arrow, or if the outcrop be a broad one, by two lines, one marking the base, the other the top of the band. The space between two such lines, in other words, the breadth of the outcrop, is determined by the thickness of the bed or beds, their angle of inclination, and the slope or contour of the ground. Among a series of vertical strata the breadth of the outcrop of a bed corresponds exactly with the true thickness of that bed. The more the angle of inclination lessens, the broader does the outcrop at the surface become. Hence, in tracing such a band across a country, attention must constantly be given to the variations of angle in the dip. Where the dip increases the band narrows in breadth, where the dip lessens the band widens. This is best seen on level or gently undulating ground; it is apt to be less distinctly shown where the ground is very uneven, and where therefore constant modifications of the line of outcrop are produced, as we have seen to be the case with horizontal strata. When strata are vertical no amount of surface irregularity makes any difference on their outcrop. They are apt in that position to run on for some distance with little deviation of direction, so that the outcrop of one of them might be marked by a straight bar or line (Fig. 8). The influence of the form of the ground tells more and more upon the outcrop in proportion as the strata approach the horizontal.

Strike.—The outcrop of a stratum, therefore, is the line which that stratum makes with the surface of the ground. This term outcrop is often spoken of as if it were the same as the term "strike." The latter word is applied to a line drawn at a right angle to the direction of dip. It is the general or average direction in which the stratum traverses the country. On a perfectly level piece of ground strike and outcrop must obviously coincide, and there must likewise be a complete coincidence among vertical strata. The more irregular the surface, and the less inclined the strata, the further must strike and outcrop depart from each other.

Difference between Outcrop and Strike.—If you look at any good geological map of England and Wales, that by Professor A. C. Ramsay, for example, you will notice that the bands of the Oolitic and Cretaceous rocks, while retaining a tolerably persistent strike from south-west to north-east, across the breadth of the country, present a most sinuous and irregular edge. The direction of the dip, and consequently the trend of the strike, change but little, yet you observe that the outcrop is continually shifting to-and-fro. The strata really follow each other in parallel bands. If we could plane down the whole country to a dead level, these bands would be marked by alternate strips of clays, limestones, and sandy rocks. But instead of being a flat, the country undulates, and hence a series of gently inclined rocks of very various degrees of durability necessarily give a diversified set of outcrops. You could not study a better illustration of the difference between outcrop and strike, and of the marked inflence even of small ridges and hollows and shallow valleys upon the outcrop of strata where the angle of dip is low. The main facts to be expressed upon the map of such a tract of country are that the formations follow each other in a certain order and cross the region in a certain direction. Of course we might record these facts by simply drawing straight parallel strips across the map, each marking the position and relative breadth of one of the formations. This was the way in which the old geological maps on a small scale were constructed. The map of England and Wales in Bakewell's *Geology*, even so late as the edition of 1838, may serve as an example. But by such a style of mapping we entirely lose one of the valuable features of a geological map—the relation between the form of the ground and the nature and outline of the rocks below, that is, between scenery and geological structure. You may readily believe that this is too important a relation to be ignored without great disadvantage when the scale of the map at all permits it to be expressed. Besides, the omission deprives the map of the chief feature by which the skilled and artistic observer is distinguished from him whose eye and hand are less quick to seize upon and delineate the characteristic varieties of form which geological boundaries assume as the surface of a country changes from plain to hill, and as the rocks themselves alter in thickness and position.

If we stand at the higher margin of a rocky valley, along the sides of which inclined beds of sandstone, limestone, or other stratified rocks are exposed, dipping gently down the valley, we observe that when the outcrop of each bed reaches the edge of the declivity, it does not go straight on to the corresponding outcrop on the opposite side. On the contrary, it descends the slope in a slant until it reaches the bottom of the valley, when it turns and mounts the opposite slope, thus forming a V-shaped indentation on the general line of strike (as in the valleys on the south side of the map, Figs. 8 and 9). Now the manner in which these windings of the outcrop of inclined strata and their relation to the form of the ground are expressed upon the geological map, is a good test of the skill and delicacy of a field-geologist's hand. Many observers are content to draw the lines of outcrop as straight bars across the valleys, thus making them coincident with the strike. On maps of a small scale, indeed, nothing else is possible. But where the scale admits of it, much advantage may be gained by faithfully depicting the curving outcrops. The map then tells its story at once, and brings the relation between geological structure and external form as vividly before the eye as a well-made model could do.

Construction of a Geological Map.—In Fig. 8 an attempt is made to convey some idea of the way in which the data are compiled and recorded in the construction of a geological map. The shaded parts of that figure represent what is actually seen by the geologist; over the blank portions he is supposed to have been unable to find any rock *in situ*. Fig. 9 shows the map as filled in and completed from these data. I shall have occasion to make frequent references to these maps in what follows.

It will be noticed that most of the observations occur along the stream-courses, these being the most frequent natural lines of section. At each point where the dip of strata has been taken, an arrow and number mark the direction and angle. The more important or stratigraphically serviceable beds have their outcrop marked in decided lines where it is actually seen. When the same stratum can be recognised in two parallel or adjacent streams or valleys, the outcrop may be drawn across the intervening ground, which of course should itself be searched for traces of the desired line. Where there can be no doubt as to the

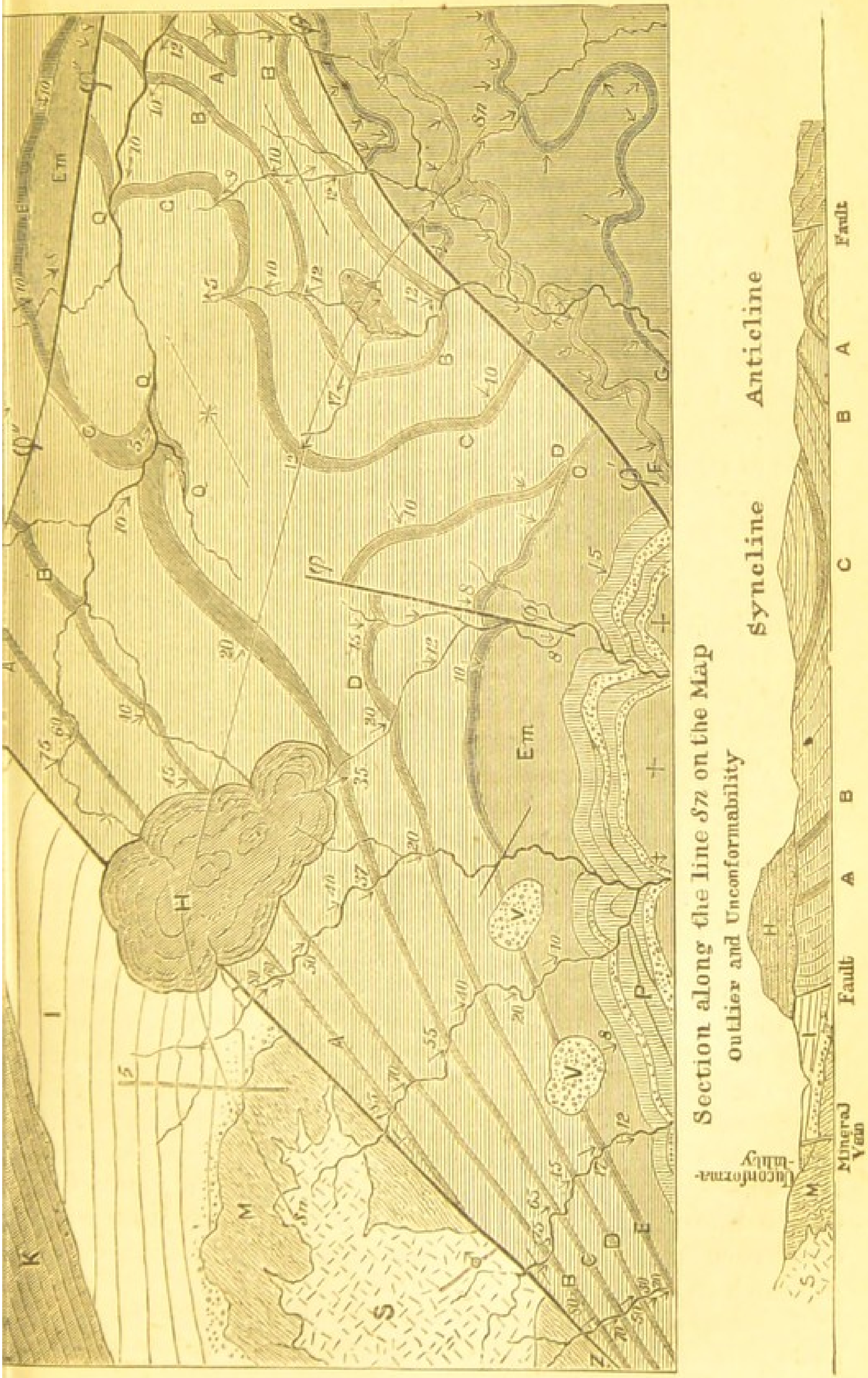


FIG. 9.—Complete geological map.

direction and position of the outcrop, it may be drawn in with continuous lines. Where, however, though it is known to occur within certain limits, some doubt may exist as to its exact position, it should be expressed by broken or dotted lines.

Establishing a Stratigraphical order of Succession.—It will be seen from the map that in the streams at the lower part of the left side the same beds are recognised following and dipping under each other at corresponding intervals. In other words, the order of succession is found to be the same in the different streams. Bed A after an interval is followed by bed B, bed B by bed C, and so on. Even, therefore, where a blank space occurs, and, owing to some surface accumulation, a particular bed may not be visible in one of the lines of section, we can be tolerably sure of the place where, judging from the strata above and below, it would be seen if it came to the surface. We do not hesitate, therefore, to draw dotted lines across that place to indicate our belief. A geological map is thus derived, partly from what is seen, and partly from what can be legitimately inferred.

I would further direct your attention to the fact that while the order in which the beds occur remains the same in all the streams upon our map (Figs. 8 and 9), the spaces between them vary considerably. This difference may arise from one or other of three causes ; either (1) variation in angle of dip, or (2) variation in thickness of strata, or (3) inequalities in the level of the ground. We have already considered the effect of a decrease of inclination in increasing the breadth of a stratum or series of strata at the surface of the ground. It is evident that if the mass of strata between two known beds should swell out or diminish, the breadth of the space between their respective outcrops must correspondingly vary. Inequalities of the surface must influence not only the direction of the outcrops, as we have seen, but also their breadth. Where the angle of dip does not change, and the surface of the ground presents no marked inequalities, but where, nevertheless, a decided widening or narrowing of the interval between two outcrops occurs, we infer with confidence that the intermediate strata must increase or diminish in thickness.

Thinning away of Strata.—Overlap.—It sometimes happens that two lines of outcrop come together, owing to the complete thinning away of the intermediate strata, and the conjoined outcrops may then be traceable for a long distance without further change. Instances of this kind sometimes occur among the coal-seams of our coal-fields. The higher portions of a series of strata now and then steal over the lower, so as to constitute what is termed an "overlap." This structure cannot always be expressed in plan upon a map, but is made clear by a section. On the map group Em overlaps group D in the neighbourhood of the locality marked O. A section of this part of the district would be as in Fig. 10.

Em

Fig. 10.—Section of an overlap.

Relation of Strike to Dip.—There is a further relation to be noted as we proceed, viz.—the constant dependence of the direction of strike upon that of the dip, and the consequent changes of strike as the direction of dip varies. The strike is of course a mathematical line cutting the dip at a right angle. If the dip is east or west, the strike must be north and south; if the dip is north or south, the strike must be east and west. You must not suppose, however, that the line of strike is always, or even most commonly, a straight one. It can only be so as long as the direction of dip continues unchanged. But a comparatively brief experience in the field suffices to show you how constantly the dip of strata varies, now to one side, now to another, every such variation producing a corresponding change upon the line of strike. Where the deviations are slight, and of local character, while the mean direction of inclination remains the same, we take that mean direction as governing the strike (as at band F in Fig. 9). Where, on the other hand, the dip is to different points of the compass in succession, we connect the arrows on our map by lines (as in band G in Fig. 9), and find that the strike becomes a curved, and even, it may be, a very sinuous one.

Faults.—We have been dealing hitherto only with such variations in the outcrop of strata as may arise from the form of the ground, from variations in the thickness of strata, or from changes in the direction and angle of dip. But the outcrop is often broken completely across, and even removed entirely out of sight, by those dislocations in the earth's crust to which the name of "faults" has been given by geologists. These lines of fracture generally form little or no feature at the surface, so that their existence would commonly not be suspected. They comparatively rarely appear in visible sections, but are apt rather to conceal themselves under surface accumulations, just at those points in a ravine or other natural section where we might hope to catch them. Yet they undoubtedly constitute one of the most important features in the geological structure of a district or country, and should consequently be traced with the greatest care.

You may perhaps hesitate to believe that a geologist can satisfactorily trace a line of fracture which he never actually sees. But a little attention to this part of our subject will, I hope, convince you that the mere visible section of a fault on some cliff or shore, does not afford by any means such clear evidence of its nature and effects as may be obtained from other parts of the region where it does not show itself at the surface at all. In fact you might be deceived by a single section with a fault exposed in it, and might be led to regard that fault as an important and dominant one, while it might be only a secondary dislocation in the near neighbourhood of a great fracture, for which the evidence would be elsewhere obtainable, but which might never be seen itself. The actual position (within a few yards) of a large fault, its line across the country, its effect on the surface, its influence on geological structure, its amount of vertical displacement at different parts of its course—all this information may be admirably worked out, and yet the actual fracture may never be seen in any one single section on the ground. A visible exposure of the fracture would be interesting; it would give the exact position of the line at that particular place; but it would not be necessary to prove the existence of the fault, nor would it perhaps furnish any additional information of importance.

The geologist, therefore, constantly finds evidence of far more dislocations than he can actually see. Those which appear, sometimes commonly enough on lines of cliff or coast-section, are apt to be but small and trifling. The larger faults—those which powerfully influence the geological structure of a country—are seldom to be caught in any such visible form. Now why is this? Different reasons may be assigned, each of weight. First of all, it is evident that along lines of great dislocation there must have been, on the whole, greater pressure and a greater grinding and fracture of the fissure-walls than in clean, sharp cracks, where the rocks have been displaced only a few feet or yards. This broken rock on the line of fault crumbles down more than the solid rock on either side beyond it, or is more easily excavated and removed. So that whether on a cliff or on a flat surface, the actual fault is apt to be concealed by superficial detritus. Then again, large faults often bring together rocks of considerably different degrees of durability. The less-lasting material decomposes, and its *débris* goes to cover the actual junction-line between the two formations. Another reason may be sought in the extensive deposits of gravel, clay, or other superficial materials which are spread over the surface of a country and conceal the solid rocks. A line of fault is one of weakness, presenting facilities for attack by the denuding forces whereby it is hollowed out, so as to become a receptacle for these superficial deposits.

In the consideration of faults, therefore, two questions obviously arise. How does a geologist recognise faults when he sees them? and how does he prove their existence when he does not, and cannot, see them?

I need not enter into any detailed answer to the first of these questions. The inspection of the section of a fault in nature will tell more in a few minutes than I could in an hour, and the lesson so received will be better remembered. A fault is not usually vertical, but inclined at a high angle. The rocks are commonly somewhat shattered on either side, the central parts of the fracture being filled with the broken rubbish. The breadth of broken material may vary up to a mass of many yards. If, on the face of a cliff, two different sets of rocks are brought together against each other along a steep line of junction, where they are both jumbled and broken, that line will almost certainly be that of a fault.

The inclination of the sides of the fault is termed its *hade*, and slopes away from the side which has been pushed up or in the direction of that which has gone down. This is a useful fact, as it enables an observer to note which is the up-throw or down-throw side of a fault. The hade ought therefore always to be noted, and in mining districts its angle of inclination may be conveniently recorded to explain the position of the same dislocation in the underground workings.

Unless the same bed can be recognised on both sides of a fault as exposed in a cliff or other section, it is evident that the fault at that particular place does not reveal the extent of its displacement. We should not be safe in pronouncing a fault to be large or small in the amount of its throw merely

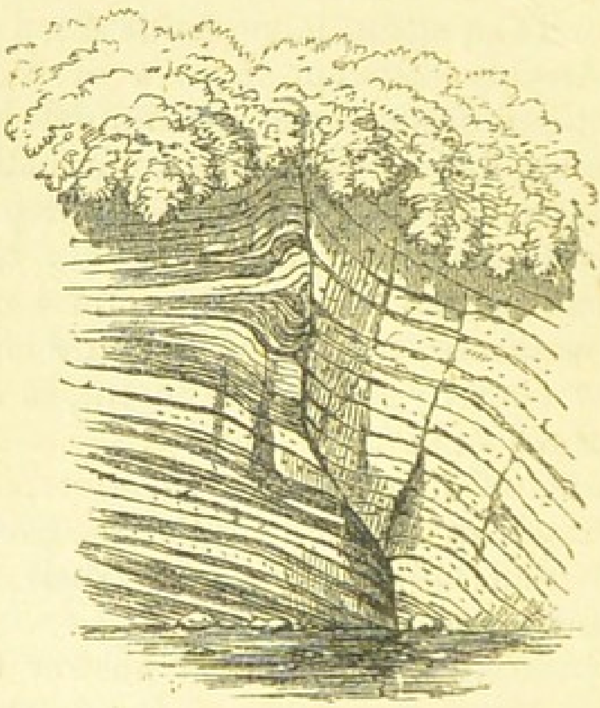


FIG. 11.—Section of a fault.

from the visible section of it. One with a considerable amount of displacement may make little show in a cliff, while, on the other hand, one which, to judge from the jumbled and fractured ends of the beds on either side, might be supposed to be a powerful dislocation, may be found to be of comparatively slight importance. I may cite in illustration the section exposed on the cliff near Stonehaven in Kincardineshire, where one of the most notable faults in Great Britain runs out to sea. This fault lies between the ancient crystalline rocks of the Highlands, and the red sandstones and conglomerates of the Lowlands of Scotland. So powerful have been its effects that the strata on the Lowland side have been thrown on end for a distance of two miles back from the line of fracture, so as to stand upright along the coast-cliffs like books on a library shelf. Yet at the actual point where the fault reaches the sea and is cut in section by the cliff, it does not appear as a line of shattered rock. On the contrary, no one placed at once upon the spot would be likely to suspect the existence of a fault at all. The red sandstones and the reddened Highland slates have been so compressed and, as it were, welded into each other, that some care is required to trace the demarcation between them.

Let us consider the nature of the evidence from which the existence and position of a fault are inferred, though the actual dislocation itself does not appear in any exposure of rock. The upper part of the earth's crust for a variable depth is traversed by a circulation of water, which, descending from the surface and performing a circuitous underground journey, comes out again in the form of springs. The divisional planes by which all rocks are marked serve as channels along which the water oozes or flows. Of these planes, none offer such ready and abundant means of escape to the water as lines of faults do. Hence, in some districts the faults are traceable at the surface by lines of springs. Without some knowledge of the country we should not indeed be justified in inferring the existence of a fault merely from finding a linear series of springs. These might arise along the boundary between two different beds or sets of beds. The springs which issue at the base of the chalk are an illustration. But if, having ascertained that there is no such water-bearing boundary line in the district, we come upon a marked line of springs, we may surmise that they indicate the position of a fault, and may use them in confirmation of other evidence bearing on the existence of that fault. In unravelling the geological structure of a country, the observer may thus often be able, by means of springs, to localise a line of fracture, the existence of which he can demonstrate otherwise.

In the same way, a marked and abrupt change in the form of the ground along a definite line may serve to show the position of a fault. It is true that here again the junction of two beds or two series of rocks of different durability, such as sandstone or limestone upon clay, or gravels lying against granite, may give rise to a long straight or curving escarpment or slope. The mere existence of such a long line of bank would not of itself justify any conclusion or inference as to a fault, but might suggest, and, taken in conjunction with other facts, might help to prove the existence of the fault. Marked forms of ground have always some geological explanation. It is the province of the field-geologist to study them in connection with their causes, and to make use of them in elucidating the structure of the rocks, and the history of the physical geography of a country.

But by far the most important and satisfactory evidence for the existence and effects of faults is furnished by the grouping of the rocks with reference to each other, and can only be put together when the rocks have been examined with some care, in other words, when some progress has been made in unravelling the geological structure of the locality. The nature of this evidence will be most satisfactorily followed by reference to the diagram, Figs. 8 and 9.

It will be observed that several lines of fault are shown upon this map. Look first at that which crosses the streams on the left or west side. In ascending the most southerly of these streams, we notice that at first the rocks consist of various sedimentary deposits—sandstones, shales, and limestones. These strata dip toward the south-east, and the angle gradually rises as we proceed up the stream, until at the last place where they are seen the beds stand at an angle of 80°. A short way higher up we encounter rocks of an entirely different character; let us suppose them to be granite and crystalline metamorphic rocks. The gradual rise of angle and the almost vertical position of the strata would be regarded as sufficient to indicate the existence of a line of fault between the stratified rocks and the crystalline masses. The section in the next stream is very similar. It will be observed that while the general order of the strata is the same, some of the beds in the former section do not come out to view here, while, on the other hand, some appear here which were not found before. It is by thus piecing different contiguous sections together that the order of strata in a district is made out. The angle of dip in this second stream rises as before towards the higher ground inland, until angles of 70° to 80° are reached. It will be observed that the last rocks seen there lie beyond the line of those last seen in the first stream; also that the obscured space between them and the crystalline masses is narrower. We get deeper into the series and find that a lower part of it than was seen before now impinges upon the granitic masses. In the next stream similar evidence is obtained, only here a little ambiguity seems at first to arise from the fact that the strata, after gradually becoming vertical, dip as it were into or below the granite. This in reality is a reversal of dip. The strata have not only been thrown on end, but actually bent back upon themselves. No more convincing evidence of the existence of a powerful fault could be given. It should be noticed, too, that here again we have still lower parts of the series of stratified rocks placed on end against the granitic hills.

Now, having put these various data upon our map, we see that the point of junction between the two kinds of rock crosses the streams in a tolerably straight north-easterly line. There cannot be any doubt that the junction is a fault, for 1st, there is no trace of any conglomerates or other indications of an original base to the formation, lying upon and wrapping round the granite; 2nd, there is no evidence of the granite having been intruded through the rocks. The latter show no granite veins or traces of alteration. 3rd. The disturbed and even vertical position of the strata all along the straight line of junction proves that line to be a fault. 4th. The upturned strata are cut across obliquely by the junction-line, so that different horizons of them are successively brought against the crystalline rocks.

We cannot hesitate in such a case to treat the line as a fault, which we mark on the map by a strong pencil-line at each point where there is good evidence as to its approximate or actual position. We should search for further traces of the line in the intermediate ground, and here may be realised the use of a line of springs or of some definite bank or hollow on the surface of the ground, in enabling us to carry the line of the fault with confidence across a tract where no actual rock may be exposed. There could be, in the present instance, little hesitation in prolonging our strong pencil-line from point to point; if we felt any uncertainty as to its course through some part of the country, we should make the line there a broken or dotted one.

The side of up-throw or down-throw may either be fixed at once from our knowledge of the order of succession among the rocks, or may be determined at a later stage as our knowledge of the district increases. Thus, in the case which has just been under notice, if we knew that the granite series was older, that is, underlay the other, we should say that the up-throw of the fault was to the granite side. This direction might be marked on the map by a short bar placed perpendicular to the line of the fault, and on the down-throw side. In the completed map (Fig. 9), the fault might be shown by a strong black line or by a white line. The latter method is adopted on the maps of the Geological Survey, where fine lines of opaque Chinese-white are placed over the geological colours to mark the position of the faults.

From the example given in the diagram which we have been considering in detail, it appears that one indication of the proximity of a fault is a rapid rise in the angle of inclination of strata. It is common to find the beds on the down-throw side bent up against the other side, and this upturning may extend for a few feet or for more than a mile. The beds on the up-throw side, on the other hand, may sometimes be observed to be bent down against the fault. This arrangement is of course what might have been looked for, but it does not always occur.

Another feature which may be regarded as a tolerably sound proof of the existence of a fault, consists in a complete divergence of strike between the formations on either side of a given line, or, in the common parlance of field-geologists, when one series of strata strikes at or against another. This may be most easily understood by reference to the diagram (Figs. 8 and 9). Towards the south-east portion of that map, two different sets of strata may be observed to crop up in the various streams and natural sections. The strike of one of these is at D and C nearly north-west. Towards the north-east, owing to a change in the direction of dip, the strike swings round, until at last it is E.N.E. and W.S.W. Now, unless some fault occurs, we may confidently expect that the strata which strike north-west and south-east will be found to continue southwards, though they may eventually participate in some other change of strike, and wheel round as before. If, then, in the line of their strike, and at a comparatively short distance, in which they have no room to turn round, we encounter, as shown here, another and different series of rocks (F and G), we may reasonably infer that a fault intervenes, and may set about the search for further evidence of it. In the case supposed upon the map, the strata on the south side strike on the whole in a north-east and south-west direction. But close examination shows that some strata are cut out as they approach the junction-line; this plainly indicates the line to be one of dislocation.

A great many faults run with the dip, and are called *dip-faults* (φφ in Fig. 9); another series runs with the strike, forming *strike-faults* (φ′φ′ in Fig. 9). But as dislocation may occur in any direction, and cross dip and strike at any angle, these two series are not very sharply marked off from, but may pass into each other, or the same dislocation may be a dip-fault when looked at from one side and a strike-fault when viewed from the other (as at φ″φ″ and z z in Fig. 9). Owing to the way in which denudation has smoothed down the surface of the ground, a dip-fault has the effect of shifting the outcrop of a stratum so as to make it appear like a horizontal displacement. In the map, for example, the beds D and E dipping south are traversed by a dip-fault with a down-throw to the east. The line of outcrop is consequently shifted northwards on the side of down-throw. If the beds had dipped northwards then a down-throw to the east would have moved the outcrop southwards. A strike-fault, when it exactly coincides with the line of strike on both sides, makes no change in the line of outcrop, except in bringing two parallel bands closer together. It may carry some important strata out of sight, or prevent them from ever being seen at the surface at all. In the map (Fig. 9), for example, the bed C is completely cut out against the strike-fault φ′ φ′. If it were not seen at the surface elsewhere, its existence could not be known unless from some underground boring.

To judge of the character and effects of faults upon the geological structure of a country, you should consult some good detailed maps, such as the large coal-field plans of the Geological Survey of Great Britain. It is good exercise, too, in the practical treatment of faults in field-geology, to study some coast section where the strata are considerably faulted, and where they are exposed in plan upon the beach as well as in section upon the cliff. A river-ravine in summer weather, when the water is low, sometimes furnishes admirable lessons in this as well as in other branches of the subject.

Unconformability.—When one set of rocks has been disturbed and denuded before the deposition of another series upon them, the latter is said to rest "unconformably" upon the former, and this kind of junction is known as an "unconformability." An extreme case of this structure presents little difficulty. It can be expressed so clearly upon a map as at once to tell its own story. Thus in Fig. 9 the sheet of rock H evidently forms a flat unconformable cake lying upon inclined and denuded strata. A section across this cake would disclose an abrupt junction of the horizontal beds on the edges of the steep and vertical series. But many cases occur where the discordance between the two series is far less strong, where indeed much care and labour may be required to make out an unconformability at all. For here again, as in the case of faults, the actual line of contact between the two groups of rocks is comparatively seldom seen. We must usually infer from their general arrangement and their relations to each other whether or not they are separated by an unconformability. In the diagram we have already used so much (Fig. 9) another and less violent unconformability is shown towards the north-west corner, where the series of beds K steal over the denuded outcrops of the series I.

In most cases it is possible so to express an unconformable junction upon the map as to make it readily apparent to the geologist. It should be the aim of the surveyor to neglect no item of evidence which will enable him to do this; for the more perfectly his map is self-interpreting, the more useful will it be. Hence where, as is so often the case, the ground is obscured by surface-accumulations, and a little liberty of choice is left to him as to the precise course along which to place his line of unconformability, he will draw his line in such a way as to show as clearly as may be that it is not a fault or an ordinary conformable junction.

In some districts, particularly in those where older formations are covered by more recent superficial accumulations, a double unconformability may often be seen. The accompanying diagram, for example (Fig. 12), represents what is exposed on a cliff section at Cullen, on the coast of Banffshire. The lowest formation consists of quartz-rock (*q*) in strata inclined at a high angle to the south-east. Their upturned ends are unconformably overlaid by red sandstones and conglomerates (*s*) dipping gently away towards the south-west. These beds are in turn unconformably covered by the glacial clays and gravels (*d*). This is an interesting and instructive section, inasmuch as it teaches us how rash it would be to form any conclusion as to the relative length of the intervals of time represented by the amount of discordance between unconformable formations. The break between the quartz-rock

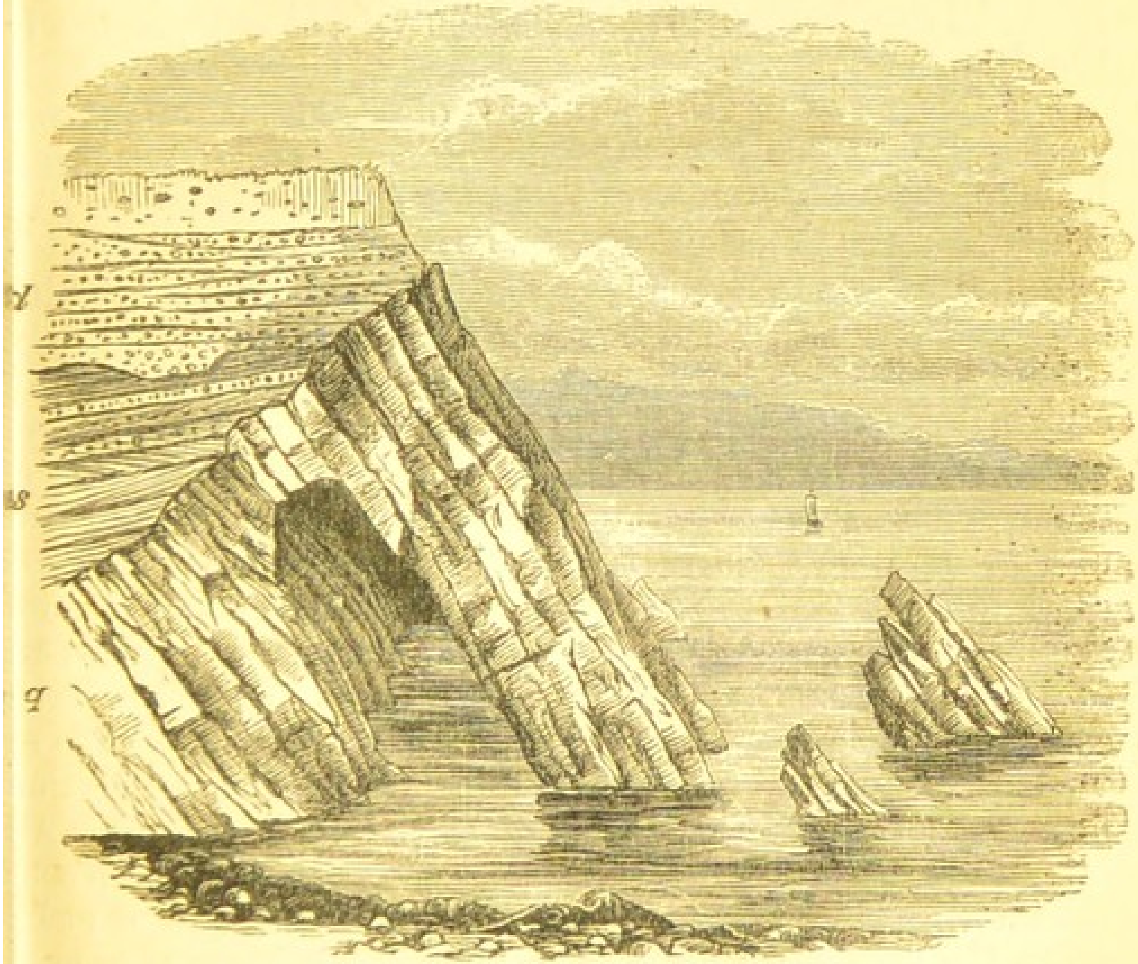


Fig. 12.—Double unconformability at Cullen, Banffshire.

and the red sandstones is apparently much more violent and complete than that between the sandstones and the glacial deposits. And yet there can be no doubt that in regard to geological age, the interval between the deposition of the quartz-rocks and that of the sandstones was greatly shorter than that between the sandstones and the overlying clays and gravels. It is evident indeed that sections might be found showing an apparently perfect conformability for a certain space between the sandstones and the glacial beds. Yet this local agreement in position would not be allowed to conceal the real and complete break between the two series of formations.

Igneous Rocks.—I have been speaking hitherto chiefly of the structure of the stratified rocks, although the same principles which serve to guide us in dealing with them are also in great part applicable to the igneous rocks. These latter, however, present some features of their own which mark them off in strong contrast with the former, and which the geologist can learn to distinguish only by actual practice in the field.

Igneous rocks for the purposes of field-geology are conveniently divisible into two great series—(1) the crystalline, including granite, syenite, with all the once melted rocks like the lavas; and (2) the Fragmental, including the consolidated volcanic ashes, tuffs, and conglomerates. The crystalline igneous rocks may either be intrusive or interbedded, that is, they may either have been intruded among the rocks with which they are associated, or they may have been poured out at the surface in sheets which in a great continuous series of deposits thus come to be interbedded between the strata below and those above them. It is of course evident that as these crystalline masses have all risen from molten reservoirs below, they were all originally intrusive in the earlier or deeper part of their course. Every interbedded sheet must have been connected somewhere underneath with the intrusive pipe or vein by which it rose to the surface, although the connection may have been subsequently destroyed or concealed. An intrusive mass, on the other hand, may never have been connected with the surface at all. Interbedded igneous rocks prove the former existence of active volcanic vents at or near the localities in which they occur. Intrusive igneous rocks may be due to ancient deep-seated movements in the crust of the earth which never gave rise to any of those surface manifestations which are usually held to be expressed by the term volcanic. An accurate discrimination between these two groups is of importance when the history of a volcanic district has to be made out.

I may briefly notice some of the main characters which distinguish the groups. An intrusive rock may occur in the form of a vein or dyke, a pipe or neck, a sheet, or an irregular amorphous mass. When it can be seen to intersect any of the beds of a series of strata, its intrusive character becomes at once apparent. But when it lies between stratified rocks, and assumes the form of a bed, some care is needed to make its intrusive character certain, for it might then be taken for an interbedded sheet. It is usually characterised by being much closer in grain near its junction with the other rocks than in the central parts of its mass. Again the rocks lying upon it are hardened, and sometimes exceedingly altered,

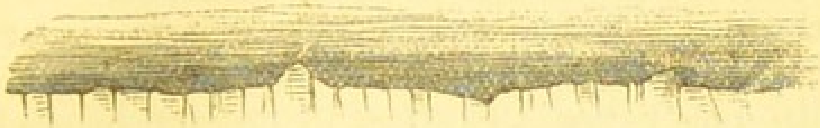


FIG. 13.—Upper surface of an intrusive igneous sheet.

while detached portions of them are now and then found to have been caught up and entangled in the crystalline mass below. A truly interbedded sheet on the other hand, is in fact a lava-bed which has been poured out at the surface, either on land or under water, and shows the distinctive characters of such a bed. Thus it is commonly rough and slag-like towards its top and bottom, and most compact about the centre. The beds lying upon it, having been

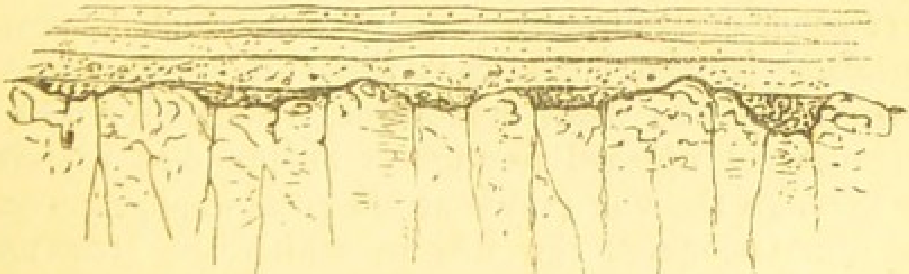


FIG. 14.—Upper surface of an interbedded igneous sheet.

deposited there after the emission of the lava, are not altered, have no portions of their strata entangled in the crystalline rock, but, on the contrary, may contain detached fragments of the latter.

Again, the position of the prismatic joints by which volcanic rocks are frequently traversed may sometimes suffice to indicate whether a rock is certainly intrusive or, possibly, interbedded. These joints start from the cooling surfaces of the original melted mass of lava. In a bed they are of course perpendicular to its upper and under surfaces; in a dyke or vein they vary according to the inclination of the mass, being horizontal when the dyke is vertical.

You will recognise the usefulness of such characters as these when you reflect that on the one hand they may enable you to trace the position of the volcanic vents or pipes; on the other, the course of the lava-streams which proceed from these points of emission. In the diagram, Fig. 9, the series of rocks marked P in the southern part of the map are examples of interbedded sheets and tuffs. They occur under circumstances very similar to those of ordinary stratified rocks. They dip one below the other in orderly succession, and are transverse by faults, like the beds of sandstone and conglomerate which lie below, between, and above them. In an actual volcanic cone, where only volcanic materials occur, a more complex arrangement is found. Lavas and tuffs there succeed each other in rapid alternations, often traversed by dykes or veins. Instances are comparatively rare where cones belonging to old geological periods have been preserved. It is not uncommon, however, to meet with what may be called the root or stump of the cone, from which all the over-lying pile of ejected materials has been worn away by denudation (V V in Fig. 9). This lower or downward prolongation of the original cone may consist either of masses of lava or other crystalline rock, or of consolidated fragmentary materials. In the latter case the tuff or agglomerate has sometimes become itself crystalline, owing, no doubt, to the long-continued upward passage of steam, hot vapours, and gases through the volcanic vent after the explosions ceased.

As illustrations of the way in which the structure of a volcanic region is worked out and expressed upon a map, I may refer you to the sheets of the Geological Survey of England and Wales, particularly 75 and 78, embracing the Snowdon region, and to sheets 22, 23, 32, 33, and 40 of the Geological Survey of Scotland, showing the development of the volcanoes of the Old Red Sandstone, Carboniferous, and Permian periods in the midland districts of Scotland.

Mineral Veins.—Like lines of fault, with which indeed they often coincide, mineral veins, that is, veins filled with segregated minerals of various kinds, different from the surrounding rock, do not in the majority of cases appear at the surface. Their existence must be determined from other evidence, therefore, than actual visible sections of them. If the geologist be at work in a district where veins of this kind occur, he should endeavour as early as possible to make himself familiar with the characteristic mineral substance which may constitute the chief part of the veins. Such minerals as quartz, barytes, calcite, and other "vein-stones," as they are called, are of common occurrence, but often exhibit local peculiarities by which they may be recognised and traced to their sources. Having examined the visible sections of some of the mineral veins, and learnt the way in which the vein-stones are associated with any metalliferous ore, he may be on the watch for evidence of the occurrence of the veins elsewhere. He follows with this view the same plan as that which I have already described with reference to the tracing of the limits of formations by means of scattered surface-fragments. In ascending a stream or a hill-side, he takes note of any marked number of pieces of vein-stone, and of the point beyond which they grow fewer or cease. Having thus got a rough indication of the existence of one or more veins, he proceeds to a more minute search over that part of the ground, and unless the rocks should be too much concealed, he may hope to meet with an indication of the actual outcrop of the vein. It is not always, nor perhaps often, safe to pronounce as to the commercial value of such a vein from surface evidence of this kind. The rock may need to be opened up, and boring or mining carried for some way below the surface before a reliable opinion can be expressed as to whether or not the vein may be worked to profit.

6. Construction of Sections.

The more clearly a geological map represents the structure of a country, the less need is there for any additional explanation, so that a perfect map, large in scale and detailed in execution, should be independent of sections or other assistance, except for data, which cannot be expressed upon a map. But such a map can comparatively seldom be constructed. We must be content with a small scale, an imperfect topography, and other defects which compel us to supplement the map with lines of section so drawn as to convey to the eyes of others exactly what we have ourselves seen or believe to be the geological structure of the district or country in question.

A section may either be horizontal or vertical, that is, it may show either what would be seen if a deep trench could be cut across hill and valley, so as to expose the relations of the rocks to each other, or else the arrangement and thicknesses of the rocks if we could pile them up into a tall column one above another in their proper order of succession. The vertical section is chiefly of use in detailed work, as, for instance, among coal-fields, where the various strata of one pit or part of a district are to be compared with those of another, or in localities like the coast-sections of the tertiary rocks of the Isle of Wight, where every stratum is exposed to view. Evidently a section of this kind requires good exposures of rock and careful measurements.

The horizontal section, on the other hand, must often be constructed where exposures of the rock are few, where minute measurements are impossible, and where the highest skill of the field-geologist is taxed to unravel the meaning of the facts he notes upon the surface, and to show their bearing upon the relations of the rocks below ground. The first point I would remark in the drawing of a horizontal section is, that where possible, the section should always be on a true scale, that is, the height and length should be on the same scale. Of course this is often impossible, for the ground may be low, and to show its true form in a section might require an extravagant and unnecessary length of paper. Still the geologist who would preserve, as he should, the relations between the external form of the ground and the structure of the rocks below it, will always endeavour to exaggerate the height of his sections as little as possible. I believe that nothing has tended so much to perpetuate erroneous notions regarding the physiography of the land as such distorted sections, sometimes almost grotesque in their exaggeration of natural forms.

As an example of the disregard which some able observers have had for truth of outline in their sections, let me place before you two sections of the same hill. On one of these (A), an eminent mineralogist, seems to have been content to represent in a kind of diagrammatic way the order of the formations, heedless of the utterly unnatural form of his hill. The other section (B) shows the true outline of the ground, on the scale of six inches to a mile, with the position of the rocks correctly inserted.

A further and familiar illustration of the effects of this neglect of the true proportions of the ground is offered to us by the case of the "London Basin." I presume most readers, when they meet with that phrase, think of a deep bowl-shaped hollow filled with clay and surrounded by a rim of chalk

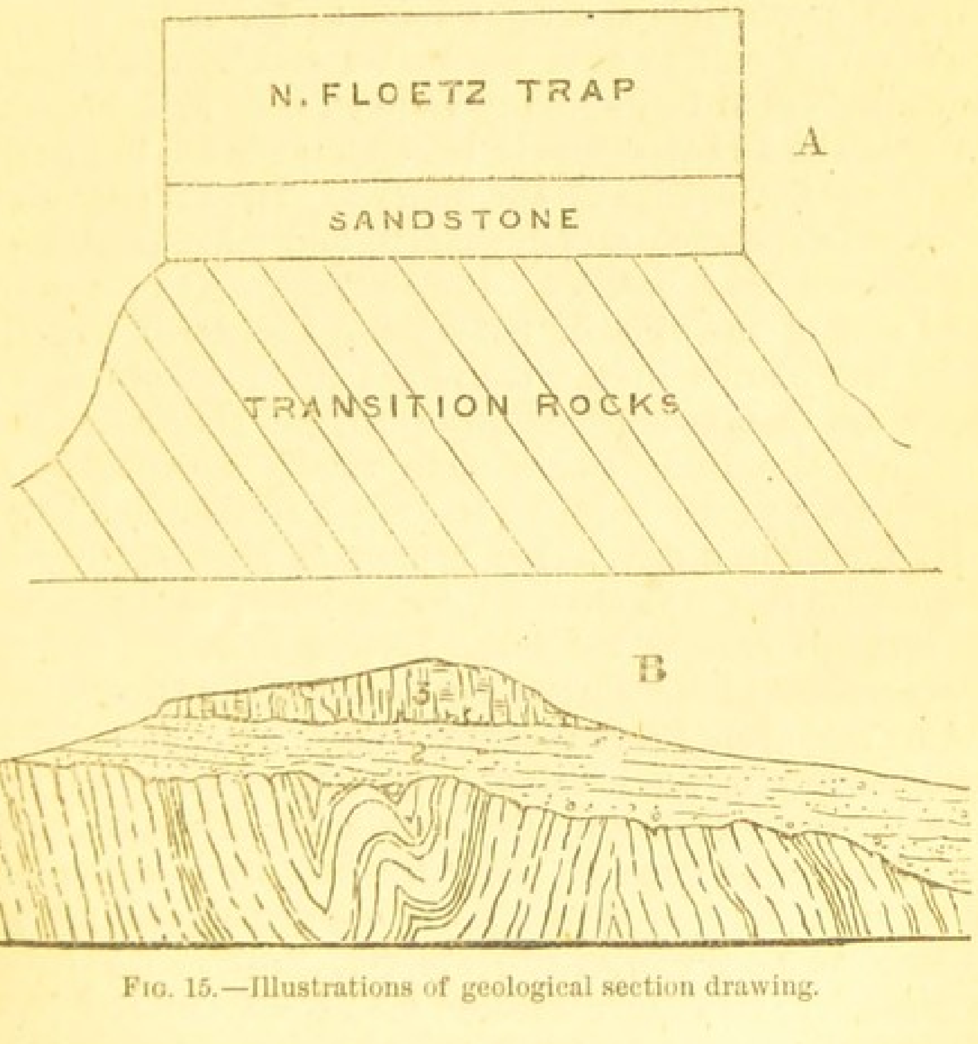


FIG. 15.—Illustrations of geological section drawing.

hills, and they probably recall one of the sections in popular manuals and text-books by which this impression was perhaps originally given to them. If, however, you construct a section across the London basin on a true scale, or if you examine that which has been constructed and published by the Geological Survey on the scale of six inches to a mile, you will find that so flat is the basin, so small the thickness of clay (500 feet) in proportion to the breadth of country over which it is spread (24 miles), that you need to look with some little care to be assured that there is really any basin at all.

The next point to be attended to in the construction of a horizontal section is the choice of the line of country across which it is to be drawn. It may be designed either to show the general structure of the country or the arrangement of the rocks in some particular part of it. In any case, while taking it over those portions of the ground where the structure is best seen, we should always bear in mind that it must pass as nearly as possible at a right angle to the strike of inclined strata. You will at once see that a section coincident with the strike would make highly-inclined beds look horizontal.

When the section comes to be actually drawn, the first thing is to insert the outline of the ground. The actually observed geological data, such as dips, faults, and other facts, are then placed upon that outline. If necessary, search is made on either side of the line of section for additional materials to fill in the blanks in the section. The lines found at the surface are then prolonged downward, and the section is filled in. To make these stages more clearly understood, let us suppose that we are required to draw a section on a true scale of six inches to a mile across a piece of ground. We fix on some datum-line, the sea-level, for instance, on which to erect our verticals for the heights. Having obtained the correct measurements of the surface from our own levellings, or those of other surveyors (in this country the contoured maps of the Ordnance Survey are invaluable for this purpose) we proceed to mark off on our datum line a series of points, the height of each of which is known. How this is done is shown in Fig. 16, A. A line is then drawn, connecting all the points together, which gives, as you observe, the general contour of the ground. To ensure greater fidelity of detail it may be well to walk over the ground with the plotted section in hand, so as to be able to fill in any little inequalities of surface, and at the same time to look once more for evidence as to the nature and structure of the rocks below. The drawing in Fig. 16 B, represents the outline as so modified by a visit to the ground. On this same drawing all the geological data are inserted which are supposed to be actually seen either on the line traversed by the section, or in the immediate vicinity of it. But a more extended examination of the district would no doubt supply many data not obtainable on the precise course of section, and permit the lines to be prolonged downward, and the whole section to be filled in somewhat in the manner shown in C. The section in Fig. 9, shows the structure of the country represented in the map, and illustrates the application of many of the terms which I have made use of in these lectures.

You may well believe how impossible it is to find a place here for all that might be said in the way of suggestions for

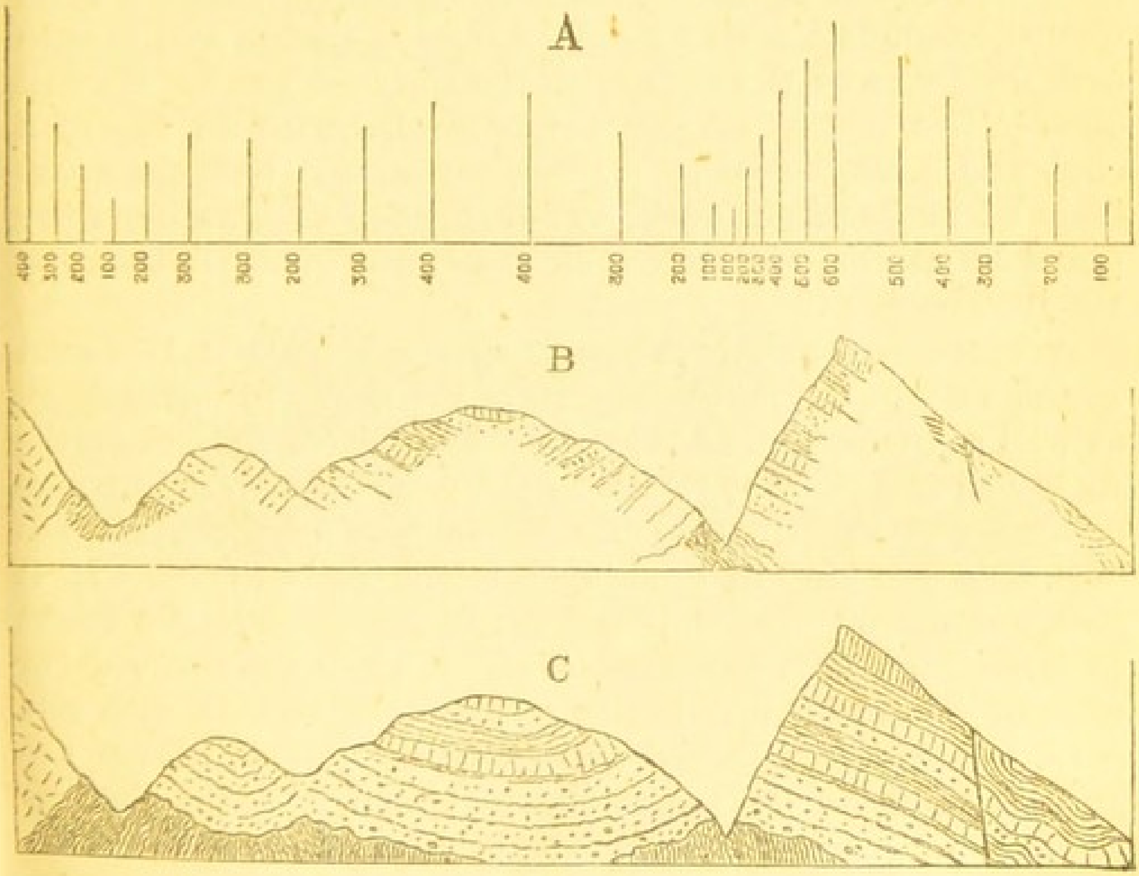


FIG. 16.—Stages in the construction of a geological section.

the field-geologist. There are still one or two parts of the subject, however, to which, at the risk of trespassing too long upon your patience, I should wish to be permitted to refer. I have been treating of the solid rocks and their underground structure. But they present some features to which I have not alluded, and which have a special interest in reference to the character and origin of diversities of landscape. One of the most familiar and important of these features presents itself in the form of what are called *joints*, that is the clean, sharp, and usually perpendicular or highly-inclined divisional planes by which all rocks are traversed. Every one who has looked into a quarry or railway-cutting, or has seen a coast-cliff or a river-ravine, has had many a joint under his eyes. They are familiar to the quarryman and miner, by whom their directions are always well-known, seeing that they determine the course along which quarrying and many mining operations proceed. When the geologist is engaged in hilly or mountainous ground, among crags and rock-pinnacles, or on exposed coast-cliffs, he should not fail to note with some care the trend of the different joints. He will soon find that they in each place run in two or more dominant directions. And a little further examination will usually suffice to enable him to connect the forms of the cliffs with the lines of joint. He will observe how one set of joints runs parallel with the face of a cliff, and is cut across by another series, and how the quadrangular buttresses of rock, which shoot up perhaps into spiry pinnacles at the top, have their shape first given to them by the intersecting lines of joint.

Another superficial character of much interest is found abundantly in the northern parts of the northern hemisphere, as well as in mountain-tracts in other regions of the globe—the smoothed and striated surfaces left upon rocks by the passage of sheets of ice across them. When the field-geologist has once seen this kind of surface, he is not likely to confound it with any other. The only one for which it sometimes might be mistaken is that termed *slickensides*, where the two walls or faces of a joint have slid upon one another so that each side is rubbed smooth, polished, and grooved. But a little practice and the study of good examples will soon give the observer such confidence in discriminating between them as he cannot acquire in any other way. He ought to take with his compass the direction of the groovings and striæ on the rock. If possible he should at the same time determine from which quarter the ice has moved. This may often be done by observing in what direction little prominences and the edges of angular projections are rounded off, and to which side the still rough and unstriated portions look. The ice must evidently have moved from the quarter to which the smoothed faces are presented and towards the quarter to which the rough parts are turned. This is shown in Fig. 17, where the arrow indicates the trend of the ice-movement. The way in which an observation of this kind may be indicated on the map is shown in the index of signs in Fig. 4. By a sufficient number of such observations in a district, the path of the ice across it may be very clearly expressed.

There is another useful method of supplementing this evidence from rock-striations as to movements of the ice; but it cannot usually be put into practice until after the observer has made some considerable acquaintance with the geology of the whole region. In countries which have been under ice, and where the rocks retain the characteristic ice-markings, the surface commonly presents abundant accumulations of boulder-clay, gravel, and other deposits belonging to different conditions of the long glacial period. A search through the

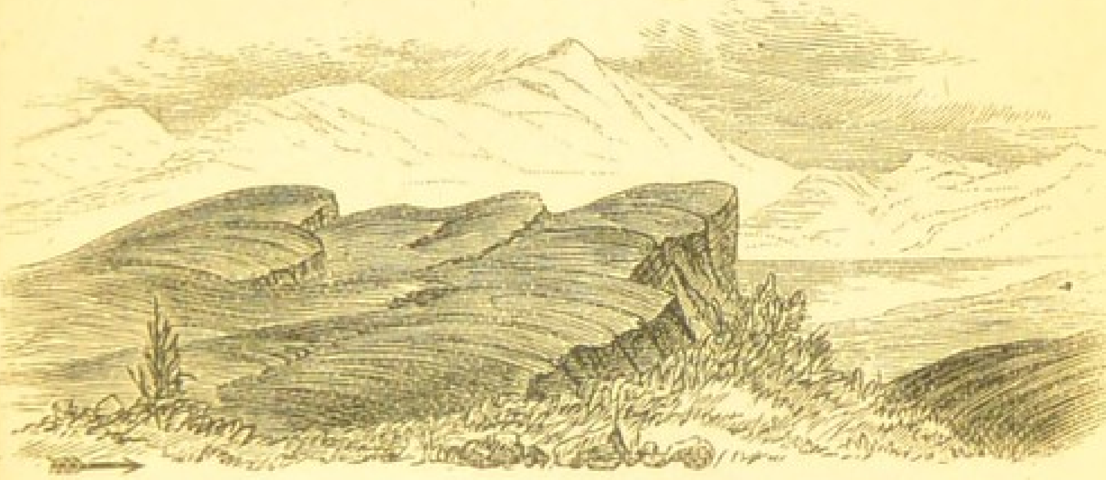


FIG. 17.—Ice-worn hummocks of rock, the arrow pointing in the direction of the ice-movement.

stones and boulders of those deposits will in most cases disclose the fact that these fragmentary materials have been moved a greater or less distance from their parent rocks. In the clays the stones are often as well striated as the solid rock below (Fig 18). Pick out at random two or three hundred stones from any section of boulder-clay or moraine-stuff, and note down the proportions in which each variety of rock occurs among them. You will find perhaps that 50 or 60 per cent. may have been derived from rocks in the immediate vicinity, that 20 or 30 per cent. have perhaps come a good many miles, while the remainder (usually small in size) may possibly be traced to some of the most distant rocks in the drainage-basin of the region. You learn from such an analysis the general direction of the ice-stream, and see that it agrees with the evidence furnished by the striæ on the rocks.

It is desirable that the field-geologist should remember that at any moment some of his observations may be found to have an economic use in the practical applications of geology. As he cannot always tell which may prove to be capable of this application, he should try to make them all as full and reliable as the evidence to be had will permit. I need not of course do more than allude to the value of any notes as to the position of metallic ores, seams of coal, or other economically valuable minerals. But not less important may be the apparently trivial question as to the direction and angle of strata at the surface, for the careful determination of these points may show the depth to which a well or mine may

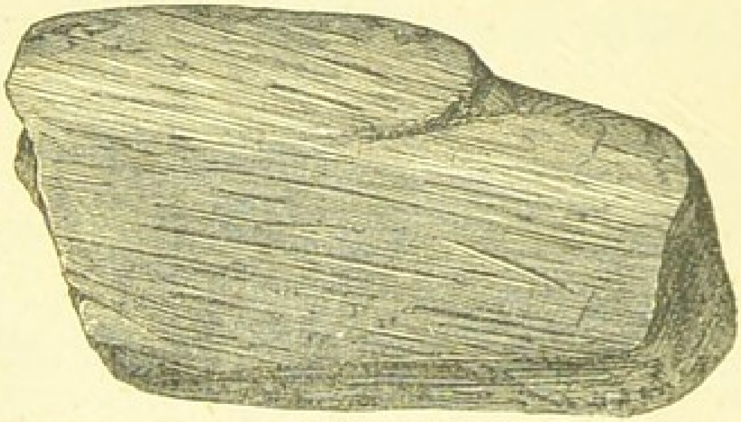
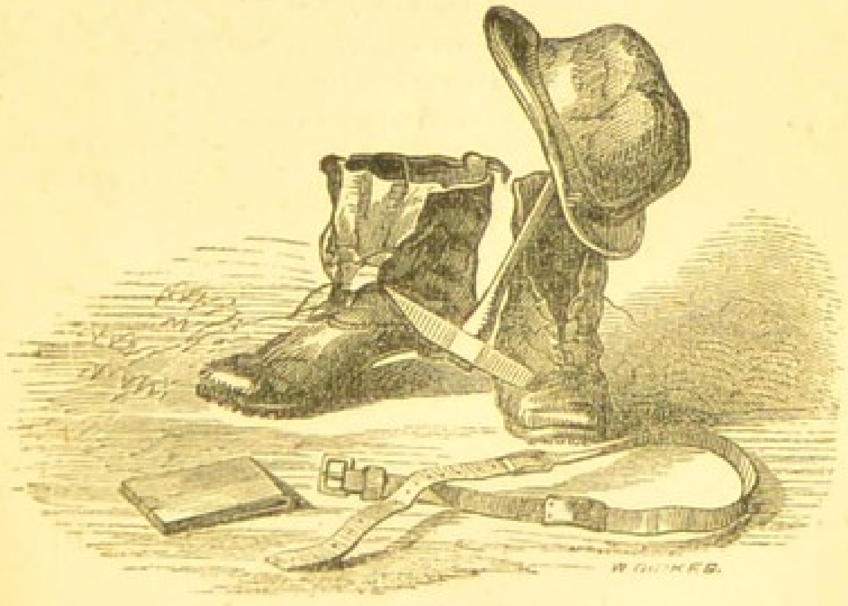


FIG. 18.—Ice-striated stone from the boulder-clay.

require to be sunk. From what I have already said regarding the method of taking the dip, and protracting the angles on a section line, you can understand how the evidence of an experienced field-geologist should be of high value in questions of water-supply, and how it is that he can often tell the depth within a few feet at which any particular water-bearing stratum will be met with.

In fine, if I have succeeded in laying before you a definite picture of the aims and methods of field-geology, you will doubtless admit that though you may never become professional surveyors, nor claim in any complete sense the title of field-geologists, you cannot devote even a small portion of your time and attention to this subject without deriving a real and solid advantage from the pursuit. It accustoms you to habits of observation, provides you with a delightful relief from the cares and routine of every-day life, takes you into the open fields, brings you to the free fresh face of nature, leads you into all manner of sequestered nooks, whither hardly any other occupation or interest would be likely to send you, sets before you problems of the highest interest regarding the history of the ground beneath your feet, and thus gives a new charm to scenery which may be already replete with attractions. Even, therefore, should you never write a single sentence of geological description, or venture to put one geological line upon a map, you gain from the prosecution of field-geology many a happy and profitable hour, alike in the country to which the pursuit leads you, and in your own homes with quiet reflection on what you have seen and done in the field.



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