But a third set may usually be noticed cutting across the columns, though less continuous and dominant than the others. When these transverse joints are few in number or occasionally absent, columns many feet in length can be quarried out entire. Such monoliths have been from early times employed in the construction of obelisks and pillars.

In rocks of finer grain than granite, such as many diorites and dolerites, the numerous perpendicular joints give the rock a prismatic character. The prisms however are unequal in dimensions, as well as in the number and proportions of their sides, a frequent diameter being 2 or 3 feet, though they may sometimes be observed three times thicker, and extending up the face of a cliff for 300 or 400 feet. It is by means of joints that precipitous faces of rock are produced and retained, for, as in the case of those in stratified masses, they serve as openings into which frost drives every year its wedges of ice, whereby huge slices are stripped off. They likewise give rise to the formation of those fantastic pinnacles and fretted buttresses so generally to be observed among igneous rocks in which they occur.

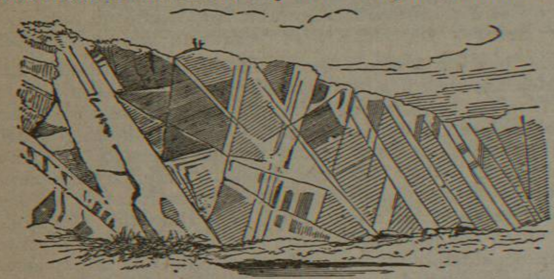
FIG. 16.—Joints in granite, Killiney Hill, Dublin. (G. V. Du Noyer.)

But undoubtedly the most striking series of joints to be found among igneous rocks is in the regularly columnar, or as it is often called, basaltic structure. This structure has been already (*ante*, p. 249) described in connexion with modern volcanic rocks. It may be met with in rocks of all ages. It is as well displayed among the felsites of the Lower Old Red Sandstone, and the basalts of the Carboniferous Limestone in central Scotland, as among the Tertiary lavas of Auvergne or the Vivarais.

3. *In Foliated Rocks.*—The schists likewise possess their joints, which approximate in character to those among the massive igneous rocks, but they are on the whole less distinct and continuous, while their effect in dividing the rocks into oblong masses is considerably modified by the transverse lines of foliation. These lines play somewhat the same part as those of stratification do among the stratified rocks, though with less definiteness and precision.

III. INCLINATION OF ROCKS.

The most casual observation is sufficient to satisfy us that the rocks now visible at the earth's surface are seldom in their original position. We meet with sandstones and conglomerates composed of water-worn particles, yet forming the angular scarps of lofty mountains; shales and clays full of the remains of fresh-water shells and land-plants, yet covered by limestones made up of marine organisms, and these limestones rising into great ranges of hills, or undulating into fertile valleys, and passing under the streets of busy towns. Such facts, now familiar to every reader, and even to many observers who know little or nothing of systematic geology, point unmistakably to the conclusion that the rocks have in many cases been formed under water, sometimes in lakes, more frequently in the sea, and that they have been elevated into land.

But examination discloses other and not less convincing evidence of movement. Judging from what takes place at the present time on the bottoms of lakes and of the sea, we confidently infer that when the strata now constituting so much of the solid framework of the land were formed, they were laid down either horizontally or at least at low angles. When, therefore, we find them inclined at all angles, and even standing on end, we conclude that they have been disturbed. Over wide spaces they have been upraised bodily with little alteration of their original horizontality; but in most places some departure from that original position has been effected.

The inclination thus given to rocks is termed their dip. Its amount is expressed in degrees measured from the plane of the horizon. Thus a set of rocks half-way between the horizontal and vertical position would be said to dip at an angle of 45°, while if vertical they would be marked with the angle of 90°. The edges of strata, where they come up to the surface, are termed their *outcrop* or *basset.* When they *crop out*, that is, rise to the surface, along a perfectly level piece of ground, the outcrop runs at a right angle to the dip. But any inequalities of the surface, such as valleys, ravines, hills, and ridges will cause the outcrop to describe a circuitous course, even though the dip should remain perfectly steady all the while. If a line of precipitous gorge should run directly with the dip, the outcrop will there be coincident with the dip. The occurrence of a gently shelving valley in that position will cause the outcrop to descend on one side and to mount in a corresponding way on the other, so as to form a V-shaped indentation in its course. A ridge, on the other hand, will produce a deflexion in the opposite direction. Hence a series of parallel ridges and valleys running in the same direction as the dip of the strata underneath would cause the outcrop to describe a widely serpentinous course. Again, should the rocks be vertical, the outcrop will necessarily correspond with the dip, and continue to do so irrespective altogether of any irregularities of the ground. The lower therefore the angle of inclination the greater is the effect of surface inequalities upon the line of outcrop; the higher the angle the less is that influence, till when the beds stand on end it ceases.

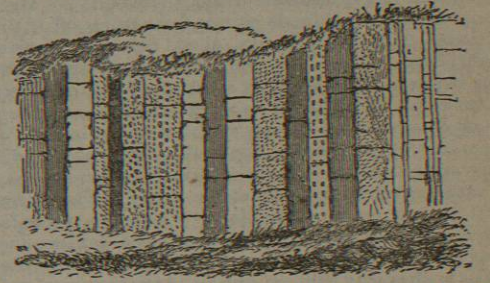
FIG. 17.—Vertical strata, originally deposited horizontally or at low angles.

A line drawn at a right angle to the dip is called the *strike* of the rocks. From what has just been said this line must coincide with outcrop when the surface of the ground is quite level, and also when the beds are vertical. At all other times they are not strictly coincident, but the outcrop wanders to and fro across the strike according to the changes in the angle of inclination and in the form of the ground. The strike may be a straight line or may curve rapidly in every direction, according to the behaviour of the dip. If, for instance, a set of beds dips for half a mile continuously to the north, the strike will run for that distance as a straight east and west line. If the dip gradually changes to north-west and west, and then by south-west to south, it is obvious that the strike must curve round by north-east, north, and north-west till it once more becomes parallel with its former course. Both of the parallel lines of strike run in an east-and-west direction, but in the one the dip is to the south, and in the other to the north.

The strike may be conceived as always a level line on the plane of the horizon, so that no matter how much the ground may undulate, or the outcrop may vary, or the dip may change, the strike will remain level. Hence in mining operations it is commonly spoken of as the *level-course* or *level-bearing.* A level or underground road-way, driven through a coal-seam at right angles to the dip, will undulate in its course if the dip changes in direction, but it may be made perfectly level and kept so throughout a whole coal-field so long as it is not interfered with by any dislocations or other disturbances of the regularity of the rocks.

The accompanying figures (figs. 18 and 19) will serve to show some of these terms as expressed on maps and sections. Fig. 18 represents a geological map in which a series of strata dips in a south-south-easterly direction (S. 28° E.). The angle of inclination increases from 35° at the northern to 50° at the southern end of the beach. On the flat shore (AA) outcrop and strike coincide, but along the inner margin, where the ground ascends in a line or cliff (BB) to the inland country (CC), the outcrop is seen to be deflected a little so as to cross the plateau along a slightly more northerly line than on the beach. A section drawn at a right angle to the strike along the line DD would show the structure represented in fig. 19. Such a section, expressing graphically the result of careful measurement in the field, would give not only the order of succession of beds at the surface, but their actual depth at any point beneath it. Thus a bore or shaft sunk at the point marked *d* on the map would have to pass through rather more than 425 feet of rock before reaching the stratum *b.*

FIG. 18.—Geological map of a portion of a rocky coast-line, and the country inland. (J. B. Jukes.)

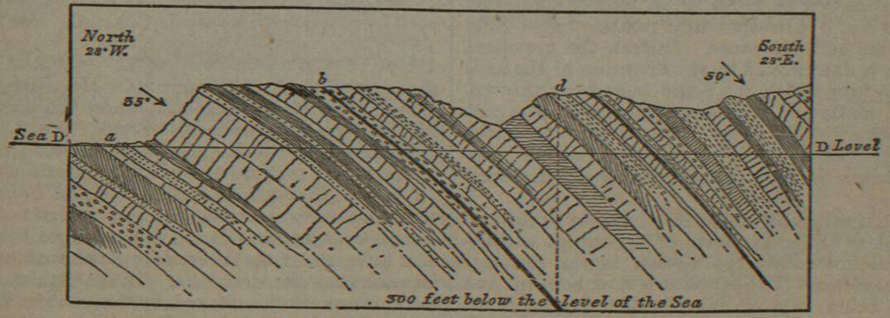

FIG. 19.—Section along the line DD on fig. 18.

The total thickness of rock measured at right angles to the dip in fig. 19 is somewhat more than 850 feet. These various strata, if restored to their original position, would lie one over the other to that depth. If they were on end they would occupy exactly that breadth of ground. But the inclined position of strata makes them cover more horizontal space; in the present instance it increases that space to 1200 feet.

A convenient rule was given many years ago by the late Mr Charles Maclaren of Edinburgh for estimating the thickness of strata inclined at angles of less than 45°. The real thickness of a mass of inclined strata is $\frac{1}{12}$th of its apparent thickness for every 5° of dip. Thus if a set of beds dip steadily in one direction at 5° for a horizontal space of 1200 feet measured across the strike, their actual thickness will be $\frac{1}{12}$th or 100 feet. If the dip be 15°. the true thickness will be $\frac{3}{12}$ths or 400 feet, and so on.

IV. Curvatures of Rocks.

A little reflexion will show that though, so far as regards the trifling portions of the rocks visible at the surface, we might regard the inclined surfaces of the strata as parts of straight lines, they must nevertheless be parts of large curves. Take, for example, the section given in fig. 19. At the north end of that section we observe the beds to plunge one after another into the earth at an angle of 35°. By degrees the inclination increases until it reaches 50°. As there is no dislocation or abrupt change of angle, but a gradual transition, it is evident that the beds at the north end cannot proceed indefinitely downward at the same angle which they have at the surface, but must bend round to accommodate themselves to the higher inclination which sets in southwards. By prolonging the lines of the beds for some way beneath the sea-level, we can show graphically the nature of the curve. In every instance therefore where, in walking over the surface, we traverse a series of strata which gradually, and without dislocations, increase or diminish in inclination, we cross part of a great curvature in the strata of the earth's crust.

Such foldings, however, can often be distinctly seen, either on some cliff or coast-line, or in the traverse of a piece of hilly or mountainous ground. The observer cannot long continue his researches in the field without discovering that the rocks of the earth's crust have been almost everywhere thrown into curves, usually so broad and gentle as to escape observation except when specially looked for. The outcrop of beds at the surface is commonly the truncation of these curves. The strata must once have risen above the present surface, and in many cases may be found descending to the surface again with a contrary dip, the intervening portion of the undulation having been worn away.

If then the inclination of rocks is so closely connected with their curvature, a corresponding relation must hold between their strike and curvature. In fact, the prevalent strike of a region is determined by the direction of the axes of the great folds into which the rocks have been thrown. If the curves are gentle and inconstant there will be a corresponding variation in the strike. But should the rocks be strongly plicated, there will necessarily be the most thorough coincidence between the strike and the direction of the plication.

The curvature occasionally shows itself among horizontal or gently inclined strata in the form of an abrupt inclination, and then an immediate resumption of the previous flat or sloping character. The strata are thus bent up and continue on the other side of the tilt at a higher level. Such bends are called *monoclines* or *monoclinal folds*, because they present only one fold, or one half of a fold, instead of the two which we see in an arch or trough. The most notable instance of this structure in Britain is that of the Isle of Wight, of which a section is given in fig. 20. The Cretaceous rocks on the south side of the island rapidly rise in inclination till they become nearly vertical. The Lower Tertiary strata follow with a similar steep dip, but rapidly flatten down towards the north coast. Some remarkable cases of the same structure have been brought to light by Mr J. W. Powell in his survey of the Colorado region.

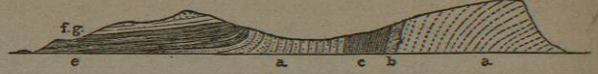

Fig. 20.—Section of the Isle of Wight—a monoclinal curve. *a*, Chalk; *b*, Woolwich and Reading beds; *c*, London clay; *d*, Bagshot series; *e*, Headon series; *f*, *g*, Osborne and Bembridge series.

It much more frequently happens that the strata have been bent into arches and troughs, so that they can be seen dipping under the surface on one side of the axis of a fold, and rising up again on the other side. Where they dip away from the axis of movement the structure is termed an *anticline* or *anticlinal fold*; where they dip towards the axis, it is a *syncline* or *synclinal fold*. The diagram in fig. 21 may be taken to represent a series of strata (1–17) thrown into an anticline (AA′) and syncline (BB′). A section drawn across these folds in the line CD would show the structure given in fig. 22. Here we see that, at the part of the anticlinal axis (A) where the section crosses, bed No. 4 forms the crown of the arch, Nos. 1, 2, and 3 being concealed beneath it. On the east side of the axis the strata follow each other in regular succession as far as No. 13, which, instead of passing here under the next in order, turns up with a contrary dip and forms the centre of a trough or syncline (B). From underneath No. 13 on the east side, the same beds rise to the surface which passed beneath it on the west side. The particular bed marked EF has been entirely removed by denudation from the top of the anticline, and is buried deep beneath the centre of the syncline.

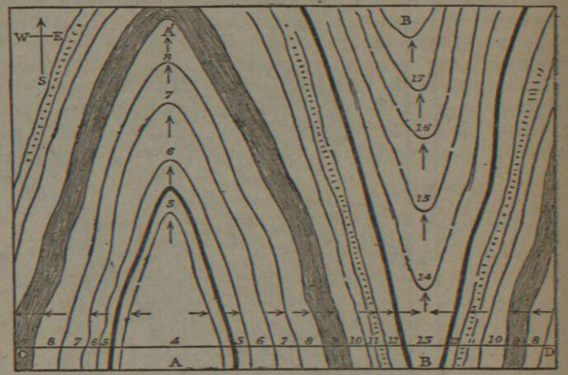

Fig. 21.—Plan of anticlinal and synclinal folds.

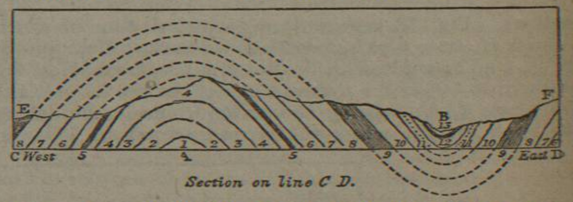

Fig. 22.—Section of antcilinal and synclinal folds on the line CD (fig. 21).

Such foldings of strata must always die out unless they are abruptly terminated by dislocations. In the cases given in fig. 21, both the arch and trough are represented as diminishing, the former towards the north, the latter towards the south. The observer in passing northwards

along the axis of that anticline finds himself getting into progressively higher strata, as the fold sinks down. On the other hand, in advancing southwards along the synclinal axis, he loses stratum after stratum and gets into lower portions of the series. When a fold diminishes in this way it is said to "nose out." In fig. 21 there is obviously a general inclination of the beds towards the north, besides the outward dip from the anticline and the inward dip from the syncline. Hence the anticline noses out to the north and the syncline to the south.

It occasionally happens that the maximum movement either of upheaval or subsidence has taken place not along a line of axis but at some one point. Hence arise, on the one hand, dome-shaped elevations of strata where the dip is outward from a centre (quaquaversal), round which the beds are disposed in successive parallel layers or rings, and, on the other hand, circular basin-shaped depressions, towards the centre of which there is a general inclination of the rocks.

So great has been the compression to which rocks have been subjected during the process of curvature that the folds may often be found inverted. This has taken place abundantly in regions of great plication. The Silurian uplands of the south of Scotland, for instance, have the arches and troughs tilted in one direction for miles together, so that in one half of each of them the strata lie bottom upwards. It is in large mountain-chains, however, that inversion can be seen on the grandest scale. The Alps furnish numerous striking illustrations. On the north side of that chain the older Tertiary rocks have been so completely turned over for many miles that the lowest beds now form the tops of the hills, while the highest lie deep below them. Individual mountains, such as the Glärnisch, present stupendous examples of inversion, great groups of strata being folded over and over above each other as we might fold carpets.

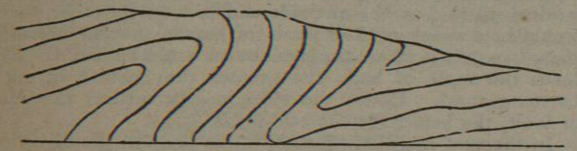

Fig. 23.—Section of inclined axes, showing consequent inversion of strata.

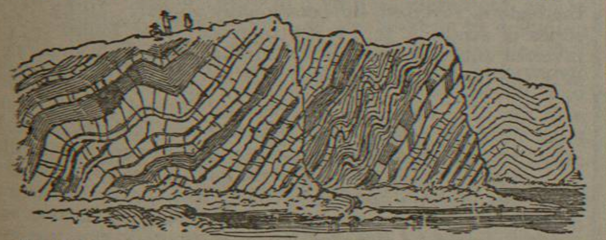

Fig. 24.—Curved and contorted rocks, near Old Head of Kinsale. (Du Noyer.)

Where curvature has been carried so far, we may nearly always discover localities at which it has been so intensified that the strata have been corrugated and crumpled till it becomes almost impossible to follow out any particular bed through the disturbance. On a small scale instances of such extreme contortion may now and then be found at landslips, where fissile shales have been pressed forward by advancing heavy masses of more solid rock. But it is of course among the more plicated parts of mountain-chains that the structure receives it best illustrations. Few travellers who have passed the upper end of the Lake of Lucerne can have failed to notice the remarkable cliffs of contorted rocks near Fluelen. But innumerable examples of equal or even superior grandeur may be observed among the more precipitous valleys of the Swiss Alps. No more impressive testimony could be given to the potency of the force by which mountains were upheaved.

V. Dislocations of Rocks.

The movements which the crust of the earth has undergone have not only folded and corrugated the rocks, but have fractured them in all directions. These dislocations may be either simple *fissures*, that is, rents without any vertical displacement of the mass on either side, or *faults*, that is, rents where one side has been pushed up or has sunk down. It is not always possible in a shattered rock to discriminate between joints and true fissures. The joints indeed have sometimes served as lines along which fissuring has taken place. It is common to meet with traces of friction along the walls of fissures even when no proof of actual vertical displacement can be gleaned. The rock is more or less shattered on either side, and the contiguous faces present numerous slickensided surfaces. Mineral deposits may also commonly be observed encrusting the cheeks of a fissure, or filling up, together with broken fragments of rock, the space between the two walls.

In a large proportion of cases, however, there has been displacement as well as fracture, and the rents have become faults as well as fissures. Faults on a small scale are sometimes sharply-defined lines, as if the rocks had been sliced through and fitted together again after being shifted (fig. 25). In such cases, however, the harder portions of the dislocated rocks will usually be found slickensided. More frequently some disturbance has occurred on one or both sides of the fault. Sometimes in a series of strata the beds on the side which has been pushed up are bent down against the fault, while those on the opposite side are bent up (fig. 26). Most commonly the rocks on both sides are considerably broken, jumbled, and crumpled, so that the line of fracture is marked by a belt or wall-like mass of fragmentary rock. Where a dislocation has occurred through materials of very unequal hardness, such as solid

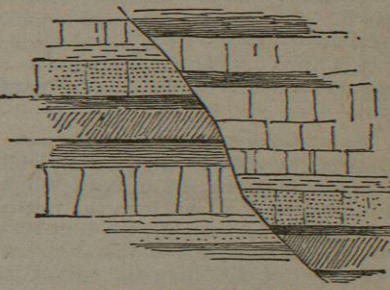

Fig. 25.—Section of clean-cut fault.

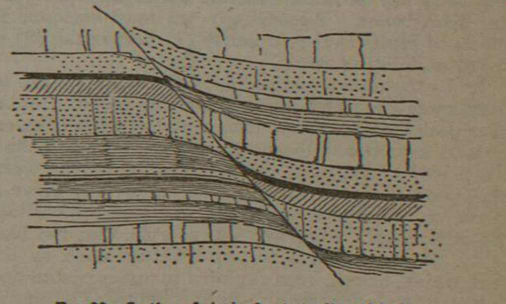

Fig. 26.—Section of strata, bent at a line of fault.

limestone bands and soft shales, or where its course has been undulating, the relative shifting of the two sides has occasionally brought opposite prominences together so as to leave wider interspaces, as in fig. 27. The actual breadth of a fault may vary from a mere chink into which the point of a knife could hardly be inserted up to a band of broken rock many yards wide. But in these latter cases we may usually suspect that so great a breadth of fractured materials has been produced not by a single fault but by a series of closely adjoining and parallel faults.

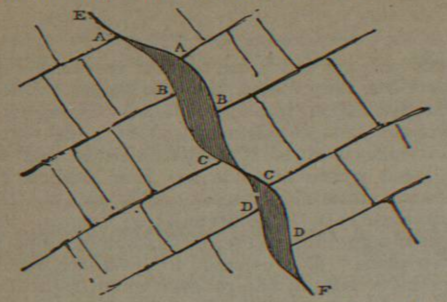

Fig. 27.—Section of fault, showing the alternate expansions and contractions due to the shifting of one side of a sinuous fissure.

Faults are sometimes vertical, but are generally inclined. The largest faults, that is, those which have the greatest vertical displacement, slope at high angles, while those of only a few feet or yards may be inclined as low as 18° or 20°. The inclination of a fault from the vertical is called its *hade*. In fig. 28, for example, the fault between A and C being vertical has no hade, but that between C and B hades at an angle of 70° from the vertical to the right hand. The amount of displacement is represented as the same in both instances, so that the level of the bed *a* is raised between the two faults at C above the uniform horizon which it retains beyond them.

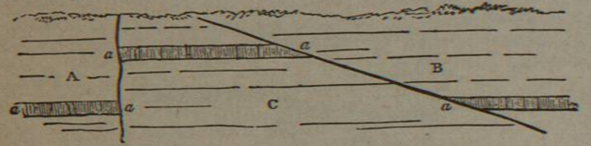

Fig. 28.—Section of a vertical and inclined fault.

That faults are vertical displacements of parts of the earth's crust is most clearly shown when they traverse stratified rocks, for the regular lines of bedding and the originally flat position of these rocks afford a measure of the disturbance. Accordingly we may consider here the effects of faults as they traverse (1) horizontal, (2) inclined, or (3) undulating strata.

1. In the above section (fig. 28) two faults are supposed to traverse a set of horizontal strata, and to displace them in opposite directions. Hence the portion between them appears as if it had been pushed up, or as if the part on either side had slipped down. The amount of vertical displacement is measured from the end of any given stratum, say *a*, on one side of the fault, to its corresponding end on the other side. Suppose, for example, that the black band in fig. 29 represents a known stratum such as a seam of coal, which, having been explored in underground operations, is known to be cut by a fault at a depth of a hundred yards below the surface at A, and to lie 200 yards deep on the other side of the fault below B. The amount of displacement is the vertical distance between the two severed ends *a* and *b*. This is termed the *throw* of a fault. From these two sections (figs. 28 and 29) we see that the horizontal distance to which the two ends of a faulted stratum may be separated does not depend upon the amount of throw but upon the angle of the hade. In the left-hand fault in fig. 28 there is no hade, for the fault is vertical; consequently there is no lateral displacement. In fig. 29, however, where the fault hades considerably, there is a lateral shift of the bed, the end *a* being 150 yards to the left of *b*. In this example the lateral shift is half as much again as the vertical. It is obvious that a fault of this kind must seriously affect the value of a coal-field; for while the coal-seam might be worked up to *a* on the one side and to *b* on the other, there would be a space of 150 yards of barren ground between these two points where the seam never could be found. The lower the angle of hade the greater the breadth of such barren ground. Hence the more nearly vertical the lines of fault, the better for the coal-fields.

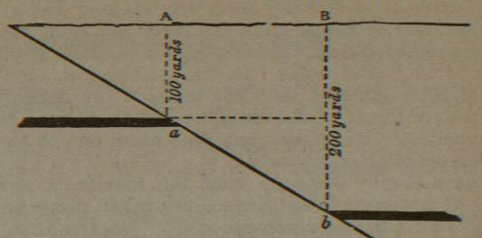

Fig. 29.—Measurement of the throw of a fault.

In the vast majority of cases faults hade in the direction of downthrow, in other words, they slope away from the side which has risen. Consequently the mere inspection of a fault in any natural or artificial section suffices in most cases to show which side has been elevated. In mining operations the knowledge of this rule is invaluable, for it decides whether a coal seam, dislocated by a fault, is to be sought for by going up or down. In fig. 29, for example, a miner working from the right and meeting with the fault at *b*, would know from its hading towards him that he must ascend to find the coal. On the other hand were he to work from the left and catch the fault at *a*, he would see that it would be necessary to descend. According to this rule a normal fault never brings one part of a bed below another part, so as to be capable of being pierced twice by the same vertical shaft. Exceptional cases, however, where the hade is reversed, do occasionally appear. In fig. 30 a series of strata, 1 to 11, are represented as folded in an inverted anticline, and broken through by a fault along the axis, the portion on the right side having been pushed up. The effect of the movement has been to make the ends of the beds on that side overlie higher beds on the other side. A shaft would thus pierce the same stratum twice. Instances of reversed faults are chiefly met with in much disturbed districts, such as mountain chains, where the rocks have been affected by great undulations and corrugations. But instances on a small scale, like that in fig. 31, may now and then be encountered even in lowland districts, where no great disturbance has taken place.

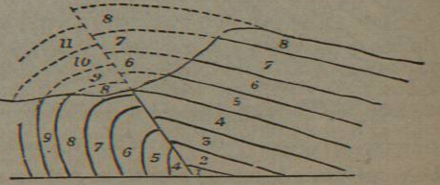

Fig. 30.—Inverted anticline and reversed fault.

2. Faults traversing inclined strata usually group themselves into two series, one running in the same general direction as the dip of the strata, the other approximating to the trend of the strike. They are accordingly classified as *dip-faults* and *strike-faults*. They are not always to be sharply marked off from each other, for the dip-faults will often be observed to deviate considerably from the normal direction of dip, and the strike-faults from the prevalent strike, so that in such cases they pass into each other.

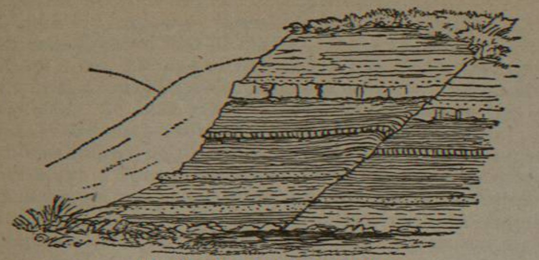

Fig. 31.—Reversed fault, Liddesdale.

A dip-fault produces at the surface the effect of a lateral shift of the strata. This effect increases in proportion as the angle of dip lessens. It ceases altogether when the beds are vertical. Fig. 32 may be taken as a plan of a dip-fault traversing a series of strata which dip northwards at 25°. The beds on the east side look as if they had been pushed horizontally southwards. That this apparent horizontal displacement is due really to a vertical movement, and to the subsequent planing down of the surface by denuding agents, will be clear if we consider what must be the effect of the vertical ascent or descent of the inclined beds on one side of a dislocation. Take the bed *a* in fig. 32, and suppose it to be still unbroken by the fault. It will then run in a straight east and west line. When the fault takes place, the part on the west side is pushed up, or, what comes to the same, that on the east side is let down. A horizontal plane cutting the dislocated stratum will show the portion on the west side lying to the north of that on the east side of the fracture. The effect of denudation has usually been practically to produce such a plane, and thus to exhibit an apparently lateral shift. This surface displacement has been termed the *heave* of a fault. Its dependence upon the angle of dip of the strata may be seen by a comparison of figs. 33 and 34. In the former figure the bed *a*, once prolonged above the present surface (marked by the horizontal line), is represented as having dropped from *db* to *ec*, the angle of inclination being 25°. The heave amounts to the horizontal distance between *b* and *e*. But if the angle should rise to 60°, as in fig. 34, though the amount of throw or vertical displacement remains the same, we see that the heave or horizontal shift diminishes to about a quarter of what it is in fig. 33. This diminution would continue with every increase of inclination in the strata till among vertical beds there would be no heave at all.

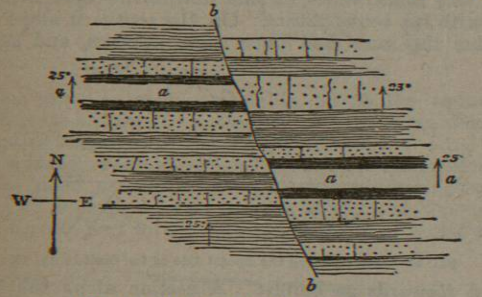

Fig. 32.—Plan of strata cut by a dip-fault.

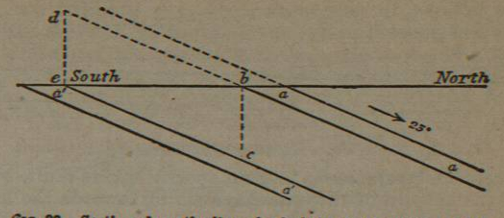

Fig. 33.—Section along the line of a fault in strata dipping at 25°

Strike-faults, where they exactly coincide with the strike, may sometimes remove the outcrop of some strata by never allowing them to reach the surface. Fig. 35 shows a plan of one of these faults (FF), having a downthrow to the north. In crossing the ground from north to south we pass successively over the edges of all the beds, except Nos. 3 and 4, which are cut out by the fault as shown in fig. 36, which is a section drawn across the ground at a right angle to the strike. It seldom happens, however, that such strict coincidence between faults and strike continues for more than a short distance. The dip is apt to vary a little even among comparatively undisturbed strata, and every such variation causes the strike to undulate and thus to be cut more or less obliquely by the line of dislocation, which may nevertheless run quite straight. Moreover, any increase or diminution in the throw of a strike-fault will of

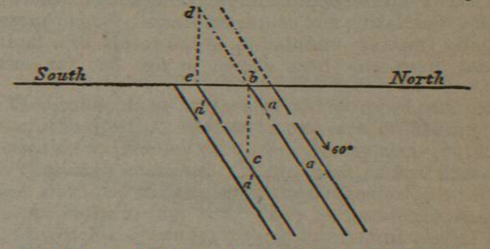

Fig. 34.—Section along the line of a fault in strata dipping at 60°.

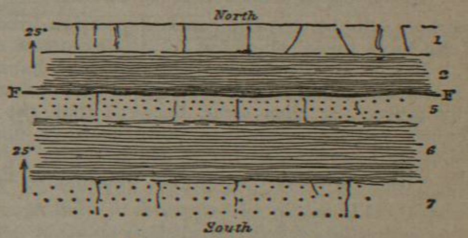

Fig. 35.—Plan of a strike-fault.

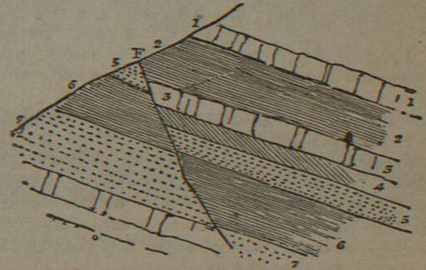

Fig. 36.—Section across the plan, fig. 35.

course have the effect of bringing the dislocated ends of the beds against the line of dislocation. In fig. 37, for instance, which represents in plan another strike-fault, we see that the amount of throw is diminishing towards the left so as to allow lower beds to successively appear, until, at the extreme left side of the ground, the fault merely brings one part of the same bed (No. 5) against another part.

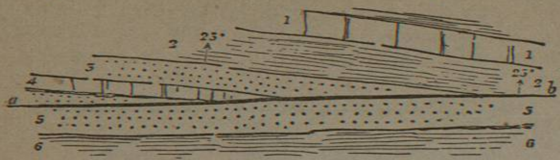

FIG. 37.—Plan of strata traversed by a diminishing strike-fault.

3. Their effects become more complicated where faults traverse undulating and contorted strata. Sometimes we can distinctly trace an undulation as the result of a fault. In the flat limestone beds shown in fig. 38, for example, there can be no doubt that the gentle depression from *d* to *c* would not have taken place but for the existence of the fault *ab*. But in all countries where the rocks have been thrown into folds and corrugations these structures are traversed by faults. It then often happens that the same fault appears to be alternately a downthrow on opposite sides. Let us suppose a series of gently rolling strata to be cut by a transverse fault as in the diagram in fig. 39.

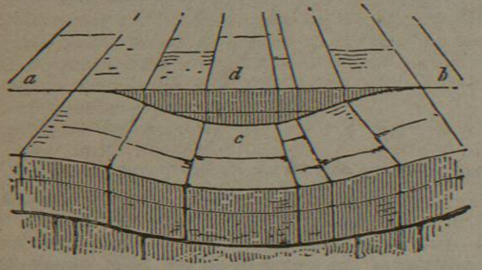

FIG. 38.—Curving of strata on one side of a fault.

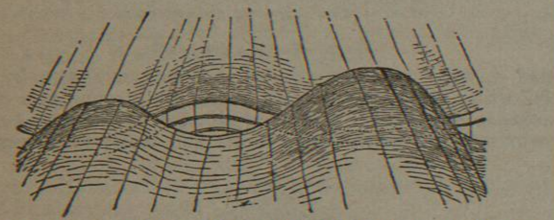

FIG. 39.—Diagram of gently undulating strata cut by a fault, with alternate throw in opposite directions.

At each of the two ridges on the near side of the fault the effect is an upthrow, while in the intervening valley it is a downthrow. On the opposite side of the fault each of these effects is reversed. It rarely happens, however, that a fault makes any such visible crack at the surface. The rocks have all been worn down so much that it is usually only by careful examination of their dip that the existence of faults can be determined.

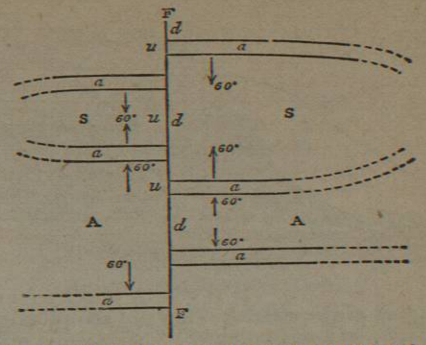

FIG. 40.—An anticline (A) and syncline (S), dislocated by a fault.

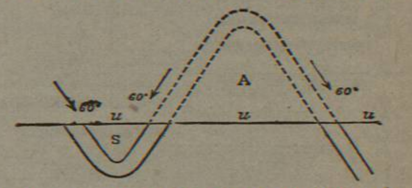

FIG. 41.—Section along the upcast side of the fault in fig. 40.

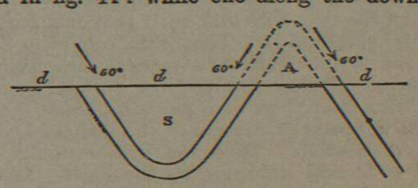

FIG. 42.—Section along the downcast side of same fault.

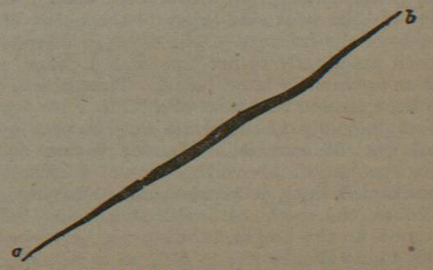

FIG. 43.—Plan of single fault.

The influence of faults upon curvatures may be illustrated by a plan and sections of a dislocated anticline and syncline, which will also show clearly how the apparently lateral displacement of outcrop produced by dip-faults is due to vertical movement. Fig. 40 represents a plan of strata thrown into an anticlinal fold AA and a synclinal fold SS, and traversed by a fault FF, which is an upthrow to the left hand. We have seen that a dip-fault always shifts the outcrop to the dip on the upthrow side, and this will be observed to be the case here. Beginning at the upper side of the diagram, which may be called north, we notice that the bed *aa*, dipping towards the lower side or south at 60°, is truncated by the fault at *u*, and that the portion on the upthrow side is shifted forwards or southward. Crossing the syncline we meet with the same bed, and as the upthrow of the fault still continues on the same side we must go some way southwards on the downthrow side before we meet with its continuation. On the southern slope of the anticline the same bed once more appears, and again is shifted forwards as before. A section along the left or upcast side (*uu*) of the fault would give the structure represented in fig. 41: while one along the downcast side (*dd*) would be as in fig. 42. These two sections clearly prove that the shifting of the outcrops at the surface can be simply explained by a mere vertical movement. They also show that faults which cross anticlinal and synclinal folds narrow the anticlines but widen the synclines on the downthrow side, while they widen the anticlines and narrow the synclines on the upthrow side.

Dislocation may take place either by a single fault or as the combined effects of two or more. Where there is only one fault, as in fig. 43, one of its sides may be pushed up or let down, or there may be a simultaneous opposite movement on either side. In such cases, there must be a gradual dying out of the dislocation towards either end; and there will usually be one or more points where the displacement has reached a maximum. Sometimes, as shown in fig. 44, a fault with a considerable maximum throw (35 feet, yards, or fathoms, in the drawing) splits into minor faults at the terminations. Examples of this kind occur not infrequently in coal-workings. In other cases the offshoots take place along the line of the main fissure (fig. 45). Exceedingly complicated examples occur in some coal-fields, where the connected faults become so numerous that no one of them deserves to be called the main or leading dislocation.

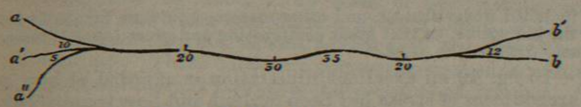

FIG. 44.—Plan of a fault splitting into minor faults.

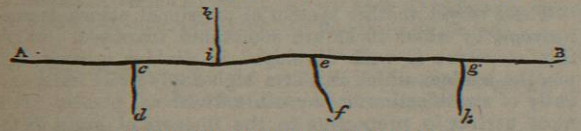

FIG. 45.—Plan of main fault, with branches.

The subsidence or elevation of a large mass or block of rock has more usually taken place by a combination of faults. If we suppose two fissures to meet at a point, as at *b* in fig. 46, and to die out respectively at *a* and *c*, the intervening triangular mass *ed* may be moved upwards or downwards, or it may remain stationary while the surrounding ground is displaced The maximum displacement in such an instance would be sought for towards *b*; in the direction *e* there would be no displacement at all.

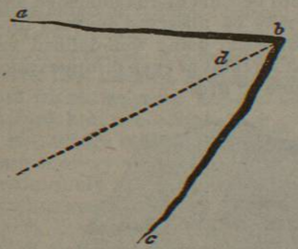

FIG. 46.—Plan of two fissures.

It often happens that, by a succession of parallel and adjoining faults, a series of strata is so dislocated that a given stratum which may be near the surface on one side is carried down by a series of steps to some distance below. Excellent examples of these *step-faults* (fig. 47) are to be seen in the coal-fields on both sides of the upper part of the estuary of the Forth. Instead, however, of having the same downthrow, parallel faults frequently show a movement in opposite directions. If the mass of rock between them has subsided relatively to the surrounding ground, they are *trough-faults* (fig. 48). They enclose wedge-shaped masses, of which the apices, formed by the junction of two faults, point downwards. In the accompanying section (fig. 49) of a portion of the thick coal of South Staffordshire, drawn to scale by Mr Johnson of Dudley (*Records of Geol. Survey*, vol. i. part 2, p. 313), the commencement of a trough-fault is shown in the centre of the figure.

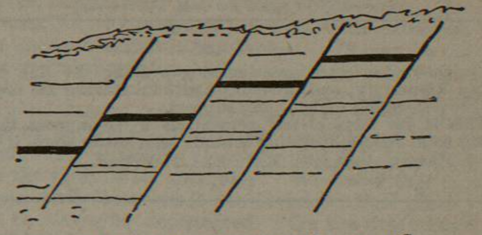

FIG. 47.—Section of strata cut by step-faults.

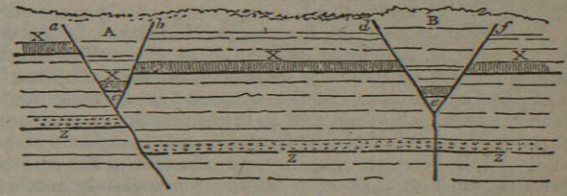

FIG. 48.—Trough-faults.

The late Mr Jukes carefully described this interesting section, and showed that the coal must once have been more arched than now, and that on the cessation of the elevatory process the fractured pieces adjusted themselves to their new position by means of dislocations. The mass of higher beds (A) driven as a wedge into the coal, has hindered the bed from regaining its horizontality, and at the same time has caused the adjacent parts of the coal (BB) to be so crushed by the enormous pressure as to have been reduced to "a paste of coal dust and very small coal" (*Memoir on South Staffordshire Coal-field*, 2d ed., p. 194).

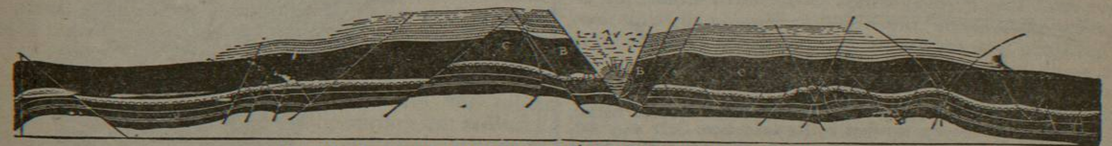

FIG. 49.—Section of a faulted part of the thick coal of South Staffordshire.

It will be observed that the hade of the faults is towards the downthrow side, and that the wedged-shaped masses with broad bottoms have risen, while those with narrow bottoms and broad tops have sunk.

It has been already (*ante*, p. 261) pointed out that faults are traceable to the effects of elevation. The general hade or inclination of faults towards the side of downthrow was satisfactorily explained by the late Mr Jukes in the last edition of the present work.

"Suppose," he says, "that in diagram fig. 50 we have a portion of the earth's crust, of which AB is the surface, and CD a plane acted on by some widespread force of expansion tending to bulge upwards the part ABCD. If then a fracture takes place along the line EF, it is obvious that the expanding force will, on the side of AC, have the widest base CF to act upon, while it will have a proportionately less mass to move in the part AECF, which grows gradually smaller towards the surface, than on the other side of the fault, where, with the smaller base FD, the mass FDBE continually grows larger towards the surface. The mass G will consequently be