much more easily raised into the position $AeCf$, than the mass H into the position $Df'Be'$, the elevation of which could hardly take

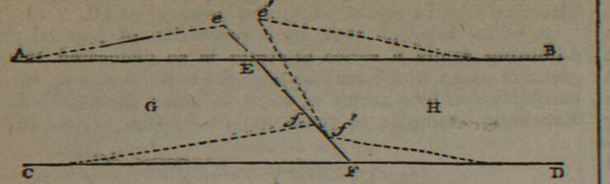

Fig. 50.

place without leaving a great open gap along the line of fault between FE and $f'e'$, and, moreover, without leaving the projecting piece e' overhanging without any support.

"This is yet more clearly perceptible if we suppose two such fissures, as in fig. 51, inclining towards each other since, if we sup-

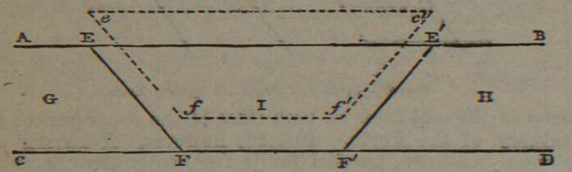

Fig. 51.

pose the included piece I to be elevated into the position indicated by the dotted lines, it becomes utterly unsupported unless we suppose huge dykes or ejections of igneous rock to issue out along each fault. But this would remove the case from the class of fractures we are at present considering."

Trough-faults offer at first some difficulty. In fig. 48, for example, it is evident that in both the wedge-shaped masses (A and B) there has been subsidence. The bed X is cut by four faults. In the space B two of these faults hade towards each other, and as they have the same amount of throw the level of the bed remains unchanged on either side. In the other trough, however, the fault *a* has a throw twice as much as that of *b* which it completely cuts off. The two faults *d* and *f* neutralize each other, and are connected with a vertical fissure without any throw. The fault *a* however descends with its persistent hade and dislocates the bed Z and the other strata below. Mr Jukes proposed the following satisfactory explanation of this kind of structure.

"Suppose the beds AA, BB, &c., (fig. 52) to have been formerly in a state of tension, arising from the bulging tendency of an

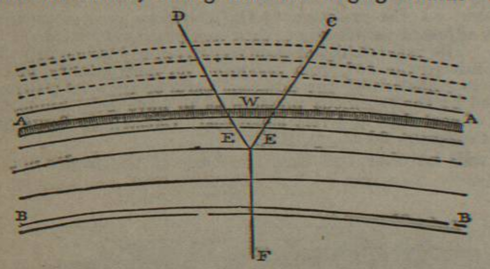

Fig. 52

internal force, and one fissure, FE, to have been formed below, which on its course to the surface splits into two, ED and EC. If the elevatory force were then continued, the wedge-like piece of rock W between these two fissures, being unsupported, as the rocks on each side separated, would settle down into the gap as in fig. 53. If the elevatory action were greater near the fissure than farther from it, the single fissure below would have a tendency to gape upwards, and swallow down the wedge, so that eventually this might settle down, and become fixed at a point much below its previous relative position. Considerable friction and destruction of the rocks, so as to cut off the corner *gh* (fig. 53) on either side, would probably take place along the sides of the fissures, and thus widen the gap, and allow the wedge-shaped piece W to settle down still further.

"When the forces of elevation were withdrawn, the rocks would doubtless have a tendency to settle down again, but these newly-

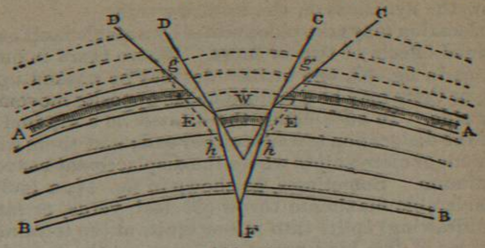

Fig. 53.

included wedge-shaped, and other masses, would no longer fit into the old spaces, so that great compression and great *lateral* pressure might then take place."

In fig. 49 an excellent illustration is afforded of how an arched mass of strata has been faulted, and how trough-faults have been formed.

VI.—Cleavage.

There is yet another system of divisional planes, termed *cleavage*, by which rocks are sometimes traversed. When this structure is well developed it divides a rock into parallel laminæ, which run at a high angle quite independently of stratification or any other divisional planes. It is most perfect in proportion to the fineness of grain of the material in which it occurs. Hence fine argillaceous rocks show it admirably. An ordinary roofing slate may be taken as an illustration of a cleaved rock; its opposite surfaces are *cleavage-planes*, while the opposite faces of a slab of shale would be stratification-planes. Though most perfectly exhibited by clay-slate, cleavage occurs in other rocks, even in old lavas and tuffs, limestones, and sandstones or greywackes; but as the texture increases in coarseness the cleavage lines become more undecided and further apart. The structure may be observed to vary in distinctness in the same face of rock, being well-defined among bands of slate, but becoming faint or even disappearing in intercalated beds of sandstone or grit.

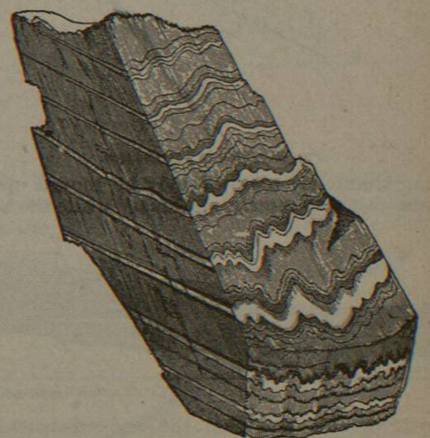

Fig. 54.—Sketch (by the late Mr Du Noyer) of a block of variegated slate from Devil's Glen, county Wicklow. The crumpled bands mark the bedding, and the fine perpendicular striæ in front are the cleavage planes; the fine lines on the darkened side merely represent *shadow*, and must not be taken for planes of division in the rock. It will be observed that the cleavage planes do not pass through the white bands.

The direction of cleavage usually remains persistent over considerable regions, and, as was shown by Sedgwick, corre-

sponds on the whole with the strike of the rocks. It is, however, independent of bedding. Among curved rocks the cleavage planes may be seen traversing the contortions without sensible deflexion from their normal direction, parallelism, and high angle. Mr Jukes pointed out that over the whole of the south of Ireland the trend of the cleavage seldom departs 10° from the normal direction E. 25° N., no matter what may be the differences in character and age of the rocks which it crosses. Some of the more obvious characters of cleavage are shown in fig. 54, which represents a block of cleaved variegated slate about 18 inches in height. The left side of the block which is in shadow is formed by a smooth cleavage plane, and the whole block might be split into laminæ parallel to that plane as shown by the cleavage lines in front. The lines of stratification are marked by the white and dark contorted bands, the axes of which evidently correspond nearly with the direction of the cleavage. These bands are commonly marked in nature by zones of different colour, and sometimes of texture. In the present instance the white bands are more sandy than the rest of the mass, and the cleavage-planes only partially enter them. This specimen is further interesting as it bears witness by its puckered bedding to the great lateral pressure in virtue of which, as we have already seen (*ante*, p. 261), the cleavage structure has been produced.

VII. Igneous Rocks as Part of the Structure of the Earth's Crust.

In this section we shall consider the part taken by igneous rocks in the architecture of the earth's crust. Their lithological differences having already been described in part ii., it is their larger features in the field that now require attention,—features which in some cases can be well illustrated by reference to the action of modern volcanoes, and in other cases bring before us parts of the economy of volcanoes which can never be reached in any recent cone. A study of the igneous rocks of former ages thus serves to augment our knowledge of volcanic action.

At the outset an obvious distinction must be drawn between those igneous masses which reached the surface and consolidated there, like modern lava streams or showers of ashes, and those which we must believe never found their way to the surface but consolidated at a greater or less depth beneath it. There must be the same division to be drawn in the case of every active volcano of the present day. But we can examine only the materials which reach the surface, and we can but speculate as to the nature and arrangement of what still lies underneath. In the revolutions to which the crust of the earth has been subjected, however, the subterranean continuations of volcanic sheets have often been laid bare, and not only so, but sections have been opened into the very heart of masses which, though molten and eruptive, seem never to have been directly connected with actual volcanic outbursts. All those subterranean intruded masses, which are now revealed at the surface only after the removal of the depth of rock which once covered them, may be grouped together into one division under the names *plutonic*, *intrusive*, or *subsequent*. On the other hand, all those which came up to the surface as ordinary volcanic rocks, whether molten or fragmental, and were consequently contemporaneously interstratified with the formations which happened to be in progress on the surface at the time, may be classed in a second group under the names *volcanic*, *interbedded*, or *contemporaneous*.

It is obvious of course that these are only relative terms. Every truly volcanic mass which, by being poured out as a lava-stream at the surface, came to be regularly interstratified with contemporaneous accumulations, must have been directly connected below with molten matter which did not reach the surface. One part of the total mass therefore would be included in the second group, while another portion, if ever exposed by geological revolutions, would be classed with the first group. Seldom, however, can the same masses which flowed out at the surface be traced directly to their original underground prolongations. It is evident that an intrusive rock, though necessarily subsequent in age to the rocks through which it has been thrust, need not be long subsequent. Its relative date can only be certainly affirmed with reference to the rocks through which it has broken. It may be older than other rocks through which it has not been intruded but which lie almost immediately above it. The probable geological date of its eruption must be decided by the evidence to be obtained from the grouping of the rocks all around. Its intrusive character can only certainly determine the limit of its antiquity. We know that it must be younger than the rocks it has invaded; how much younger must be otherwise determined. On the other hand, an interbedded or contemporaneous igneous rock has its date precisely fixed by the geological horizon on which it lies. A lava-bed or tuff intercalated among strata containing *Sphenopteris affinis*, *Lepidodendron veltheimianum*, *Leperditia*, and other associated fossils, would unequivocally prove the existence of volcanic action at the surface during the Lower Carboniferous period, and at that particular part of the period represented by the horizon occupied by the volcanic bed. An interbedded and an intrusive mass found on the same platform of strata would not necessarily be coeval. On the contrary, the latter, if clearly intruded along the horizon of the former, would necessarily be posterior in date. It will be understood then that the two groups have their respective limits determined solely by their relations to the rocks among which they may happen to lie.

The value of this classification for geological purposes is great. It enables the geologist to place and consider by themselves the granites, quartz-porphyries, and other crystalline masses which, though lying sometimes perhaps at the roots of ancient volcanoes, and therefore intimately connected with volcanic action, yet owe their special characters to their having consolidated under pressure at some depth within the earth's crust; while he arranges in another series the lavas and tuffs which, thrown out to the surface, bear the closest resemblance to the ejected materials from modern volcanoes. He is thus presented with the records of hypogene igneous action in the one group, and with those of superficial volcanic action in the other. He is furnished with a method of chronologically arranging the volcanic phenomena of past ages, and is thereby enabled to collect materials for a history of volcanic action over the globe.

In adopting this classification for unravelling the geological structure of a region where igneous rocks abound, the geologist will encounter instances where it may be difficult or impossible to decide in which group a particular mass of rock must be placed. He will bear in mind, however, that after all, such schemes of classification are proposed only for convenience in systematic work, and that there are no corresponding hard and fast lines in nature. He will recognize that all crystalline or glassy igneous rocks, whether the portion visible be interbedded or intrusive, must be intrusive at a greater or less depth from the surface. Every contemporaneous sheet has proceeded from some internal pipe or mass, so that though interbedded and contemporaneous with the strata at the top, it is intrusive in relation to the strata below. But we cannot always assert that an intrusive mass must have been connected with an outflowing interbedded sheet above.

Section I.—Plutonic, Intrusive, or Subsequent Igneous Rocks.

Under this section we have to consider the part played by igneous rocks which, either possessing a crystalline (sometimes glassy or felsitic) structure have been injected in a fluid or at least viscous condition into other rocks, or having been blown into fragments have consolidated in volcanic pipes. After some practice in the field the geologist learns to recognize these rocks, and to distinguish them from the similar masses which must be placed in the contemporaneous series. As a rule their crystalline texture is coarser than in that series; only in a few rare cases does a cellular or amygdaloidal character appear, and the fragmental accompaniments so characteristic of the contemporaneous sheet are only found in the actual vents of eruption. Granite, syenite, felsite, diorite, basalt, and agglomerate occur in this form.

The general law which has governed the intrusion of igneous rock within the earth's crust may be thus stated: every fluid mass impelled upwards by pressure from below, or by the expansion of its own imprisoned vapour, has sought egress along the line of least resistance. What that line was to be has depended in each case upon the structure of the terrestrial crust and the energy of eruption. In many instances it has been determined by an already existent dislocation; in others by the planes of stratification, or by the surface of junction of two unconformable formations, or by irregular cracks and rents, or by other more complex lines of weakness. Sometimes the intruded mass has actually fused and obliterated some of the rock which it has invaded, incorporating this portion into its own substance. The shape of the channel of escape has necessarily determined the form of the intrusive rock, as the mould regulates the form assumed by a mass of cast-iron. This offers a very convenient means of classifying the intrusive rocks. According to the shape of the mould in which they have solidified, they may be arranged as—(1) amorphous masses. (2) sheets, (3) veins and dykes, and (4) necks.

I. Amorphous Masses.—These consist chiefly of crystalline coarse-textured rocks. Granite and syenite are the most conspicuous, but there are to be included also various quartz-porphyries, felsites, diorites, &c. Where rocks occur in this form which also are found in sheets and dykes as well as contemporaneous beds, it is commonly observed that they are more coarsely crystalline in the form of amorphous masses than in any other. Doleritic rocks afford many examples of this characteristic.

Granitic Bosses.—It was once a firmly-held tenet that granite is the oldest of rocks, the foundation on which all other rocks have been laid down. This idea no doubt originated in the fact that granite is found rising from beneath gneiss, schist, and other crystalline masses which in their turn underlie very old stratified formations. The intrusive character of granite, shown by its numerous ramifying veins, proved it to be later than at least those rocks which it had invaded. Nevertheless the composition and structure of gneiss and mica-schist were believed to be best explained by supposing these rocks to have been derived from the waste of granite, and thus, though the existing intrusive granite had to be recognized as posterior in date, it was regarded as only a subsequent protrusion of the vast underlying granitic crust. In this way the idea of the primeval or fundamental nature of granite held its ground.

From what has already (*ante*, p. 258) been said regarding the fusion and consolidation of rocks, and the evidence supplied on this subject by granite itself, it will readily be understood that the first or original crust could hardly have been one of granite. That rock, so far as can be made out by careful microscopic examination, appears to have always consolidated under considerable pressure, and in the presence of superheated water and even of liquid carbonic acid—conditions which probably never obtained at the earth's immediate surface. The original crust may have been of a glassy character like some of the vitreous lavas; but whatever it was, no trace of it has ever been or is ever likely to be found.

The presence of granite at the existing surface must in all cases be due to the removal by denudation of the masses of rock under which it originally consolidated. The fact that, wherever extensive denudation of an ancient series of crystalline rocks has taken place, a subjacent granite nucleus is apt to appear does not prove that rock to be of a primeval origin. It shows, however, that the lower portions of crystalline rocks very generally assume a granitic type, and it suggests that if at any part of the earth we could bore deep enough into the crust we should probably come to a granitic layer. That this layer, even if general round the globe, is not always of the highest geological antiquity is abundantly clear from the fact that in many cases it can be proved to be of later date than fossiliferous formations the geological position of which is known; that is, the granitic layer has invaded these formations, rising up through them, and probably melting down portions of them in its progress. This is true not only of ancient Palæozoic but of other stratified rocks of various much more recent ages. So that we must conclude that granite does not belong exclusively to the earliest nor to any one geological period, but rather that it has been formed at various epochs, and may even be forming now, wherever the conditions required for its production have existed. As a matter of fact granite occurs much more frequently in association with older and therefore lower than with newer and higher rocks. But a little reflexion shows us that this must be the case. Granite having a deep-seated origin must rise through the lower and more ancient masses before it can reach the overlying more recent formations. But many protrusions of granite would doubtless never ascend beyond the lower rocks. Subsequent denudation would be needed to reveal these protrusions, and this very process would remove the later formations and at the same time any portions of the granite which might have reached them.

Granite frequently occurs in the central parts of mountain chains; sometimes it forms there a kind of core round which the various gneisses, schists, and other crystalline rocks are arranged with more or less irregularity. More frequently it appears in large eruptive bosses which traverse indifferently the rocks on the line of which they rise. Sometimes it even overlies the schistose and other rocks, as in the Piz de Graves in the upper Engadine, where a wall-like mass of granite, with syenite, diorite, and altered rocks, may be seen resting upon schists. In the Alps and other mountain ranges it is found likewise in large bed-like masses which run in the same general direction as the rocks with which they are associated.

Many of the most characteristic features of granitic bosses can be admirably studied where the rock has risen through contorted sedimentary formations, which form undulating or hilly ground rather than mountains. The granite of the south-east and east of Ireland, the south of Scotland, and the south-west of England may be taken as illustrative examples.

In the south-east of Ireland a mass of granite 70 miles in length and from 7 to 17 in width stretches from north-east to south-west, nearly along the strike of the Lower Silurian rocks. These strata, however, have not been upraised by it in such a way as to expose their lowest beds dipping away from the granite. On the contrary, they seem to have been contorted prior to the appearance of that rock; at least they often dip towards it, or lie horizontally or undulate upon it, apparently without any reference to

movements which it could have produced. As Mr Jukes has shown, the Silurian strata are underlaid by a vast mass of Cambrian rocks, all of which must have been invaded by the granite before it could have reached its present horizon. He infers that the granite must have slowly and irregularly eaten its way upward through the Silurian rocks, absorbing much of them into its own mass as it rose. For a mile or more the stratified beds next the granite have been altered into mica-schist, and are pierced by numerous veins from the invading rock. Within the margin of the granitic mass belts or rounded irregular patches of schist are enclosed; but in the central tracts where the granite is widest, and where therefore we may suppose the deepest parts of the mass have been laid bare, no such included patches of altered rock occur. From the manner in which the schistose belt is disposed round the granite, it is evident that the upper surface of the latter rock where it extends beneath the schists must be very uneven. Doubtless it rises in some places much nearer to the present surface of the ground than at others, and sends out veins and strings which do not appear above ground. If, as Mr Jukes supposes, a thousand feet of the schists could be restored at some parts of the granite belt, no doubt the belt would there be entirely buried; or if, on the other hand, the same thickness of rock could be stripped off some parts of the band of schist, the solid granite underneath would be laid bare. The extent of granite surface exposed must thus be largely determined by the amount of denudation, and by the angle at which the upper surface of the granite is inclined beneath the schists. Where the inclination is high, prolonged denudation will evidently do comparatively little in widening the belt. But where the slope is gentle, and especially where the surface undulates, the removal for some distance of a comparatively slight thickness of rock may uncover a large breadth of underlying granite.[1]

Recent observations by Professor Hull and Mr Traill of the Geological Survey have shown that in the Mourne Mountains a mass of granite has in some parts risen up through highly inclined Silurian rocks, which consequently seem to be standing almost upright upon an underlying boss of granite. The strata are sharply truncated by the crystalline mass, and are indurated but not otherwise altered. The intrusive nature of the granite is well shown by the way in which numerous dykes of dark melaphyre are cut off when they reach that rock.[2]

In the Lower Silurian tract of the south of Scotland several large intrusive bosses of granite occur. The strata do not dip away from them on all sides, but with trifling exceptions maintain their normal N.E. and S.W. strike up to the granite on one side, and resume it again on the other. The granite indeed occupies the place of so much Silurian greywacke and shale. There is usually a metamorphosed belt of variable width in which, as they approach the granite, the stratified rocks assume a schistose or gneissoid character. Numerous small, dark, often angular patches or fragments of mica-schist may be observed along the marginal parts of the granite. Similar features are presented by the granite bosses of Devon and Cornwall which have risen through Devonian strata.

The manner in which some bosses of granite penetrate the rocks among which they occur strongly reminds one of the structure of volcanic necks or pipes. The granite is found as a circular or elliptical mass which seems to descend vertically through the surrounding rocks without seriously altering or disturbing them, as if a tube-shaped opening had been blown out of the crust of the earth up which the granite had risen. Several of the granite masses of the south of Scotland exhibit this character very strikingly. That granite and granitoid rocks have actually been associated with volcanic action is shown by the way in which they occur in connexion with the Tertiary volcanic rocks of Skye, Mull, and other islands in the Inner Hebrides. As Mr Jukes suggested many years ago, granite or granitoid masses may lie at the roots of volcanoes, and may be the source whence the more silicated lavas, such as trachyte and liparite, proceed.[3]

That some granite, however, is of metamorphic origin, that is to say, has been produced by the gradual softening and recrystallization of other rocks at some depth within the crust of the earth, seems to be now satisfactorily established. Such granite may be looked upon as the extreme of metamorphism, the various schists and gneisses being less advanced stages of the process. Provided the chemical composition of the altered rock be the same as that of granite, it is not necessary that the granite resulting from its alteration should be supposed to differ in any noteworthy particular from ordinary intrusive or igneous granite. The members of the Geological Survey of Ireland have indeed distinguished two granites in Galway, one of which they regard as metamorphic, the other as igneous. The former is characterized by the occurrence of two felspars (orthoclase and oligoclase); the latter contains only one (orthoclase). More recently, however, in the east of the country they have separated two groups of granites, of which the intrusive masses are composed of dark-coloured quartz, orthoclase, albite, and black mica (Mourne Mountains), while the metamorphic variety is formed of grey felspar, quartz, and black mica. The mineralogical composition of granite formed by the metamorphism of other and specially sedimentary rocks must necessarily vary with that of the masses out of which it has arisen. In some cases there is a regular gradation from true granite outward into the schistose and gneissose masses. But this passage need not always occur, for if the granite was subject to unequal pressure (which it assuredly would in most cases be) it would in its soft, pasty condition undoubtedly be squeezed into any rents made in the surrounding rocks, and would thus imitate exactly a truly igneous mass, which in actual fact it would then be. When a mass of granite rises through unaltered or only locally altered strata, it may fairly be assumed to be igneous and intrusive. When, on the other hand, it is intimately associated with extensive masses of schist and gneiss, many of which can only be distinguished from it by their foliated structure, its metamorphic origin may at least be strongly suspected. Fundamentally, indeed, igneous and metamorphic granite seem to be due only to different modifications of the same subterranean processes. A mass of originally sedimentary rocks may be depressed to a depth of several thousand feet within the earth's crust, subjected there to vast pressure and considerable heat in presence of interstitial water or steam, and may thus be metamorphosed into crystalline schists. A portion of this mass, undergoing extreme alteration, may so completely lose all trace of its original fissile structure as to become amorphous crystalline granite, some of which may even be thrust as veins into the less highly changed parts above and around. One stage further would bring before us a connexion opened between the surface and such a deep-seated granitic mass, and the consequent ascent and outburst of acid lavas and their fragmental accompaniments.

Amorphous Masses of Diorite, &c.—On a smaller scale usually than granite, other crystalline rocks assume the condition of amorphous bosses. Syenite, diorite, quartz-porphyry, and members of the basalt family have often been erupted in irregular masses, partly along fissures, partly along the bedding, but often involving and appar-

[1] See Jukes's *Manual of Geology*, 3d ed., p. 243. *Horizontal Section No.* 22. *Geol. Surv. Ireland.*

[3] *Manual of Geology*, 2d ed., p. 93; Geikie, *Trans. Geol. Soc. Edin.*, ii. 301; Judd, *Quart. Journ. Geol. Soc.*, xxx. 220.

ently melting up portions of the rocks through which they have made their way. Such bosses have frequently tortuous boundary-lines, since they send out veins into or cut capriciously across the surrounding rocks. In Wales, as shown by the maps and sections of the Geological Survey, the Lower Silurian formations are pierced by huge bosses of different crystalline rocks, mostly included under the old term "greenstone," which, after running for some way with the strike of the strata, turn round and break across it, or branch and traverse a considerble thickness of stratified rock. In central Scotland numerous masses of dolerite and quartziferous diabase have been intruded among the Lower Carboniferous formations. One horizon on which they are particularly abundant lies about the base of the Carboniferous Limestone series. Along that horizon they rise to the surface for many miles, sometimes ascending or descending in geological position, and breaking here and there abruptly across the strata. There can be little doubt that they have actually melted down some parts of the stratified rocks, particularly the limestone. Considerable petrographical differences occur among them which may perhaps be in some measure due to the incorporation of such extraneous material into their mass. Gaps occur where these intrusive rocks do not rise to the surface, but as they resume their position again not far off, it may be presumed that they are really connected under these blank intervals.

The amount and nature of the alteration produced on contiguous rocks by the invasion of an intrusive boss vary necessarily with the character and bulk of the igneous mass, as well as with the susceptibility of the surrounding rock to metamorphism. Induration is generally traceable; shales are hardened into porcelain, jasper, Lydian-stone, or some other flinty argillaceous rock. Sandstones are converted into a kind of lustrous quartz-rock. Limestones are made to assume a granular or crystalline texture, passing into marble or sometimes into dolomite. Under favourable conditions crystals of garnet, analcime, pyrite, and other minerals are developed in the surrounding altered rock.

There can be little doubt that, though the portions of these rocks now visible consolidated under a greater or less depth of overlying rock, they must in many cases have been directly connected with superficial volcanic action. Some of them may have been underground ramifications of the ascending molten rock which poured forth at the surface in streams of lava. Others may mark the position of intruded masses which were arrested in their ascent in the unsuccessful attempt to open a new volcanic vent.

II. SHEETS.—These are masses of crystalline rock which have been intruded as sheets between other rocks, and now appear as more or less regularly defined beds. In almost all cases it will be found that these intrusions have taken place between the planes of stratification. The ascending mass of molten matter, after breaking across the rocks, or rather after ascending through fissures either previously formed or opened at the time of the outburst, has at last found its path of least resistance to lie along the bedding planes of the strata. Accordingly it has thrust itself between the beds, raising up the overlying mass and solidifying as a nearly or exactly parallel cake or bed.

It is evident that one of these intercalated intrusive sheets of igneous rock must present such points of resemblance to a truly contemporaneous bed of lava as to make it occasionally a somewhat difficult matter to determine its true character, more especially when, owing to extensive denudation, only a small portion of the rock can now be seen. The following characters mark intrusive sheets, though they must not be supposed to be all present in every case. (1.) They do not rigidly conform to the bedding, but sometimes break across it and run along on another platform. (2.) They catch up and involve portions of the surrounding strata. (3.) They are commonly most close grained at their upper and under surfaces, and most coarsely crystalline in the central portions. (4.) They are very rarely cellular or amygdaloidal. (5.) The rocks both above and below them are usually hardened and otherwise more or less altered.

Many of the older volcanic rocks occur in this form, as felstone, quartz-porphyry, diorite, melaphyre, diabase, dolerite, basalt, and others. The remarks above made regarding the connexion of intrusive bosses with volcanic action may be repeated with even greater definiteness here. Intrusive sheets abound in old volcanic districts intimately associated with dykes and surface outflows, and thus bringing before our eyes traces of the underground mechanism of the volcanoes.

The same kinds of alteration may be observed along the line of junction of intrusive sheets with the adjacent rocks as in the case of amorphous masses; but as the boundary lines are often very sharply defined they present the process of alteration in a more generally accessible and interesting form. Sandstone, for example, besides being indurated and acquiring the distinct lustre of quartzite, may occasionally be seen to possess a distinctly prismatic structure—the prisms or columns diverging at right angles to the line of junction with the igneous rock. Even microscopic black microlites, like those which occur in basalt-rocks, have been detected in altered sandstone, in the minute fissures of which they may be supposed to have been sublimed from the molten injected mass. Argillaceous rocks are commonly converted into hard flinty textures to which the names of flinty-slate, Lydian-stone, jasper, and porcellanite have been applied. Coal-seams when invaded by intruded sheets of igneous matter assume different aspects according to the thickness and nature of the invading sheet, the depth of the coal-seam, and probably to other less easily recognizable causes. In some cases the coal has been fused and has acquired a blistered or vesicular texture, the gas cavities being either empty or filled with mineral matter such as calcite. In other cases it has nearly disappeared, the remaining portion being a black soot or ash. In others it has become hard and brittle, and has been converted into a kind of anthracite or "blind-coal," owing to the loss of its more volatile portions. In the Ayrshire coal-fields the coal seams have sometimes become beautifully columnar owing to the intrusion of a sheet of basalt along them. The hexagonal and pentagonal columns diverge like rows of stout pencils from the surfaces of the basalt. In one coal-field of that county a seam of coal has been converted into graphite. The accompanying section (fig. 55) by the late

FIG. 55.—Sheets and strings of intrusive rock in the Ten-yard Coal, South Staffordshire.

Mr Jukes represents one of the numerous sheets of "white rock" intruded into the South Staffordshire coal-field. The horizontal distance shown in this section is more than 100 yards. The coal (*b*) resting on sandstone (*c*) is traversed by irregular strings and sheets (*a*) of what the miners term "white-rock," which proceed from the large basalt masses of the district. The coal has there become dull and anthracitic, and is not worth being extracted.

When a coal-field is much invaded by igneous rocks the seams of coal are usually found to have suffered more than the other strata, not merely because they are specially liable to alteration from the proximity of heated surfaces, but

because they have presented lines of more easy escape for the igneous matter pressed from below. The molten rock has very generally insinuated itself along the coal-seams, sometimes taking the lower, sometimes the upper surface, and not infrequently forcing its way along the centre.

In the destruction or alteration of coal and bituminous shales a process of subterranean distillation must often have been set in progress. The gases evolved would find their way to the surface through joints and pores of the overlying rock. The liquid products, on the other hand, would be apt to collect in fissures and cavities. In central Scotland, where the coal-fields have been so abundantly pierced by igneous masses, petroleum and asphaltum are of frequent occurrence in many districts, sometimes in chinks and veins of sandstones and other sedimentary strata, sometimes in the cavities of the igneous rocks themselves.

It is a remarkable fact that, striking as is the change produced by the intrusion of basalt into coals and bituminous shales, it is hardly more conspicuous than the alteration effected on the invading masses themselves. A compact crystalline black heavy basalt or dolerite, when it sends sheets and veins into a coal or highly carbonaceous shale, becomes yellow or white, earthy, and friable, loses weight, ceases to have any apparent crystalline texture, and in short passes into what any observer would at first unhesitatingly pronounce to be a mere clay. It is only when the distinctly intrusive character of this substance is recognized in the veins and fingers which it sends out, and in its own irregular course in the coal, that its true nature is made evident (see fig. 55). Microscopical examination shows that this "white-rock" or "white-trap" is merely an altered form of basalt, wherein the felspar crystals, though much decayed, can yet be traced, the augite, olivine, and magnetite being more or less completely changed into a mere pulverulent earthy substance. A specimen of this altered rock was analysed by Mr Henry with the following results:—

Silica	38·830
Alumina	13·250
Lime	3·925
Magnesia	4·180
Soda	0 971
Potash	0·422
Protoxide of iron	13 830
Peroxide of iron	4·335
Carbonic acid	9 320
Water	11·010
	100·073

It is evident that most of the alkalies and much of the silica have been removed, and that most of the iron exists as carbonate of the protoxide.

In connexion with the alteration produced by igneous sheets upon their contiguous stratified rocks, reference may here be made to the lithological differences traceable within the igneous masses. The close grain already referred to as characteristic of the upper and under portions of an intrusive sheet evidently depends upon more rapid cooling towards the surface of contact with the adjacent cold rocks. When thin slices of these marginal parts are placed under the microscope, they sometimes show abundant black microlites which disappear as the rock is traced away from the margin. They may be regarded as incipient stages in the crystallization of the magnetite, arrested in their development by the rapid consolidation of the outer parts of the rock. In the central portions they have had an opportunity of coalescing into octahedra or groups of definite isometric crystals. A series of sections of a rock, from the outer edge where the arrested crystallites occur to the centre where definitely-built crystals appear, brings in this way before us a history of the stages in the consolidation of the mass.

But considerable differences in composition may also be detected in different portions of the same intrusive sheet. A rock which at one place gives under the microscope a coarsely crystalline texture with the petrographical elements of dolerite will at a short distance show abundant orthoclase and free quartz—minerals which do not belong to normal dolerite. These differences, like those above referred to as noticeable among amorphous bosses, seem too local and sporadic to be satisfactorily referred to original differences in the composition of various parts of the molten mass, or to segregation by gravitation or otherwise. They suggest rather that the great intrusive sheets, in their passage through the rocks underneath, have here and there involved and melted down portions of these rocks, and have thus acquired locally an abnormal composition.

III. VEINS AND DYKES.—Veins of igneous rock may occur indifferently in igneous, aqueous, or metamorphic rocks. They may range in diameter from mere thread-like filaments up to huge bands many feet or yards broad. In regard to their origin they may be grouped into two series —(1) veins of segregation, and (2) veins of intrusion.

Veins of Segregation.—These include most of what were formerly and not very happily termed "contemporaneous veins." They are peculiar to crystalline rocks. They abound in many granites, likewise in some gneisses and schists. They may not infrequently be observed in sheets of diorite, dolerite, and diabase. They run as straight, curved, or branching ribands, seldom exceeding a foot in thickness. Most frequently they are finer in texture than the rock which they traverse, though now and then the reverse is the case, more especially in granite. Close examination of them shows that they are not sharply defined by a definite junction line with the enclosing rock, but that on the contrary they are welded into that rock in such a way that they cannot easily be broken along the plane of union. This welding is found to be due to the mutual protrusion of the component crystals of the vein and of the surrounding rock—a structure sometimes admirably revealed under the microscope. Veins of this kind are evidently to be referred to the earliest condition of the rocks in which they occur. They point to some process, still unexplained, whereby into rents formed in the deeply buried, and at least partially consolidated or possibly colloid, mass there was a transfusion or exosmosis of some of the crystallizing minerals.

Veins of Intrusion.—These are portions of once-melted or at least pasty matter which have been injected into rents of previously solidified rocks. When traceable sufficiently far, they may be seen to swell out and merge into their large parent mass, while in the opposite direction they may become attenuated into mere threads. Sometimes they

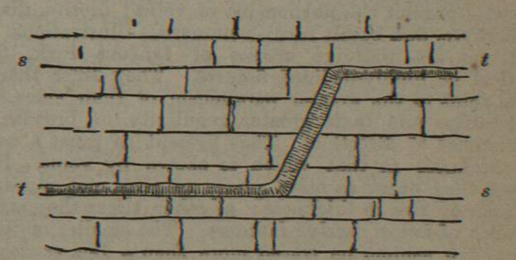

FIG. 56.—Intrusive igneous rock.

run for many yards in tolerably straight lines, and when this takes place along the stratification they look like beds. At these parts, they are of course really intrusive sheets. But they may frequently be found to start suddenly upward or downward, and to break across the bedding in a very irregular manner. In fig. 56 *t* represents an intrusive