rain. Consequently, as the ages rolled on, layers of them were uncovered, and the softer parts decayed under the subaerial agencies, which unceasingly acted upon them. Hence the weather-worn corroded faces which many of them now present; effects which could not have been produced within the human era, because they are apparent on those which are disinterred from clay-pits, as well as on the surface blocks. Subsequently, through some convulsion of nature which depressed the dry land, the sea returned for a time to its former bed. Tides and currents in some places undermined their foundations, lowering them till they rested upon the ancient Chalk formation, and at others overwhelming them by deposits of sand and clay. Surging waves pounded all that were soft and friable to their original elements, and scattered small nodules, too hard to be crushed, broadcast everywhere; so that we can easily understand how it is that so many triturated fragments of Sarsens are now found in our gravel-pits, and why it is that the masses on our downs are scattered about in such profusion.

Since they were stranded where they now lie, they have been rapidly diminishing in numbers; for, like everything else among the natural stores which God has given us, they have an economical value. Several examples remain of the way in which they were utilized in primeval times. The huge tri-lithons of the outer circle at Stonehenge, the stupendous temple of Abury, the cromlech at Clatford, and Wayland Smith's cave, were all constructed with Sarsens; and in modern times they have been extensively used for various purposes. We find them in the foundations of churches and old houses in this district, many of our streets are paved with them, and they are still quarried and broken up in certain places for building materials.

Well may those venerable relics of a former world be called Sarsens, or "sad stones." Their name, if such be its meaning, has a fitness far beyond that which the unlettered Saxon dreamt of when he gave it; for they are the waifs and strays of an appalling wreck, and their condition is akin to that of shipwrecked mariners on some foreign shore. They are, in fact, the lonely survivors of a land which the wasting elements have dissolved, and the floods have utterly swept away.

IV.—ON FISSURES, FAULTS, CONTORTIONS, AND SLATY-CLEAVAGE.¹

By CHARLES RICKETTS, M.D., F.G.S.

IT was contended in a previous communication² that all valleys have been formed by sub-aërial agencies alone, and that the disintegrated materials, being carried seaward by the rivers traversing them, have accumulated to immense thicknesses in what had been formerly a continuation of these valleys, and have, by their weight,

¹ An Abstract of a paper read before the Liverpool Geological Society as the President's Address for the Session 1872-73.

² "On Subsidence as the Effect of Accumulation," GEOLOGICAL MAGAZINE, 1872. Vol. IX., p. 119.

caused progressive subsidence, and so have formed bays and to some extent deltas at and near their mouths.

As a consequence of subsidence in one place, there must of necessity be elevation in another. Elevation would also result from the removal of pressure. The subject was then alluded to only for the purpose of accounting for the partial emergence of the land, upon the melting of the snow which covered its surface during the Glacial period; but it continually happens that those strata which are physically highest above the sea-level, are geologically the lowest in the series, the greatest amount of upheaval occurring where denudation has taken place to the greatest extent.

These innumerable evidences of changes of level occur in all parts of the globe; they date from the earliest period registered in the geological record, and extend down to the present time. Their occurrence cannot be so general, or their progress so continuous and gradual, if the interior of the earth is not to a certain extent in a state of fluidity, and covered with what, compared with the whole mass, must be a thin crust.

It is very generally conceded that "the effect of elevatory force by raising the mass under which it acts, would place the strata in a state of extension, and therefore of tension," which continuing will produce fissures even so as to extend through the whole thickness of the earth's crust. To fractures thus induced the volcanos of the Andes may be attributed. But a similar result has not so frequently been ascribed to the effect of subsidence, though tension and extension, and therefore fissures, must occur under such circumstances, commencing from a depth coinciding with that of the chord of the arc of the earth's circumference included within the subsiding area. That such fissures do occur in areas which are those of depression is proved by volcanos being frequently situated in localities known to be subsiding, and the presence of Trappean rocks is very frequent in the Palæozoic formations of Britain interstratified with sedimentary deposits; they were at their respective periods erupted, and poured forth either as volcanic ash or lava-flows in areas which were not only subaqueous but also subsiding, as is proved by the large amount of subsequent accumulations.

An examination of Trappean dykes tends to prove that the molten rock "has been forced up through previously formed fissures to a certain height," in its passage baking but not disturbing the rocks which form the walls of the fissures. Lava can only proceed so far as the fracture extends, and, as in subsiding areas there must be compression of the *upper* strata, it can only make its way upwards, as such, so far as the chord of the arc before referred to. The only manner by which I can suppose the vent to be formed in such a case is by water, on obtaining access at a greater or less depth to the incandescent lava contained in the fissures, exploding, and carrying away the superficial strata; for it frequently happens that in what in all probability are the pipes of volcanos passing through contemporaneous strata, there is no appearance of fracture or fault extending to a distance into the sedimentary rocks. This coincides

also with the general sequence given of volcanic phenomena, which more frequently commence with an explosion of steam and gases, carrying upwards immense quantities of scorïæ and ashes, and not unfrequently blowing off the summits of cones formed by previous eruptions. Such explosions may be compared to those induced by water obtaining access to metal molten in a crucible, and the effects are very similar. This state, after continuing for a time, is followed by streams of lava, which "well out, sometimes almost with the tranquillity of a water spring, from the same or contiguous openings."

Most remarkable has been the intrusion of lava between beds. However powerful the force which has produced this effect, there is in innumerable instances no indication of violence. Belts of Greenstone and Basalt have been frequently insinuated between the strata, so exactly in the direction of the bedding, that were those situated above not altered by heat as well as those below, it would be with great difficulty determined that they were intruded, and not interstratified.

There is much proof of a local connexion between volcanos and earthquakes; the former being generally preceded and accompanied by the latter. Earthquake-shocks are far from being confined to the neighbourhood of volcanos.¹ They appear to be prevalent in localities which there is reason to conclude are areas of elevation or else of depression. In endeavouring to account for their production, those who have paid most attention to the phenomena accompanying them appear entirely to overlook the geological changes produced by faults, each of which must be a register of at least one, and most, in all probability, record a succession of earthquake-shocks.

Previous to a fault being formed, a fissure must have taken place in the crust of the earth, and have progressed so as to cause a greater or less interval between the sides of the fissure. This will occur either upon depression or elevation of the surface, increasing as the depression or elevation becomes greater. Should there be a stratum so far unconsolidated that (as the rocks have lost their lateral support by the separation of the sides of the fissure), it cannot support the pressure of the overlying beds, the result must be that wedge-shaped masses will separate and fall or slip downwards, in a manner similar to what occurs to a block of masonry, however solid, if its foundations are undermined; or in the same manner as that of landslips along our coasts, only that in faults the wedge-like mass is checked when it comes in contact with the opposite side of the fissure, causing that thud or blow which occasions the vibration of the earth's surface, and constitutes the earthquake.

Few, if any, will now believe that any great faults are the result of one single movement, but that they are rather to be attributed to a long succession of displacements; and it is likely that some do not, through their whole extent, belong to the same geological era. Faults not unfrequently have caused enormous dislocations of the strata; in North Wales to the extent "of 2,000, 5,000, or even 12,000 feet." Immense wedge-shaped masses, such as in these cases

¹ See Scrope, "Volcanos," p. 8.

have fallen downwards and filled up what would otherwise be extensive chasms in the earth's crust, have increased to some extent the superficies of its surface.

The displacement or downthrow which occurs on the formation of a fault is simply a falling or slipping downwards of separated rock-masses along planes of fracture; it is evident that by such movement the strata cannot become bent or contorted, nor can the original direction of the dip be altered, for the mass is prevented from tilting over in consequence of the impulse being checked by the opposite wall of the fissure.

Slickensides are frequently met with in connexion with faults, and indicate the direction of some movement which has taken place. They may sometimes have been caused by the friction induced on the occurrence of a fault, but in such a case the striations could only have a direction downwards along the hade of the fault. Such is the direction of the marks in the principal or north and south faults, of this district (the neighbourhood of Liverpool); but as the strata have been subsequently exposed to compression at right-angles to these faults, it is to the latter circumstance their presence must be attributed, for the action of the second movement would obliterate the effects of the first. In those faults having an east and west direction, or nearly approaching it, the striations are sometimes nearly horizontal; in others, and more frequently, more or less oblique, and seem to indicate that in the one case there has been a lateral movement, in the other that, in addition to this, there has been at the same time an amount of upward pressure. As the lateral pressure by which these Triassic rocks have been acted on has been in an east and west direction, the tendency would be, in the instances referred to, to compress into a less lateral compass the slightly consolidated beds of the Upper Bunter Sandstone, and, by causing a re-arrangement of the particles of which they consist, or by inducing foldings in the beds, occasion some amount of elevation of the superincumbent strata, and the movement thus produced would cause that friction along the sides of faults which has rendered their surfaces polished and striated.

The opinion of Sir James Hall, illustrated by him in 1813, that contortions and flexures of stratified rocks have been the result of lateral compression, forcing the strata more closely together laterally, but elongating and making them to rise upwards in a direction perpendicular to the pressure, is generally accepted. The principle is even admitted by those who attribute these foldings to the effect of upheaval alone; but "that would stretch instead of crumpling the surface," and therefore contortions under such circumstances would be impossible.

The researches of Sedgwick, and of Phillips, of Sharpe, Sorby and Tyndall, have successively demonstrated that cleavage differs essentially from stratification, being the result of a change in the structure of sedimentary rocks; due to mechanical causes; and that it has been induced by pressure of the mass in a direction perpendicular to the planes of cleavage.

Observation thus proves that changes in the dip of strata, contortions, and cleavage, have been induced by lateral pressure, often propagated in the same direction over extensive areas, and in innumerable instances the same force has caused both the contortion and cleavage.

Sir Charles Lyell, in 1850, suggested that to some extent flexures might be caused by the subsidence of mountainous masses beneath the floor of the ocean, which, sinking for miles vertically, must occasionally be forced to pack themselves into smaller spaces than they previously occupied.¹ Depression must necessarily cause compression of the subsiding portion, until a certain depth is reached, but as it acts in every direction, the contortions must be irregular, unless there exists some cause to give that definite tendency which they so frequently assume. The chief causes capable of producing this effect appear to be valleys and faults.

Valleys at their seaward extremities become gradually submerged and filled up with sedimentary matter brought down by rivers. If this depression continues, compression must be induced, and the unconsolidated material, confined as it were between walls of hard rock, would have the direction of the pressure applied to it determined by that of ancient submerged and filled-up valleys. Therefore the hollows and ridges of the contortions would extend parallel to the course of the valley; the flexures being greater near the sides, in consequence of the resistance afforded by the harder rock. The greatly contorted Silurian strata to the west of the Malverns may be cited as an example.

As cleavage is dependent on similar pressure, so likewise it would be induced under the same circumstances if the conditions are favourable. To such an origin I would attribute the cleavage as well as the contortions of the Wenlock rocks, at a distance of four miles to the north and the same to the south of Llangollen; these strata appear to be a deposit in a pre-Wenlock valley.

The presence of dykes, or other masses of intrusive volcanic rock, by forming points of resistance, have, upon the occurrence of similar changes of level, also influenced the formation of contortions.

A more powerful agent in influencing the degree and direction of pressure is the occurrence of faults; and it is generally recognized that their presence has "an intimate connexion with those foldings which constitute anticlinal and synclinal axes." But their formation must be attributed to a different movement from that by which faults have been produced. The wedge-shaped masses, which have fallen down on the formation of faults, have by so much enlarged the area they occupy, as the width of the angular portion is increased from the original width at any point previous to the dislocation; but there would be no difference, or very little, in the angle at which the depressed portion lies from that which it previously occupied.

As the space occupied by the occurrence of faults, whether they

¹ Presidential Address, Quart. Journ. Geol. Soc., vol. vi., p. liv.

result from depression or from upheaval, is larger than it was originally, upon a change to upheaval or depression, as the case may be, the strata must be compressed into a smaller compass, and therefore foldings and contortions will be induced, the general direction lengthwise being the same as that of the faults. This same action would originate cleavage, but not in any beds which have been elevated above the sea-level, as, in consequence of the drainage of the water they contain, such consolidation would take place that the necessary movements amongst their constituent particles would be rendered impossible.

This method of accounting for the production of contortions was first proposed by Prof. Phillips in 1848,¹ and was afterwards, but independently, used by the late Prof. Jukes, to account for the formation of certain contortions observed by him in the Coal-strata of Staffordshire.²

In this and in a previous communication (*GEOL. MAG.*, Vol. IX., p. 119) my endeavour has been to prove the strict interdependence of geological phenomena. Change cannot take place in one direction without causing alteration in another. Prolonged and almost imperceptible are the actions that have produced the immense amount of denudation on the earth's surface; fully as slow has been the re-deposit in other localities of the debris resulting from that denudation. The most enormous contortions, and the most abrupt bendings of strata, as well as that change in the position of the constituent particles by which slaty cleavage has been induced, have occurred in the most gradual manner. They have been effected with great power, it is true, but without violence. I believe the time must shortly arrive when it will be generally accepted by geologists that "the most gigantic curvatures of strata have been the result of intense pressure so moderated in its application as to have been just sufficient to overcome the resistance opposed to it, and that this motion has been as insensible as the unfolding of the petals of a flower."³ Even the volcano and the earthquake must be removed from the category of cataclysms and convulsions. With more probability may they be considered as the necessary result of those slow and imperceptible changes, by whose accumulated power certain physical alterations have been made in the earth's crust. In conclusion, I must express my conviction that a careful examination of the phenomena under consideration will demonstrate that the prime mover which has produced them is denudation, with its consequent deposition, acting and re-acting on the crust of the earth, equally balanced on its fluid interior.

¹ *Memoirs of the Geological Survey*, vol. ii. *Geology of the Malvern Hills*, p. 142.

² *Student's Manual of Geology*, chap. xiii.

³ Sir C. Lyell, *Presidential Address*, 1850, *Quart. Jour. Geol. Soc.*, vol. vi., p. lxi.