presence of pseudomorphs of chloride of sodium, show that a new condition of things set in with the Keuper. In conclusion, I may point out while on negative evidence that the absence of saline deposits in the Bunter is on the other hand against the subaerial river-delta hypothesis, as the sandy deposits to which they are compared often eventually absorb the rivers which create them; and this applies to the North of Africa as well as to the Asiatic example.

NOTICES OF MEMOIRS.

THE GEOLOGY OF DEVON, FACTS AND INFERENCES, FROM THE PRESIDENTIAL ADDRESS TO THE DEVONSHIRE ASSOCIATION. By W. H. HUDLESTON, Esq., F.R.S., Sec.G.S., etc. August, 1889.

Part II.

(*Concluded from November Number*, p. 514.)

TAVISTOCK COUNTRY.

THE geological phenomena in the neighbourhood of Tavistock are of such interest that I cannot do better than close this address with a brief allusion to some of the features of the west side of Dartmoor, and the adjacent country.

It is a region which has always presented peculiar difficulties, but the new line of railway in course of construction may help to clear matters up. The subject can be grouped under four headings: (1) The structure of the country; (2) the nature of the basic igneous rocks, or "greenstones"; (3) Dartmoor; (4) the metalliferous deposits.

(1) *The structure of the country* on the west side of Dartmoor differs considerably from that on the east side, more especially in the fact that the Devonian beds are represented as dipping towards the sea instead of away from it; at least this is the case for several miles immediately north of Plymouth. Further towards the north, in the direction of Tavistock and beyond, there would seem to be a complexity of structure unusual even for Devonshire. Consequently the boundary between the Devonian and Carboniferous, as laid down in the Survey Map, may be subject to considerable revision. Mr. Worth astonished us lately at the Geological Society by the statement that the town of Tavistock is actually on the Carboniferous, and yet that, owing to a complex series of foldings, the Devonian rocks are brought up on both sides. I know of no spot in the United Kingdom where the geological boundary-lines seem to be so much under discussion at the present moment.

Although Mr. H. B. Woodward, in the map attached to the "Geology of England and Wales," follows De la Beche in assigning the Brent Tor district to the Carboniferous, it has long been claimed as Devonian by some geologists. These views are perhaps the result of Mr. Rutley's interesting work on the schistose volcanic rocks west of Dartmoor, described as consisting of alternations of lava-flows, tuffs, and tufaceous sediments. That this class of rock, locally

known in its vesicular form as "honeycomb dunstone," was of a volcanic nature, had long ago been recognized by De la Beche; but it was the late Mr. John Arthur Phillips who first clearly demonstrated, in his classical papers on the Cornish "greenstones," that many of these beds were actually lava-flows. Mr. Rutley went a step further, and considered that he had found in Brent Tor a fragment of one of the old volcanic necks. His famous diagram, with its column of ashes flattened by the wind, described by himself as as "a chimæra which may embody a certain amount of truth," is familiar to all geologists. Nay so graphic was the picture, and so convincing the arguments, that a certain Mr. Thorpe fancied that he had corroborative evidence of the prevalence of the south-west wind in Devonian times, because, forsooth, he had found lapilli from Brent Tor in the joints of a limestone at Newton Abbot.

Let us express a hope that before the Association next meets at Tavistock the boundaries between the Devonian and Carboniferous may have been made as clear as noonday, and accurately laid down on a six-inch map, which shall itself be a model of chartography.

(2) We must now take into consideration the *nature of the basic igneous rocks*, commencing with those which are interbedded, most of which are now said to be of Devonian age. Before doing so it will be necessary to say a few words about the "killas," a very loose term better understood by miners than geologists. Judging from Mr. Worth's remarks on the stratigraphical relations of the Devonian rocks of South Devon, most of the "killas" of this district belongs to the grey and drab slates intersected by lodes and elvans, which was described by Conybeare as the metalliferous series: above this comes a group more variable in its nature, which is especially characterized by interbedded volcanic rocks, and Mr. Worth suggests that the Brent Tor series may belong to this group: above these again are the purple and green slates immediately underlying the Plymouth limestone. The main point to notice is, that the whole of this slaty series is regarded as below the Plymouth limestone. Consequently it must belong to the lower part of the Middle Devonian, and possibly to even lower beds. Mr. Rutley, if I recollect rightly, regarded the Brent Tor series as possibly in the Upper Devonian.

The interbedded basic igneous rocks, then, are placed by Mr. Worth a long way below the Plymouth limestone; whereas the late Mr. Champernowne, in an interesting posthumous communication to the Geological Society, was disposed to regard his Ashprington volcanic series as above the main limestone of that district. In reference to this difference of opinion two points seem to present themselves for consideration. Firstly, that the schalsteins need not be confined to any particular horizon in so thick a series as the Middle Devonian; secondly, that the phenomena of extravasation, whether interbedded or transgressive, is limited, with very unimportant exceptions, to the southern portion of the county, from whence the line of igneous products may be traced into Cornwall. Hence the area of erupted rock is local, and to a certain extent

linear, and is probably not absolutely confined to any particular geological horizon.

The interbedded basic igneous rocks have been described by numerous authors, and their general petrographic features are fairly well known. In Northern Cornwall, according to Mr. J. A. Phillips, these ancient lavas are called "dunstones." Specimens analyzed by him were found to contain 42 per cent. of silica, over 20 per cent. of alumina, and the alkali is almost entirely soda: the amount of lime is nearly twice that of magnesia, and there is over 12 per cent. of protoxide of iron. From a chemical point of view these rocks, then, are allied to the basalts.

The intrusive "greenstones" are classed by Mr. Worth under three heads. They are sporadically developed, but seem to be most numerous and of the largest size in the vicinity of Dartmoor: they are believed to be older than the Dartmoor granite, which is said to alter them. If the Survey mapping is correct, the so-called gabbros between Marytavy and Wapsworthy occur in Carboniferous rocks, and must of course be younger than the beds into which they are intruded. These gabbros, Mr. Worth considers, are the vestiges of a widespread pre-Dartmoor igneous activity, producing basic rocks. He points out that their relations to the granite, both here and in Cornwall, are too persistent to be accidental, and he suggests that they may represent the basic forerunners of the more acidic granites. The age of the rocks into which the Marytavy "gabbros" have been injected still remains to be settled, but the notion that either they or the granites have brought up the lowest stratified rocks is not borne out by experience in other parts of the area round Dartmoor.

(3) Having now cleared the way a little by a brief glance at the containing rocks, we are in a position to attempt the study of *Dartmoor* itself, that supreme monument of the old eruptive forces. Dartmoor, as every one knows, is contained partly in Devonian and partly in Carboniferous rocks, and from the position of the *Posidonomya*-beds it is probable that the lower part of the Carboniferous adjoins the granite. Mr. Ussher, speaking of the beds on the northern and eastern flanks of Dartmoor, observes that the Culm-rocks dip off the granite above Belstone in a marked manner. He also says that the Culm-rocks on the north are roughly parallel in their strike to the margin of the granite, whilst on the east and west their strike is cut off, so to speak, by the granite or else deflected. These considerations are of importance as showing how the granite lies in its case.

From what has already been said, it is perfectly clear that this granite is in nowise connected with anything of the nature of an anticlinal axis bringing up older rocks. In fact on the east side, where it abruptly terminates, its relations to the adjacent country are almost those of a synclinal. On the Tavistock side its relations with the adjacent country are more obscure, owing to the stratigraphy of the district being as yet undetermined. Moreover, there is probably underground connection on this side, through Hingston Down, with the granite boss of Brown Willy.

The above considerations tend to show that the relations of the granite to the surrounding rocks are somewhat peculiar, and that it is not exactly easy to frame a theory to satisfy all the conditions. The composition, which is that of a normal potash granite, and the contact phenomena, are clearly against the notion of any large absorption of the containing rocks, such as are now accessible to observation. There has been much nonsense talked about granites being the result of the extreme metamorphism of the beds in which they occur. Mr. J. A. Phillips in his paper "On the Rocks of Cornwall in relation to Metalliferous Deposits"[1] showed very clearly that, although the different kind of killas vary materially in composition, under no circumstances could the mere re-arrangement of the constituents result in the production of granite.

He gives a table with the chemical compositions of ten varieties of Cornish killas, showing a range in silica from 33 to 68 per cent. and of alumina from 10 to 24 per cent. The alkali is mainly soda, and of this there is a considerable amount in some specimens, pointing to the conclusion that killas has been largely derived from the dissemination of very fine volcanic matter of a basic composition. This coincides with the prevalence of contemporaneous volcanic phenomena. It is worth noting that the roofing-slate of Delabole affords an exception to this rule, in containing more potash than soda.

As there is no reason to suppose that the early chemical history of the Dartmoor granite differs materially from that of the Cornish granites, their sources must have been deep-seated, and they must have originated under the ordinary conditions which produce the granitic magma, whatever those may be. The main questions remaining to be considered are the period and circumstances under which the Dartmoor granite assumed its present position.

There is no evidence at present, as far as I know, which would enable us to fix the period any nearer than the somewhat vague date "the close of the Carboniferous." Dr. Barrois says that many of the Brittany granites are of Carboniferous age. But in the case of Dartmoor it is probable that the great foldings of the Hercynian mountain-system had been mainly effected, and the synclinal of Devonshire formed, before the granite was insinuated. In position the mass of Dartmoor is outside the axis of the Cornish granite; if their alignment was followed the centre of Dartmoor would be about Hatherleigh. Hence the stratigraphical position differs somewhat from that of the Cornish granites, although possibly their age may be quite the same. It is enough to know that an immense physical revolution was effected all over the British Isles between the close of the Carboniferous and the beginning of the Permian, and the intrusion of the Devon-Cornwall granites must have taken place either then or in early "red rock" times.

Next, as to the circumstances under which the Dartmoor granite found its way into its present position. Last year Mr. Ussher treated

[1] Quart. Journ. Geol. Soc. vol. xxxi. p. 319.

this great question with characteristic ingenuity, and showed pretty conclusively that neither the punching theory nor the absorption theory would meet the facts of the case. De la Beche gave us a valuable hint, as indeed he was in the habit of doing, when he inferred that, owing to the volcanic activities which had prevailed in the area during the deposition of the Palæozoic series, a line of least resistance to a body of granite, impelled upwards, might have been formed. In this way the granite of the great bosses may have been forced through ground already weakened as the site of old volcanic vents—such as Brent Tor, we might add.

Of course, it must be remembered that the contacts we now see only represent a certain stage in the relations between the granite and its case. A million years ago, when the country was much higher relatively, the contacts may have presented a somewhat different phase, whilst it is certain that those who are able to inspect the contacts after another million years of atmospheric denudation, will at least get much nearer to the roots of the matter. As far as I am able to judge from Mr. Ussher's descriptions, there are indications of a considerable lateral thrust on the north and on the south side of the mass, parallel to the mean strike of the enclosing beds. This looks very much as if the main displacements which took place were lateral, the beds yielding to the pressure gradually, and thus helping to intensify the flexing of the district.

How far the evidence is in favour of Mr. Ussher's suggestion that Dartmoor is a laccolite, insinuated at the junction of Devonian and Carboniferous rocks, I am unable to say. This seems a somewhat ignominious termination to a career which patriotic Devonians have regarded as nothing less than the plutonic supply-pipe of a regular volcanic cone, more lofty than that of Etna. Possibly the two theories may be reconciled by regarding the supposed laccolite as a kind of reservoir, or local thickening in the pipe.

It was Professor Bonney who first set the Devonshire geologists on the look-out for the vestiges of the great Devonshire volcano. Not a mere Brent Tor this time, erupting its lavas into the Devonian Sea, but one of a line of lofty peaks of far later date. "Among the many excellent geologists and enthusiastic students of the West of England," said he, "is there no one who will undertake to replace the covering which has been stripped from the granitic bosses?" He also indicated that a thorough study of the "red rocks" of Devonshire would yield important results in this direction.

Mr. Worth is amongst those who have responded to this challenge, a circumstance to which allusion has already been made in dealing with the New Red question. It is somewhat singular that if there really was a volcanic cone covering the Dartmoor pipe, the traces of it should have to be sought at the eleventh hour in the "red rock" breccias. These ought to be full of unmistakeable fragments of old acidic lavas, and of the felsites which are structurally intermediate between such lavas and granite. Possibly the want of adequate petrographic knowledge may have hitherto retarded the discovery, and we naturally await the result of further investigations.

But Mr. Worth himself has supplied evidence which goes far to explain the presence of remnants of felsitic, and even of volcanic rocks, in accumulations more recent than the "red rock" breccias. Such remnants are much more likely to have been derived from the elvans, which form so characteristic a feature in the country between the Dartmoor and Brown Willy granites, and some of which probably reached the surface in a more glassy condition than the portions now accessible to operations. Besides, even the existing dykes are represented in some cases as developing a semi-vitreous ground-mass with porphyritically imbedded crystals.

Theoretically it is extremely probable that the granite bosses of Devon and Cornwall may have passed upwards into volcanic rocks, and that consequently they represent a line of eruptive vents which were possibly active in Permian times, or those immediately preceding. But the petrological evidence alone is not conclusive. If we suppose that the "red rock" breecias are of Triassic and not of Permian age, all, or nearly all, traces of the volcanoes might have been removed before the breccias were accumulated. Clearly the granite, with its characteristic crystals of orthoclase, had been laid bare when the beds containing Murchisonite were deposited.

As regards the composition of the Dartmoor granite, the accessory minerals such as schorl, and the proneness of portions to kaolinization, are especially noteworthy. This latter feature has a tendency to produce unequal weathering, and it is not at all improbable that the Tors are in a great measure due to the unequal weathering brought about by this cause. They represent portions which, in the hour of trial, were harder and perhaps chemically more stable, and consequently less liable to disintegration. The forms of the Tors, as was pointed out by Prof. Rupert Jones and more recently by Mr. Ussher, have been largely determined by the arrangement of divisional planes, the mass being intersected by what the latter calls impersistent cracks, running more or less horizontally and crossed vertically or obliquely by joints. Variation in the direction of these joints is accountable for much of the variety in the Tors themselves.

(4.) *The Metalliferous Deposits.*—The abundance of schorl, especially on the edges of the granite, and the kaolinization of the felspars, are indirectly connected with the last subject which it is proposed to bring to your notice; viz. the origin of the metalliferous deposits for which this region is so famous.

It is, I believe, admitted that the great east-and-west fissures through which the elvanite has been injected were formed after the consolidation of the main mass of the granite, though their chemical composition points to their having been derived from the same magma as the granite. The next step in this curious underground history appears to have been the formation of a series of empty fissures, most of them having a more or less east-and-west orientation. And now commenced a fresh set of phenomena which, in an extremely modified sense, may be said to be still in operation.

The fissuring of this region was probably due to reaction after the strain consequent on the system of folding, to which allusion

has been so often made. When first this fissuring, or gaping of the rocks, occurred, there was a supply of molten silicates from below more than sufficient to fill up the void. But, as often happens in volcanic regions of modern date, the last stage of primary activity is represented by fissuring without injection of molten matter. A number of open cracks are thus formed, which favour the circulation of underground waters, often intensely heated, and not seldom passing off as condensed steam where they happen to reach the surface.

In Devonshire and Cornwall, the period when this phase was at its height occurred most likely in late Permian and early Triassic times.[1] But, as every one knows, there have been many periods of shifting amongst the rocks; and doubtless the country must have participated in the great Tertiary earth-creep which folded the Downs and the Isle of Wight, about the same time that the Alps were being raised into a mountain-chain. Each successive movement would be apt to produce modifications in the underground circulation, cramping it here and stimulating it there; and doubtless, as the temperature decreased, the solvent powers of the waters would diminish also.

To such underground circulation in old volcanic districts like this, most of the phenomena in connection with metalliferous veins are due, though it must always be remembered that here we see a plutonic phase of what were volcanic activities at higher levels in earlier times. Fifty years ago De la Beche and the first Surveyors evinced an intense interest in this subject, and in the Memoir already referred to many hypotheses of origin are discussed. Since those days the world has been revolutionized in more ways than one, and in no way more than in the transfer of mining enterprise. But the experiences of the last five-and-twenty years in the Tertiary volcanic districts of North America have not been lost upon the numerous able men who have been employed as engineers or surveyors in those highly metalliferous regions. The late John Arthur Phillips left a record of his great knowledge and experience in his excellent treatise on *Ore Deposits*. And I have no doubt that many here are more or less acquainted with the important works of the French *savant* Daubrée, whose "*Etudes synthétiques de Géologie expérimentale*," and "*Les eaux souterraines aux époques anciennes*," furnish us with an immense amount of information on the origin of metalliferous veins.

Briefly, it may be said that the underground circulation theory is the one most generally adopted, the chief difference of opinion being as to the relative importance to be assigned to *lateral secretion* and to *ascension* respectively; or, stated in simpler terms, whether

[1] Since the publication of portions of the address in the local papers, Mr. Thomas Collins, of Redruth, has written to say, "he considers there is evidence in the Tavistock district that the metalliferous deposits containing copper-ores had been formed in the Devonian rocks before the deposition of the main mass of the Carboniferous. The large copper-lodes of Mary Tavy, for instance, are in Devonian rocks, and cease altogether on coming into contact with the black schists of the Carboniferous." It is suggested that this may be due to faulting at the junction.

the vein-material comes from the sides or from below. It is reasonable to suppose that both sources may have contributed to the supply, though in certain cases a change in the deposits, accompanying a change in the country rocks, would seem rather to favour the notion of lateral secretion. Thus Mr. Phillips remarks, with regard to the Tavistock district, that the copper-ores are often associated with a blue clay-slate. If the slate becomes deeper in colour, iron-pyrites alone occurs; and if the rock becomes quartzose, even the pyrites disappear.

Whilst endeavouring to trace the source of the ores in metalliferous lodes we should bear in mind the experiments of Sandberger, who found that the heavy metals occur in the silicates of the crystalline rocks of every age. Augite and the magnesia-micas are especially rich, and the lithia-micas are noted as being stanniferous. The origin of tin-ores is probably different to that of the sulphuretted ores, though both are often best developed at the junction of igneous and sedimentary masses. This, of course, is partly accounted for by greater facilities for fissuring, and still more by an increase of heat, which is likely to promote the underground circulation, and above all to increase the solvent power of underground water.

The question of solution has always been a difficult one, and has inclined some people to adopt the notion of sublimation of the metallic sulphides. As an alternative theory we have had the reduction of sulphates by organic agency. But people are beginning to think that both these agencies may be dispensed with, and that, under peculiar conditions of heat, pressure, and dissolved gases and salts, the solvent powers of water may be largely increased. Anyhow, it is perfectly certain that metallic sulphides, such as cinnabar and pyrites, are being deposited from hot springs along with various forms of silica, both in California, and at Steamboat Springs in the State of Nevada. We may well believe that this latter place, of which an account was given in the Quarterly Journal of the Geological Society as long ago as 1864, represents with a certain amount of fidelity the conditions which prevailed in the upper portions of the metalliferous lodes of Devon and Cornwall during a period, not of maximum activity, but when a considerable deposit was taking place.

The solution and transport of tin-ores are capable of a different explanation. As is well known stanniferous deposits are not only very local, but are also accompanied by a peculiar group of minerals, such as topaz, schorl, axinite, and fluor, which contain a notable quantity of either Fluorine or Boron, and in the case of schorl of both these elements. Daubrée observed that this is the case wherever tin-ore has been found, and he suggested that, in the first instance, tin was brought up from what he calls the general reservoir of the heavy metals as a fluoride. The interesting chemical experiments connected with this ingenious hypothesis are detailed in his great work on Experimental Geology. According to these views stannic-fluoride and steam would decompose each

other at a moderately high temperature, the result being a deposit of binoxide of tin or cassiterite. The liberated hydrofluoric acid, besides helping to form such minerals as schorl and other fluo-silicates and fluorides, would enter into the general circulation of the rocks, and thus tend to facilitate that kaolinization of the felspars which has produced so much china-clay on the south-west side of Dartmoor, and in the mass of the Hensbarrow granite.

It is also worth noting in this connection that, according to Dr. Le Neve Foster, the great flat lode of Carn Brea, near Redruth, is in the main a band of altered rock, and he is inclined to suspect that half the tin-ore in Cornwall is obtained from tabular masses of altered granite. In such cases there is no regular lode, but very fine cracks in the rock have evidently given access to stanniferous solutions, which have deposited oxide of tin more or less abundantly in the vicinity of such cracks, and materially changed the nature of the original granite.

The phenomena in connection with these impregnations of tin-ore appear to favour Daubrée's views; but such points are to be commended to the notice of local geologists, who alone can test their suitability to explain the facts which come before them. I would merely remark that too much stress should not be laid on such cases as those of deer's antlers having been found partly replaced by cassiterite in the old river-gravels. This has been effected at ordinary temperatures, most probably by the aid of alkaline carbonates arising from the atmospheric decomposition of felspars, and proves that the most insoluble minerals may be successfully attacked by agencies now or lately in operation, and their metallic element moved from point to point, but only in very small quantities.

It is to be feared that chemical questions such as these possess but little interest for the members of the Association, and I apologize for having introduced them, however briefly, before a general audience. But there are certain conclusions which we are able to draw without any special reference to chemistry. In the great metalliferous lodes we see the roots of old mineral springs and geysers, which spouted their water and steam into the air, and perhaps covered the surface of the ground with siliceous sinter. That was a time when the volcanic forces of this remarkable region were on the wane, and after the great outpourings of lava had taken place upon a surface of which every trace, perhaps, has been swept away. How long these hydrothermal agencies continued to be active we cannot tell; but it is by no means improbable that they were in operation throughout a considerable part of Mesozoic time, during which period the spoils of this western land, brought down by the ceaseless forces of denudation, partly found their way into the eastern sea, and thus helped to build up the deposits which were afterwards to be fashioned into the Secondary rocks of England.