# THE DARTMOOR VOLCANO.

BY R. N. WORTH, F.G.S.
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Dartmoor is a broken tableland of Granite, of irregular outline. The greatest length, North to South, is 22 ½ miles; the greatest breadth, East to West, 18 1/3 miles. The average breadth cannot, however, be taken as more than 15 miles; nor the average length as more than 20. The area is therefore about 300 square miles. These are the measurements of the visible granite; but the granite is surrounded by a belt of altered rocks — slates and grits — beneath which it dips, which have been changed in character by its proximity, and which indicate its wider presence at no great depth. Including this zone, the area affected by the physical phenomena of Dartmoor is not far short of 400 square miles.

Other elevated granitic regions of similar character, which cannot be dissociated from Dartmoor in origin, occur at intervals to the westward. Chief are the Hingston, Brown Willy, Hensborough, Carnmenellis, Land's End, and Scilly bosses; but more or less closely grouped with these are smaller patches, which, in several localities where mining operations are carried on, have proved to be connected with the main masses at no great depth, the surface interval being occupied by shallow basins of the slaty rocks commonly grouped as killas. There is every reason to assign all these granitic areas to one and the same geological age, and to one and the same series of causes; and there is good ground also to suggest that the connection proved to exist between the minor masses exists, at a greater depth, between the larger; and that from Dartmoor to Scilly, therefore, we are dealing with one and the same granitic axis, most strongly marked in Dartmoor, and gradually decreasing in elevation and importance westward, where initial causes seem to have been least active and subsequent changes most prominent. Denudation seems to have increased in activity from the north-eastern flank of Dartmoor, where Carboniferous rocks occupy the surface, exposing in turn the lower strata of Devonian, Silurian, and probably Cambrian rocks in the West Cornwall mining district, with Archaean in the Lizard promontory. Dartmoor is about as large as all the other granitic areas of the West together, and has always had great relative importance.

On a wide view Dartmoor presents the aspect of a tableland, with an elevation more decided in relation to the surrounding country than the rise of its highest points above its average level. This plateau character is best recognised in such a distant view as that from the Cheesewring. It can be seen from Staddon Heights, Maker, in a minor degree from Roborough Down, and several other points; but the Cheesewring *coup d'oeil* is most distinctive. It is far more strongly marked on the south of the Moor than on the north, where isolated heights are more common in the outskirts.

The average height of Dartmoor above sea-level is 1200 feet, whereas the two highest points — High Willhayse and Yes Tor — are 2039 feet and 2029 feet respectively. The general contours are peculiar. The outer hills, the boundary rampart of the granite region, rise as a rule between 800 and 1000 feet, while the more broken belt of heights immediately succeeding averages between 1200 and 1400. Still further in are two main areas of special elevation — the one in the northern and the other in the southern quarter — and these are divided by a line which follows practically the main road across the Moor from Dousland Barn to Moretonhampstead, and undulates between 1000 and 1400 feet.

The most elevated tract of Dartmoor is six miles in length NNW. to S.S.E., from Yes Tor to Cut Hill, and three miles wide. None of the heights here are under 1800 feet, and they range up to 2039. Near the centre of this region, approaching 1900 feet above sea-level, is Cranmere, from the bogs around which, at a general elevation exceeding 1800 feet, issue the head waters of the Dart, Tavy, Okement, Taw, and Teign.

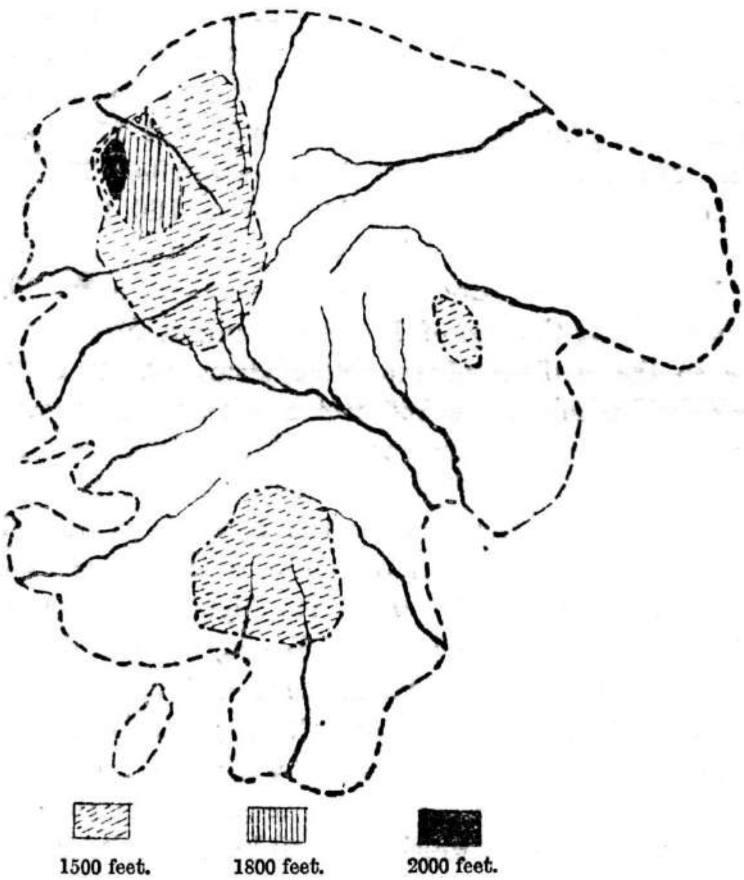
East, and west, and south of this area, for a space of five miles broad and seven miles long, the tors attain a height of 1700 feet; and beyond it, on the N.E., Cosdon Beacon rises in solitary majesty to 1784. The descent from the Moor at its extreme N.W. corner, near Okehampton, is more sudden and marked than at any other point, but otherwise it is somewhat less decided on the west than on the east.

A tongue of the northern high ground trends southward by Great Mis Tor, Bair Down, and North Hessary Tor, each over 1700 feet.

The high land of the southern quarter rises at Peters Bound Stone to 1694 feet, and for an area of about six miles by four has an elevation of 1500.

The only other specially-elevated region is in the east, where Rippon Tor and Hamildon are the most prominent heights.

These points will be more clearly recognised in the diagram, where it will be seen that Dartmoor has two main areas of elevation and two main systems of watershed, the principal rivers flowing east, west, north, and south from around Cranmere; while the Avon, Erme, Yealm, Plym, and Meavy issue west, south, and east from the southern centre, the northern streams of which flow into the Dart.




SKETCH MAP OF DARTMOOR, SHOWING CONTOUR AREAS, AND MAIN WATERSHEDS.

**This map represents the Dartmoor granite, with a general height of 1200 feet. The contours shown are those in which the leading points reach the elevations given. They are general contour *areas*, not *lines*.**

The Dartmoor heights are mainly connected ranges of high land, with a general run north and south. There are only two points where a contrary tendency is strongly marked. South of Fur Tor and Cut Hill a ridge runs irregularly east and west from the valley of the East Dart to that of the Tavy. In the southern quarter a semicircle of high ground sweeps round Fox Tor Mire eastward and southward, and extends westward toward Cramber Tor. The heights are more continuous in the central portion of the Moor, east and west of which there are many isolated hills.

The fall in the upper waters of the Dartmoor rivers is very considerable, and if their volume in these regions were any way proportionate (only the case in very rainy weather), their excavating work would be enormous. The two branches of the Dart, to Post Bridge and Two Bridges respectively, fall about 150 feet a mile; thence to Dartmeet and to the edge of the Moor at Holne, 80 feet. Holne Bridge is just 200 feet above datum. The Teign gives much the same results. The Taw and the Okements fall still more rapidly — from 180 to 200 feet a mile. The Tavy, between its source and Tavistock, averages about 140 feet a mile; from Tavy Cleave onward about 90. The Walkham falls at the rate of 160 feet a mile to Merivale Bridge, thence to the confines of the Moor about 80. The Plym to Shaugh Bridge falls some 160 feet a mile. The Meavy about 120-150 between the source and the Head Weir, 90 thence to Shaugh Bridge.

The sudden drop from the inferior outskirts of the Moor to the bordering lowlands is strikingly shown in the ravines through which the chief streams descend. The Plym, at the Dewerstone; the Meavy, at Yannadon; the Walkham, at Huckworthy; the Tavy, at Tavy Cleave; the Lyd, at the Gorge; the West Okement, at Meldon; the Taw, at Belstone Cleave; the Teign, at Fingle Bridge; the Bovey, at Lustleigh Cleave; the Dart, at Holne; the Erme, at Ivybridge; the Yealm, at Awns and Dendles. All these tell one tale, as to which we shall have more to say anon.

Such are the chief physical characters of modern Dartmoor. The key to the origin and geological history of Dartmoor is the nature of the rock of which it is mainly formed, to which its other physical conditions are subordinate. The idea that granite is the primary rock of the world — once firmly held — is long quite out of date, since it has been recognised that there are granites of differing geological ages; and instead of one hypothesis for the origin of granite, there are now four — (1) The original primary idea, repeated only by the uininformed; (2) The generally received view that granite is of igneous origin; (3) The suggestion that it is really an altered stratified rock; (4) The compromise theory that as there are granites of different ages, so there may be granites of different origins — some igneous and some metamorphic.

With the first and fourth of these we have nought to do. The one is dead; and as for the other, we are only concerned with the granite of Dartmoor and its continuation west, and what may be proved touching them.

The difference between the second and third hypotheses is not absolute. We are not really troubled about the prior condition of the material which now forms the Dartmoor granite. It may have been igneous from the beginning (and all rocks were originally igneous), or it may have been a sedimentary rock, subjected to destructive action and reconstitution. At the same time it should be mentioned that in 1875 the late Mr. J. A. Phillips clearly proved that granite and elvan could not have been formed out of killas, which is deficient in silica, and contains more soda than potash, while granite and elvan are potassic [*Quar. Jour. Geol. Soc.* xxxi. 338]. If therefore our granites and elvans are metamorphic, special forms of sedimentary rock must have been provided, occupying exactly the same areas, which have left no trace behind!

Our business, however, is not with original character, but with agency. And here again the dispute is in part one of terms. Most, if not all, geologists are agreed that what is now granite has been in a fluid or semi-fluid, or at least pasty condition, produced in some way by heat. The controversy, so far as we have to do with it, is narrowed to one point — whether the heat was dry or wet, thermal simply, or hydrothermal — whether, in plain English, our granite was smelted or stewed.

And the advocates of the rival views also agree that, however the fluid state was originally produced, the consolidation of the granite must have taken place under considerable pressure.

Liquid and gaseous inclusions frequently occur in cavities in the constituents of granite, notably in the quartz, and arguing from these Mr. Sorby long since announced that the Cornish granites had as a mean consolidated at a temperature of 216 C, and under a pressure equivalent to that of 55,000 feet of rock [*Quar. Jour. Geol. Soc.* xiv]. The late Mr. Clifton Ward in the same way estimated the granites of Westmoreland and Cumberland to show a mean pressure of 44,000 feet — the Skiddaw granite indicating 52,000, with a suggested temperature of 360 C. Mr. Sorby's mean for the Highland granites gives a pressure-equivalent of 76,000 feet.

Mr. Sorby's conclusions as to the origin of granite are that it might have been formed under conditions "combining at once igneous fusion, aqueous solution, and gaseous sublimation," and that the pressure under which granite solidified was analogous to that of lavas "solidified at the focus of their activity, as though these rocks were the non-erupted lavas of ancient volcanos variously protruded among the superincumbent strata."

Professor Prestwich, adopting the hydro-thermal or extreme metamorphic view, criticises Mr. Sorby's details, while agreeing in the main with his inferences, and thinks that "granite must have consolidated under extreme pressure, and at a temperature probably not exceeding about 700 Fahrenheit, or under that of low red-heat."

It may thus be accepted as a definite article of geological faith that granite was at one time in a highly heated and plastic state — to go no further.

But it has been argued that granite rocks have been changed in situ — that the granite is simply the product of a gigantic stewing operation, on strata which practically occupy the same position now as before, though changed in character.

The answer in our case is perfectly clear, whether on physical or on chemical grounds. If our granites are only altered forms of the rocks among which they lie, then one must pass into the other by gradual change. This is never the case. Wherever you trace the Devon or Cornish granites in contact with other rocks you find the line of junction perfectly sharp and distinct. Sir Warington Smyth has asserted "positively that careful research will reveal numerous places on these granite hills, to be seen sometimes with great distinctness underground . . . where the ends of schistose strata may be seen to abut against the face of granite."

Moreover, granite veins may be seen at many places thrust into the adjacent rocks, in a manner utterly irreconcilable with any metamorphic hypothesis. Again, the rocks bordering the granite all more or less exhibit traces of alteration, gradually dying away from the granitic margin, just as the granite should if it had been the result of a metamorphic process, and were not of independent origin. I put the inevitable conclusion in the words of Sir Warington Smith, " From these various indications ... it is clear that the slaty rocks . . . have been rudely disturbed and broken through by the granite, and that they are probably based upon a vast mass of that material lying at unknown depths between the hills where it rises into view."

This identification of the Dartmoor granite as a true igneous rock is the first stage in our inquiry. Igneous rocks are commonly classed in two great divisions — volcanic, " such as have been ejected, or have welled out on the surface," and plutonic, "such as have been formed under conditions of depth and pressure." [PRESTWICH'S *Geology,* i. 35]. Petrological research has, however, made it absolutely certain that (and I use the words of Professor Prestwich rather than my own) this "in many cases indicates a difference of conditions rather than of origin. The volcanic rocks having erupted on the surface, and having cooled quickly and without pressure, have solidified as non-crystalline and amorphous rocks, whereas the so-called plutonic rocks, not having been erupted at the surface, and cooling slowly and under great pressure, have solidified as crystalline rocks." [*Geology*, i. 381].

There is another classification of igneous rocks, according to their composition, into acidic and basic. These form two great series, in both of which plutonic and volcanic varieties are found. The acidic rocks have an average percentage of silica of 70; the basic of 50; and while alkalies are largely represented in the one, alkaline earths are conspicuous in the other.

As long ago as 1874 Professor Judd, writing on the "Tertiary Volcanoes of the Highlands," [*Quar. Jour. Geol. Soc.* xxx. 220, *et seq*] proved that in the acidic series the plutonic form, granite, passed upwards through syenitic granite into felsite (quartz –porphyry), then into trachytic-lava (felstone, or rhyolite), and finally into a volcanic glass (pitchstone).

The basic in like manner passed from the plutonic gabbro, through augitic-gabbro and dolerite, into basalt-lava, and finally into the basalt-glass known as tachylyte.

These are but main varieties, and the unvarying result of petrographic research since then has been to prove full intermediate gradations from the plutonic to the volcanic types, so that one and the same original fluid mass of molten matter may put on all these varieties of lithological form. Granite, if it reaches the surface, becomes lava.

In the paper from which I have quoted, Professor Judd traced the history of the great Tertiary volcanoes of Mull, Ardnamurchan, Rum, Skye, St. Kilda, and of the Grampian chain — in each and all of which volcanic rocks have been associated with great central granitic masses; and in his concluding passages observed :

"From the active volcanoes of Etna, Vesuvius, and Skaptar Jokul, the step to the ruined piles of the Mont Dore and the Cantal is an easy one, and with these last we have little difficulty in perceiving the parallelism of the phenomena displayed by the rocks in the central mountain group of Mull. From the condition of the volcanic rocks in Mull to that in Skye the transition is obvious, and from the latter to Beinn Nevis, and thence to the granitic bosses of Cairngorm, the Moor of Rannoch and the Ross of Mull, can easily be made; nor will any difficulty be experienced in passing from these latter to the wide-spreading tracts of granite, such as that of Leinster. . . .

"Whilst, on the one hand, we are led to conclude that great tracts of granite like that of Leinster may once have been surmounted by vast volcanic piles, we cannot, on the other hand, doubt that the subaerial volcanic phenomena of Iceland, Sicily, and the Andes are accompanied by innumerable igneous injections in subjacent strata, and the formation of masses of granite, syenite, diorite, and gabbro at great distances beneath them."

For Leinster read Dartmoor, and the parallel is complete.

We find then that the granite of Dartmoor is an igneous intrusive rock, formed at a great depth beneath the surface, and therefore exposed by the removal of the rocks beneath which it consolidated. We learn also that granite is but a phase; and that the same matter now found as granite would, had it issued to the light, have formed a trachytic-lava. [Mr. J. A. Phillips, in 1875, illustrated the practical identity between granite, elvan, and rhyolite. — *Quar. Jour, Geol. Soc*. xxxi. 338] Just as we find water in the solid form as ice, the fluid as water, the vaporous as steam, the gaseous as oxygen and hydrogen — the change is less in the thing than in its conditions.

The next question is whether we have any evidence that the intrusive mass, of which the granite of Dartmoor formed a basal part, ever reached the surface as a volcano. We have seen that this granite must have consolidated at a great depth beneath vast masses of rock now removed. Can we gather what these rocks were?

We have had the figures of Mr. Sorby and Mr. Ward touching the pressure under which various granites have consolidated, the mean for the Cornish and Devon granites being the equivalent of 55,000 feet of rock. But it is not to be understood that our present Dartmoor granite was ever buried beneath ten miles of strata. Mr. Sorby remarks that "in some cases the pressure was probably much greater than that of the superincumbent rocks, for otherwise they could never have been fractured and elevated; whereas in other cases it may have been much less, if the internal pressure had been in any way relieved." [*Quar. Jour. Geol. Soc.* xiv. 491]. In other words, if the weight of the overlying rocks were equal to the pressure of consolidation there would be practically no surface change. If it were less, the extra force indicated would be expended by the eruptive granite in upheaval and distortion, to which relief might or might not be given by a volcanic vent.

Now as there is abundant evidence of a great elevating force in and around Dartmoor, in the tilting of the slates, &c, it is clear that the superincumbent mass cannot have been anything like the ten miles whose equivalent pressure has been calculated.

The Dartmoor granite rises through Devonian strata on the south, and partially on the west and south-east; through Carboniferous strata on the north, partially on the west, and to a larger extent on the east. And as it sends veins not only into the Devonian, but into the Carboniferous rocks, it is plainly younger than they are, since it could not transverse that which did not previously exist [Certain of the veins on the north of Dartmoor contain fragments of Carboniferous rocks, some not quite detached, some with perfect angles. (G. W. Ormerod, *Trans. Devon. Assoc.* ii. 128.)]. On the other hand, as pebbles and fragments of Dartmoor rocks are found in the local breccias and conglomerates which represent the margins of the ancient Triassic sea, it is clear not only that Dartmoor must have been erupted, but that some of its underlying rocks must have been liable to denuding influences — *i.e.*, that some of its granites must have been exposed at the surface — before these derived beds were formed.

Thus we are led to conclude that before the elevation of the Dartmoor region began the area was occupied by Carboniferous and Devonian rocks, the former resting upon Devonian, and the latter possibly in part upon Silurian, as traces of that system seem to exist in Devon as well as in Cornwall. Both the Devonian and the Carboniferous rocks of the Dartmoor area had been disturbed by igneous action before the upheaval of the granite. Not only have we lava- and ash-beds contemporaneous with the Devonian rocks, especially in the south-west of the county, but around the Moor there are bands and bosses of intrusive plutonic rocks partially following the outline of the granite in great curves, as at the north-western corner, and specially prominent near Mary Tavy and Tavistock, where they form the eminences of White Tor and Cocks Tor — the highest non-granitic points of the county. These gabbros, as they have frequently been called, though chiefly falling among the modern epidiorites, are the vestiges of a widespread pre-Dartmoor igneous activity in the intrusion of basic igneous rocks, and their exceptional development in the Mary Tavy district has been thought to indicate that we have there exposed some of the lowest stratified rocks brought up by the granite in this county. It may be that they represent the earlier stages of the eruptive epoch which eventually gave us Dartmoor, for their relations to the granite, here and also in Cornwall, are too persistent to be accidental. It is not unusual for one eruptive centre at one time to produce basic and at another acidic rocks.

Thus we have to account for the presence of the granite, the disappearance of the rocks which once covered it, and the relations between the granite and its stratified surroundings.

We at once dismiss, with Sir Warington Smyth, "the old Wernerian idea, that" the associated "schists were deposited after the solidification of the granite, wrapping smoothly round it." Indeed, that notion had to be abandoned with the exploded hypothesis of the primary granitic character.

As an igneous rock, the Dartmoor granite might have been intruded in four ways.

A. It might have risen directly through the Devonian and Carboniferous strata, bearing up on its surface the displaced rocks of its area. But in that case, its boundaries must have been broken or "fault" boundaries, and the fractured ends of the surrounding rocks must have terminated abruptly against it, instead of being tilted with it and lying partially upon it.

B. It might have elevated the superincumbent mass in a huge unbroken dome. But in that case, the removal of the upper portion of this dome would have shown the lowest rocks, in all cases, next the granite; whereas it is seen to pass under Devonian slates on the south, and under Carboniferous slates and grits on the north.

C. To avoid these difficulties, Mr. Ussher, F.G.S., recently suggested a laccolitic origin. His hypothesis was, that the granite came up from below through a central channel, and then forced itself in all directions between the beds and along lines of weakness under the surface, the final form being comparable to that of a gigantic mushroom. This would fully account for the relations of the granite to the investing rocks, but is, I think, inadmissable for other reasons. *First*. We cannot treat the Dartmoor granite as an isolated fact; hence, instead of one laccolite, we should have to accept several. *Second*. On the laccolite view there must be stratified rocks, except at the neck, below the granite as well as above, and in sinking through the granite we should come upon them. This is contrary to all experience. In the Cornish mines the lodes are continually followed down from the killas into the granite, and the two rocks invariably meet at an angle, as if the slate were lying in a huge granitic lap. But when the granite is once reached, there is no return to the killas, with the single exception that in the Breage district the rule is proved by the granite being cut in veins protruded into the killas. *Third*. It is impossible to me to conceive of such an immense body of molten matter as a laccolite the size of Dartmoor, three to four hundred square miles in area, and from existing data at least half a mile thick, forming a subterranean lake, without finding its way to the surface somewhere, and putting on volcanic characters.

D. There remains therefore only the volcanic hypothesis.

The point on which I wish to lay special stress is this — that there must have been a period in the eruption of the Dartmoor granite when the superincumbent mass ceased only to be lifted, and began to be thrust. Coming up from below — as the granite must have done from its present contour — partially in a wedge-shaped or conical form, the first erupted material leading the way in the line of greatest weakness, the Devonian and Carboniferous rocks must eventually have been driven apart as well as heaved. This thrust would become stronger as the erupted body increased in mass, and it would continue to grow in force until the tension near the surface was relieved. The lower rocks would be the first to feel the separating action. Hence upheaval would be quite consistent with Devonian and Carboniferous strata still retaining their relative positions on the flanks.

There is absolute proof that something of this sort took place, in the fact that the Carboniferous and Devonian rocks about Dartmoor, the latter especially, now occupy, by tilting and repetition, a much narrower lateral area than originally. They were once horizontal, or approximately so; they are now mainly inclined at high angles and plicated.

Some of these rocks, however, were simply lifted; where they were caught in a hollow of the irregularly uprising granite. There are talcose slates, for example, approximately horizontal near Slade, in the lap between the main granitic mass and the Crownhill island, saved from tilting by the protecting elevations on either side.

It will suffice if I confine my illustration of the effects of thrust to the Devonian rocks between Dartmoor and Plymouth Sound. They have not only been tilted, but thrown into a series of folds, partially identified by the repetition of certain beds; so that the nine miles or so of Devonian rocks between Shaugh and Wembury must contain, at the very lowest estimate, strata that originally extended over twelve or fourteen. These thrust effects are thus well marked in this locality, because there was a great buttress of Archaean rock in the Channel, now represented by the Eddystone Reef, against which the Devonians were driven, and which, by its resistance, increased the plication. Where the rocks were freer to move the folds are less pronounced; but similar effects are visible at many points round the Moor, where they have not been obscured by complicated earth movements or subsequent disturbance.

If the stratified rocks between Dartmoor and the Channel are largely in excess of those that originally filled that space, whence have they come if not from part of the Dartmoor area? And if the Dartmoor area, here and elsewhere, was cleared by the eruption of the granite of so much of its pre-granitic strata, is it not inevitable that the molten mass must have issued to the light as a volcano?

It is possible that to some of my hearers this may seem too large a draft on the powers of Nature; but in the most recent conclusions of the Geological Survey on Highland Geology I find the following passage:-

“By means of powerful thrusts the Silurian strata were piled on each other, and huge slices of the old Archaean platform, with the Cambrian and Silurian strata resting on it, were driven westwards for miles.”

We are dealing with gigantic phenomena, and we must allow adequate causes.

It is a natural suggestion, that if the Dartmoor granite ever passed upwards into volcanic equivalents of the acidic series, some of these rocks ought to be found. Considering the enormous amount of denudation to which the area has been exposed, and the comparatively small proportion these rocks would bear to the main intrusive mass, their absence, however, could be accounted for. Professor Judd has shown that in Ben Nevis, a volcano of the newer Palaeozoic period, much of the same date as Dartmoor, we have resting on the basal mass of coarse-grained porphyritic granite, and graduating thence, a fine-grained granite, graduating into felsite, which in turn sends veins into the fine-grained granite, and is surmounted by felstone lavas and volcanic agglomerates alternating; the whole existing upper series being comprised in an upward range of 2000 feet only.

The preservation of these volcanic rocks is quite exceptional at Ben Nevis and at Glencoe, and the district generally is as free from them as Dartmoor. But if we have no beds of felstone, we have what amounts to much the same thing — veins of felsitic rock — in the elvans; and I can speak from personal observation of the similarity between some of our felsites, or quartz-porphyries, and those of Glencoe.

The fact that our elvans [The indefiniteness of this local term, while disqualifying it for strict scientific reference, gives it a special value here, where strict definition is not required, and is indeed at this stage undesirable] are of later date than the consolidation of the granite which, in common with the associated rocks, they traverse, has long been recognized; but sufficient emphasis has not hitherto been laid upon the different physical conditions which the formation of these two classes of rocks, from what is practically the same magma, or mother-liquor, indicate. The elvans point incontestably to the long continuance of violent eruptive action under another stage of environments than those attending the formation of the granite. Some of them run for miles as dykes of unknown depth, and it is idle to assume that the forces producing their intrusion expended themselves underground, and that all upward movement stopped short of the surface in the more prominent examples. They are essentially illustrations of volcanic as distinct from plutonic activity, and while not in themselves true lava, are the next thing to it, and readily graduate into it. [Since this lecture was delivered, a paper by the writer on the "Elvans and Volcanic Rocks of Dartmoor" has been read before the Geological Society.]

These elvans demand closer study than they have had, and some of them illustrate the wide range of rock varieties produced from one original magma in a very remarkable manner. The Grenofen elvan, which at the Grenofen quarry is rather a syenitic-granite with a little interstitial felsitic matter than an elvan, is cut in the tunnel near Shillamill on the new line from Tavistock, and might there be regarded as an ordinary loose-textured granite — a fact easily accounted for by the greater depth of consolidation. Still further west, on Morwell Down, at a greater elevation, it has a more distinctive felsitic type, and presents a semi-vitreous compact ground -mass, in which quartz, felspar, and mica are porphyritically developed. The Roborough Down elvan on the Down itself has generally a granular-felsitic base, with pyramidal crystals of quartz, and hollows from which similar crystals have disappeared. But in the valley at Milton and on to Lophill it displays a much wider range. One variety has a compact granular-felsitic base, thickly studded with well-formed porphyritic crystals of quartz and felspar — much nearer the granitic type. Another has a semi-vitreous quartzose base, with porphyritic felspars and a quantity of black mica. Yet another is so even grained and granular that the untrained observer would take it for a sandstone. But the most remarkable illustration of the protean characters an elvan may assume within a short distance is supplied by the dyke cut through on the new Tavistock line near Shillamill. The variation here in breadth is so well marked that examples taken within a few feet of each other might be supposed to come from as many different dykes. The centre is porphyritic, much like the Grenofen, and this graduates into more even-grained and felspathic varieties on each side, while the outer portions are largely quartzose. We have the passage from all but typical granite into syenitic quartz-porphyry within a few yards, and there is every reason to believe that this, with similar elvans, passes into true granite in depth. [The frequent passage of granite into veins of pegmatite is worth noting in this connection. Many of the elvans are really micro-pegmatites, and differ from these veins only in the smaller size of the quartz and felspar crystals, between which and indeterminable felsitic matter there is every stage of gradation.]

Here and there in *débris* of Dartmoor origin, both on and off the Moor, are found fragments of felstone of a more or less rhyolitic character, remnants of genuine felsitic lava streams. We do not find them in situ like the granites and elvans, but there they lie — relics of rocks that could not have consolidated in depth and under pressure, and which must have had a surface origin.

The best example of these in my possession is from the neighbourhood of Lee Moor — a grey compact felstone, partially banded, with well-marked fluidal structure, and enclosing fragments of quartz and felspar, and of igneous rock, apparently of andesitic type, closely resembling some in the volcanic grit from Cattedown, to be described hereafter.

We find similar indications in the ancient detritus preserved in the Triassic conglomerate. While granites are few, elvans abound, and rhyolites (using that term in a wide general sense) are fairly prominent — precisely what we should expect to result from an early stage of denudation, when the rocks dealt with were generally of the middle and surface types, and the area of granite exposed was comparatively small. The Teignmouth conglomerate has yielded trachytic rock with large vesicles elongated in the direction of flow, more ordinary rhyolites, perlitic felsite, vesicular felsite, mica-andesite, and a wide range of elvans — granular, compact, and porphyritic — some identical in character with varieties occurring on the Moor *in situ* now.

It is further noteworthy that the great bulk of the granitoid pebbles found on the beaches of the south coast of Devon are felsites, or elvans. Making every allowance for the frequently superior lasting powers of compact over granular rocks, we see here also that the felstones must once have been far more abundant in the moorland area than now. I have noted this at Slapton, near the mouth of the Erme, and elsewhere; and a number of granitoid pebbles, collected by my son at Grey Lake Cove, outside the mouth of the Yealm, proved to be all more or less felsitic. The modern river beds of the Moor present very different characteristics; yet the ancient detrital deposits in the bottoms are often as markedly elvanitic, telling the same tale as the beaches. But the most interesting facts under this head have yet to be noted. The fortunate discovery by Mr. E. Burnard of a very ancient detritus at Cattedown, clearly in its main features of Dartmoor origin (but so old that it carries us back to a time when Cretaceous and Liassic rocks still existed on the southern flanks of the moorland region, within the watershed of the Tavy and the Plym), has yielded examples of volcanic rocks hitherto unknown in this county. There are two varieties of andesite, which Professor Bonney says closely resemble those of the Andes; and a volcanic grit, which he regards as one of the most remarkable rocks he has ever seen, and which he has very kindly described as follows:

“The rock is composed of more or less rounded fragments, cemented by a little ‘paste’ which is probably quartz, sometimes clear and chalcedonic, sometimes crowded with dust-like articles. Some of the fragments are felspar, fairly irregular in outline, in part at least plagioclase. One or two may be quartz; one or two are a kind of viridite, probably replacing a pyroxenic mineral; and one small grain resembles epidote. The rock fragments are all, so far as I can see, of igneous origin. Some are fairly clear, some a rich brown colour, some almost black with opacite; some are homogeneous, except for a little opacite and some belonites or trichites of a dark grey colour, which often are grouped in more or less dendritic forms or bundles like rootlets. A few of these grains are still isotropic, but most of those which are transparent exhibit devitrification structure. Small spherulites, showing the black cross with the two nicols, are rather common; one fragment seems part of a large spherulite. Other fragments show flow structure; one is perlitic. Clearly several varieties of rock are present, but I think the majority may be referred to andesites, some of which may not be far removed from basalt; others may have a tolerably high percentage of silica. I think the materials have undergone attrition, and have been deposited by water, but believe they have been obtained by the denudation of volcanic cones.”

It is very remarkable that this testimony to the existence of local acidic rocks of the volcanic series should have come to light while this lecture was in hand; but in all probability there is more behind. Still, the peak of Dartmoor disappeared so very long ago that the absence of all traces would have been less surprising than their preservation, even in this meagre though unmistakable form.

An attempt to reconstruct the Dartmoor volcano must needs be largely hypothetical; but we can reach sufficiently accurate results by applying conclusions derived from a study of other volcanic piles — ancient and modern. What we commonly find is a central cone, with the sides rising at angles of about thirty degrees, in the midst of a lower elevation formed by slopes of small gradients, six to ten degrees, extending a considerable distance. Hence there are two ways of estimating the size of a volcanic mountain. The igneous base from which the cone of Etna rises is forty miles in diameter; but the mountain proper, as distinct from the lava-covered plains, is some ten miles only. Though truncated, the height of Etna is 10,834 feet. Professor Judd [*Quar, Jour. Geol. Soc*. xxx. 259] assigned the Tertiary volcano of Mull a basal diameter of thirteen or fourteen miles; and on the analogy of Etna, gave it a height of 14,500 feet.

If we are to treat Dartmoor as a single mountain, we cannot reckon an average basal diameter of less than sixteen miles; with a circumference of fifty, against the forty of Mull and the thirty of Etna;

and from this we might fairly infer a total height of 18,000 feet, or three and a half miles.

If we are to regard the two elevated sections of the Moor as representing the degradation of a twinned peak we should not reach so high; but the conclusion that these higher regions of the present day indicate the original contour involves the assumption that denudation had proceeded on tolerably average rates over the whole tract; whereas we know that denudation has been more active on the south, since not only is the elevation less, but Devonian rocks are exposed, in which the work of alteration is greater, indicating greater heat and depth, while the more irregular boundaries suggest a nearer approximation to the base of the eruption. Existing denuding agencies are most powerful where the Moor is highest. Still, the transverse trends by Fur Tor and Fox Tor may give some indication of the basal outlines of a crater.

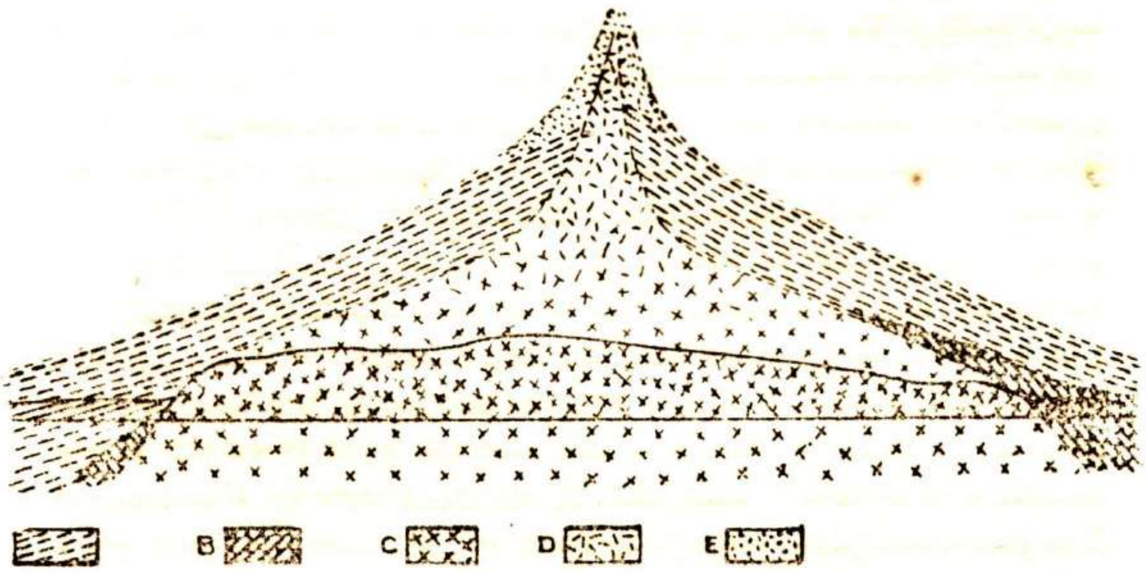
But we can enquire in other directions. We have seen that there is a fairly gradual rise from the outskirts of the granite. This varies in different parts of the Moor, but in the main approximates the six to ten degrees already cited as that of the exterior slopes of volcanoes, until we reach the 1500 feet range. If we take that area contour as representing the base of the central pile or ridge, which would describe an irregular oval some seven and a half miles east to west by fifteen north to south, a slope of thirty degrees on the shorter axis would give a total height of nearly three miles.

To treat the dip of the granite under the marginal rocks as the general slope would imply a regularity of elevation contrary to experience, and involve a theoretical height of at least four and a half miles.

Upon the whole, therefore, I think we may fairly put the height of the central portion of the Dartmoor volcano at three and a half miles, or 18,000 feet. This would involve the disappearance at the peak of more than three miles, or 16,000 feet.

No doubt these are large figures, but they are not by any means exceptional; and the removal of enormous masses of superincumbent rock has to be faced in any event, in order that the granite should be exposed at all. The active presence of a volcano really lessens the amount of work left to be done by the ordinary process of denudation.

Mull is a Tertiary volcano — quite an infant of days as compared with Dartmoor — and its highest point is but 3172 feet.




Diagrammatic Reconstruction of Dartmoor.

It must be understood that this sketch is diagrammatic and has no pretensions to scale, and that it is mainly suggestive and purposely made as simple in its conditions as possible. All below the horizontal line, which represents datum, is purely hypothetical; and all above the curved line, which indicates generally the present surface contour of the Moor and bordering rocks from north to south. This superstructure has been removed.

A represents Carboniferous rocks; B, Devonian; C, Granite; D, Felsite; E, Volcanic Material and Ejectamenta. The wedge-like intrusion of the granite has tilted and broken through the upper or Carboniferous rocks, and has thrust as well as heaved the lower or Devonian.

A few moments' consideration will show that if Dartmoor had not some such magnitude as here assigned, it could never have sustained the enormous wear and tear to which it has been exposed. Not a shower that falls or wind that blows upon it but wastes it somewhat; and when we reflect that such degradation has been going on not merely for thousands, but for millions of years, and in earlier days at a much more rapid rate than now, what is left can only be a wreck of what must have been.

The Mississippi is estimated to carry into the sea every year a quantity of sediment equivalent to the lowering of its whole drainage basin by the six-thousandth part of a foot of rock, at which rate the entire mass of North America would be reduced to the sea-level in four and a half millions of years.

Our Dartmoor streams with their rapid fall do proportionately much higher work; and that their volume and activity were much greater once than now, let the great gorges at Fingle, Holne, the Dewerstone, and Tavy Cleave attest. However the rivers may have been helped, to imagine that these ravines were worn by such streams as now occupy them is to assign to our latest geological epoch an antiquity perfectly unconceivable.

Still there are times when even these modern rivers develop a remarkable amount of energy. We may see granite pebbles, two and three pounds in weight, ten or a dozen miles down their
courses from the nearest point of origin; and the old beds frequently contain large boulders far more remote. Granite pebbles were discovered on the bed rock of the Laira in sinking for the new Laira Bridge; huge boulders beneath 75 feet of silt at the mouth of the Tavy; and Mr. T. M. Hall records them in the Taw, at Taddiport, twenty to twenty-five miles from a possible source.

A good deal of this rock sculpture may indeed be due to ice action.

“It is no more possible,” recently wrote Professor Prestwich, “to judge of the rate of denudation during the Glacial period by the river and ice action of the present day than it is of the rate of flow of Greenland ice by modern Alpine experience. The enormous pressure and wear of ice 2000 to 6000 feet thick in contracted valley channels . . . the powerful disintegrating effects of extreme cold on rocks, the annual action of ground ice in rivers, and of the sweeping and devastating floods resulting from the melting of the winter’s snow and surplus ice, combine to produce results of which it is impossible to judge by the moderate work of these temperate latitudes.” [*Geology,* ii. 553-4].

The more severe, however, the degrading influences to which Dartmoor has been exposed, the more important must have been its mass, by comparison with that which remains. We are again and again forced back upon our hypothesis as an a priori necessity, for I do not see how any local elevation of the height required could have been other than volcanic.

I do not know a better description of the operation of weathering upon granite rocks than that of Dr. Geikie. He is speaking of Lochnagar, but in its degree the passage equally applies to Dartmoor.[ *Scenery of Scotland,* pp. 39, 40].

“Granite ... is remarkable for the perfection of its jointing, and generally for its toughness. It may crumble away on the surface, but otherwise may remain coherent and durable, though there are some varieties that decay far down into their mass. Its numerous joints, however, afford full scope for the action of frost. On lofty mountain crests, accordingly, granite frequently presents a most impressive array of splintered crags. [Our tors have a more mural character, caused by the horizontal and stratiform jointing, [Hence what have been taken for artificial benches and tables on Crockern Tor] perhaps due in part to the outward slip of the superincumbent rocks.] Pinnacles and buttresses of the most varied forms and dimensions rise along the face of the precipices. Vast rifts, descending for several hundred feet, show where the joints have most easily opened, and naked vertical walls mark where the ice wedges, driven home by the winters of centuries, have at last detached huge slices from the face of the cliffs. . . . Inch by inch the vertical joints are . . . opened further into the face of the cliff. Along the edge one can, as it were, watch all the stages of the process, from the fine rift, just starting like a crack in a window-pane, up to the loosened pillar, which now stands gaunt and alone in front, and awaits the fate that is eventually to hurl it into the gulf below. Far down ... we can see the grey slopes cumbered with *débris* . . . avalanches of blocks . . . which in the course of ages have been wedged off from the cliffs and are now travelling slowly to the plains, still however a prey to frost and rain, sun and storm, and slowly breaking up into loose fragments as they descend" — the clitters of our tors.

Then there are the milder and more constant influences of aerial and aqueous action combined :

"After weeks of dry weather everything looks baked and dusty. The soil crumbles into powder at a touch. Each fitful gust of wind raises a cloud of dust from the roads, and blows away the sand that has been loosened on the surface of bare rocks. But the sky darkens, and at length rain descends. In a few minutes every channel on the roadways, every gully on the slopes, every runnel and watercourse, is the track of a muddy torrent, which sweeps down into the nearest brook. The brooks, swollen from bank to brae by the sudden descent of such innumerable tributaries, rush along laden with the fine particles of sand and disintegrated rock, which they bear into the main stream of their drainage basin. And the rivers, dark with all this accumulated mud, sweep it downwards into the nearest lake or away out to sea." [GEIKIE, *op. cit.* pp. 20-1].

Before the formation of our present coast line; before the days of our submerged forests, raised beaches, and bone caves; before our Glacial epoch; before the Pliocene and Miocene and Eocene deposits originated; before the Chalk was formed, and the Oolitic building stones were laid down, and huge marine monsters thronged the Liassic seas — long before all these great stages in the world's physical history, the destruction of the great mountain, of which Dartmoor is but the stump, began.

No doubt there were pauses in the operation. No doubt at times it was more rapid and again more slow. No doubt the sea has borne its part as well as wind and rain and ice and snow. [Rain-wash has played a more prominent part in the modelling of the surface contours of the outer portions of the Moor than is commonly recognised. This is well seen at Blacket, where the Plymouth Lunatic Asylum is being built, on the flank of Ugborough Beacon. The granite in the hill immediately at the back of the asylum is moderately fine-grained, abounding in black mica, and porphyritic. Towards the surface it becomes loose textured and crumbly, and is seen (in a quarry section) to pass upwards into an incoherent mass of granitic sand, which apparently continues until the peaty subsoil is reached. Further investigation shows, however, that the upper part of this sandy stratum is distinguished from the lower by colour-bands indicating a quasi-stratification generally dipping with the hill, but with irregularities which suggest the filling up of hollows; and that this stratified material contains large angular fragments of rock. These are absent from the loose stuff below, in which we recognise disintegrated granite pure and simple. All is granite sand throughout; but while the lower portion is in situ, the upper has been gradually washed down the hill, and collected in gullies or hollows — or, where the conditions are favourable, in sheets — to a thickness ranging up to four feet — the solid rock being denuded on the higher slopes of the tor to a similar extent. The quarry where these observations were made is close to the junction of granite and hornblendic slate; and at one point this granitic rain-wash is seen to overlie a subsoil of angular fragments of slate in clay formed by the breaking up of the outcrop of the schistose rocks, and itself showing traces of " hill creep." In more favourable localities the results of such subserial denudation may be very important, so that we need not always call in the agency of constant streams or ice-caps to account for extensive detrital deposits at hill bottoms].

But that the rocks of Dartmoor were exposed and broken down to form part of the materials of the beaches of the ancient Triassic sea of Devon, which once stretched at least from Sidmouth to Plymouth, but have been themselves all but wholly swept away to the westward of Torbay, is as certain as that these rocks are as steadily, if less quickly, wasted now. Nor are we without materials for filling up part at least of the interval. The Miocene lake of Bovey Tracey, twelve square miles in area, is a mass of Dartmoor *débris*[9] brought down by the Teign and its tributaries; and if the other rivers of the Moor then did a proportionate amount of work, we can gain some idea of the enormous quantity of matter removed from its face during that period alone — a mass equivalent at least to hundreds of feet in thickness over the whole of the central region. Nearer to us we have the scraping and scooping of the Glacial age. The evidence for this indeed is inferential rather than direct; but I do not myself see how, apart from ice action, we are to account for some of the expanding hollows and filled-up lakelets along our river valleys, or for sundry of the deposits of clay and subangular stones which not only occupy bottom lands, but coat in so many places the slopes of the granite hills [So with the granite boulders frequently carried forward a considerable distance over the slates. They are not only remarkable testimonies to the strength of the denuding forces, but of the existence of heights long planed away. In like manner the occurrence of non-granitic *débris* within the granite area recalls the days when the covering rocks stretched up the slopes of the Moorland region far beyond their present limits. The fragmental deposits of the Moor are full of interest] and are frequently cut through in miniature ravines by the brawling little torrents of sudden and heavy rainfall — all indicating an amount of denudation of which the material left behind is a very inadequate gauge.

And then we have the remains of old river gravels at high levels along the courses of various Dartmoor streams, with such allied proofs of former waste as we find in the pebble and sand and clay beds of the Hoe (distinctly of Dartmoor origin); in such isolated patches of granitic gravel — the poor remnants of wide sheets — as that of Petrockstow, twelve miles from the nearest point of the Moor; and in the granite pebbles of the Haldon gravel, 800 feet above the sea — each and all themselves but denuded vestiges of the ancient demolition which gave them birth.

The Lundy granite is probably of the same age as the Dartmoor, and Professor Prestwich [*Geology*, i. 100] has shown that ten miles of rock which formerly connected that island with the main must have been worn away previous to Pleistocene times. I do not take this as indicating the rate of Dartmoor denudation, for marine waste is one thing, and subserial is another; but it enters into our calculation thus far : it shows that prior to the inauguration of the existing relations of sea and land Dartmoor must have been exposed to denuding influences for a period long enough to enable the sea to do this work.

The volcano of Mull dates only from early Tertiary times — the Eocene; but it has been reduced from 14,500 feet to 3172. The volcano of Dartmoor has probably been reduced from 18,000 feet to 2000; but the additional work bears no calculable relation to the additional time given by its higher antiquity.