BRITISH TERTIARY VOLCANOES.[1]

DURING the last twenty-seven years, the study of the volcanic rocks of the British Isles has been a constant and favourite pursuit with Dr. A. Geikie. It is now seventeen years since he read before the Geological Society of London the most important of the numerous memoirs which he had from time to time up to that date put forth on this subject. It was the well-known paper on the Island of Eigg, and was intended to be the first of a series of papers descriptive of localities where the characteristic features of the British volcanic rocks are well displayed. But man proposes: for the promised continuation of the series geologists have waited long and anxiously, no further instalments having till now appeared. The delay however, though trying while it lasted, has been productive of good result in the end; for we have now the long-wished-for consummation, not scattered through a long string of isolated papers, but in one connected whole. Dr. Geikie has garnered his harvest, and has summed up the results of the labours of more than a quarter of a century in a memoir which may fairly be looked upon as one of the most important of the contributions to the geological history of Britain which have seen the light since the days of William Smith.

And it gives to this elaborate communication a further importance that it is controversial as well as descriptive. In January 1874, Prof. J. W. Judd read before the Geological Society a paper "On the Ancient Volcanoes of the Highlands." It is a singularly fascinating production; its story is concisely and graphically told, and hangs well together; and I shall not easily forget the interest with which I read it for the first time, and which frequent reference to it subsequently has not abated. But Dr. Geikie's study of the subject has led him to conclusions directly in the teeth of two at least of the most important of those arrived at by Prof. Judd. Both authorities are agreed that the great basaltic plateaus of the Western Islands of Scotland and the North-East of Ireland are formed of sheets of sub-aërial lava piled one above another, the products of a long series of eruptions. Prof. Judd holds that the lavas were poured out from great central volcanoes of the type of Etna and Vesuvius, and he has endeavoured to fix the sites, and form an approximate estimate of the size of these volcanoes. Dr. Geikie is unable to find evidence for the former existence of central volcanic piles, and he believes that the lavas were emitted from fissures and numerous scattered vents of inconsiderable size. Again Prof. Judd thought he had established a threefold order of events during the period of volcanic activity. The first series of eruptions was marked by the discharge of lavas belonging to the acid class. Then came an abatement or cessation of the volcanic energy, and during a quiescent interval the cones and products of this period were largely denuded. Volcanic activity was resumed during the second period, but its products were of the basic class, and now form the basaltic plateaus. During the third period the volcanic energy was dwindling down, and had so far spent itself that it was equal to the production only of sporadic cones of small size, which are paralleled with the "Puys" of Auvergne.

And Prof. Judd further maintained that the great intrusive masses of granite and gabbro, which now form some of the boldest heights of the district, are the hardened contents of the reservoirs which fed the volcanoes of the first two periods. They had originally been buried beneath the cones that were heaped over them by the eruptions, and have been bared by denudation. The granites belong to the volcanoes of the first period, and Prof. Judd maintained that a gradual passage could be traced from them into sub-aërial lavas of acid composition that were emitted during that period. Similarly the gabbros were relegated to the second period, and pass gradually into its basic lavas. Dr. Geikie on the other hand brings an overwhelming mass of evidence to show that the intrusive masses of granite and other acid rocks are younger than the plateau-basalts. He mentions nothing that can possibly correspond with the sub-aërial sheets of acid lava which Prof. Judd states were poured out during his first period; he shows, indeed, that the one solitary known instance of a true superficial stream of acid lava is that of the Scuir of Eigg, which is unquestionably considerably younger than the plateau-basalts.

Though Dr. Geikie does not express a positive opinion on the subject, it seems to me that there is nothing to forbid our looking upon some at least of the smaller vents which he describes as Puys as belonging to Prof. Judd's third period. The vent, for instance, at Faskadale (p. 106) must be later than the great acid protrusions.

It is a serious matter for one whose acquaintance with the field of dispute is but slight to endeavour to hold the balance fairly and evenly between the conflicting views of two such eminent authorities, who have both made a study of the ground itself. Nor is the delicacy of the task diminished by the fact that the disputants have been for many years among the writer's most valued brethren of the hammer, and that to their teaching and example he owes more than can be put into words. This circumstance has fortunately however a certain advantage, for in attempting to decide between the conclusions of two equally valued and equally respected friends he will at least be free from any suspicion of partiality.

Some general considerations may be noticed before coming to detailed criticism. Dr. Geikie has known the ground ever since he was a boy: he has roamed over it again and again; he has had opportunities without number of reviewing, and in some cases of correcting, his first impressions. He has had, to some extent, the assistance and co-operation of his colleagues on the Geological Survey, and has had free access to all the details of their elaborate surveys. I believe I am right in saying that Prof. Judd was able to devote to his examination of the district the summer months of not more than two or three years. Without in the least implying that his observations were hasty, it must be clear that his opportunities for going into detail were very inferior to those of Dr. Geikie.

Further I am bound to confess that, though I was fairly carried away by the charm of Prof. Judd's paper, he did not succeed in bringing conviction to my mind to the same extent as the perusal of Dr. Geikie's memoir has done. His story had on the face of it an air of reality, but his statements were broad and general, and I could not help wishing that he had interpolated among his sweeping conclusions some details of the evidence on which those conclusions were based. I should have been sorry to miss the bold and strikingly graphic sections of his folding-plate; but I should have liked to have had, in the text, woodcuts, such as those which crowd Dr. Geikie's memoir throughout, of the actual exposures out of which those generalized representations had been constructed. It is easy to imagine good reasons for the omission of these details in Prof. Judd's paper, but all those who have made it a business of their life to cultivate a healthy tone of scepticism must have regretted their absence. No such charge can be brought against Dr. Geikie; more than sixty woodcuts, most of them representing actual sections, give ample opportunity for deciding for or against the sufficiency of his evidence.

We may now examine more in detail the main points of difference between the two readings; and, first of all, as to the vents from which the lava-flows were discharged.

[1] "The History of Volcanic Action during the Tertiary Period in the British Isles." By Archibald Geikie, LL.D., F.R.S., Director-General of the Geological Survey of the United Kingdom. Transactions of the Royal Society of Edinburgh, vol. xxxv., Part 2. (Edinburgh: R. Grant and Son, 1888.)

Dr. Geikie relies on the absence of any obvious vent from which the molten matter flowed. But surely the huge orifice of Strath, in Skye, was large enough to have served such a purpose. True there are appearances which seem to show that some of the plateau-basalts once extended right across the mouth of this funnel, but Dr. Geikie himself admits with perfect candour that the relation of this neck to the plateau-basalts does not admit of satisfactory treatment, owing to the destruction of the evidence by later intrusion of masses of granophyre in its immediate neighbourhood, and likewise to enormous denudation. I see nothing unlikely in the supposition that, from this enormous funnel, basaltic lava may have flowed in a manner to be shortly described; that the chimney became afterwards choked by agglomerate, too coarse to be spread far over the neighbourhood; and that, above all, basalt emitted from some new adjoining vent may have afterwards extended itself. Dr. Geikie further lays stress on the uniformity of the plateau-basalts in petrographical character, thickness, and persistent flatness, and on the almost total absence of interbedded fragmental deposits; and he maintains that these distinctive characters lead us to seek the modern analogues of the volcanic phenomena, not in large central cones like Vesuvius and Etna, but in the vast basalt-fields of Western America, where the lavas have issued from innumerable minor, and sometimes almost imperceptible, vents. With the first part of this opinion everyone must, I think, side with Dr. Geikie; but the method of formation which he advocates is by no means the only one possible or likely. Ever since I read Captain Dutton's account of the Hawaiian volcanoes,[1] it has seemed to me that it is to them we must look, if we are to understand the machinery by which great lava-plateaus have been produced. Speaking of the enormous flow which issued from Mauna Loa in 1855, he says: "As I looked over this vast expanse of lava, I was forcibly reminded of the great volcanic fields of the western portion of the United States, where the eruptions are of such colossal proportions that they have received the name of massive eruptions." After noticing Richthofen's view that these lavas had been poured forth through great fissures, and stating that the volcanic rocks of Western America, well as they are laid open to view, would be considered relatively obscure by one who has had an opportunity of inspecting the recent lavas of Mauna Loa, he goes on thus:—"I am by no means certain that Richthofen's conclusions are wrong. But here is a lava-flow, the dimensions of which fully rival some of the grand Pliocene outbreaks of the West, which demonstrably differs in no material respect, excepting in grandeur, from the much smaller eruptions of normal volcanoes" (*loc. cit.*, p. 156). But the differences between the modes of action of volcanoes of the Vesuvian and the Hawaiian types, whether we designate them as material or not, are striking enough, and they are just those which seem to have accompanied the discharge of the plateau-basalts we are now engaged with. Captain Dutton has well described them. "Mauna Loa and Kilauea," he says, "are in many important respects abnormal volcanoes. Most notable is the singularly quiet character of their eruptions. Rarely are these portentous events attended by any of that extremely explosive action which is characteristic of nearly all other volcanoes. The lava wells forth like water from a hot, bubbling spring; but so mild are the explosive forces that the observer may stand to the windward of the grandest eruption, and so near the source that the heat will make the face tingle, yet without danger. A direct consequence of this comparatively mild and gentle behaviour is the absence of those fragmental products which form so large a portion of the products of other volcanoes" (*loc. cit.*, pp. 84, 85). Fissure-eruptions are, to say the least, hypothetical; but here we have a way in which huge lava-fields, of the type of basaltic plateaus, are being produced before our eyes. The universally adopted canons of geological reasoning leave us no alternative as to which of the two explanations we should favour.

[1] United States Geological Survey, Fourth Annual Report, 1882–83.

But if the view just expressed be correct, we ought certainly to find some indications left, even among these ruined volcanoes, of the position of the vents from which the lavas issued. And here I cannot help going a long way with Prof. Judd in thinking that the great eruptive bosses of gabbro in Skye, Rum, Ardnamurchan, and Mull, are plugs filling in some of the main orifices of discharge. Prof. Geikie lays stress on the facts that the gabbros send off intrusive sheets into the plateau-basalts, and even overlie them. But this proves merely that the plugs which now fill the vents are later than the plateau-basalts: the vents themselves may be older. There must be some reason why the great intrusive bosses cluster thickly round a few centres, and are elsewhere conspicuous by their absence; and the following seems not unlikely. It was at these spots that vents were opened early in the volcanic period; from them there flowed, in the mild undemonstrative fashion of the Hawaiian volcanoes, the lavas which now build up the basaltic plateaus; as sheet was laid down upon sheet, the chimney gradually rose in height; and when, for this reason, and perhaps also on account of a temporary abatement of volcanic energy, the lava was no longer able to flow out at the top, it solidified in the vent, and, being under pressure, hardened into gabbro instead of dolerite. And indeed, though Dr. Geikie speaks of the eruption of the gabbro bosses as an event sufficiently marked and independent to characterize a distinct epoch in the volcanic period, he at the same time expresses himself in a way that shows he shares in the view I have just put forward, for he says: "We must remember, however, that the gabbro in many places found its readiest ascent in vents belonging to the plateau-period."

So far then the views of Dr. Geikie and Prof. Judd may admit of modifications which render them less conflicting than they seem at first sight. But there is one point on which reconciliation is impossible, viz. the nature and relative date of the eruptions of acid composition. Prof. Judd recognizes not only acid eruptions of the massive type—granites and their allies—but he speaks of thick bodies of felstones, disposed in regular sheets and of amygdaloidal structure, which alternate with beds of scoriæ, lapilli, and ashes, that lie upon the skirts of the central bosses of granite. These he believes to be the remnants of a volcano formed mainly of acid lavas, which was piled up and largely ruined by denudation before the discharge of the plateau-basalts began. The existence of the granite bosses admits of no doubt; but Dr. Geikie has depicted numerous sections which leave no doubt that these rocks intrude into the basalts and gabbros, and are therefore of later date than them. Now that all these details are before us, the question of relative age can admit of only one answer, but it is evidently a point on which observers, who had not opportunities of entering minutely into details, were apt to go wrong. Both Principal J. D. Forbes and Prof. Zirkel seem to have come to the same conclusion as Prof. Judd, and Dr. Geikie has supplied the explanation. "That there should ever have been any doubt," he says, "about the relations of the two eruptive masses is possibly explicable by the facility with which their junction can be observed. Their contrasts of form and colour make their boundary over crag and ridge so clear that geologists do not seem to have taken the trouble to follow it out in detail. And as the pale rock (granophyre or granite) underlies the dark (gabbro), they have assumed this infraposition to mark its earlier appearance." All this is graphically brought out in Fig. 43 of Dr. Geikie's memoir, which is reproduced here (Fig. 1). Anyone trusting to surface-feature

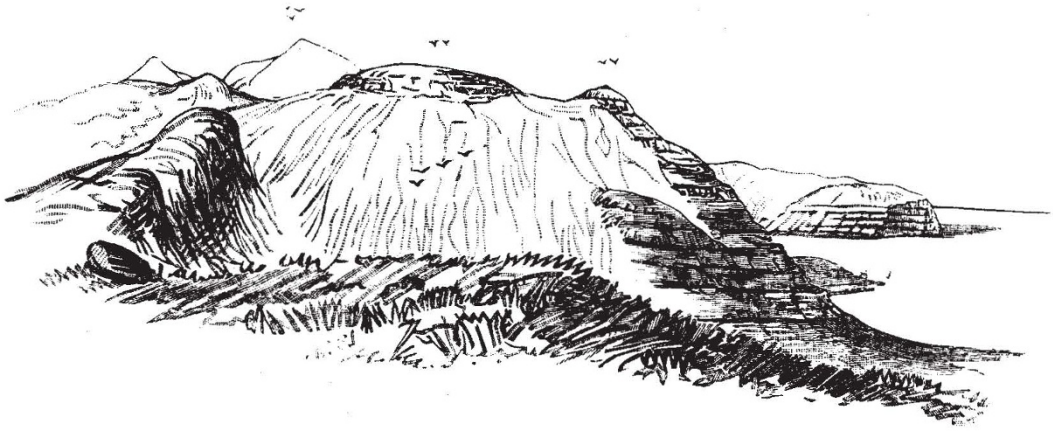

FIG. 1.—View of the hills on the south side of the head of Loch na Keal, showing the junction of the granophyre and the bedded basalts. One bird, the bedded basalts of the Gribon plateau; two birds, the bedded dolerites and basalts of Beinn a' Chraig adhering to the northern slope and capping the hill; three birds, summit of Ben More, with A'Chioch to the left and the top of Beinn Fhada appearing in the middle distance between them; four birds, the granophyre slopes of Beinn a' Chraig with the great dyke-like mass of felsite on the left.

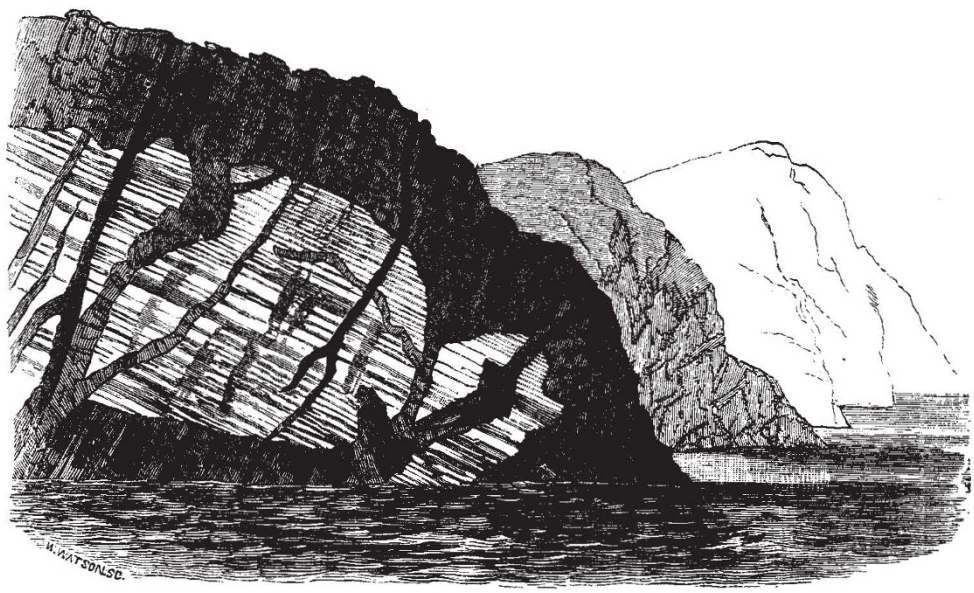

FIG. 2.—Basic veins traversing Secondary Limestone and Sandstone on the coast cliffs, Ardnamurchan.

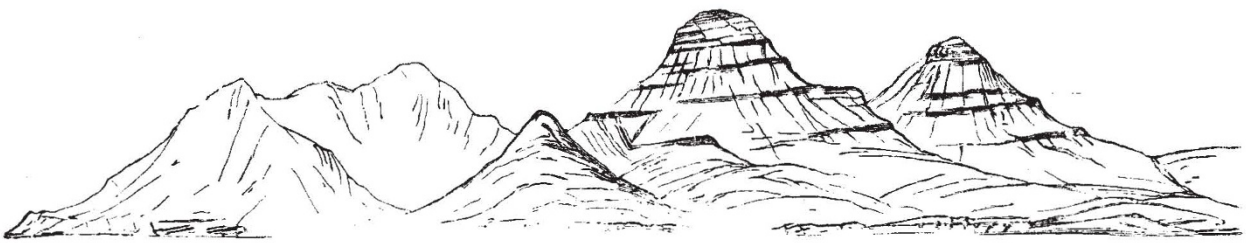

FIG. 3.—Outline of the hills of the Island of Rum, sketched from near the Isle of Eigg.

might well fancy that the basalts marked by two birds lay upon, and were newer than, the granophyre marked with four. Let us all take warning thereby.

But it is time to leave this perilous ground, and come to matters on which there can scarcely be difference of opinion. If it were desired to direct a student to a paper from which he could gather a clear and comprehensive view of the manifold forms under which volcanic products present themselves, not treated in the abstract but brought home to him by concrete examples, none could be found better fitted for the purpose than the memoir before us. And if a beginner would learn a lesson of the way in which a geologist goes to work when he wishes to unravel and interpret a complex group of geological documents, he will here find both precept and example. A point or two may be specially noticed. The enormous area which is seamed across by dykes, presumably of the same date, enables us to realize the importance of underground volcanic action, which is necessarily hidden from view in the case of volcanoes now in activity. I first learned this lesson while traversing a similar district, fully three times as large as that treated of by Dr. Geikie, in South Africa In connection with the striking parallelism of a large number of the dykes, reference is fittingly made to the classical paper of Mr. Hopkins, which he used so pathetically to complain had proved of interest neither to geologists nor mathematicians. But the mention of this paper again makes me lapse into criticism. When I first, many years ago, made acquaintance with Mr. Hopkins's investigations, two of his conclusions struck me as on the face of them so improbable physically, that, though I felt the presumption of the notion, I could not help suspecting some hitch in his analysis. One such oversight, so obvious that I can now hardly believe it to have been made by so first-rate a mathematician, I then detected. The other I have no doubt will reveal itself to careful inquiry. But from a hasty reperusal of the paper I do not think that either of these slips, supposing both to exist, affects the conclusions appealed to by Dr. Geikie; and the agreement, as far as they are concerned, between theory and observation is as complete as can be. The skill with which Dr. Geikie uses his pencil to bring out the geological features of a landscape is well known: that his right hand has not lost its cunning will be evident from the two illustrations here reproduced (Figs. 2 and 3).

Reference has been repeatedly made to the proofs of enormous denudation since Tertiary times which the volcanic rocks we are dealing with furnish in lavish abundance; it has not been so often noticed that denudation has during the same interval made its effects felt on harder and more intractable rocks. But dykes furnish proof of this in a way which I believe has not been made the subject of comment. "The evidence of this denudation," says our author, "is singularly striking in such districts as that of Loch Lomond, where the difference of level between the outcrops of the dykes on the crest of the ridges and the bottom of the valley exceeds 3000 feet. It is quite obvious that, had the deep hollow of Loch Lomond lain, as it now does, in the pathway of these dykes, the molten rock, instead of ascending to the summits of the hills, would have burst out on the floor of the valley. We are therefore forced to admit that a deep glen and lake basin have in great measure been hollowed out since the time of the dyke." A point this in favour of the "gutter-theory."

A. H. GREEN.

THE THEORY OF PLANETARY MOTION.[1]

IN the work the title of which is printed below, Dr. Otto Dziobek seeks to develop the theory of the motion of bodies subject to attraction according to Newton's law. The author, in his preface, draws attention to the objectionable practice of the majority of writers of the present day, of treating the subject so briefly that many students scarcely get beyond Kepler's laws in their knowledge of the theory of the solar system. He has therefore prepared a work which is intended not only as an introduction to the study of this branch of astronomy but especially for those desiring an acquaintance with the higher productions of the masters in this science.

The book is divided into three sections. The first begins with the assumption of Newton's law, and then treats of the motion of two bodies about their centre of gravity, giving the usual deductions relating to the motion of the centre of gravity, to the projections upon the three co-ordinate planes of the areas swept out by the radius-vector in a given time, and to the form of the orbit described. In determining Gauss's constant of attraction, k, the author says that the unit of length is the major axis of the earth's orbit (he doubtless means semi-axis, though the statement is repeated on the same page, and a like oversight occurs on pp. 11 and 16); and then with 1 : 354710 as the earth's mass and 365·2563835 mean solar days as the length of the sidereal year, k is found = 0·017209895. This is the value found by Gauss, and given in his "Theoria Motus." This constant has been incorporated in many tables, and any change in its value would be attended with considerable inconvenience. But since the time of Gauss more accurate values of the earth's mass and of the length of the sidereal year have been found, and consequently a more accurate value of k may be deduced. To avoid this inconvenience, the above value of k is retained, and with the new values of the earth's mass and the length of the sidereal year the unit of length is determined. This unit of length is slightly greater than the earth's mean distance from the sun, but differs from it by less than a unit of the eighth decimal.

A collection of formulæ giving the relations between the radius-vector, the mean, eccentric, and true anomalies, as in Gauss's "Theoria Motus," is added, together with the usual expansions in series of these quantities. The expressions for the expansion of the eccentric anomaly and of the radius-vector by means of Bessel's functions are also added.

We next come to the general treatment of the problem of the motion of any number of bodies projected in any manner in space, and subjected only to their mutual attractions. Here, considering n bodies, we have the usual deductions relating to the invariable plane of the system, and to the sum of the products of the mass of each body into the area described by its radius-vector. The author then proceeds to simplify the case by discussing the motion when $n = 3$, and thus the case of the celebrated problem of the three bodies. Of this the usual outline is given, together with certain special cases of the problem, the lines of the investigations of Lagrange and of Jacobi being chiefly followed. A brief historical outline of the problem, and of the chief investigations thereon from the time of Lagrange up to almost the present day, closes the first section of the work.

The second section of the book treats of the general properties of the integrals introduced in the consideration of the problem of n bodies. The investigations of Poisson and Lagrange are discussed, and the development by these writers of formulæ for the elements of the elliptic orbit of a planet is given. And here, on p. 98, we again note the oversight before referred to, viz. that of putting a = the major axis of the orbit instead of the semi-major axis. Of course such a proceeding if it were carried on throughout would have no effect upon the developments which are obtained, except on their symmetry, but the author, after mentioning that the quantity a represents the major axis, immediately proceeds to use the quantity with its usual signification, viz. the semi-major axis. The oversight occurs again on p. 112, and again in discussing the canonical constants for the elliptic motion of a planet, and again

[1] "Die mathematischen Theorien der Planeten-bewegungen." By Dr. Otto Dziobek. (Leipzig: Johann Ambrosius Barth, 1888.)