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1. NOTES *on some* RECENT SECTIONS *in the* MALVERN HILLS. By A. H. GREEN, Esq., M.A., F.R.S., V.P.G.S., Hon. Fellow of Caius College, Cambridge, and Professor of Geology in the University of Oxford. (Read November 7th, 1894.)

THE main mass of the Malvern Hills consists, as is well known, of crystalline schists and massive igneous rocks which we may with safety admit have an Archæan aspect. These have been largely studied; but at one spot at least there are rocks of a very different character, which have hitherto received scant attention. They occur on the eastern side of the Herefordshire Beacon. The summit-line of the ridge runs generally north and south, but here it takes a bend away to the west, and encloses an amphitheatre-like recess, in which stands a group of lower hills known as Tinker's Hill, Broad Down, and Hangman's Hill, that are composed of the rocks in question.

It will be convenient to give them a name, and they may be called shortly the 'Warren House Rocks,' after a farm in the recess.

These rocks have not been altogether overlooked by former observers. Prof. Phillips must have been aware of their existence, for in the Oxford Museum I have found a few specimens of them collected by him. He realizes, but does not lay stress upon the fact that they differ in character from the rocks of the greater part of the Malverns.¹

The area which these rocks cover is correctly delineated by Dr. Holl; he describes them as 'Altered Primordial Rocks and Post-primordial Trap.'²

Among the rocks analysed by the Rev. J. H. Timins are some belonging to this group.³

¹ Mem. Geol. Surv. vol. ii. (1848) pt. i. pp. 30, 31.

² Quart. Journ. Geol. Soc. vol. xxi. (1865) plate facing p. 72.

³ *Op. cit.* vol. xxiii. (1867) p. 352.

Mr. Rutley has described some rocks from this group.¹ He states in the latter paper that these rocks form 'a buttress faulted against the eastern flank of the Herefordshire Beacon' (p. 743); but he gives no evidence for the existence of the fault.

Recently a reservoir for supplying water to Great Malvern has been constructed in the valley between Tinker's Hill and Broad Down, and the excavations made in the course of this work have opened out the rocks in question and thrown some little additional light on their character and lie.

My attention was drawn to these cuttings by Prof. Hughes in 1892, and during the summer of that year I gave some time to a study of them and the surrounding country, with, I fear, slender results; but, as most of the sections are now covered up, it seemed worth while putting on record what they showed; and this must be my excuse for troubling the Society with a paper which is little more than a statement of facts, and leads but to meagre conclusions.²

The rocks are bedded. In the puddle-trench of the reservoir they strike about north, and are nearly on end. In the cutting for the diverted road along the south-western side of Tinker's Hill the strike is still northerly, but the dip comes down to 75°, and a little farther south-east is only 25°. Whether the same strike is maintained over the whole tract we are concerned with cannot be definitely asserted, for the great bulk of the rocks are very much alike, and no beds occur which have distinctive individuality enough to enable them to be traced with certainty across the open country. In some few cases my attempts at detailed mapping have been attended with qualified success; and, if my tentative identifications be correct, the general strike is north and south.

Of the rocks themselves it is impossible to speak with satisfaction. The great bulk of them are hard, closely grained, and splintery, such as could be conveniently grouped in the field under the vague term of 'felsites.' Of these some under the microscope have much that is rhyolitic about them, and are not improbably lavas, some perhaps devitrified glasses. Others are seen to be decidedly fragmental, and may well be tuffs. They are largely altered, so thickly veined with calcite in many cases that they effervesce freely with acids. This seems to have led some observers to call them limestones, but a little attention shows that in nearly all the effervescence is confined to the veins. Epidote in veins and disseminated through the rock is also common.

There are also dolerites, some of which are not unlike the felsitic rocks macroscopically, but are clearly characterized under the microscope. Whether these are flows or intrusive sheets is an open question; I rather incline to the opinion that they are intrusive, for, as will appear later on, they seem to be wedge-shaped masses and not continuous beds.

¹ Quart. Journ. Geol. Soc. vols. xliii. (1887) pp. 498, 499, & xliv. (1888) p. 740.

² I acknowledge, with many thanks, the assistance which I have received from my friends, Mr. Rutley and Mr. Teall, in my examination of the rocks dealt with in this paper.

A few details as to the distribution of the rocks may now be given.

Along the western boundary of the area there is a broad strip of ground occupied by dolerite. A specimen from Clutter's Cave has been figured and described by Mr. Rutley.¹ He says that the felspars are chiefly labradorite, in laths generally corroded and frequently bent; augite appears in irregular grains, few distinct crystals; ilmenite and white opaque matter, probably leucoxene, and pyrites in very minute specks occur; also a small vein of epidote. I have only to add that in my slide there are vesicular cavities filled with a zeolite-like mineral. For about 10 chains north and 20 chains south of the Cave all the rocks seen have a strong general resemblance to this one. They vary in grain and in the relative proportions of the component minerals, but they are sufficiently near one another to make it possible that they may all belong to the same mass.

Analyses xxxvi. to xxxviii. of Mr. Timins's paper give the composition of the rock at the Cave and rocks in its neighbourhood.

East of this dolerite there is a belt of ground over which many of the rocks have a fragmental aspect. In some slides angular chips of quartz and felspars are bedded in fine dust; others consist entirely of fine dust, but their fragmental character is fairly obvious. Rocks of this character, lying on the same strike, run from Broad Down on to Hangman's Hill; they are probably tuffs. On the south side of Hangman's Hill, 200 yards east of Hill Cottage, there is a very conspicuous crag. The rock from this is crowded with small grains of magnetite and slender laths of felspar. A very similar rock occurs about 100 yards to the north, in which a crystal or two of augite remain unaltered. These rocks resemble very closely the matrix of some of the lavas of Etna. No rock like this has been detected elsewhere in the area, a fact which suggests that it may be intrusive.

Going now eastward, we come on to another belt of dolerite, not differing essentially from the rock of Clutter's Cave. It was seen in the cuttings made for enlarging the reservoir on its northern bank, and a similar rock seemed to run along the same strike across Broad Down. It appeared to die out before reaching the valley between Broad Down and Hangman's Hill; and the rocks on the same strike south of that valley are of a totally different character.

The rocks that follow to the east are of rather a perplexing character, and many of them largely decomposed. A hard bed stood up towards the northern end of the puddle-trench, and a rock of the same character was seen on the same strike in the cutting for the pipe-track. It is a very problematical rock. There may be an isotropic base, but the doubly-refracting particles lie so thick that it is difficult to be sure of this. The doubly-refracting grains are small, have most of them no definite outlines, and polarize in dull grey tints. There is a strong rhyolitic aspect, and this is probably

¹ Quart. Journ. Geol. Soc. vol. xliii. (1887) p. 498, pl. xx. fig. 9, & pl. xxi. figs. 4, 5.

the character of the rock. Another band, somewhat coarser in grain, but otherwise similar to the last, I was able to trace from the south-western side of Tinker's Hill, across the valley, on to Broad Down. Many other rocks of a similar character, some banded and showing ill-defined fluxion-structure, occur along the same belt.

East of these a rock with fragmental texture occurs on the northern side of Broad Down, and a rock very similar in character crops out on the same strike on the southern side of that hill. I think that no one possessing a reasonable amount of caution would speak with certainty about the rocks of this belt; but the probability is that we have here a series consisting of alternations of rhyolitic lavas and tuffs. The exact localities of the specimens analysed by Mr. Timins cannot be fixed, but it is not unlikely that nos. xli. to l. belong to this belt. In it lies the rock in which Mr. Rutley believes that he detected perlitic structure.

A very singular rock belonging to the same belt was exposed in the cutting for the diverted road. The matrix may contain some isotropic matter, but it is thickly crowded with very minute doubly-refracting grains and hairs. Its peculiarity consists in the presence of a large number of ring-shaped patches, edged with a mineral that polarizes in brilliant colours, the centre of each ring being like the matrix, but rather darker in colour. This rock was analysed for me by Mr. R. Hornby (Queen's College, Oxford). As it was thickly veined with calcite the powder was first treated with cold dilute hydrochloric acid for 24 hours. The insoluble residue had the following composition:—

Silica	78.41
Iron and alumina	16.38
Magnesia	0.88
Lime	0.55
Alkalies, by difference	3.78

My friend Mr. Rutley has spent some time over this rock, but without coming to any definite conclusion as to the meaning of its peculiarity.

Next follows a belt of dolerite, which resembles the rock of Clutter's Cave. It was well shown in the cutting for the diverted road at the south-western end of Tinker's Hill, in a quarry on the opposite side of the valley, and in the cutting for the catchwater. It is traceable up to the summit of Broad Down, and indications of a similar bed on the same strike were seen on the southern slope of that hill. The bed seemed here to be thinner than on Tinker's Hill, and I could find no trace of it on the opposite side of the valley on Hangman's Hill. At one spot on Tinker's Hill Mr. H. D. Acland called my attention to parts of this bed which are vesicular and amygdaloidal.

East of the band of dolerite last described the rocks look, to the unaided eye, very much alike—hard, splintery, and felsitic in aspect. Those which I have examined under the microscope are some of them fragmental, while others have the rhyolitic character of the rocks to the west. Probably we have here a second belt of rhyolitic lavas and tuffs.

So far, then, as I dare have an opinion, I am inclined to think that we have here a group of bedded acid lavas and tuffs, crossed by three bands of dolerite.

The question arises whether these dolerites are flows or intrusive sheets. What little balance of evidence there is seems to me to be in favour of their being intrusive. Though they are fairly well marked in appearance and not difficult usually to distinguish from the felsites, I have not been able to trace them across the whole of the area; they show vesicular structure only very sparingly, and I have not recognized fluxion-structure in them.

One rock different from any yet noticed deserves mention. It was cut into at the north-western corner of the excavation for the filter-beds, and a rock exactly identical with it was noticed 100 yards south-west of Warren House. It is a dull-white granular rock, speckled with soft greenish needles and spots. Under the microscope the matrix is seen to consist of quartz-granules, decomposed felspathic matter, and grains of magnetite. In this lie long needles of a soft greenish decomposition-product, and large crystals of decomposed felspar, some of which are triclinic and some may be orthoclase. The line joining the two points where this rock was seen runs a little north of west. It is probably a dyke. Mr. Harker looks upon the rock as a much decomposed mica-lamprophyre.

The large amount of calcite in many of the Warren House rocks led me to keep a look-out for limestone. The following are the only cases in which I detected rocks that in the least deserve this name; partial analyses were made of them for me by Mr. R. Hornby.

A calcareous nodule was noticed in one of the beds cut through in the pipe-track. It effervesced briskly with cold acid all over, and contained 56.40 per cent. soluble in cold dilute hydrochloric acid, chiefly calcium carbonate. The microscope shows that, besides the numerous veins of calcite, the whole rock is permeated by what appears to be that mineral; but there are angular grains of quartz, and some perhaps of felspar. The rock in which this nodule lay has a matrix, which may be isotropic, thickly set with a tangled mass of hairs and grains of doubly-refracting mineral, and containing blebs of quartz and some larger crystals of felspar; it is thickly veined with calcite, but effervesces only along the veins.

A similar nodule was noticed in a bed in the cutting for the diverted road. It contained 38.57 per cent. of soluble matter, nearly all calcium carbonate. The microscopic slide shows a mass of broken felspar-crystals, chips of quartz, and patches of a green decomposition-product, the interstices between these being filled up mainly by calcite. It has the look of a decomposed tuff permeated by calcite.

In both these cases it was perfectly clear that we were dealing with a single isolated nodule, and that there was no bed of limestone, not even a string of nodules. They would seem to be cases in which calcareous matter has been introduced into a rock and aggregated round certain centres. Some large calcareous nodules of

a similar character were dug out of loose decomposed surface-rock at the western end of the reservoir.

A calcareous bed was cut through towards the northern end of the puddle-trench, which contains 65 per cent. of calcium carbonate. About one half of it is seen under the microscope to be made up of strings and ramifying masses of what is probably calcite; the remainder is transparent and structureless, and polarizes in a dark-grey colour.

An adjoining bed has evidently been originally a crystalline rock, for the outlines of the crystals are still visible, though they are too decomposed to be identified. It contains what seems disseminated calcite, but in much smaller quantity than the last rock, and its analysis yields only 13 per cent. of calcium carbonate.

It looks as if we had here two rocks belonging to the volcanic group, one of which has been very largely and the other slightly calcified.

I deferred the publication of these notes in the hope that I might be able to find elsewhere in the Malverns rocks similar to those of the Warren House area. I cannot say that even now my examination of the hills has been exhaustive; but I have been over the whole of them, and have found rocks which bear some resemblance to those just described at two spots only. One is on the southern part of Raggedstone Hill. We have here rocks which have a bedded aspect, and some of which have externally a felsitic appearance resembling that which prevails so largely among the Warren House group. The general resemblance between the two was noticed by Prof. Phillips (Mem. Geol. Surv. vol. ii. pt. i. p. 26); it is hardly so close as appears at first sight.

The accompanying figure shows the section along a line running due east from the Trigonometrical Station.

No. 1 is pale grey, soft, micaceous schist. The space No. 2 is grass-grown. No. 3 has a crushed and rolled-out look; it contains wavy films of a chloritic mineral; streaky bands of quartz showing strong strain-shadows; felspar, some triclinic; augite, and (?) epidote. It may well be a crushed and sheared dolerite. No. 4 contains fibrous hornblende, shattered felspar, and much disseminated limonite. Mr. Teall tells me that it is very like some Cornish epidiorites. No. 5 is confused by a network of quartz-veins. No. 6 scarcely differs from No. 3. No. 7 is a felsite; it shows no signs of mechanical deformation, and it may be intrusive. No. 8 and another rock a little farther east are epidiorites, which Mr. Teall tells me are like some Cornish rocks that have resulted from the alteration of gabbros. Slides taken from bosses a little north of the line of section and some way to the south are practically identical with No. 3. Another rock south of the line of section consists of rolled-out quartz and felspar-grains foliated by thin films of mica; it is just such a rock as would be produced by the shearing of No. 7.

In a quarry 20 chains south-east of the Trigonometrical Station the upper beds consist of green fibrous hornblende, torn and wrenched and dragged out into wavy films, and plagioclase. There is probably a little augite, so this is most likely an epidiorite. The bottom bed is

a quartz-schist slightly foliated by chloritic films ; it seems to contain too much quartz to be an igneous rock. The dip along the section in the figure is due east ; in the quarry last mentioned it is north-east.

The rocks of this group differ in several respects from those of the Warren House area. They are more basic in composition ; out of twelve examined only two can be called felsites ; and they have been subjected to very considerable mechanical deformation. No signs of crushing or shearing, and no strain-shadows, occur in the Warren House rocks ; in all but one of the rocks of Raggedstone Hill these are palpably apparent.

I am unable to say whether these rocks are among those dealt with by Dr. Callaway in his last paper on the 'Origin of the Crystalline Schists of the Malvern Hills,'¹ because I cannot identify his localities with any certainty. But though the rocks I have been speaking of may well be on the road to become schists, they are all of them very far from having arrived at that consummation.

Relation to the Crystalline Schists.

Unfortunately, neither in the Warren House area nor on Raggedstone Hill have we anywhere a junction or anything like a junction shown between the special rocks of these districts and the schists that make up the main mass of the hills.

Several hypotheses present themselves as to the relationship between the two. The Warren House rocks may be totally distinct from the schists. If this be so, the absence of mechanical deformation in them would indicate that they are the younger. If we accept the view that the schists of the Malverns have been formed by dynamic metamorphism out of volcanic rocks, the rocks of Raggedstone Hill may be a portion of this volcanic complex which has undergone only partial transformation. And there is again the possibility that the Warren

¹ Quart. Journ. Geol. Soc. vol. xlix. (1893) pp. 401 *et seqq.*

House rocks may be a part of the complex that has altogether escaped metamorphism, that the Raggedstone Hill rocks are a part in which metamorphism has been arrested at an early stage, while the schists represent the final step in the process.

The only other rock that need be mentioned here forms an isolated boss south of Chace-end Hill, 30 chains north of Bromsberrow Place. It is reddish and brecciated, and all one can say about it is that it is a shattered felstone thickly impregnated with limonite. There is nothing to show its relationship to the adjoining rocks.

[I had forgotten to state that Mr. J. F. Bryant has made a study of the Warren House rocks, and has kindly furnished me with a copy of Mr. Harker's notes on his slides, which the Author has given me leave to quote. Mr. Harker says:—"The rhyolites are just like many in North Wales, and the ashes with rolled bits of lava could be matched there, and especially in the Lake District."—December, 1894.]

DISCUSSION.

Mr. WATTS asked whether the rocks were the same as those described by Dr. Callaway.

Dr. HICKS was glad that Mr. Watts had called attention to Dr. Callaway's researches amongst these rocks. He had gone over these sections some years since under Dr. Callaway's guidance, and found that the rocks resembled in a marked manner the Pebidian rocks of St. David's.

Mr. RUTLEY said that he agreed in almost every respect with the Author's statements. The rocks occurring in this small area were lavas of acid and basic characters, associated with tuffs. The felsitic lavas sometimes contained epidote, at others calcite, the latter mineral being often present in considerable quantity. The structures in these lavas were exceedingly obscure. That these volcanic rocks were totally distinct from the crystalline schists which constitute the main mass of the Malvern range, there could, he thought, be no doubt whatever; and of the different hypotheses alluded to by the Author, he was inclined to adopt that of the volcanic rocks being of later age than the crystalline schists—a view which led to the inference that the former had been let down between faults. While admitting that various parts of the range showed evidence of having been affected by pressure and earth-movements, he did not agree with Dr. Callaway in considering that the stresses had resulted in shearing, except on a very limited scale in certain zones.

Mr. HARKER testified to the resemblance of the rocks from the new reservoir at Malvern to the old acid lavas of Caernarvonshire. He had had the opportunity of studying a series of rocks collected from that locality by Mr. J. F. Bryant. The type is well characterized by its containing only a few scattered porphyritic crystals of plagioclase (without quartz or any ferro-magnesian mineral) in a crypto-crystalline groundmass. Among newer rocks this type is represented by the rhyolites of Iceland.

The AUTHOR replied.