13. *On the IGNEOUS ROCKS at SPRING COVE, near WESTON-SUPER-MARE.* By WILLIAM S. BOULTON, Esq., B.Sc., A.R.C.S., F.G.S., Lecturer in Geology at University College, Cardiff. (Read January 20th, 1904.)

I. INTRODUCTION.

IN the Summary of Progress of the Geological Survey for 1898 (pp. 104–11), Sir Archibald Geikie & Mr. Strahan, in a description of a ‘Volcanic Group in the Carboniferous Limestone of North Somerset,’ published for the first time the evidence for the contemporaneity of these igneous rocks.¹ The authors refer briefly to the basalt and associated tuffs at Spring Cove, immediately to the west of the town of Weston, and describe in more detail the basalt-lava and beds of tuff interbedded with the fossiliferous limestone along the ridge of Middle Hope, 2 miles north of Weston.

At the time of the publication of this account, I had already made a detailed examination of these rocks in the field, and of microscopic and chemical preparations; but as my results seemed in general accord with those of the authors named, especially in regard to the rocks of Middle Hope, I felt that little or nothing was to be gained by the publication of my work as a whole.

In the rocks at Spring Cove, Weston, however, there appear to me to be points of considerable interest which are only briefly touched upon, or not mentioned at all, in the account to which I have referred, and I therefore venture to submit some additional observations in regard to them.

II. GENERAL DESCRIPTION OF THE ROCKS.

The basalt at Spring Cove, immediately north of Weston Pier, runs obliquely to the high road, and is exposed from low-water mark along the foreshore into the face of the cliff, the exposed length being about 150 yards. The massive beds of Carboniferous Limestone, between which the basalt is intercalated, strike north-eastward, and dip south-eastward (towards Weston) at about 40°. The basalt-sheet is parallel to the bedding of the limestone, and has a thickness of about 45 feet.

A traverse from end to end of the exposure shows clearly that the rock varies considerably in structure and appearance, and that it is by no means a simple basalt-lava flow. Starting from low-water mark, the rock is a hard, compact, red, slightly-amygdaloidal

¹ In this account reference is made to the observations of previous investigators.

olivine-basalt, containing very occasional lumps of limestone, from a few inches to a foot or more across. For the first 100 yards its upper junction with the limestone cannot be seen, because of the accumulated boulders at the foot of the cliff, while the lower junction is covered with water, even at lowest spring-tide. Then, a little more than halfway from the low-water end, and along to the cliff, the basalt changes in character somewhat suddenly. It now contains big lumps of burnt limestone, and the whole mass becomes broken up into a very coarse tuff or agglomerate, containing great lenticular masses of highly-slaggy basalt, 5 to 6 feet long, together with lumps and bands of limestone, often considerably fractured, and up to 10 or 12 feet in length. About 20 or 30 yards farther on, and as far as the end of the exposure in the cliff, the rock is more uniform in character, being a 'pillowy' basalt, though considerably brecciated and very amygdaloidal, with comparatively little tuff. But it still contains masses of limestone, even larger than those in the middle of the exposure.

Fig. 1.—Lenticles of lava and tuff making up the 'main sheet of basalt.'
(Length=about 40 yards.)

The whole mass appears to consist of great lenticles of basalt, or tuff, or both confusedly mixed, together with the included limestone. The median planes of these lenticles run obliquely to the limestone-beds above and below, so that the lenticles dip at a steeper angle than the sheet as a whole (fig. 1). It would thus appear that the mass is capable of being roughly divided into three portions. Commencing at the cliff-end to the north (in which direction the vent was probably situated), the rock for the first 30 yards is a 'pillowy' basalt, with tuff and limestone often occupying irregular spaces between the spheroids of amygdaloidal basalt; then, for about 20 yards, the rock is mainly a coarse

agglomerate, with lapilli and bombs of basalt and lumps of limestone; while, for the remaining 100 yards or so, it is an ordinary basalt-coulée, with very few, and always small, lumps of burnt limestone.

III. RELATION OF THE BASALT TO THE LIMESTONE BELOW IT.

The basalt rests upon a hard bed of pink limestone, about 9 feet thick. Immediately under the basalt the red coloration is intense, but passes down into reddish-yellow and yellow; and the limestone, especially in its upper portion, is markedly crystalline to the naked eye. Below this bed is the typical, purplish-brown, fossiliferous limestone about 25 feet thick; and this again is underlain by a soft, pink, nodular rock, showing oblique lamination, and containing the remains of corals and encrinites. This last bed is somewhat tuff-looking, but an examination of the residue, after treatment with boiling hydrochloric acid, shows that it is an excessively-fine red mud, without any recognizable volcanic lapilli, but probably derived from some volcanic centre. This residue is in striking contrast with those from the calcareous tuffs at Middle Hope, all of which show abundant lapilli of basalt-glass, felspar-crystals, etc.

Sir Archibald Geikie & Mr. Strahan tabulate the following succession of these rocks at Spring Cove (*op. cit.* p. 105):—

‘Massive limestone, full of fossils. The lowest 3 feet of the rock are crowded with fine volcanic dust, which, under the microscope, is seen to consist of fine vesicular lapilli.

‘Highly-amygdaloidal altered basalt, having a “pillow”-structure, and with abundant calcareous and hæmatitic veins, and threads of carbonate of copper; about 35 or 40 feet.

‘Red limestone, full of fine volcanic dust, and passing down into the ordinary grey, fossiliferous limestone.’

In the limestone under the basalt I have been unable to detect any undoubted igneous fragments, of the nature of volcanic dust or lapilli (despite a diligent search in thin slices under the microscope), from the basalt-junction down to a depth of 9 feet in the limestone. But the soft red rock, some 35 feet below the basalt, may represent, as stated above, very fine volcanic dust, while a section of the reddish-purple limestone, 8 feet below the basalt [23],¹ has a very tuffy appearance, as remarked below.

The following is a description of some of the sections cut from this underlying limestone:—

[3] Reddish limestone, in contact with the basalt. The slice clearly shows elliptical and rounded oolitic grains, set in a matrix of calcite, occurring in small, irregularly-outlined crystals, and with well-marked cleavage. As the rock approaches the junction with the basalt, the oolitic structure gradually disappears, and the rock comes to consist of a confused aggregate of minute calcite-

¹ The numerals in square brackets, throughout this paper, refer to the numbers of the slides in the Author's ‘Weston collection.’

crystals, with no definite outlines or cleavage. With this change comes in much reddish-brown colouring-matter, occurring in irregular veins and fissures. In places the brown substance shows distinct rhombohedra, sometimes with curved faces and projecting into the vein, which is filled up with clear secondary calcite. This brown substance, which is bright yellow and red by reflected light, is doubtless carbonate of iron, carried down by percolating waters from the basalt above, deposited in the limestone as chalybite, and subsequently oxidized, giving to the limestone its pronounced red tint, more especially for the first few feet below the junction.

[28] Another junction-specimen is a reddish-brown rock, with the appearance of a breccia in the hand-specimen. Under the microscope, the basalt can be seen penetrating and absorbing the limestone. The contact has evidently much affected both rocks. The basalt is represented at the actual junction by a host of minute, pale-green or nearly colourless needles (? tremolite), which are largely masked by iron-oxide. These needles are associated with some brown and yellow glass and much secondary calcite, forming a fine groundmass. The limestone is reddish-brown, structureless, and polarizes faintly.

[24] Another junction-specimen is intensely red, and shows under the microscope the 'ghosts' of the original oolitic grains.

[21] A slice from a specimen taken 3 feet below the junction shows, besides the usual reddish-brown ferruginous matter in the spaces between the oolitic grains, which in places has a marked superficial resemblance to fragments of palagonitized glass, a large number of nearly colourless rhombs of dolomite, fringing cavities or veins filled with water-clear calcite.

[23] A sample taken 8 feet below the junction, of a reddish-purple colour, effervesces strongly with acid, and has a very tuff-like appearance. Under the microscope it shows angular and rounded fragments of oolitic limestone in a dark reddish-brown matrix, and the borders of the fragments are strongly marked with the same colouring-matter. But even here no certain igneous material was detected, although it is possible that the highly-coloured matrix is fine volcanic dust, and not colouring-matter brought down in solution from the overlying basalt.

IV. RELATION OF THE BASALT TO THE LIMESTONE ABOVE IT.

The determination of the precise nature of this junction is obviously important, as bearing on the contemporaneity or intrusion of the basalt. In the Survey account referred to above it is stated (p. 106) that

'fine volcanic dust appears in the overlying limestone for about 3 feet above the surface of the lava, and thereafter the calcareous rock assumes its usual highly-fossiliferous character.'

I have cut and examined sections at and near the junction and for about a foot above it, and can confirm the above observation. At the actual junction, and for about a foot from it, lapilli of basalt, one-

eighth to one-sixteenth of an inch across, are very numerous, often with the typical concave surfaces, due to fracture across vesicles. In among these lapilli, calcite-crystals occur, and round their borders is a brown, yellow, or red ring of iron-oxide derived from the basalt-fragments, while fringing some lapilli are clusters of small, pale-yellow rhombs of dolomite, showing patches of bright yellow and borders of red iron-oxide by reflected light.

V. SOME SPECIAL CHARACTERS OF THE BASALT-SHEET.

The characters of this igneous flow which are of especial interest are (a) the 'pillowy' structure, together with the tuffy or agglomeratic structure; and (b) the included lumps and masses of limestone.

Fig. 2.—Oval, slaggy lumps of basalt-lava surrounded by fluxion-tuff.

Fig. 3.—Lump of basalt-lava, enclosing a lump of tuff and of limestone, and itself enclosed in coarse fluxion-agglomerate.

The pillowy, oval, or spheroidal masses of basalt, 2 to 8 feet across, usually very amygdaloidal, especially round their periphery, and sometimes containing small oval or angular cores of a slightly different and earlier lava, are usually embedded in a tuff made up of lapilli up to 2 or 3 inches across (figs. 2 & 3).

Near the middle of the sheet, covered and underlain by massive lava, is a band 5 to 6 feet wide, with a dip roughly parallel to the other lenticular masses, consisting of a confused mass of coarse tuffy material, made up of angular fragments of lava 1 to 2 inches across, embedded in a fine red-and-green matrix, and containing lenticular cakes of vesicular lava, phacoids (often broken and torn) of limestone, and higher up the cliff larger spheroidal lumps of lava. The whole band suggests forcibly the augen-structure characteristic of gneisses. It probably represents, however, a torrent of agglomeratic material that flowed down a slope on the surface of an already-extruded bed of lava, carrying in among the finer

lapilli larger, irregular, and plastic masses of scoriaceous basalt-lava of the nature of bombs, together with lumps and fragments of limestone, which from their form and broken character suggest that they were ejected from the vent with the basaltic material (fig. 4).

In all cases where the phacoidal or lenticular structure is seen, whether on a large or on a small scale, the material forming the groundmass is fragmental and tuff-like, while the included phacoidal masses consist of vesicular lava, or limestone, or very occasionally masses of coarse tuff (figs. 2, 3 & 4).

A thin slice of the typical tuffy matrix [20] shows small sub-angular or rounded, closely-fitting, equal-sized lapilli, about an

eighth of an inch across, with little or no interstitial matter except secondary calcite and iron-oxide. The lapilli consist of basalt-glass crowded with felspar-microlites, and in all general characters suggest strongly an analogy with the 'volcanic sand' of the recent West-Indian eruptions, so graphically described by Dr. T. Anderson & Dr. J. S. Flett.¹

It is highly probable that this basaltic mass, like other pillow lavas containing portions of sedimentary material, was ejected under water; and it is certain, I think, that the tuff or agglomerate was not in the main forced into the air by an eruption and deposited in the sea-water. There is no evidence of sedimentation, or the quiet accumulation of dust and lapilli; all the appearances point to flow. It might be termed a fluxion-tuff or agglomerate.

Possibly, if the vent had been situated in very shallow water, or on the land, much of this fragmental material would have been blown into the air, fallen in the water, and settled down quietly on the sea-floor, as, indeed, appears to have been the case with much of the tuff at Middle Hope, 2 miles to the north. At Weston, however, the greater weight of water above may have prevented this, and compelled the fragmental material to flow as lava. Or again, as in the West-Indian examples already cited, the expansive force of the imprisoned vapours may have been sufficient to break up the lava within the vent, but insufficient to do more than just force the tuff over the lip of the vent, whence it flowed along the sea-floor in obedience to gravity, and impelled forward, in part, by the expanding gases.

One of the most remarkable features of the sheet is the abundance of lumps and irregular masses of limestone, enclosed in the amygdaloidal and 'pillowy' basalt, or occurring as phacoids and lumps in the tuffy material.

In the accompanying diagrams (figs. 5, 6, 7 & 8, pp. 165-67) some of these masses are shown, ranging in size up to 10 or 12 feet, often broken and torn, in part eaten into and absorbed by the basalt, and sometimes tailing off into smaller and smaller fragments. Characteristic features are the concave surfaces of the limestone, often due to the fact that the latter occupies an irregular space between a number of spheroids or 'pillows' of the basalt, looking as if either the limestone had been absorbed by the hot lava, or, more probably, squeezed into its present shape by the distending and moving spheroidal masses.

There can be no doubt that this limestone is not secondary, due to the deposition of calcareous material from aqueous solution subsequent to the outflow and consolidation of the lava; nor has it been deposited as sediment in irregular spaces between the spheroids after the cooling of the basalt; but it is unquestionably part of the calcareous floor upon which the basalt-flow rests. Many of these included masses are oolitic, the structure being visible sometimes to

¹ Phil. Trans. Roy. Soc. ser. A, vol. cc (1903) pp. 448-49.

the naked eye, while a microscopic examination shows the oolitic grains distinctly, together with the remains of encrinites, etc.; and the basalt has penetrated, fused, and absorbed the limestone along its borders.

Fig. 5.—*Junction of the basalt and an included mass of limestone.*

Fig. 6.—*Included lump of limestone in basalt.*

A thin slice through the junction of the basalt and an included mass of limestone [30 c] shows that the basalt, here a brown, yellow, red, or green glass, in places distinctly variolitic, penetrates and absorbs the limestone, which is turned yellow and red, owing to the staining of iron-oxide; while, along the edge of the limestone at

the junction, occur wavy bands of reddish-brown and yellow alteration-material, reminding one of agate-structure. Here, as

FIG. 7. Limestone included in basalt.

in the limestone under the basalt, rhombs of chalybite fringe the walls of drusy cavities and veins, the rest of the space being filled

in with clear secondary calcite, while limonite and hæmatite have been subsequently deposited.

In some instances the limestone, more especially that occurring as irregular lumps in the tuff, is so cracked and broken, evidently during the movement of the flow, as to suggest that it must have

Fig. 8.—*Portion of an included lump of limestone in basalt.*

been hard and consolidated before the extrusion of the lava, and was probably torn from the vent and ejected with the igneous matter.

Small oval bodies, generally a few inches long, occur in the basalt: these, when broken, show a yellow or red shell of carbonate of lime,

the rest being filled with pure white, secondary calcite, and in some cases quartz; indeed, in a few instances, rounded or oval bodies up to a foot in length consist entirely of silica. These may be lumps of limestone, burnt and hardened on the outside by the hot lava, their centres being subsequently removed in solution, the hollows thus formed serving as receptacles for secondary calcite or quartz; while in a few cases the whole lump of limestone has been replaced by silica. It is possible, however, that some of them may be large vesicles filled with secondary minerals.

But, in most cases, the general shape and behaviour of the limestone-masses, particularly between the spheroids of basalt, seem rather to suggest that the calcareous material must have been only in part consolidated, so that it behaved as a pulverulent or more or less plastic substance, and got rolled in or picked up by the lava, and was able to fit itself in between the moving and distending spheroidal masses.

In this connection, it is interesting to compare the general shape and appearance of these included masses with those in other localities, as, for example, in the Arenig lavas of Ballantrae and elsewhere, with their marked pillow structure, so well illustrated and described by Sir Archibald Geikie and the officers of the Geological Survey.¹ There the included material is jasper, radiolarian chert, graptolite-shale, and limestone. In the memoir describing these rocks in the Ballantrae district it is stated (*op. cit.* p. 432) that

‘the calcareous matter does not seem to have penetrated far down through the successive beds, being confined mainly to the surfaces of the flows.’

In the case at Weston it must be admitted, as already pointed out, that the calcareous material did not come from above, but from the underlying floor.

In the account of these Weston rocks by the officers of the Geological Survey, it is suggested that the vent from which the rocks of Spring Cove were derived lay somewhere to the west, where now the Bristol Channel lies; but from the fact that the included masses of limestone dwindle rapidly in size and number from north to south, and that the lenticular sheets of lava and tuff, representing individual minor flows, also slope from north to south, it would seem more probable that the vent lay somewhere to the north of this Spring-Cove exposure.

Except for the presence of lapilli of basalt in the base of the limestone resting at once on the basalt, it might be difficult to show that the whole is not an intrusive sheet. The conditions in these submarine flows appear to be very like those in a sill or intrusive sheet, where, as Prof. Lapworth has suggested, we may get tuffs, lava, and included masses of sedimentary material confusedly mixed, and drawn out into lenticles as here described.

¹ Mem. Geol. Surv. (1899) ‘Silurian Rocks of Britain’ vol. i, Scotland.

DISCUSSION.

The CHAIRMAN (Sir ARCHIBALD GEIKIE) remarked that, since the publication of the joint description with Mr. Strahan, referred to by the Author, he had had an opportunity of re-examining the fine series of intercalated lavas in the Carboniferous Series of Fife. In most, if not in all, of those basalts which show the pillow-structure the materials that now fill up the interspaces between the ellipsoids have come from above and evidently belong to the series of sediments—tuff, sandstone, shale, limestone, etc.—which followed the emission of the lava. There is no trace of an explosive character in the lavas themselves; and he greatly doubted the possibility of a lava which had once escaped from the vent and flowed for some distance, subsequently blowing itself to pieces by the expansion of its own imprisoned vapours. No doubt, sudden contact with water might cause some lavas to break up; yet it was nevertheless the fact that in the case of those in question, though they had all flowed out over the bottom of a lagoon or the floor of the more open sea, none of them showed more than the usual irregular cracked surfaces. He did not think that there was ever much resemblance between the behaviour of a sill and that of a submarine lava-flow. He welcomed the additional information now supplied regarding an exceedingly-interesting little volcanic district, and hoped that the Author might be induced to study the other exposures in the same careful and detailed manner.

Prof. WATTS remarked that the paper constituted a very important contribution to volcanic geology. It enabled us to realize that conditions of vulcanicity prevailed in Carboniferous times similar to the vulcanicity of the present day. He was greatly impressed with the suggestion that the eruption described in the paper was of the Peléan type: the lava was blown to atoms, and the pulverized material formed a fluxion-tuff. In the Llandeilo of the Shelve district the speaker had formerly been perplexed how to classify a rock similar to that described by the Author. There was no reason why lava should not be blown to dust beneath the sea as well as on land, and the pressure of the water would induce conditions reminiscent of an intrusive sill. The Author had satisfactorily proved that most of the sedimentary material caught up in the lava had been derived from below, and his evidence was not inconsistent with that brought forward by the Geological Survey from the Southern Uplands of Scotland.

The AUTHOR thanked the Fellows for their reception of the paper. He quite agreed with the Chairman that limestone, and sedimentary material generally, found within the body of pillow lavas, might have come about in different ways in different cases, and that in some cases the material had doubtless come from above, either in solution or as sediment; but, from the evidence at Weston, it appeared certain that it might have come from below, ejected from the vent or picked up by the moving lava from the sea-floor. He did not think that it was necessary to assume a great depth of water at Weston during the outpouring of the lava.