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XXIII.—*The Cheese Bay Sill, Gullane.* By T. CUTHBERT
DAY, F.C.S. (With Plates XXIV-XXIX.)

(Read 17th December, 1913.)

JUST three quarters of a mile to the north-north-east of the railway station at Gullane there is a small indentation in the coast, which has received the name of Cheese Bay, and is well known to geologists because of the discovery there of a band of shale containing beautifully preserved fossil fishes, shrimps, etc. (*Tealliocaris Loudonensis*, etc.).¹ At the same spot, on the south side of the bay (see map, Fig. 1) and close to the shrimp band, is an outcrop of roughly columnar basalt extending about 80 yards by 55 yards. Immediately to the south, and separated by a narrow strip of sand, is a curious assemblage of rocks occupying an area which runs due south for about 200 yards and apparently terminates in an isolated stack about 15 feet high. This group of rocks is marked d¹ in the Survey Map, but I do not find any definite allusion to them in the "Memoir on East Lothian." Trending in a south-westerly direction from the stack for about 400 yards is a sill of basalt, overlaid at the centre and southern end by sedimentary rocks not much disturbed. This sill is called No. 3 intrusion in the Memoir above referred to, the Cheese Bay basalt being No. 2, I presume, and the basalt on the coast opposite Eyebroughty Scar counting as No. 1. Immediately succeeding the sill in a south-westerly direction for 150 yards or so is a series of

¹ R. H. Traquair, "Report on Fossil Fishes collected by the Geological Survey of Scotland from Shales exposed on the Shore near Gullane, East Lothian," *Trans. Roy. Soc. Edin.*, vol. xlv., 1907, p. 103.

"The Geology of East Lothian," *Mem. Geol. Surv. Scot.*, 1910, pp. 59, 84, 207, 215.

B. N. Peach, "Monograph of the Higher Crustacea of the Carboniferous Racks of Scotland," *Mem. Geol. Surv., Palaeont.*, 1908.

sedimentary rocks on a somewhat higher horizon and dipping towards the south at an angle of about 9° .

The whole section covers about half a mile of coast, seldom more than 60 yards across except where the large intrusion runs out to sea. It is almost wholly covered at high water, and on the land side everything is obscured by blown sand.

My purpose in this paper is to show that there is only one mass of basalt, and not two, and to adduce definite evidence of its intrusive nature.

The sill is black and white, large portions of it having the appearance of the well-known "white trap," and showing peculiarities of quite an uncommon nature in a sill. The character of the intrusions will also call for remark as they have an appearance not often observed in the field, and will, I think, prove of very considerable interest. Notice must also be taken of the sedimentary rocks belonging to the section; they are Lower Carboniferous, but I am not able to state their exact horizon. I intend in the present communication to notice more particularly their composition as sediments.

In order to study the section to advantage a start should be made at Cheese Bay itself. It is here only that we can see the under side of the sill (Plate XXV, Fig. 1). An examination of the northern edge of the basalt shows that all along, for a thickness of a foot or more, the igneous rock is white at the base where it comes in contact with various beds of shale, mostly dipping to the south, these latter being much hardened by the contact. Much white rock is also seen in the centre of the area of basalt, with shale below, some intensely hardened. In the white basalt at this spot is a small section (Plate XXV, Fig. 2) showing the shale caught up in a very peculiar manner. Though a small exposure, it is of considerable importance. The igneous rock is plainly unbroken, but the included shale is much brecciated. This is a feature which is repeated in many places, and goes to show that the shale especially was really much brecciated at the time of the intrusion, apart from any crushing by subsequent movement. There is also a thick band of shale underlying the basalt. It is finely veined with calcite or dolomite as if it, too, had been fractured somehow at the time of the intrusion and subsequently cemented by infiltration. It will be well to bear this shale in mind when examining other parts of the ground, for a very similar shale, veined in much the same way, will be encountered at various spots in disturbed areas, and speculation is sure to arise as to the cause and time of fracture.

Rising from the white part of the basalt, at another spot, is a dyke-like feature running for some distance nearly east and

FIG. 1. Map of the District South of Cheese Bay, Gullane.

west from the sea, and about 3 feet wide (Plate XXVI, Fig. 1). It is composed of highly crystalline dolomite intimately associated with the white basalt. It has evidently been brecciated by a later movement, the fragments of dolomite and white igneous rock being recemented firmly throughout. I am inclined to consider that it was originally a mass of dolomite caught in the intrusion, and not that the whole is simply of the nature of a vein.

We can now leave the basalt of Cheese Bay at its south-west corner where much of it is white. Here on the side towards the sea, the igneous rock, mixed somewhat with sedimentary material, can be easily traced up to and across a small fault which at this place cuts across the section, the down-throw being to the south. We now enter upon the second part of the series extending for about 200 yards to the high stack before mentioned.

At the fault (see map, Fig. 1) this series is separated from the basalt of Cheese Bay by a narrow strip of sand where nothing can be seen except at the place where we have just bridged the fault on the side towards the sea. On the land side, too, we have good evidence to connect the Cheese Bay basalt with the intrusive rocks to the south.

Lying on the same side of the fault as the basalt is a large block of nearly undisturbed shale underlaid by the intrusive white basalt of the sill and greatly hardened. This exposure gives us the upper contact of the sill on the north side of the fault. The fault itself, which is vertical and of but small throw, can be seen running into the bank above high-water mark. It is a clean cut, and some of the sedimentary rocks are thrown quite on end. The sediments to the south side of the fault are dolomites, and at this spot, only slightly removed from the fault, are lying nearly flat. They have shale below of the same nature as that just across the fault. The dolomite and shale are so blended and mixed that a polished section reminds one of a variegated marble. The rock is also intensely hard. This blending must have occurred before or during the intrusion, for the igneous rock where exposed is not disturbed.

A specimen of the dolomite from the lower part close to the fault gave, when subjected to chemical analysis, 58·7 per cent. soluble in hot hydrochloric acid, giving a moderate amount of iron, much lime and magnesia and much carbonic acid; the insoluble portion gave silica and alumina only (probably a clay). There was no free silica or quartz. I may say here that all the sedimentary rocks connected with this extensive sill are remarkably free from quartz. A specimen near the

centre of the compact dolomite showed 84·7 per cent. soluble in hot hydrochloric acid, with very little iron, much lime, and rather less magnesia than the previous specimen.

These two analyses give a fair idea of the composition of these dolomites. The crystalline variety contains always much more clay than the compact dolomites.

South of the fault, the ground for 40 yards or so is mostly occupied with exposures of various kinds of dolomite, with shale here and there. There are many boulders, but a careful search will easily establish the fact that below all is the sill, always white and now beginning to show a vesicular nature particularly when in contact with dolomite. There is a portion of the sill, dark in colour, which rises a little above the general surface, showing a remarkable spheroidal weathering which has caused it to resemble a bunch of cabbages. As we proceed south we find much more evidence of the presence of the sill. There are a few elevated patches of dolomite and some shale, all exhibiting proof not only of intrusion but of very considerable disturbance. In one place the horizontal strata have been broken, and tilted ridges follow one another, apparently partly sunk in the upper surface of the sill. At another exposure there are distinct signs of inversion, the shale, which is usually found below the dolomite, being on top (Plate XXVI, Fig. 2). An interesting intrusion of the white basalt into shale is also seen (Plate XXVII, Fig. 1) where the brecciation of the shale at intrusion is clear. Tongues of the sedimentary rock can be seen going down into the igneous rock in much the same way as in the case of sediments laid on the cracked upper surface of a lava flow.

There are considerable exposures of shale, but not laminated as shale usually is; it appears rather massive, but veined much like that seen in the basalt at Cheese Bay; it probably is the same bed and originally had its proper place but a short way below the dolomites. Though we may be nearly sure that a bed of shale perhaps of some thickness lay close below the dolomites, it is curious that only isolated exposures of it in any quantity should be found. A possible explanation is that the exposures now observed are but the remains of a large bed which has been removed or even incorporated by the intrusive magma.

The shales and dolomites are now apparently much jumbled up and mixed together by movements which accompanied intrusion. There is also good evidence that movement subsequent to the date of intrusion has taken place. It appears to have been of the nature of thrusts at or near the surface of the sill, affecting parts only. As a result of these thrusts, breccias

composed of fragments of the sedimentary and igneous rocks have been formed and small slickensides are also to be seen in their neighbourhood.

It is plain that most of the sediments on this part of the sill, besides having suffered considerable displacement and even folding, are also more or less hardened by heat, not that the dolomites are metamorphosed at all, except perhaps in the way of recrystallisation, but the clay they contained is probably more or less baked hard. In Plate XXVII, Fig. 2, a micro-section of some of the compact dolomite is shown which is without doubt "marmorised." It was obtained in actual contact with the sill.

The peculiar jointing in these rocks is suggestive of a baking at some time and subsequent shrinkage and splitting.

One may say that, roughly speaking, there are two kinds of dolomite on this part of the ground, a coarsely crystalline and a compact cryptocrystalline variety. The compact dolomites are the purest, containing least clay. The crystalline dolomites are always found below the compact variety. They differ somewhat in texture and composition, but they always contain a notable quantity of carbonate of iron. In some, indeed, the carbonate of lime has been replaced by carbonate of iron, leaving the carbonate of magnesia untouched. Of a finely crystalline specimen 56.1 per cent. was soluble in hot hydrochloric acid. These crystalline dolomites always contain a variable but notable quantity of clay. The compact dolomites usually show a concretionary structure which can be readily detected by the eye or by using a pocket lens.

Enough has now been said to give a fair idea of the nature of the section so far, and to show that, up to this point, we have traversed the upper surface of a sill, the intrusive nature of which is sufficiently demonstrated by the fact that the igneous rock is found in contact with three kinds of sedimentary rocks, namely shale, crystalline dolomite and the compact dolomite. This upper surface is covered to a large extent by sedimentary rocks either sticking on it or half buried in it.

We must now examine the most prominent feature, the stack before mentioned, and a small exposure of dolomite and shale in the bank near the same point. They are undoubtedly connected, and are also the last we see of the sedimentary rocks for more than 100 yards (see Map, Fig. 1).

To begin with the section in the bank; we can at once see that the compact dolomite has a concretionary structure on a much larger scale than anything we have yet met with. The rock has been beautifully sculptured by blown sand which has happily brought out the details of structure. At its base it is

invaded by white basalt, which can be traced here and there in connection with the rest of the exposure, which consists chiefly of a very crystalline dolomite and shale much disturbed and contact-hardened. By following the trend of the shale and crystalline dolomite we are led to the stack which is worthy of special study. Many peculiarities which occur separately in other parts, are here brought together and can be studied at leisure. The stack may be said in itself to curiously epitomise that part of the section already described (Plate XXIV).

The base of the stack, except just at the south end, is composed entirely of the white intrusive rock of the sill, more or less vesicular, with inclusions, which rises to about 6 feet at its highest point. It is found in contact with a band of crystalline dolomite. There is hardened shale below the dolomite but it varies greatly in quantity; in some places it is nearly absent, while in others there are considerable masses of it riddled through and through by the white basalt. It looks as if the shale was once quite a continuous and even bed below the dolomite, and that at the time of the intrusion the magma had eaten it away in the irregular manner now seen. At the south end of the stack the shales appear to have been sheared by a small thrust (which involved the above-mentioned section in the bank). But the shales on the north side are not sheared. I believe we see them exactly as they were being incorporated by the intrusive magma. They are certainly much brecciated, but I do not observe that at this particular point the white basalt is broken at all. A micro-section makes it clear that the intrusion has no chilled edge; and this is due possibly to the invaded rocks being at a high temperature during the intrusion.

Above the band of crystalline dolomite already mentioned is a considerable mass of white compact dolomite with curious inclusions identical with those seen in the small exposure on the shore close by. It is concretionary, but a very pure dolomite. An analysis revealed 93 per cent. soluble in hot hydrochloric acid, leaving 7 per cent. residue composed of alumina and silica, no doubt clay. The soluble portion contained a noticeable quantity of iron, much lime and magnesia, and carbonic acid. There is a decided tendency to separation at the junction of the two dolomites. The white rock, just at the junction, is the colour of pale ochre, and appears to have shrunk somewhat, though not in all places, from the underlying rock. It is a remarkable feature, but may have been caused by unequal shrinkage, after baking, of the two kinds of dolomite. An evident fold in the two dolomites is to be seen on the west side of the stack (Plate XXVIII, Fig. 2). The lower part of this

fold is plain enough, but I believe it is more extensive than might at first sight appear. There is a band of very crystalline dolomite on a part of the top of the stack and separated from the white compact dolomite below by the same ochre-coloured mark that is seen elsewhere. The joint has not opened however. There are also a few very small patches of shale on the top of this crystalline band and also scattered through it. One is certainly led to infer that there has been an inversion here affecting the south half of the stack. This remarkable overfolding is of much the same character as we have observed on other parts of the sill. It is difficult to assign a cause for this apart from movement at the time of intrusion.

A curious feature of the dolomites of the stack is the large number of small white spots very irregularly distributed through them. They have been identified as kaolinite by Mr McLintock. Their origin is a mystery, but a natural thought connects them with the presence of so much white trap in the vicinity. As a rule the kaolinite in the stack is more abundant in parts near the white igneous rock. This can be well observed on the north side of the stack. The large inclusions in the white dolomite are peculiar to this part of the section and would no doubt repay further study. They are usually lined with iron oxide, possibly derived from the decomposition of siderite, and always seem to contain numerous spots of kaolinite.

Having now considered the large stack in some detail, we may proceed to examine the remainder of the section towards the south-west and south. Shale is not met with again except on the outskirts of the sill towards the sea, where many sedimentary inclusions are found for a short distance only. For 130 yards or so only the bare upper undulating surface of the sill is seen (see map, Fig. 1), made up of more or less decomposed basalt, and then we come to the small shallow syncline "lying above the third intrusion along the coast"; according to the *Geological Survey Memoir* (p. 84). But, as I have mentioned before, there is really no break at all in this sill from the starting point at Cheese Bay. As we come upon the syncline we find its margin marked by a small fault running nearly east and west. Several patches of white igneous rock are to be seen at the shore end of this fault, and by tracing the margin towards the sea it can be found in many places as indicated on the map. The lowest bed of the syncline is a crystalline dolomite containing a considerable amount of siderite, immediately overlying the white igneous rock. The beds in this part of the syncline are patchy and irregular and a good deal stained with red iron oxide. They are clayey dolomites and

dolomitic clays. Proceeding for another 50 yards or so from the small fault last mentioned we come upon another small fault running nearly east and west. High up on the shore near the line of this fault is a considerable exposure of the white igneous rock overlaid directly by dolomite containing much carbonate of iron and compact in texture. The white igneous rock is highly vesicular, and has very much more the appearance of a lava than an intrusive rock. The vesicles appear to be filled with crystalline dolomite and kaolin or clay. The overlying rocks certainly look as if they descended through cracks more or less wide into the igneous material below. But a careful examination reveals the fact that tongues of the white igneous rock are undoubtedly penetrating the dolomites. It will be observed, too, that there is brecciation of the dolomites below, including all the portions apparently descending into the cracks. This shattering was done at the time of the intrusion, for the white igneous rock can be seen running into the cracks of the split dolomite, in places; but we shall have further ample evidence as we proceed. The characters of the upper surface and jointing of the dolomites here again suggest that the rocks have been baked.

By tracing the last-mentioned fault to its western limit near the sea (see map, Fig. 1), we come upon some truly remarkable exposures. The white part of the sill is here seen to great advantage and its connection with the darker basalt can everywhere be readily traced. It is highly vesicular and contains large, more or less rounded portions of the overlying clayey dolomites ("stoping"). In one place a large irregular block, detached from the overlying rocks, and well sunk in the magma may be seen. At one spot in particular the white igneous rock is so full of more or less rounded fragments of clayey dolomite that it presents the appearance of a dyke built of boulders and cemented together with mortar. The somewhat shattered under surface of the overlying dolomites is very evident and also the presence of a few tongues running up into the rocks.

A really interesting object is a rounded boulder of clayey dolomite (Plate XXIX, Fig. 1) rather low down in the magma. When this stone was broken open it was found that the white igneous rock was actually invading it; the lower part of the boulder is seen to be quite eaten into. The upper part is curiously etched and bitten on the surface so as to produce a mammillated appearance. The micro-section made from a portion of this boulder has not sufficient white igneous rock attached to it to make the relationship clear, but one made from an intrusion of a similar character reveals the

peculiar nature of the intrusions to be seen here (Plate XXVIII, Fig. 1). This specimen was obtained from a spot about 30 yards south of the section I have just described, where there is a good junction exposure of the surface of the clayey dolomites of some square yards in extent (see map, Fig. 1).

In the hand specimen from which this section was taken the vesicular white igneous rock is seen to diffuse itself, as it were, through the substance of the clayey dolomite almost like a froth. That the clayey dolomites are being dissolved or incorporated seems pretty evident, but we have to account for the presence of so many vesicles, and also for the fact that the igneous rock is white. This latter character may have been caused by the magma coming through shales before it reached the clayey dolomite. There is no shale to be seen in this part of the section, but I have a specimen of the white igneous rock containing small carbonaceous particles. The vesicles are not so easily accounted for. In most places, where we find the white rock in contact with shale *only*, the vesicles are practically absent. We must look then to the clayey dolomite as an agent. As a rule the sill is the more vesicular the closer it is to the clayey dolomite. A consideration of the hand specimens above mentioned shows that many vesicles were at least temporarily formed by the magma detaching in a very curious way small rounded particles from the clayey dolomite. The chemical action of the molten magma on the clayey dolomites may have caused the production of a considerable quantity of carbonic acid gas (by the interaction of polysilicates or metasilicates and the carbonates). Very many true vesicles may have been formed in this way, the empty spaces being subsequently filled with crystalline dolomite or other minerals by infiltration.

There is yet another small fault crossing the section and just against it the white igneous rock is also well seen, and can be traced quite round the edge of the sedimentary rocks till they are obscured by sand on the shore. The sill itself extends still further south underlying another patch of sedimentary rocks of the same character as those last noticed, but the white igneous rock can only be seen at the southern margin. A few yards further on another series of sediments are encountered and the last of the sill is seen as it disappears beneath them. The point of contact can be well observed, and there is also a considerable tongue of the igneous rock running up into the overlying sediments.

A peculiarity of this extremity of the sill, both white and dark, is the number of geodes, containing for the most part calcite and quartz crystals (Plate XXIX, Fig. 2). They are

found in many places in the sill where it borders the shallow syncline. Some of the geodes or druses are quite large. The smaller ones are surprisingly numerous.

The last series of sediments above referred to cover a considerable amount of ground; they may be called dolomitic and sandy clays. The curiously jointed character of the northern portion together with their hardness suggests baking.

Those to the south are more sandy and dip pretty regularly to the south at an angle of about 9° till they are obscured by sand. There are many inclusions; angular and rounded fragments of dolomite are often met with and, especially in the southern half of the series, many blocks of lava and sedimentary rocks of considerable size, apparently belonging to series almost immediately underlying; from which it may very well be inferred that before these beds were deposited a considerable amount of contemporaneous erosion had taken place.

The intrusion of the sill, however, must be of later date and at a time when the cover was considerable. One would hardly expect to see intrusive phenomena of the kind met with here if the cover were small.

A further investigation of this interesting half-mile of coast might well repay the enquiring geologist. The shore north of the basalt of Cheese Bay especially would yield something to further search. The basalt exposed on the shore opposite Eyebroughty Scar is of the same type as that at Cheese Bay. They are separated by a small anticline, but for all that they may prove to be connected. The dolomites are there, too, and the ground has some points at least in common with that immediately to the south of the Cheese Bay basalt. In conclusion I desire to express my grateful thanks to Dr Flett for his kindness in examining and determining the various microscopic rock sections.

EXPLANATION OF PLATES.

PLATE XXIV.

The Stack, Cheese Bay Sill, from south-east. Length about 19 yards; height about 15 feet. *Photo, T. Cuthbert Day.*

A, compact, very pure dolomite with concretions. B, band of coarsely crystalline dolomite with more or less shale below. C, band, similar to B, above the compact dolomite A, having some shale above. D, the much decomposed igneous rock invading the shale and dolomite.

PLATE XXV.

FIG. 1. Basalt, at Cheese Bay, resting on shale S, with white trap at contact. *Photo, T. Cuthbert Day.*

FIG. 2. Cheese Bay basalt, A, with included mass of shale. *Photo, T. Cuthbert Day.*

PLATE XXVI.

FIG. 1. Ridge of crystalline dolomite, A, in white basalt at Cheese Bay. *Photo, T. Cuthbert Day.*

FIG. 2. Overfold in dolomite, D, and shale, S. *Photo, T. Cuthbert Day.*

PLATE XXVII.

FIG. 1. White igneous rock, W, and shale, S. *Photo, T. Cuthbert Day.*

FIG. 2. Marbled dolomite, thin section, magnified 12 diameters, nicols crossed. *Photo, T. Cuthbert Day.*

PLATE XXVIII.

FIG. 1. Vesicular white igneous rock, A, invading dolomite, D. The sinuous margin between the two is readily traced. Thin section, magnified 12 diameters. *Photo, T. Cuthbert Day.*

FIG. 2. Hinge of the overfolded dolomite of the stack. A, compact white dolomite enveloped by B, band of coarsely crystalline dolomite. *Photo, T. Cuthbert Day.*

PLATE XXIX.

FIG. 1. Corroded lump of dolomite, A, enclosed in highly vesicular white trap, W. *Photo, T. Cuthbert Day.*

FIG. 2. Upper surface of sill, showing numerous geodes. *Photo, T. Cuthbert Day.*

FIG. 1.

FIG. 2.

FIG. 1.

FIG. 2.

FIG. 1.

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