XXXIII. *An Analcite Diabase and other Rocks from Gullane Hill.* By B. ROBERT YOUNG, M.A.

(Read 19th February 1903.)

A BRIEF general account of Gullane Hill, which owes its existence to those igneous rocks that form the principal subject of this paper, will not, I think, be out of place.

This hill overlooks the eastern shore of Aberlady Bay, and is distant about eighteen miles in an easterly direction from Edinburgh. From Aberlady Bay it rises in distinct terraces to about 100 feet, and then in a somewhat crescentic ridge running in a north-westerly direction, mounts up to a little over 200 feet.

These terraces, which are referred to by Milne-Home,¹ are undoubtedly raised sea-beaches. They rise by distinct banks or cliffs from the 25-feet to the 50-feet level and from that to the 100-feet level. Rivulets which cut these banks show them to consist of thin-bedded sandstones dipping gently south-west. A section of the 50-feet beach is exposed in Gullane Quarry, where 5 feet of well-stratified sandy gravel and shingle are seen to overlies the clean-cut horizontal surface of sandstone. During a boring for water on the 100-feet beach, 4½ feet of sand and 15 feet of boulder clay were recorded as having been passed through before reaching firm rock. All three beaches have been slightly elevated and otherwise modified by blown sand.

Recently exposed surfaces of the igneous rock which forms the main ridge of the hill show marks of glaciation. These are especially well seen at the point named "Old Quarries." Here from beneath the shallow turf shoot out, straight as arrows, a multitude of long, strongly cut grooves. These and a series of very gently rounded furrows and ridges all run in an E.N.E. direction. In front they point to the steep "crag" side of North Berwick Law, and behind to the "tail" side of the Edinburgh hills. From a glance at the sketch map it will be seen that Gullane Hill itself shows to a certain extent the phenomenon of "Crag and Tail."

From the coast section, the quarries and other exposures on the hill itself, and the records of two borings for water, one on either side of the main ridge, the geological structure, which is very simple, can be easily made out. A series of sandstones, shales, and calcareous rocks, dipping from 10° to 20° in a S.W.

¹ "The Estuary of the Firth of Forth," pp. 102-103.

ANALCITE DIABASE AND OTHER ROCKS FROM GULLANE HILL. 327.

direction, is seen to have had thrust into it, at a slight angle to the prevalent dip, the thick mass of igneous rock which forms the ridge of the hill. There is also intercalated among the sedimentary rocks another igneous mass of less extent.

The sandstones, which vary considerably in colour, exhibit false-bedding, worm-castings, and ripple-marked surfaces. With the exception of a bed of sandstone containing abundant *stigmatariæ* with rootlets attached, and a band of shale near Gullane Point yielding ferns, the sedimentary rocks are barren of organic remains. If we suppose that there is no fault intervening, these rocks lie a few hundred feet below the Aberlady limestones, whose deposition is supposed to have corresponded in time to that of the Yoredale series of the North of England. On the Geological Survey Map they are represented as of Calcareous Sandstone Age.

Of the igneous rocks the large intrusion of the main ridge is the more important and interesting. The smaller rock, which forms Gullane Point, is a much altered ophitic olivine dolerite. It contains abundant short laths of plagioclase felspar, with occasional phenocrysts, all considerably decomposed. Calcite and vermicular chlorite probably represent ophitic plates of augite. Some magnetite is present. The most interesting feature of this rock, however, is the pseudomorphs after olivine. These are of calcite and a green fibrous substance much resembling some varieties of Mica. It is pleochroic, from a light yellow to green, the greatest absorption taking place when the short axis of the Nichol's prism is parallel to the fibres. It is uniaxial or nearly so, and has strong negative double refraction. Being impressed by the strong resemblance of this mineral to the pseudomorphs after olivine, first described by Arnold-Bembrose,¹ from the toadstones of Derbyshire, I sent a rock-slice to that gentleman, who definitely identified the mineral with that of his "Potluck pseudomorphs," and most courteously sent me some specimens and slices of the Derbyshire rocks for my own comparison. These pseudomorphs are, I believe, not at all rare in Scottish rocks of basic composition, but seem to have hitherto been mistaken for bastite, from which their strong pleochroism and small optic axial angle, if any, definitely separate them. They differ from mica in being quite brittle.

As far as can be seen the Gullane Point dolerite lies conformably with the surrounding sedimentary rocks, and the view that it is a contemporaneous lava-flow is supported by the amygdaloidal bands which traverse the rock, though these may be of secondary origin. In these bands are contained abundant small agates.

¹ *Quart. Journ. Geol. Soc.* (1895), li. pp. 613-16.

In an exposure a little to the south of Gullane Point, the olivines are represented by bronze-like pseudomorphs of ferric oxide with calcite. In specimens from other points I was enabled to trace the gradual alteration of the green "Potluck pseudomorphs" into these latter forms. They sometimes occur clustered together into what were at one time olivine nodules. These measure three or four inches in diameter.

Outcrops of the large intrusive mass, previously mentioned as building up the main ridge of the hill, can be observed from the Hummel Rocks, lying between high and low-water marks, right along the ridge till it terminates in Gala Law Quarry. At Corby Craigs it forms a precipitous cliff which runs for some distance up the hill. On the foreshore at this point, where it is seen to cut gently through sandstones and shales, the sill is rapidly thinning out. Veins penetrate the underlying strata, which are slightly altered at the edges of contact, the sandstone being changed to quartzite and the shale hardened and slightly bleached. During the boring already quoted 165 feet 4 inches of "whinstone" were passed through, and supposing the dip to be 30°, the thickness of the sill at this point would be about 140 feet.

A typical hand-specimen of the rock resembles very much an ordinary "greenstone," but is dappled over with white and yellow spots. These vary in diameter from three millimetres downwards, and on a broken surface are seen to be composed of a mineral which, but for its hardness, might easily be mistaken for quartz. This mineral proves to be analcite, the yellow spots being due to a fibrous zeolite, which very frequently accompanies the former. The lowest foot or two of the sill, as exposed at Corby Craigs, is changed to a compact mass of calcium carbonate with some secondary silica, and its originally igneous nature is only revealed by its intrusive character and by microscopic examination. In the degree to which it has suffered weathering, the rock varies considerably from point to point.

On preparing a few thin microscopic slices the abundance of analcite was confirmed, and there were revealed several new features definitely connecting this rock with the teschenites. Its further investigation was undertaken with a view to ascertaining what bearing, if any, its composition had on the much-debated question of the origin of the analcite in rocks of this type.

Analcite is a hydrated silicate of alumina and soda, and but for the water, is identical in composition with albite and the albite factor which appears in most other plagioclase feldspars; but as the feldspar commonly found in basic rocks contains little albite,

ANALCITE DIABASE AND OTHER ROCKS FROM GULLANE HILL. 329

it is assumed that some one of the rarer soda-rich minerals, such as nepheline, was originally present. The problem is usually complicated by the much-altered condition of the felspars making their exact position difficult to determine. Rosenbusch favours the view that basic rocks rich in analcite originally contained nepheline; but Rohrbach, on investigating rocks of this type, termed "teschenites" by Tschermak, and said to contain nepheline, could find none of that mineral, but thought that a sufficient explanation of the abundant analcite was to be found in the composition of the felspars present. Fairbanks in his paper on the analcite diabase of the Cuyamas Valley of California finds the felspars zonal, but so much altered as to make the determination of the extinction angles difficult; yet he favours the view that nepheline was the source of the analcite.¹

Teall describes an analcite diabase from Car Craig near Inchcolm,² and Dr Flett a "teschenite" from Spalefield near Anstruther.³ In both of these rocks the felspar is much altered, and the petrologists mentioned do not come to any definite conclusion as to the origin of the analcite.

The analcite diabase of Gullane Hill contains plagioclase felspar, augite, hornblende, biotite, magnetite, ilmenite, pyrites, apatite, analcite and other zeolites, chloritic matter, calcite and pseudomorphs of doubtful composition after olivine.

The felspar, which is idiomorphic with respect to the augite, occurs in long lath-shaped crystals. These are commonly zonal, and judging from the angles of extinction in sections approximately perpendicular to the twin lamellæ, there are represented in the various layers from within outwards a series of plagioclase felspars from labradorite to oligoclase. The outer zones are most often untwinned. There frequently occur patches of felspar neither twinned nor zoned, which invariably extinguish straight or at a very low angle.

The augite occurs in allotriomorphic plates of moderate size which are penetrated by the felspars, though a few idiomorphic crystals may be observed. It is purplish or occasionally reddish-brown in tint, and in the latter case is pleochroic. The intensity of colour increases towards the margins of the crystals.

The hornblende, which is sparingly distributed, is brown and pleochroic, and almost without exception occurs as a peripheral intergrowth with augite, usually in parallel position. This is a very characteristic feature of the teschenites, being found in

¹ *Bulletin of the Department of Geology, Univ. of California*, vol. i., No. 9, pp. 273-300.

² "British Petrography," p. 191, pl. xxii. fig. 1.

³ *Geol. of East Fife*, "Mem. Geol. Surv. Scot.," pp. 392, 393.

those of Moravia, Silesia, Portugal, and Scotland. Macpherson, in his description of the teschenite of Cezimbra in Portugal, holds that the hornblende is paramorphically derived from the augite, and that the increased pleochroism towards the margin frequently found in the latter mineral is due to an increase in the number of ultra-microscopic intercalations of hornblende.¹

The biotite occurs very sparingly in ragged flakes, which are intensely pleochroic, changing from a light syrupy yellow to a deep chestnut brown. It is probably of secondary origin.

The iron oxides are abundant and frequently occur in large and characteristic growths. The ilmenite is often largely altered to an almost opaque leucoxene.

Thin prismatic crystals of apatite are plentiful, and are frequently found in thick patches, or clustered round what were probably at one time steam cavities.

Pseudomorphs of a green pleochroic substance, very evidently after olivine, are scattered abundantly throughout the rock. No fresh olivine, however, is to be seen.

Chloritic matter is plentiful in the more altered portions, and appears to have resulted mostly from the decomposition of augite. It is often aggregated into spherulitic clumps. Occasionally it has filtered into the cores of decomposing feldspars.

Apart from the marginal portions of the rock, calcite is abundant only in one region, and there it occurs in fairly large patches, having much the same relations to the other minerals as the analcite in the normal rock.

Coming to analcite, we find it so abundant as to form a conspicuous macroscopical feature of the rock. Under the microscope it is quite isotropic, or exhibits that anomalous birefringence which constitutes its principal optical diagnostic character. It may be dusty from inclusions, or quite clear. In contact with other zeolites it frequently shows crystalline outlines belonging to the trapezohedron. The characteristic cleavage is seen in crystals which have been fractured during the preparation of the slice. While preparing microscopic slices I found that the frequency with which the rock tore itself off from the glass slide was a fair indication of the amount of analcite present. This peculiarity is probably due to loss of water by the analcite on being heated, and its subsequent expansion on making good the loss.

It occurs in conjunction with a fibrous zeolite, possibly natrolite, in patches which may in some cases represent what were originally steam cavities. The mineral also occupies

¹ *Bulletin de la Société Géologique de France*, 1881 à 1882, pp. 289-95.

ANALCITE DIABASE AND OTHER ROCKS FROM GULLANE HILL. 331

angular spaces among the feldspars and augites. In certain portions of the rock it is found replacing feldspars, more often the more acid untwinned individuals.

I have already mentioned that in rocks of a similar character to this the feldspars are usually much decomposed. This diabase is no exception, though in the fresh quarried rock the alteration has not proceeded nearly so far as in the Spalefield teschenite. A short distance north of Gala Law Quarry there exists a local variation which throws considerable light on the question of the origin of the analcite. Here the alteration has taken a quite contrary course. Whereas in the typical Gala Law rock the augite is perfectly fresh, the feldspar much decomposed, and analcite an abundant secondary product, in this other variety the augite is much decomposed, the feldspar remarkably fresh, and calcite takes the place of analcite. On comparing specimens in which the augite has reached the same stage of decomposition the contrast is especially striking, the feldspar being in the one case very fresh, and in the other almost entirely obliterated. This points unmistakably to feldspar as the source of the analcite. This conclusion is further supported by the zonal habit of the feldspars and the abundance of soda-rich members of the series.

Rosenbusch, in supporting the view that in teschenites, where no nepheline can be observed, the analcite, nevertheless, has been derived from nepheline, argues that otherwise these rocks must have been remarkably porous. That in certain parts of the Gullane diabase such a miarolitic structure did exist, seems very probable from an examination of the calcite-bearing portion just referred to. Here can be observed patches of calcite four millimetres or less in diameter, into which there project on all sides idiomorphic crystals of the later formed, untwinned, and more acid feldspar. Behind and encircling these there is usually a stream of apatites, with their long axes tangential to the outline of the infilled cavity. These features, owing, doubtless, to some extent to the corrosion of the feldspars, cannot be well seen around the analcite patches.

Within the Gullane diabase are found two distinct and well-developed types of veins. One set obviously belongs to the class known as "acid segregations," the other is the result of intrusion subsequent to the consolidation of the surrounding rock. The former are seen to greatest advantage on the north face of Gala Law Quarry. These vary in thickness from eight inches to half an inch or less. Though the length of the larger veins cannot be determined, this must be considerable. The smaller veins are seen to branch, thin out, and disappear. In tint they are pink, and in hand specimens they can be seen

to be coarser than the surrounding rock, and to be composed mostly of felspar. The exposed surfaces have frequently a porous appearance, and this is obviously due to the washing out of decomposition products, which, however, may have occupied what were originally steam or gas cavities. Some large and undoubtedly original cavities are met with on fracturing some parts of the veins. There is no selvage, and the coarseness of texture is independent of the thickness of the veins. The larger segregations are usually bordered by mineral veins, and the surrounding rock is much decomposed. The latter is sometimes full of irregular patches, from an inch to a quarter of an inch in diameter, composed of the same material as the veins.

Under the microscope the rock composing these veins is seen to consist mainly of idiomorphic crystals of untwinned or simply twinned felspar, somewhat clouded through decomposition. These are, in great part at least, orthoclase. Chlorite, and some of the iron oxide, probably represent a ferro-magnesian. Apatite is common. Large patches of a brown fibrous zeolite are abundant in certain portions. In one part an interesting thing has happened. Round the margins of the original felspars, and in optical continuity with them, there has been deposited a thin secondary band of the same mineral. This clear border is found not only about good crystalline contours, but also where the outlines are broken and irregular. The large interspaces between the felspars are occupied by a mosaic of secondary quartz, which also occurs in patches in the felspars themselves. In one slice a similar mosaic, accompanied by calcite, is seen to be replacing felspar.

The mode of origin of such segregations is doubtful. Waller, after describing similar veins in the rock of Rowley Rag, and in an estatite diabase between Penmaenmawr and Llanfairfechan, suggests that they originated after the rock had partly consolidated, when, through contraction due to cooling and to crystallisation, fissures arose, into which the residual acid magma oozed.¹ This would account for their highly acid composition, but not by itself for the existence of the acid patches which I have described as occurring in the adjoining rock. Monckton notes similar acid patches accompanying veins in the Stirling dolerites.² I would suggest that these fissures arose, as one might expect, in areas of low pressure, where there would naturally be a larger proportion of water in solution than in the surrounding regions; this becoming concentrated in the fissures, and irregularly in patches in the

¹ *Midland Naturalist*, vol. viii., 1885.

² *Quart. Journ. Geol. Soc.*, vol. iv. 481, 482.

ANALCITE DIABASE AND OTHER ROCKS FROM GULLANE HILL. 333

neighbourhood, would give rise to all the phenomena just described.

There can be little doubt that all igneous rocks intruded into the earth's crust contained, before consolidation, large amounts of water in solution. This has been proved in the case of plutonic rocks like granite; and no one questions that the eruptive energy of volcanic outbursts is mainly derived from this source. Exactly how and at what stage the bulk of this water would escape from an intrusive sheet no one can say, but it is not inconceivable that during the process of cooling this water might become irregularly distributed throughout the magma, becoming concentrated in any areas of low pressure that might arise. The presence of water would, as has been abundantly demonstrated by experiment, bring about an increase in the molecular mobility of the saturated magma, and would thus lower the temperature of consolidation. Sorby, as the result of his investigations in 1858, concluded that the magma of granite had consolidated at a not higher temperature than would produce a dull red glow. Those areas of the magma, then, containing a relatively large amount of water, would remain liquid longer than the surrounding regions, and becoming more and more acid by diffusion, would on consolidation give rise to light-coloured acid portions of rocks. Waller notes that the quartz of the acid veins contain liquid inclusions, and the porous structure in the Gullane veins has already been mentioned. These acid segregations were observed only in the flanks of the sill, where it is obviously thinning out, and where cooling would take place rapidly and irregularities would be the more likely to occur. Williams comes to the conclusion that pegmatite veins, which bear a certain analogy to acid segregations, have mostly originated from a residual magma rich in dissolved water and other mineralising agents, whence the coarse texture and absence of all selvage.¹

The second type of veins occurs, as far as I have observed, only at Corby Craigs, where, as might also be said of the acid veins, they run roughly parallel to the margins of the main intrusion in which they occur. They are numerous, and vary in thickness from two and a half feet to half an inch. The larger veins do not differ much in colour from the surrounding rock, from which they could not easily be distinguished but for the well-marked dark selvages which they all possess. The smaller veins might be described as all selvage except for the strings of phenocrysts, which are usually found running along the centres, and to this latter peculiarity is due their

¹ *Annual Report, U.S. Geol. Surv.*, p. 684.

liability, on the application of the hammer, to split longitudinally through the middle. The smaller veins are often easily detached, whereas the larger ones are always firmly welded to the surrounding rock, portions of which they sometimes enclose. They are seen to branch, thin out to nothing, or abruptly disappear.

On microscopic examination they do not appear to differ much in composition from the surrounding rock, which is, however, at this point somewhat abnormal, from its proximity to the margin of the sill. The selvage is crowded with minute microlites of felspar, which are frequently arranged in radiate bundles. The dark colour is due to a dense multitude of small particles of magnetite or ilmenite which are generally gathered into clumps as observed by Monckton in the Stirling dolerites, and, as the margin is left, these particles are seen to arrange themselves into strings and skeleton forms. Phenocrysts of felspar, often in clusters, are scattered throughout, and that some of these at least are derived from the adjoining rock is proved by the dense fringe of iron oxide surrounding them, which represents on a small scale the dark borders of the larger and obviously derived fragments. A similar fringe is always to be found marking the junction of the selvage and the rock outside, and in some veins this is curiously repeated again in a line parallel to and about three millimetres from the margin. Small and somewhat circular patches of chlorite are very numerous. As the centre of the vein is approached, the rock becomes coarser in texture. Augite appears to have been at one time fairly abundant in ophitic plates, though it is now almost entirely replaced by calcite. The crystalline strings extending along the centres of the small veins are composed of felspar laths cutting into calcitic pseudomorphs after augite, which frequently retain the outlines of the original mineral with small unaltered portions of the latter. The grey colour of the small veins is due to the alteration of ilmenite to leucoxene. In all the veins, large or small, there is a very considerable amount of iron pyrites, which, in hand specimens, is sufficient to distinguish the coarser portions of the veins from the surrounding rock.

The injection of such veins is usually ascribed to a recurrence of the eruptive force, though they might be brought about by the difference in internal pressure between the still molten central portion and that first consolidated. These veins, as already mentioned, occur where the rock is rapidly thinning out, that is, in the region which would cool and consolidate earliest.

The following table of specific gravities is instructive:—

ANALCITE DIABASE AND OTHER ROCKS FROM GULLANE HILL. 335

	Sp. Gr.
1. Typical analcite diabase	2.79
2. Portion of diabase containing calcite but no analcite	2.77
3. Acid segregation	2.57
4. Interior of "subsequent veins"	2.74
5. Selvage of do. do.	2.81

The low specific gravity of the acid segregations mark them off distinctly from the enclosing diabase and the subsequent veins, which are practically identical in relative weight. The highest specific gravity is that of the selvage of the subsequent veins. The difference between Nos. 1 and 2 is probably due to the greater amount of unaltered augite in No. 1 than in No. 2.

Throughout the rock, veins of calcite, quartz, and zeolites are met with. In the centre of one calcite vein I found a string of chalcedony opening out to form a small agate. The fragmental nature and abundant twinning of another calcite vein in Gala Law Quarry point to its having been crushed at some period of the rock's history. Twinning can be produced artificially in calcite by pressure. On exposed surfaces of this vein the twin lamellæ are dissolved out, giving the mineral the appearance of possessing an additional cleavage. Occasionally it fractures along the twinning planes.

The most important features of the igneous rocks I have just described are, in the Gullane Point dolerite, the peculiar pseudomorphs after olivine and the olivine nodules; and, in the diabase, the abundance of analcite and other zeolites, with the remarkably clear indications of their origin from felspar; the hornblende peripheral to the augite, and the fine exposures of two distinct types of veins.