XIV. "On some supposed changes Basaltic Veins have suffered during their passage through and contact with Stratified Rocks, and on the manner in which these Rocks have been affected by the heated Basalt." By I. Lowthian Bell, F.R.S. Received May 27, 1875.

The northern counties of England afford very satisfactory evidence of the intrusion, in former geological times, of a large area of fused matter beneath portions of the then-existing surface, and through the vertical, or nearly vertical, faults and fissures of thin sedimentary strata.

Through the observations and writings of N. J. Winch*, Sir Walter Trevelyan†, Prof. Sedgwick‡, William Hutton§, John Buddle‖, Nicholas Wood¶, Westgarth Forster**, and several other observers of earlier†† and more recent‡‡ date, we have been made acquainted with many details of the existence, appearance, and direction at the surface of extensive whin-dykes and beds of intercalated trap, basalt, or whin, using the terms which have hitherto been generally and locally applied to the igneous rocks found in connexion with the Carboniferous formation of these districts.

In the most northerly part of Northumberland a broad dyke of igneous rock occurs on Holy Island, and is continued on the mainland to the west. Several other dykes, too numerous, indeed, to be specially mentioned in this communication, occur in the Carboniferous rocks between this locality and the banks of the Tees, having for the most part a direction from west to east. In addition to the dykes which may have filled up old lines of faults and fissures, we have bedded igneous rocks, where fused matter, instead of coming to the surface, has forced its passage or way, horizontally between the regular and previously stratified sedimentary rocks. Sometimes also the igneous matter is found between the central portions of individual beds of shale and limestone, and in its course has oftentimes enclosed in its mass considerable portions of such preexisting beds, as in the examples figured by Prof. Sedgwick in the second volume of the Cambridge Philosophical Transactions.

* Trans. Geol. Soc. 1814, vol. iv. pp. 21 & 73.

† Wernerian Soc. Memoirs, 1821–23, p. 253, and Trans. Nat. Hist. Soc. Northumberland and Durham, 1830, vol. i. p. 58.

‡ Cambridge Phil. Trans. vol. ii. pp. 21 & 139.

§ Trans. Nat. Hist. Soc. Northumberland and Durham, 1831, vol. ii. p. 187.

‖ *Ibid.* 1830, vol. i. p. 9.

¶ *Ibid.* 1831, vol. i. p. 327.

** Section of the Strata &c., 1821.

†† Hon. H. G. Bennett, M.P., F.R.S., Geol. Trans. 1812, vol. iv. p. 102; Conybeare and Phillips, Geol. of England and Wales, 1821, pt. 1; Michael Forster, Trans. Nat. Hist. Soc. Northumberland and Durham, 1830, vol. i. p. 44; Francis Forster, *ibid* p. 75; Henry T. M. Witham, *ibid.* vol. ii. p. 343.

‡‡ George Tate, Trans. Tyneside Nat.-Hist. Field-Club, vol. ii. new series.

The Whin-sill, as it is termed by the lead-miners of the Alston-Moor district, is the most remarkable example of bedded igneous rock in the northern counties, extending as it does from the Farne Islands in the north to the county of Northumberland; and after passing the Stublick Dyke, by which it is faulted, it skirts the escarpment of the Pennine range in its outcrop, and terminates, so far as we are informed, in the neighbourhood of Lunedale in Yorkshire.

There is another but smaller occurrence of bedded basaltic rock near Stanhope, in Weardale, which was formerly, and very accurately, described by Sir Walter Trevelyan in the first volume of the 'Transactions of the Natural-History Society of Northumberland and Durham.'

Another lateral intrusive mass of whin exposed by denudation at the surface occurs at Bolam, in South Durham, in connexion with the celebrated Cockfield-Fell Dyke. This mass has been figured and graphically described by Prof. Sedgwick in the Cambridge Transactions above quoted.

A further instance of the lateral or horizontal intrusion of igneous rock which we have now to describe occurs in connexion with the basaltic dyke which extends from Egglestone Moor along the Bedburn Beck, through Bitchburn Colliery, Constantine Farm, Whitworth, Tudhoe, Hett, Tursdale, and Crow Trees, to Quarrington Hill, on the escarpment of the Magnesian Limestone. This dyke was first described, and its direction traced, by Prof. Sedgwick. Though it is nowhere seen in contact with the Magnesian Limestone, its existence is proved in the colliery of Shotton, which is worked entirely under that formation.

At the point where the Hett Whin-dyke crosses the Wear are the workings of Pagebank Colliery, which is in the occupation of Messrs. Bell Brothers. A little more than two miles to the north is a second basaltic dyke, running parallel to the Hett Dyke for some distance; but I am not aware that any actual point of junction has hitherto been observed between these neighbouring dykes*.

Connected with the mining-operations of the above-named colliery a bore-hole, to prove the position of the coal, was commenced about 730 yards to the south of the more northern dyke. The usual well-known strata of that district were passed through; but on reaching a depth of 56 fathoms a hard rock was struck, which proved to be whinstone. Fourteen weeks were consumed in penetrating 26 inches into this obstacle, after which it was abandoned; and a second hole was commenced 940 yards to the west of the first, but with no better results, for at a depth of 65½ fathoms the same impediment was met with. After much labour and loss of time a length of 4 feet 9 inches was bored into the whin, and then no further progress was attempted.

* I am indebted to my friend Mr. Richard Howse, of Newcastle-on-Tyne, for the information given above respecting the localities in which basaltic rock is found in the North of England.

In the mean time a neighbouring firm had sunk a pit in the immediate vicinity without meeting with any trace of whin rock; and as circumstances demanded it, two shafts were commenced by Messrs. Bell Brothers 185 yards N.E. of the first bore-hole. The area within these three points amounts to something like 15 acres. When the more advanced of these pits was sunk to a depth of 67 fathoms, the men came upon the hard obstacle met with in the bore-holes; and the same thing happened in the second shaft, situate 60 yards to the west of its neighbour.

In each case fully four months of incessant labour, accompanied with considerable expense, was required before the lower surface of this hard stratum was reached, which proved to have a thickness of 19·75 feet. In all probability, however, its dimensions are subject to considerable fluctuations, for in one of these two pits the bed is 4 feet thinner on the north side of the shaft than on the south.

It was now clear that it was a bed of basalt lying in a horizontal position which was encountered, in which direction it had spread itself as one offering less resistance than that to be overcome by forcing an exit at the surface. At what point a communication exists between this interjected mass and its subterranean source we have had no means of ascertaining.

Above and below the basaltic bed, as found in the pits, there are two well-known seams of coal. In the neighbouring colliery spoken of (Littleburn) these are separated by 50·25 feet of fire-clays, shales, and sandstones, while in the present case the intervening rocks measure 103·66 feet, showing an increase of 53·41 feet. Of this only 19·75 feet is due to the whin, the remaining 33·66 feet arising from a thickening of the sandstone and other deposits.

During the entire progress of sinking specimens of the rocks were preserved, which enabled me at my leisure to examine not only the whin but also the altered character of the adjacent strata.

The change experienced by the latter has frequently formed the subject of comment; but I am not aware that much attention has been directed to any modification in the composition of the basalt itself, caused by contact with the substances through which it had penetrated.

It would of course be highly instructive if any sedimentary rock could be accepted, in respect to its constituents and their relations to each other, as a normal type of whinstone. If, for example, an aqueous rock were found in the immediate vicinity of basalt, and the compositions of both were the same, one might infer the physical difference to be due to the mere influence of igneous action.

There are, however, to be found in nature many substances which more or less resemble in constitution the matter filling whin-dykes, clay-slate being one, some specimens of which contain the following ingredients:—

Silica	54
Alumina	24
Protoxide of iron	14
Magnesia	5
Potash	3
	100

Now there would be nothing extravagant in the supposition that clay-slate of this character reduced to a state of fusion by heat might be materially altered in passing through the Mountain Limestone and Millstone-grit before reaching the surface in the county of Durham, and that it then might resemble the composition of the whin-dykes of the district. That the Hett Dyke and its parallel one derive their origin from one common source, and if changed by subsequent contact with other rocks have been altered in each case by the same cause, is apparent on referring to their respective compositions.

	Hett Dyke.	Parallel Dyke.
Silica	51·35	50·60
Alumina	17·61	17·38
Protoxide of iron	12·04	12·22
Lime	9·65	9·20
Magnesia	5·68	5·66
Potash	1·40	1·64
Soda	·56	·50
Carbonic acid	1·53	2·57
	99·82	99·77

In some measure the interior portions of the horizontal bed found in the pits resemble these two specimens in the nature of their constituent parts, and in physical appearance there is little or no difference among them. Fragments taken from the bed gave:—

Silica	51·90
Alumina	15·46
Protoxide of iron	12·87
Lime	13·80
Magnesia	4·02
Potash	1·21
Soda	·48
Carbonic acid	1·02
	100·76

As stated, the specimen just described was obtained from the interior of the mass of whin; but its exterior, both on the upper and lower surfaces, is covered with a coating 10 inches thick in the one, and

something under this in the other case. These coatings exhibit a marked similarity to each other; but a striking difference in some respects is observed to the interior of the mass they surround.

	Upper surface.	Lower surface.
Silica	43·22	40·62
Alumina	17·44	18·18
Protoxide of iron	13·03	14·00
Sulphide of iron	....	1·31
Lime	6·26	4·37
Magnesia	2·86	3·94
Potash	} 1·28	·78
Soda		·33
Carbonic acid	14·72	13·23
Water	1·46	2·36
	100·27	99·12

In colour these coatings are of a light buff, and are close in texture, in both of which particulars they differ considerably from the unchanged basalt. It would appear that any difference in composition between the interior of this horizontal bed of basalt and its outer surfaces is entirely independent of that which might be supposed to arise from mere contact with the adjoining strata. Lying above it is 8 feet of a siliceous rock known among miners in the North of England as a "white post." It was found to consist of:—

Silica	88·25
Alumina	5·69
Peroxide of iron	1·71
Lime	1·53
Magnesia	·69
Potash	·80
Soda	·21
Water	1·75
	100·63

The underside of the basalt rests upon a thin seam of coal, greatly charred by its proximity to so large a volume of matter, which must have arrived at its present position in a state of intense heat. This coal is of course deficient in volatile constituents, and contains a large percentage of ash, one half of which is carbonate of lime. Its composition is as follows:—

Carbon	56·58
Hydrogen	1·00
Oxygen	3·52
Sulphur	·18
Ash	38·65
	99·93

It will be observed that, in the first three instances quoted of the component parts of whinstone, carbonic acid is named as a constituent varying in amount from 1·02 to 2·57 per cent. of the whole. This is a little remarkable, because I confirmed by actual experiment that when protoxide of iron, lime, magnesia, potash, and soda, in the form of carbonates, are fused with silica and alumina in the proportions in which these substances are found to exist in the whin, the resulting mass does not contain, as might be expected, a trace of carbonic acid. Whether the small quantities just mentioned of this acid represent portions which under immense pressure could not escape from the lime with which it was perhaps originally combined, is a question to which no satisfactory answer can be given.

On the other hand, it is not improbable that basalt may, after or possibly during the act of cooling, be placed in circumstances where carbonic acid may be absorbed by such of its constituents as are known to form carbonates.

The following experiments were tried on a sample of the pounded whin-rock previously ascertained to contain 1·97 per cent. of carbonic acid:—

	per cent. CO_2.
a. 2·5 grammes having been exposed during four days to dry carbonic acid, then contained (being practically unchanged)	1·94
b. 2·5 grammes, after exposure during four days to moist carbonic acid, contained	2·04
c. 2·5 grammes had passed over it during five hours, at a temperature of about 500° C., a current of carbonic acid. It gave	1·10
d. 2·5 grammes treated as in *c*, the carbonic acid being moist, gave	1·70
e. 2·5 grammes, exposed at a low-red heat for five hours to a current of dry carbonic acid, contained	·29
f. 2·5 grammes treated as in *e*, but moisture was present, gave	·49

The experiment *b* in the series would indicate that when moisture is present a small quantity of carbonic acid is absorbed at ordinary temperatures. When the temperature was raised, as in *c*, *d*, *e*, and *f*, there was a perceptible loss of acid; but in *d* and *f* this loss was materially retarded by the presence of vapour of water. It is therefore conceivable that carbonic acid, if at one time entirely expelled from the fluid basalt, may have been reabsorbed, when aided by the presence of moisture and probably under enormous pressure, during the countless ages which have elapsed since it first occupied its present position.

This idea is confirmed to some extent by an examination of the com-

position of the outer coverings of the basalt, already described. These in all probability would, from their position, be more freely exposed to the action of carbonic acid than the interior of the mass of which they formed the coating. That these portions are in reality identical with the bed itself, merely altered by the rate of cooling, or by a change in composition due to absorbing carbonic acid, or by these causes combined, is easily seen when the proportions of their fixed elements are compared with those as they exist in the whin-rock of the neighbourhood.

Fixed elements.	Covering of horizontal bed.	North dyke parallel to Hett Dyke.	Interior of horizontal bed.
Silica	51·56	52·05	52·05
Alumina	20·72	17·88	15·50
Protoxide of iron	15·47	12·58	12·90
Lime	7·38	9·47	13·83
Magnesia	3·33	5·82	4·02
Potash and soda	1·54	2·20	1·70
	100·00	100·00	100·00

The chief change, therefore, in composition which the outer portions of the bed of whin have experienced is a much greater absorption of carbonic acid, amounting to nearly nine tenths of the total quantity required for converting the iron, lime, magnesia, and alkalies into carbonates.

It is perhaps a difficult task to speak with any degree of confidence on the precise nature of the causes which have given rise to certain differences in the proportions of some of the earths as exhibited in the above figures. We may, however, readily imagine that a liquefied rock, during its passage through a series of stratified beds of various kinds and of different thickness, will continue for a longer or a shorter time in contact with any given substance, according to the size of the latter, or according to the rate at which the stream of fluid matter for the time being is travelling. It is also equally easy to suppose that the exterior may solidify by contact with cooler surfaces when the basalt has assumed the composition resembling that of the crust or coverings already described. The liquid torrent continues to flow through beds in which lime preponderates, such as the mountain limestone: an additional quantity of this earth is dissolved, and the basalt, thus altered in composition, is expelled through a kind of gigantic tube formed by the cooling of the first portions of the ejected mass.

As a source of silica and alumina I would point to the composition of the rocks immediately below the thin seam of coal underlying the horizontal bed of basalt under consideration.

	Charred coaly shale.	Strong blue shale.	Grey post stone.	Fire-clay.
Thickness	0 ft. 3 in.	9 ft. 4 in.	1 ft. 3 in.	3 ft. 0 in.
Silica	39·80	52·85	67·30	61·65
Alumina	29·91	28·15	9·47	23·77
Protoxide of iron	2·60	4·62	11·81	4·64
Sulphide of iron	....	....	....	·03
Lime	·64	·68	1·01	·15
Magnesia	1·19	2·13	2·16	2·49
Potash	2·60	1·52	·61	2·24
Soda	·84	·92	·81	·21
Carbonic acid	....	....	4·53	....
Water	....	8·05	3·35	5·41
Carbon	22·24	1·30	....	....
	99·82	100·22	101·05	100·59

Having now considered the changes which the intruded igneous rock has undergone, the alterations may be examined which the presence of a vast mass of highly heated matter has effected on the adjacent sedimentary rocks.

The small amount of volatile constituents left in the thin seam of coal immediately underlying the bed of whin in the pit has been already explained. At a distance of about 17 feet below this is a second bed of coal 5 inches in thickness; but to it the intervening rocks have acted in some degree as a protection against the volatilizing power of the heated basalt lying above.

By its analysis the following results were obtained:—

Carbon	78·05
Hydrogen	3·78
Oxygen	4·32
Sulphur	4·33
Ash	10·15
	100·63

At a further depth of about 35 feet from this perhaps slightly altered coal, or 52 feet below the bed of basalt, is another nearly 5 feet thick, known as the Busty, which is one of the well-known coking seams of the country. When the coal from it is compared with that obtained from the same bed two miles away, there is perceptible difference to be observed. We may therefore infer that the emission of heat from the thick body of melted basalt lying about 50 feet above it was at the time of cooling so slow as not to have affected the composition of this coal, which loses at moderately high temperatures 35 per cent. of its weight.

Looking at the very complex nature of the composition, already referred to, of the coaly shale, strong blue shale, and grey post stone, it

seems not impossible but that some of the constituents of these strata, common to all, may owe their origin to the basalt itself, from which they may have been emitted in the form of vapour.

Although silica, alumina, and lime are regarded, and justly so, as being little affected by exposure even to a very intense heat, I am nevertheless disposed to believe that all three are susceptible of being evaporated at temperatures not unfrequently used in the arts. From iron blast-furnaces, and particularly from those in the North of England, a vast quantity of white fume or smoke is emitted, which readily condenses on a cold surface. To one of these furnaces in the county of Durham I attached an air-pump worked by steam, and by its means the whole of this fume from a given volume of gas, as it escaped from the furnace, was condensed in water.

On analysis it was found to be composed of—

Silica	14·06
Alumina and some peroxide of iron	25·70
Lime	2·30
Magnesia	trace
Chlorine	·61
Sulphuric acid	·64
Oxide of zinc	19·99
Carbonates of potash and soda	29·05
Carbonic acid	7·83
	100·18

Not being prepared to find certain of these bodies carried away in the vaporous form, the idea suggested itself that they might, in the first instance, be deoxidized in the powerfully reducing atmosphere of the hearth of the furnace, and subsequently reoxidized in its upper regions. To satisfy myself on this point, I drew a considerable volume of the gases as they exist in the hottest portion of the reducing zone and passed it through cold mercury. Had any such action as that indicated been effected, I would expect to find potassium or sodium in the mercury. No trace, however, of these metals was detected, and I therefore concluded that the furnace-vapours in question must be regarded as true sublimates. If so, and if the estimate of the quantity be correct, many thousands of tons of alumina &c. are annually evaporated on the banks of the Tees during the process of smelting iron.

If similar vapours were emitted by basalt when intensely heated, it is almost certain that, under the great pressure then prevailing at the depth of this particular bed, some portion would find its way into the adjoining strata. Lying above the basalt is some 8 or 9 feet of a rock spoken of as "white post." On referring to the analysis formerly quoted, it will be seen that this bed contains 88·25 per cent. of silica (it is there-

fore a true siliceous rock), and that its remaining 11·75 parts consist of substances all of which occur in the basalt. It is true the same may be said of the rocks underlying the stratum of whin, and that in both cases these ingredients, found in small quantities, may have been deposited with the material constituting the main body of the bed.

Believing, however, in the possibility of the basalt having been the source of all or a part of what may be designated as foreign ingredients in this white post, three specimens were submitted to examination. One was taken from the bed where it adjoins the whin, a second from its middle, and the third from its upper portion; and certainly, so far as some of these ingredients are concerned, they tend to confirm the view just expressed. This view is based on the fact that the substances in question are found in greatest quantity next the basalt, and that they gradually diminish in this respect as the distance from the basalt increases.

	Adjoining bed of whin.	Middle portion.	Upper portion.
Silica	83·17	84·31	86·22
Alumina	8·34	8·80	8·47
Peroxide of iron	....	·57	1·00
Protoxide of iron	1·32	1·03	·64
Lime	1·74	·93	·91
Magnesia	·94	·83	·22
Potash	1·02	·89	·81
Soda	·58	·52	·38
Carbonic acid	1·20	·77	·60
Water	1·50	1·70	1·20
	99·81	100·35	100·45

Before any well-established conclusions can be arrived at on the changes of composition experienced by basalt, as well as by those strata through which it has been ejected, a very extended series of observations is indispensable. At some future opportunity I may pursue this inquiry into other geological districts traversed by the 170 miles of whin-dyke described in my opening remarks; in which case, should it be the wish of the Society, I would lay before its members the results of my examination.

The analyses referred to in this communication were made at the Clarence Iron Works by Mr. Rocholl, the superintendent of the laboratory attached to the establishment.

P.S. Since writing the above, I have ascertained that the late Professor Jukes met with in the Staffordshire coal-field, and described under the name of "white rock," an altered basalt. Its composition as given is:—

Silica	38·830
Alumina	13·250
Protoxide of iron	13·830
Peroxide of iron	4·335
Lime	3·925
Magnesia	4·180
Potash	·422
Soda	·971
Carbonic acid	9·320
Water	11·010
	100·073

Although Professor Jukes expresses himself as confident of the origin of this substance, he nowhere had an opportunity of examining it in contact with basalt previous to its alteration. The presence of carbonic acid and water he ascribes to subsequent infiltration.

XV. "Results of Magnetical Observations made in Little Namaqualand during a part of the Months of April and May, 1874." By E. J. Stone, M.A., F.R.S. Received June 11, 1875.

An eclipse of the sun was to occur on April 16, 1874, which would be total throughout Little Namaqualand. I made arrangements for a visit to this country to observe the eclipse. The country is one rarely visited. I was not aware that any determinations of the magnetic elements had been made there, except a few of the variation by the Admiralty surveyors at one or two points along the coast. It appeared to me desirable that the opportunity afforded by my visit to observe the eclipse should not be lost of securing magnetical observations at several stations in Namaqualand. An application was made to the Colonial Government for some assistance. An ox-waggon was required for the transit of the magnetical equipment and of a wooden building which had been prepared to protect the instruments and the observers whilst at work. The sum asked for was sixty pounds. The request thus made was, however, refused, although with great courtesy and apparent reluctance, from a supposed difficulty in passing such a grant through Parliament. I was, however, most unwilling to abandon the idea of making these magnetical observations. When the facts of the case became known, I received offers of assistance from some gentlemen in Namaqualand, and His Excellency Sir Henry Barkly, K.C.B. &c., kindly interested himself in the matter and afforded me all the facilities in his power. I determined therefore to carry out, in a somewhat modified form, the scheme of observations which I had arranged. The wooden building was left behind. I found that good observations could be made without cover of