

15. *GEOLOGY of the ASHBOURNE & BUXTON BRANCH of the LONDON & NORTH WESTERN RAILWAY:—ASHBOURNE to CRAKE LOW.*
By H. H. ARNOLD-BEMROSE, Esq., M.A., F.G.S. (Read January 4th, 1899.)

[PLATES XVII & XVIII—Sections].

CONTENTS.

	Page
I. Introduction	224
II. Description of the Cuttings	225
(1) Sandybrooke.	
(2) Alders Farm.	
(3) Ashes Farm.	
(4) Bentley Hall.	
(5) Washbrook.	
(6) Tissington.	
(7) Highway Close Barn.	
(8) Crake Low.	
III. Crake Low Quarry	231
IV. Petrography of the Rocks	233
(1) The thick Ash-bed.	
(2) The Ejected Blocks in the thick Ash.	
(3) The thin Tuffs and Tufaceous Limestones above the thick Ash.	
(4) The Limestones.	

I. INTRODUCTION.

THE railway from Ashbourne to Buxton, when completed, will cover a distance of about 20 miles. It runs nearly due north, passing near the villages of Fenny Bentley, Thorpe, Tissington, Parwich, and Alsop-en-le-Dale, and will enable visitors from the north to reach conveniently some interesting parts of the limestone-district, besides rendering the beauties of Dovedale more accessible to the tourist.

For the first 6 miles the railway runs on the Bunter Beds, Boulder Clay, and Yoredale rocks, and for the remaining 14 miles on the Mountain Limestone. The northern section, from Buxton to Parsley Hay, was completed several years ago, and I believe that no geological description of it was published. The southern section is now in progress of construction. The cuttings as far as Crake Low, about 6 miles from Ashbourne, are practically completed, but farther north there are several through which a passage has not yet been made. For this reason, I confine myself in the present paper to a description of the geology of the line from Ashbourne to Crake Low.

Undoubtedly the most interesting portions are the three cuttings near Tissington, Highway Close Barn, and Crake Low. Sir A. Geikie,¹ speaking of the latest traces of volcanic activity in Derbyshire, points out that 'though no contemporaneous tuffs have yet been

Fig. 1.—Section through Tissington Cutting.

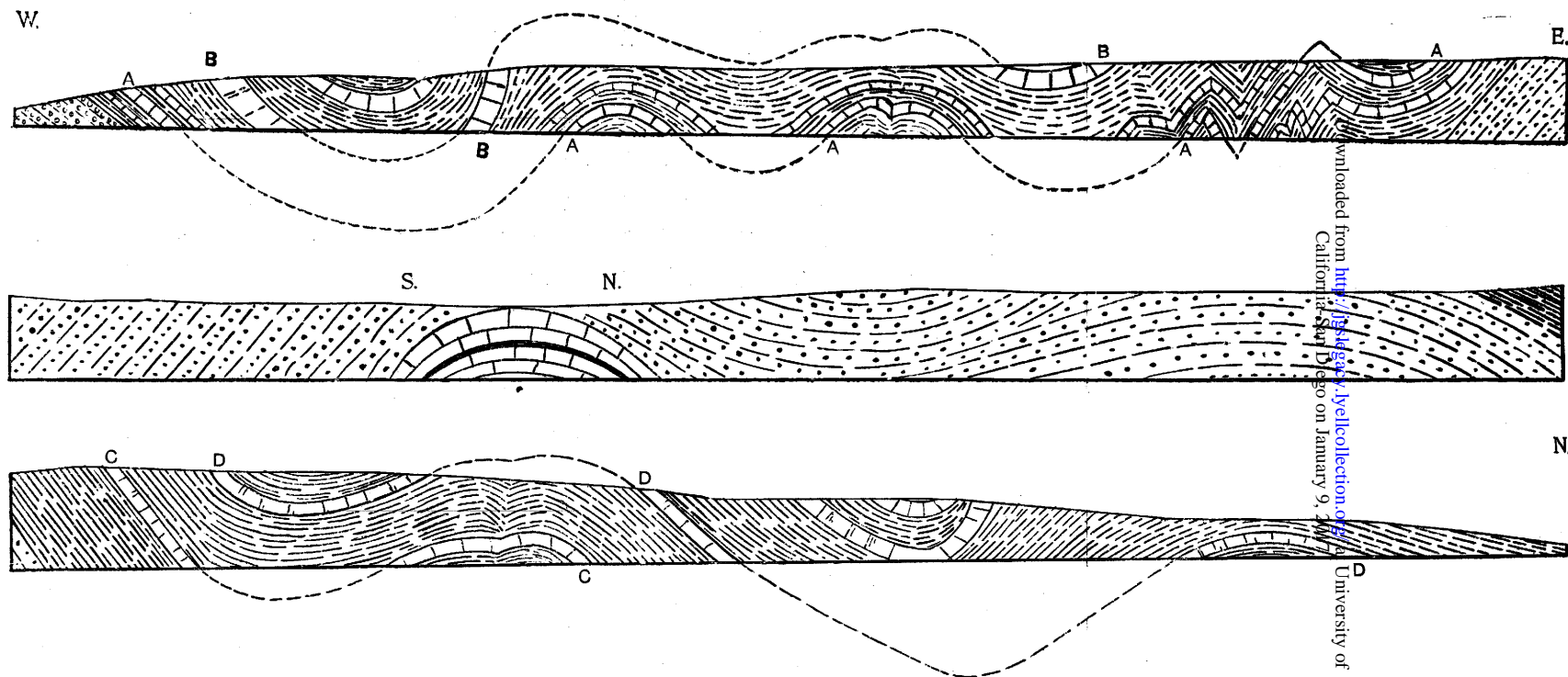
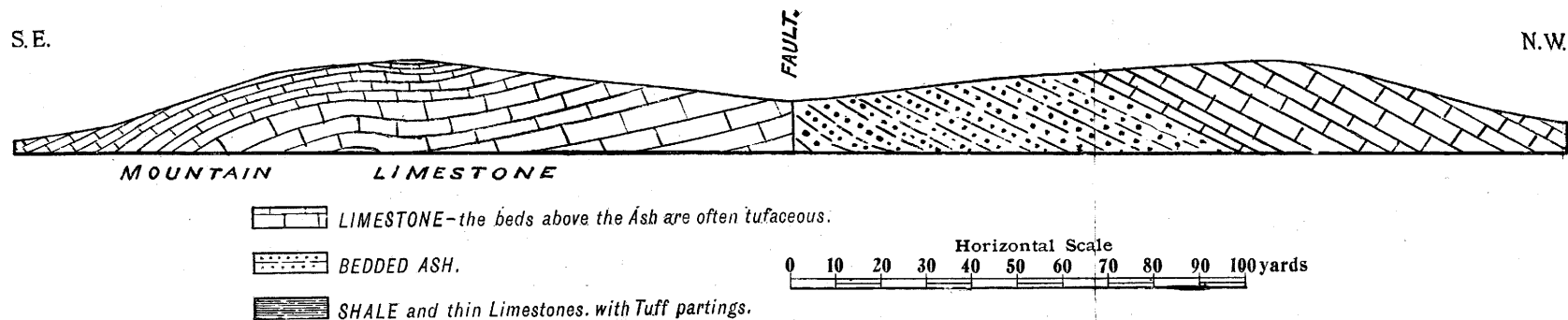


Fig. 2.—Section through Highway Close Barn Cutting.

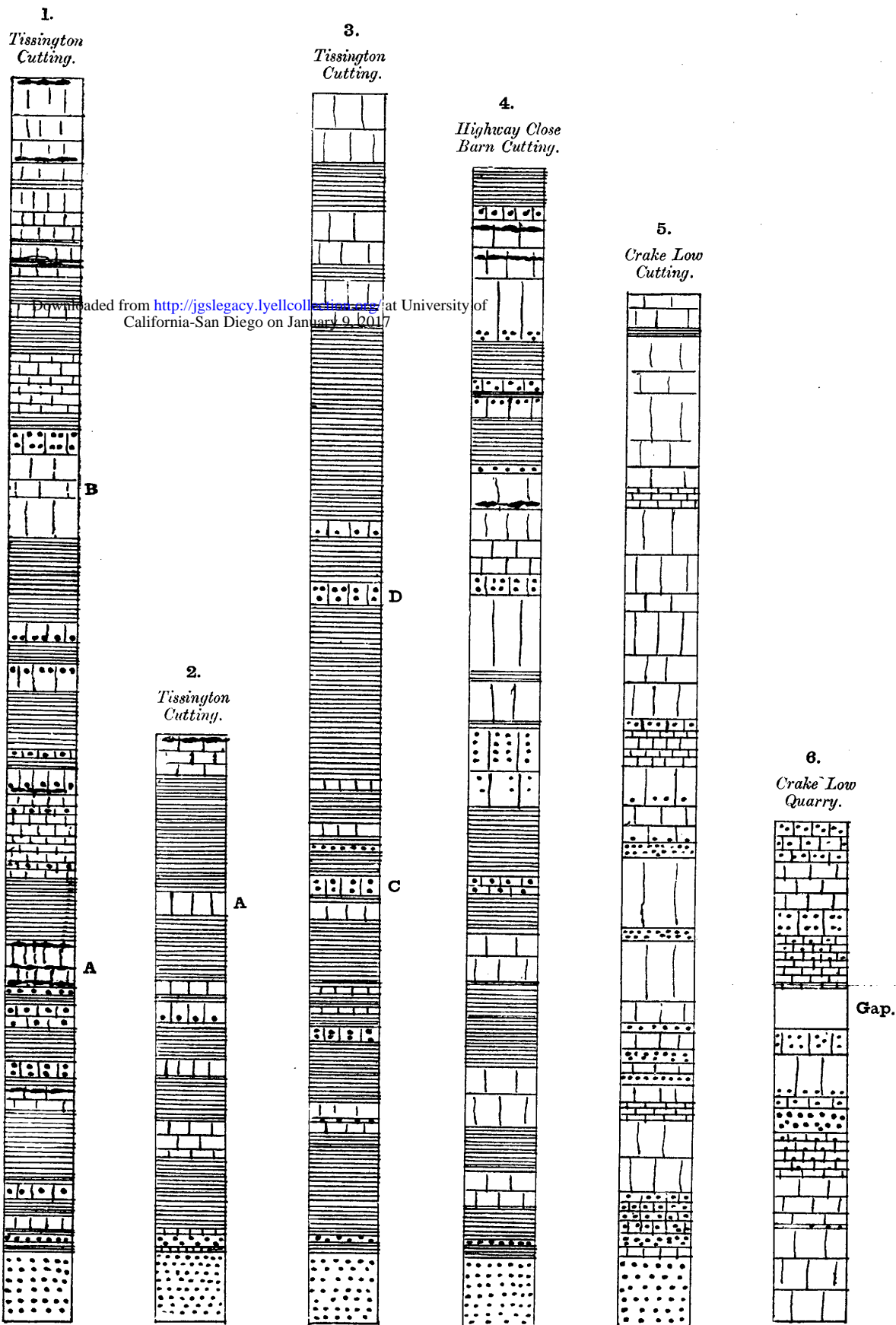


Fig. 3.—Section through Crake Low Cutting.



VERTICAL SECTIONS OF BEDS ABOVE THE THICK ASH BETWEEN TISSINGTON AND CRAKE LOW.

Quart. Journ. Geol. Soc. Vol. LV, Pl. XVIII.



Limestone.
 Tufaceous limestone.
 Shale and thin limestones.
 Ash or tuff.

[Scale : 1 inch = 12 feet.]

found among the Yoredale rocks, coarse agglomerates do traverse the Yoredale group at Kniveton.' A careful examination of these cuttings has enabled me to fill this gap in our geological knowledge. The railway-excavations bring to view no less than four exposures of bedded ash, the existence of which in the Yoredale rocks of this district had not been previously known. They also show a fine series of contorted limestones and shales, which occupy a horizon above the ash. This series of rocks contains numerous intercalations or thin beds of tuff, and many of the limestone-beds in it have volcanic lapilli disseminated through them. Thus they afford a proof of the existence of a vigorous, followed by an intermittent, volcanic activity, contemporaneous with the deposition of the Lower Yoredale Beds.

After crossing under Church Street, Ashbourne, the railway passes through the Bunter Beds in a tunnel, 370 yards long. Unfortunately, I was unable to visit the tunnel before it was bricked in, and, therefore, cannot give any details regarding the structure of the rocks through which it is cut.

II. DESCRIPTION OF THE CUTTINGS.

(1) Sandybrooke.

The first cutting opposite Sandybrooke is about 730 yards long, and shows a thick deposit of Boulder Clay. It contains pieces of sandstone, grit, and Mountain Limestone, the last often having a well-polished and striated surface. The greater part had been sloped down before I saw it, but the boulders are numerous and project above the surface of the Clay.

(2) Alders Farm.

The second cutting, opposite Alders Farm, about 250 yards long, is in Boulder Clay. It contains numerous boulders of Mountain Limestone, grit, sandstone, shales, chert, and igneous rocks foreign to the county.

(3) Ashes Farm.

The third cutting, opposite Ashes Farm, Fenny Bentley, about 330 yards long, is in Boulder Clay, which in one place is seen to rest upon a bed of sand. A large number of foreign igneous rocks were found here, in addition to boulders from the Carboniferous sedimentary rocks.

These three cuttings were visited by me after they had been practically finished; but the others as far as Parsley Hay, where the new railway joins the previous extension from Buxton, were frequently examined during the course of excavation. By this means, much information was gained about the stratigraphy of the beds, which would have been missed had the cuttings only been seen when finished.

(4) Bentley Hall.

The fourth cutting, opposite Bentley Hall, about 690 yards long, is in a tough Boulder Clay which contains many well-polished and grooved limestone-boulders. At the end nearer Tissington the Clay rests upon shales. Immediately north of the cutting, in an old quarry near the point where the railway crosses the Buxton road, is an exposure of shales and limestones dipping in an easterly direction. The limestones are black in the interior, but covered by a weathered crust, which gives them the appearance of sandstone: they contain bands of chert in which foraminifera occur.

(5) Washbrook.

The fifth cutting, east of Washbrook Cottage, about 290 yards long, is in Boulder Clay at either end, underneath which shales and thin limestones are seen for a short distance in the centre.

The railway now makes a curve to the east, and describes nearly a semicircle round the eastern part of the village of Tissington. After leaving the cutting in Boulder Clay, it crosses a small valley in the soft ash, and enters the sixth cutting.

In the three cuttings to which the remainder of this paper is devoted, four exposures of thick ash may be seen, each overlain by shales and limestones, with intercalations of tuff. For the sake of distinction only, and not implying thereby any difference in composition, the term ash will be restricted to these four exposures, while the thinner intercalations of volcanic detritus will be called tuffs.

(6) Tissington. (Pls. XVII & XVIII.)

This cutting is about 1060 yards long, and may be naturally divided into three nearly equal portions—the northern, central, and southern. A bed of ash about 144 feet thick, below which is seen a few feet of cherty limestone on the eastern bank of the cutting, occupies the whole of the central portion, and dips beneath the contorted shales and limestones in the two other parts of the cutting. The cherty limestones below the ash are now only visible on the eastern side, where they are bent into an anticline: they were formerly to be seen across the railway. During the excavation they were seen dipping at an angle of 40° across the cutting, and thus only 2 feet of the uppermost beds appeared at the bottom of the eastern bank under the ash, which dipped with and overlay them. After a short time they were hidden by débris. The line at this point passes through a dome, composed either of the upper cherty beds of the Mountain Limestone, or of the basement-beds of the Yoredale Series. The ash is exposed for a much greater distance north of the dome than south of it, and there are indications that this part of the volcanic deposit has been bent into a long syncline and anticline before it dips under the shales in the northern portion of the cutting.

It has, in fact, been subjected to the same foldings as the beds above and below it.

The ash is generally of a rather coarse texture, has in many places a distinct lamination, and contains numerous blocks of a dark blue or grey amygdaloidal rock, distributed irregularly throughout its mass.

A thick bed of volcanic ash also occurs at the southern end of the cutting. It is much decomposed, and only the upper 36 feet of it is seen. It is overlain by a succession of shales and thin limestones (some of which are tufaceous) with thin partings of tuff. The limestones often contain chert, *Productus*, and encrinite-stems, and in places are dolomitized. The beds at first dip in a north-easterly direction and then become bent into a number of troughs and arches. The railway turns northward, the beds dip south-westward, and under the shales one again finds the bedded ash.

The occurrence of four exposures of ash in this and in the next two cuttings led me to try and ascertain whether they all belonged to the same deposit, or were due to several eruptions. They all occur within a mile of Tissington, and one would hardly expect to find, within so short a distance in this district, evidence of several great outbursts, each followed by a succession of more feeble eruptions.

The structure of the ground, the numerous folds into which the beds have been thrown, and the fact that the country is largely covered by Drift, render it difficult, if not impossible, to connect directly the four outcrops of ash by tracing their relations in the field. I have already mapped a large area of ground covered by the second exposure of ash, through which the central portion of Tissington cutting passes, in order to trace it, if possible, to its source. But it would be beyond the scope of the present paper to enter into any further details regarding the surrounding country, and that part of the subject must be left until I have more fully worked out the rocks of the district. I have been able, however, to trace this ash in a northerly direction, up to within a short distance of the third exposure of ash, which is seen in the Highway Close Barn cutting (p. 229).

In order to ascertain whether the two beds of ash in the Tissington cutting belonged to the same deposit, I made careful measurements of the thickness of the beds, at right angles to the bedding-planes, from one end of the cutting to the other. I measured from the southern ash up to the top of the first syncline, then down to the base of the adjacent anticline, and so on, to the second exposure of ash: the total up-and-down measurement differed by 6 feet. I then plotted ten vertical sections to scale, and found that the ash at the second exposure was 6 feet lower in the series than that at the first. The measurements were then checked in several ways in the field, and the difference of 6 feet was found to hold good.

A comparison of the sections showed that there were several well-defined beds of limestone, one of which appeared six times, and another three times in this part of the cutting above the ash. The lower of these two beds is denoted by the letter A, and the upper bed by the letter B, in Pl. XVII, fig. 1, and in Pl. XVIII, figs. 1 & 2.

The distance of A above the ash was $22\frac{1}{3}$ feet at the southern end. The bed A was easily traced through this part of the cutting, and at its last appearance was found to be $28\frac{1}{4}$ feet above the second exposure of ash. It varies in thickness, thinning out from $3\frac{1}{2}$ feet at the southern end to 1 foot at the northern. It contains chert, and in many places volcanic lapilli occur disseminated in it.

The upper beds, marked B, are easily distinguished by the fact that they are thicker than the other limestones in the series. They are first found near the southern end, at a height of $59\frac{1}{2}$ feet above the ash. They are seen again in the middle limb of the first fold, and then at the top of the cutting immediately beyond the temporary bridge over which the road to Matlock passes. They contain encrinite-stems, *Productus*, and sometimes lapilli. Like the bed A, they vary in thickness: in a distance of about 43 yards, measured parallel to the original bedding-plane, they thin out from $9\frac{3}{4}$ to 6 feet, and when seen for the third time are $7\frac{1}{2}$ feet thick.

There is, therefore, no doubt that the first and second exposures of ash in this cutting are of one and the same bed, the shales and thin limestones above it having been bent into a number of small folds which amount in effect to a syncline.

The total thickness of these beds above the ash in the first part of the cutting amounts to 94 feet; and the intermittent showers of lapilli were continued, until beds at least 66 feet above the main body of ash had been deposited. It will be noticed from vertical section No. 1 (Pl. XVIII) that the limestone becomes thicker and the shales decrease in quantity towards the top of the series. Chert is found in lenticles and in bands in many of the limestones, some of which are dolomitized, and others of which are dark and fine-grained. Dr. Wheelton Hind found fish-teeth in the thicker beds of limestone.¹

The beds in the northern part of the cutting above the second exposure of ash consist of shales and thin limestones, often ashy, folded into two troughs and crests. A thickness of 97 feet of strata is seen above the thick ash-bed, and the intercalated tuffs were found up to a height of 61 feet in the series.

It is impossible to correlate the thin limestones in the northern and southern portions of the cutting. They vary in thickness, and are probably not persistent for so great a distance, wherefore some of them thin out and disappear while fresh limestones make their appearance. There is, however, one band of limestone in the northern part, which may be the same as that seen six times in the southern part. It is $1\frac{3}{4}$ feet higher in the series, namely, 30 feet above the ash-bed, and is marked C in Pl. XVII, fig. 1, and in Pl. XVIII, fig. 3; it is seen twice in this part of the cutting.

An ashy limestone, marked D in the above-mentioned sections, 54 feet above the ash, is seen three times, and a well-marked group of cherty limestones (in which galena was found) near the top of the series

¹ 'Descr. of Section in Carb. Limest. Shales at Tissington,' N. Staffs Field-Club, Nov. 17th, 1897, 3 pp.

appears once in this part of the cutting. At the northern end, the railway runs through beds about 54 feet above the ash. After I had plotted the vertical and horizontal sections, and arrived at the foregoing conclusions, I received from Dr. Wheelton Hind his description, which deals with the section in Tissington cutting only. He states that the Toadstones seen at the south and centre of the cutting belong to 'the same bed, so that the whole of the first part is one complete synclinal basin, itself thrown into many minor folds by contortions,' and concludes that 'the beds immediately overlying the Toadstone' are not 'identical with those which rest on it in the first part of the section.'

The line passes along a small embankment, and soon enters the Highway Close Barn cutting. Between these two cuttings the beds probably form a syncline.

(7) Highway Close Barn. (Pls. XVII-XVIII
& text-figs. 2-3, p. 230.)

This and the next cutting pass through ground which was mapped as Mountain Limestone by the officers of the Geological Survey. The beds consist of limestones and shales, which lie above the third exposure of ash at the northern end of the cutting. They have been folded into an anticline and syncline. A thick group of ashy limestones, which occupies the middle of the series in the cutting, is seen three times. The limestones at first dip south-eastward, then bend sharply over, dipping north-westward, and are brought up again on the other side of the syncline. A reference to Pl. XVII, fig. 2, and Pl. XVIII, fig. 4, will explain the position and sequence of the beds. Above the ash 86 feet of strata may be seen. The limestones are thicker, lie more closely together, and have thinner partings of shale than is the case in the Tissington cutting. There are, however, several thick beds of shale with a few thin limestone-bands. Thin beds of tuff are also intercalated with the shales, and lapilli are numerous in some of the limestones, up to a height of 80 feet above the thick ash-bed. The limestones are often cherty, and contain *Productus*. The upper part of the ash-bed is seen at the northern end of the cutting, below the shales and limestones. Some portions of it are finely laminated, others are of a coarser texture, and a few ejected blocks are found in it. After crossing the valley which runs down to Shaws Farm, the railway enters the next cutting.

(8) Crake Low. (Pls. XVII-XVIII & text-fig. 1, p. 230.)

About the first half of this cutting is in Mountain Limestone, 40 feet of which is seen. The upper beds are thin and cherty, and there is an absence of shale. They dip 15° southward, and probably lie conformably beneath the thick ash in the last cutting; they may belong to the same series of beds, the top of which is seen below the thick ash in the Tissington cutting. *Productus* abounds, and

lead-ore was found in the lower and more massive beds. The lowest visible beds of these limestones are faulted against the fourth exposure of thick ash. The limestones end abruptly, and abut against a clay containing several large pieces of limestone. The clay is soon succeeded by bedded ash dipping north-westward on the western bank, and north-eastward on the eastern bank of the cutting. The

Fig. 1.—*Diagrammatic section across the northern end of Crake Low cutting, showing an anticline in the limestones above the ash.*

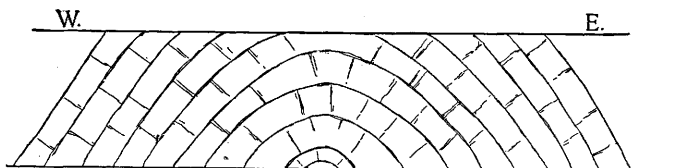


Fig. 2.—*Diagrammatic section across the northern end of Highway Close Barn cutting: shales and limestone above the ash.*

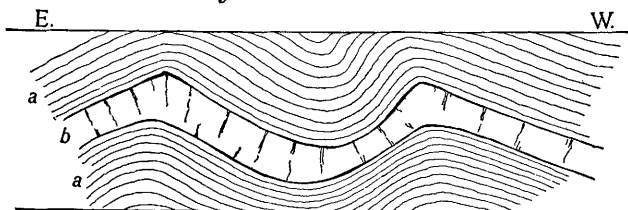
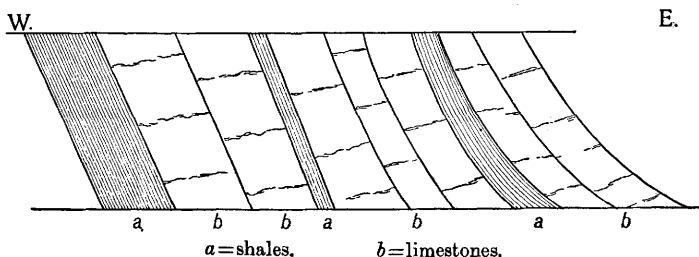


Fig. 3.—*Diagrammatic section across the southern end of Highway Close Barn cutting.*



ash and the beds above it must have been thrown down at least 40 feet. This ash was blue when freshly exposed, and some silicified beds in it were very hard: like that in the other cuttings, it soon weathers to a rusty red. It is succeeded by tufaceous limestones, with very thin clay- or shale- or tuff-partings. No thick shale-beds were seen. The thin beds immediately above the ash are much contorted, and some of the thin layers of tuff very soon thin out,

their place being taken by limestone, which is often tufaceous; and thus sections across the beds, only a few yards apart, would vary much in detail.

III. CRAKE LOW QUARRY. (Pl. XVIII, fig. 6.)

Two fields west of the last cutting, and about 100 feet above it, are two old quarries on the south-eastern slope of Crake Low. Though at first sight they seem to be beyond the limits of the ground covered by the present paper, a short description of them may be fittingly introduced, since they throw some light on the sequence of the beds in the last two cuttings.

The smaller quarry has not been worked for a long time, but the beds in it are similar to those in the larger one. The limestones from the latter were formerly burnt for lime, but now are broken up for road-metal. Forty feet of a very interesting succession of beds is seen. A reference to Pl. XVIII, fig. 6, shows them to consist of limestones, many of which contain volcanic material, separated by thin beds of tuff: they generally contain *Productus* and encrinite-stems. A limestone is seen to be free from lapilli in one place, while a foot away the same bed is crowded with them; or a limestone free from volcanic sediment in its centre often contains lapilli near its bottom and top surfaces. This is especially the case if there be a layer of tuff or tufaceous limestone above and below it.

A little more than halfway down the face of the quarry is a bed of coarse tuff, 2 feet thick, with tufaceous limestone above and below it. From this tuff I obtained numerous *Productus*-shells and a block of igneous rock. The block was very vesicular, and of the Kniveton type. Some of the layers of tuff intercalated with the limestones and shales in the three cuttings already described contain *Productus*-shells and fragments of large encrinite-stems, and are very similar to the bed of tuff in this quarry.

Some of the tuff-partings thin out very quickly. In one place a bed of tuff and tufaceous limestone, together about 9 inches thick, thin out in a distance of 6 feet, and are replaced by limestone free from volcanic ejectamenta. The beds at the bottom of the quarry where the section was measured are of a massive bluish-grey limestone containing foraminifera, and are free from ash. A few yards away they pass into thinner beds, and contain lapilli. No chert was found, and very few partings of shale were noticed. It was an examination of this quarry which led me to search carefully for intercalations of tuff in the limestones and shales above the four exposures of ash in the cuttings. The beds dip in a westerly direction into Crake Low, and lie stratigraphically above the Mountain Limestone in the Crake Low cutting.

We are now in a position to discuss briefly the relations of these beds to those in the two adjacent cuttings. The thick ash in the Highway Close Barn cutting can be traced for a short distance in the fields towards the quarry, and there is little doubt that it is

continued and lies between the quarry and the Mountain Limestone in the Crake Low cutting, though I have not been able yet to find it *in situ* on the slope of the hill. On the eastern side of the line the ash can be traced only for a short distance from the Highway Close Barn cutting, because the limestones above it dip rapidly down towards the east and cover it up.

The rocks through which the Highway Close Barn and Crake Low cuttings have been made form on the whole a long narrow dome, with minor basins in it, through the long axis of which the railway runs. Fig. 1, p. 230, gives a section across the railway, seen in the limestones above the ash at the northern end of Crake Low cutting, before the rocks were cut through.

Fig. 2 (p. 230) is a similar section across the northern end of Highway Close Barn cutting in the shales and limestones above the ash, and fig. 3 (p. 230) a section across the same cutting at the southern end. This dome brings up the small inlier of Mountain Limestone seen in Crake Low cutting.

The tufaceous limestone and shales in the Highway Close Barn cutting are apparently carried up by the dip to Crake Low Quarry, and then brought down by the fault which passes near the farm of the same name. It would seem, therefore, that the deposits of ash in the two cuttings, which are the third and fourth exposures of ash, belong to the same bed. I have shown that the two beds of ash in the Tissington cutting, which are the first and second exposures, are really one bed, and so far as the evidence obtained by mapping goes, it points to the conclusion that the second and third exposures are also of the same bed. We are, therefore, compelled to conclude that there is only one thick deposit of ash in the three cuttings, succeeded by limestones and shales with intercalations of tuff.

A comparison of the vertical sections (Pl. XVIII) shows a difference in the beds above the ash in the three cuttings. The limestones become thicker, and the shales decrease as one goes northward from sections 1 to 5; in one place shale and thin limestones have been deposited above the thick ash, and in another numerous beds of limestone with thin shale-partings: in the former is a preponderance of shallow-water deposits, and in the latter a preponderance of rocks formed in deeper water. If my contention that only one thick ash-bed is present be correct, there was deposited immediately after the great outburst in one place what would be called Lower Yoredale Beds and what were mapped as such by the officers of the Geological Survey; and in another place, not far distant, what are lithologically more like the upper beds of the Mountain Limestone Series and have been mapped as such by the officers of the Survey. These beds, though totally unlike in character and apparently belonging to different series, are really of the same age.

In only one place is the ash-bed exposed to view from top to bottom, namely, in the middle of the Tissington cutting. Here it is about 144 feet thick. In the three other places in which it appears, only the upper portions are seen; a thickness of about

36 feet is exposed at the southern end of Tissington cutting, about 42 feet in Highway Close Barn cutting, and about 96 feet in Crake Low cutting.

According to the Geological Survey Memoir 'a fault ranges along the south-west side of the valley of Parwich Leys, the limestone rising in a bold cliff and dipping away from the shales.'¹ The evidence given by the last two cuttings described removes any necessity for the fault by Highway Close Barn and Crake Low, which is marked on the Geological Survey map, Sheet 72 N.E. Though the beds do indeed dip into the hill at Crake Low Quarry, they soon bend over in an anticline, and dip eastward under the shales in the Parwich Leys Valley.

IV. PETROGRAPHY OF THE ROCKS.

(1) The thick Ash-bed.

When freshly cut into, the ash is light-blue or grey, a colour due to the presence of pyrites, but after a short exposure to the air it changes to a rusty red, and later to a greenish-brown.

The ash is distinctly bedded, and the different beds vary much in texture. The lapilli consist of fragments of a pumiceous rock, from microscopic dimensions up to an inch or so in diameter. The outlines of the lapilli are very irregular, some being more or less rounded, while others, in the more finely laminated portions of the deposit, are elongated in a direction parallel to the bedding, and the vesicles in them are often drawn out in the same direction. The outer surface of the lapillus generally cuts across the vesicles. When fresh, the lapilli are either isotropic or exert only a feeble action on polarized light, and are, therefore, glassy or a devitrified glass. Sometimes they are altered to calcite or dolomite, or to a palagonitic substance, and in one cutting are very much silicified. They are never crystalline. (I have found only one lapillus in which felspar-microlites are present.) There are no small fragments of basalt or dolerite among them, and their structure has no counterpart among the lavas of Derbyshire.

The vesicles are filled with crystalline calcite, iron-oxide, a light-green fibrous material which exerts only a feeble action on polarized light, and sometimes with an isotropic substance.

In some cases, as in the ash at the southern end, and in the greater part of that at the centre of Tissington cutting, the lapilli are crowded closely together, and only separated by what is probably a volcanic dust. In others, as in the Highway Close Barn and Crake Low cuttings, where it was possible to obtain less weathered specimens, they are cemented by crystalline calcite.

Pyrites is largely distributed throughout the ash. The latter has generally a specific gravity of about 2·5 when fresh, but in one specimen of ash which contains an unusually large amount of pyrites the specific gravity is 2·9.

¹ North Derbyshire, 2nd ed. (1887) p. 32.

The lower part of the thick ash-bed is seen only in Tissington cutting. It is made up of small pieces of a vesicular rock about 1 inch in diameter, closely packed together. These are spherical or discoidal in shape, and when weathered are spotted with carbonate of lime, which at a short distance gives the rock the appearance of an amygdaloidal lava. They are not bombs, but large lapilli, which have probably derived their present shape from having been rubbed together in the volcanic vent, prior to their final ejection.

A thin slice from one of these spheroids, $\frac{3}{4}$ inch in diameter, was examined under the microscope. During the process of grinding it was broken up into small pieces, which looked like separate lapilli; but on further examination it was seen that the outlines of any two in juxtaposition correspond in such wise that if placed close together they would fit exactly. The structure is very similar to that of the minute lapilli described above. Some of the vesicles are circular in section. Others are very much elongated, but their longer axes bear no relation to the outer boundary of the fragment. On the contrary, the boundary breaks across the vesicles, as in the case of the smaller lapilli, and also in that of the larger included blocks described below.

In Crake Low cutting some parts of the ash-bed are very hard. Both lapilli and matrix have been altered to silica, calcite, and pyrites: the various stages in this alteration can be traced. A fairly fresh specimen is composed of isotropic lapilli in a calcitic matrix. Cryptocrystalline silica then appears in small patches the lapilli are next altered to calcite, and embedded in calcite and cryptocrystalline silica with pyrites; and, in the final stage of alteration, the rock is entirely composed of the above-mentioned minerals, the outlines and vesicular structure of the lapilli being visible in ordinary light.

In the upper part of the thick ash, at the northern end of Highway Close Barn cutting, several beds of a fine-grained and laminated mudstone were seen. The specific gravity of two specimens was 2.32 and 2.4, which is less than that of the ash. One had the appearance of a dull, fine-grained basalt, though it was not crystalline: the other was softer and less coherent. Under the microscope they are almost structureless, and contain iron-oxide, with a small quantity of crystalline calcite, but no traces of lapilli. There is no microscopic evidence of their volcanic origin.

(2) The Ejected Blocks in the thick Ash.

The ejected blocks found in the ash are generally rounded or subangular in shape, and either vesicular or amygdaloidal. When the vesicles are filled with a dark material, the rock looks (on a freshly-fractured surface) very much like limestone. The blocks vary in size from several inches up to about a foot in diameter, and are not arranged in beds, but scattered irregularly through the finer ash. They differ from the small fragments in the ash by being finely

crystalline, and not so glassy. They are similar to the blocks in the Kniveton vent, the structure of which was described by me in a former paper read before this Society,¹ but the felspars are much smaller, and there are very few traces of olivine. Their specific gravity varies from 2·53 to 2·62.

Two blocks found in Highway Close Barn cutting are probably ejected fragments of the older ash which solidified in the vent, and were blown out by subsequent eruptions. They consist of isotropic and well-preserved lapilli in a cement of cloudy calcite.

(3) The thin Tuffs and Tufaceous Limestones above the thick Ash.

Among the thin limestones and shales which lie above the thick ash-bed are numerous intercalations of tuff, varying in thickness from about $\frac{1}{4}$ inch to 2 feet. They are very similar to the thick ash just described, but differ from it in containing *Productus* and large encrinite-stems: they weather rapidly, and are generally too incoherent for slicing.

A bed of coarse tuff (2 feet thick) in Crake Low Quarry, and containing *Productus semireticulatus* and an ejected block, proved sufficiently hard for a thin slice to be prepared. It is light-brown, with light-grey patches, in a hand-specimen. Under the microscope, it consists of numerous lapilli, altered to crystalline calcite, unevenly distributed throughout the slice, and mingled with small pieces of previously consolidated limestone, which often contain a foraminifer or a portion of one, or of some other organism. All these fragments are cemented together with crystalline calcite. The vesicular block, several inches in diameter, found in this bed is similar to those from the thick ash in the cuttings.

In the thick ash-bed there appears to be an absence of ordinary mechanical sediment, while in the limestones and thin partings of tuff above this bed there is a commingling of volcanic and ordinary sediment in rapidly varying degrees, even on the same horizon, within a short distance. Some of the limestone-beds are free from tuff, and others contain varying proportions of volcanic ejectamenta; and thus what is a limestone free from volcanic sediment in one place will pass into a tufaceous limestone or a shelly tuff in another. Some beds, which in a hand-specimen resemble a hard tuff, when examined under the microscope are seen to contain so many fossils that they may be considered as a tufaceous limestone.

The lapilli distributed through the limestones are almost invariably altered to crystalline calcite or dolomite and oxide of iron. Only one small lapillus, in a limestone 20 feet above the ash in the northern part of Tissington cutting, contained felspar-microlites. When altered to calcite or dolomite they are hard to distinguish

¹ 'Microsc. Struct. of Carb. Dolerites & Tuffs of Derbyshire,' Quart. Journ. Geol. Soc. vol. 1 (1894) pp. 638, 639.

in polarized light, and their vesicular structure is seen with such difficulty in ordinary light that they might be easily overlooked.

The limestones in which they are embedded generally contain foraminifera, shell-fragments, and small encrinite-stems. In many cases the tuffaceous limestones consist (in addition to volcanic material) of worn shell-fragments and small pieces of a previously consolidated limestone, which sometimes contain a few quartz-crystals. Patches of cryptocrystalline silica are present in some specimens. Parts of a limestone-bed are often dolomitized.

In a few cases the lapilli are isotropic, as, for example, in a tuffaceous limestone resting upon the top of the ash at the centre of Tissington cutting, in a tuff (10 inches thick) immediately above it, and also in a tuff-parting (6 to 8 inches thick) 2 feet above the thick ash in Highway Close Barn cutting and separated from it by shales.

The tuffaceous limestones in Crake Low Quarry are similar in every respect to those in the cuttings. About 28 feet from the top of the quarry is an interesting bed of banded limestone, which shows a series of rapid alternations of ordinary and volcanic sediment. Above and below it are 2 and 3 inches of tuff respectively, which die out in a distance of 6 feet to the south, and are replaced by limestone.

In a hand-specimen nine black bands occur in a space of less than 1 inch, then follows $\frac{3}{4}$ inch of limestone free from bands, and lastly seven more bands in the space of an inch. Under the microscope the bands consist of elongated lapilli, coloured with iron-oxide: these are isotropic, and often are penetrated by and contain small rhombohedra of dolomite.

(4) The Limestones.

The limestones interbedded with the shales vary considerably in structure and texture, and often contain layers of chert. Some of them are coarse in texture and composed mainly of encrinite-stems and *Productus*; others are dark, fine-grained, and free from fossils. Many of them contain foraminifera. The coarse and fine-grained varieties are often found in different layers of the same bed. Many of the limestone-beds are partly or wholly dolomitized, and in extreme cases all traces of fossils are obliterated. When the dolomitized beds are weathered they have a sandy feel and appearance, and on a cursory examination might be mistaken for a sandstone. They sometimes contain cryptocrystalline silica.

Two thin slices of the compact limestone below the ash-bed in the centre of Tissington cutting were examined. The rock is a very close-grained and partly crystalline limestone, with a few small encrinite-stems.

Altogether, forty-six thin slices were examined from the rocks in the three cuttings and Crake Low Quarry.

EXPLANATION OF PLATES XVII & XVIII.

PLATE XVII.

Figs. 1-3. Horizontal sections through Tissington, Highway Close Barn, and Crake Low cuttings, on the scale of 40 yards to the inch.

PLATE XVIII.

Figs. 1-6. Vertical sections of the beds above the thick ash, between Tissington and Crake Low, on the scale of 12 feet to the inch.

DISCUSSION.

Prof. HULL said that he had listened with interest to the paper, knowing the district of Derbyshire to which it referred. He reminded the Fellows that on the Geological Survey maps and sections there were two outpourings of lava intercalated among the Carboniferous Limestones—the upper lava being near the top of the limestone-series. These had been originally traced by the late Sir Warrington Smyth. He was not quite clear, from the Author's account of the ash-beds, whether or not these represented the uppermost of the two lava-flows mapped by the officers of the Survey, or whether they were the products of a third and later eruption. One of the finest examples of submarine volcanic energy at the close of the Carboniferous Limestone period in the British Isles was to be found in County Limerick, at Cahircnlish, where no fewer than ten successive eruptions of lava and ash-beds were interposed between the limestone and the overlying 'Yoredale' shale. These beds appeared to be representative of those described by the Author.

Prof. SOLLAS remarked that an examination of the specimens on the table recalled the association of calcareous sands and volcanic detritus now frequently presented by islands in the Pacific. He had seen precisely similar ball-like lapilli in Oahu, where in some cases they formed beds deceptively resembling lava-streams. Similar basaltic glass, passing into palagonite, occurred in association with detrital limestones in some of the islands of Torres Straits. In one of the slides of limestone exhibited by the Author structures were to be seen superficially resembling sponge-spicules. The speaker also called attention to a series of contemporaneous basaltic rocks associated with the Carboniferous Limestone of Limerick: these had been studied in detail by Prof. Watts.

Mr. LAMPLUGH commented on the strongly-marked difference between the character of the Glacial Drift in the sections described by the Author and that of the country a few miles farther south, and on the importance of this difference as an indication of the direction of ice-flow. He asked what other boulders besides local rocks were found in this Drift.

Mr. STRAHAN thought that the Author had made two important points. In the first place, he had proved the contemporaneous age of the igneous series by the existence of limestones containing ashy material. Contemporaneous igneous rocks were now known in so

many parts of England, in the Carboniferous Limestone, that they evidently could not all have proceeded from one source. There seem to have been a number of small vents scattered over an area that was undergoing prolonged subsidence. In the second place, the Author had shown that this outburst occurred in the so-called Yoredale Series, and therefore at a later date than any known in the Isle of Man, in other parts of Derbyshire, or in Somerset: in all these districts the contemporaneous igneous rocks lay some distance down in the limestone.

Prof. WATTS pointed out that the volcanic rocks of Limerick appear to occur on about the same horizon as those of Derbyshire. The Limerick basin is surrounded by a series of small volcanic necks, and thus the point mentioned by the previous speaker is also paralleled in Ireland.

The PRESIDENT, Mr. BARROW, Mr. TEALL, and Dr. HINDE also spoke.

The AUTHOR thanked the Fellows for the kind way in which they had received his paper. In reply to Mr. Barrow, he said that what he (the Author) had described as a thickly-bedded ash was undoubtedly, from its occurrence in the field and behaviour under the microscope, a fragmental rock and not a lava. In reply to Prof. Hull, he said that the old idea of the restriction of the term toadstone to two beds of lava no longer applies; that the term includes rocks from volcanic necks of the puy type, from lava-flows, from volcanic ashes, and from intrusive sills.

In answer to Mr. Lamplugh, he said that similar Drift was found in other parts of the county. The foreign igneous rocks were probably derived from the Lake District. He had not gone more fully into the subject of the Drift in the cuttings, as Mr. Deeley was working out various problems connected with the direction of travel of the Drift.