No. XX.—A Puddle-trench Section at North Third, near Bannockburn, with Notes on the Geology of the Surrounding District. By N. Martin, B.Sc., C.E., and G. W. Tyrrell, A.R.C.Sc., Assistant in Geological Department, Glasgow University.

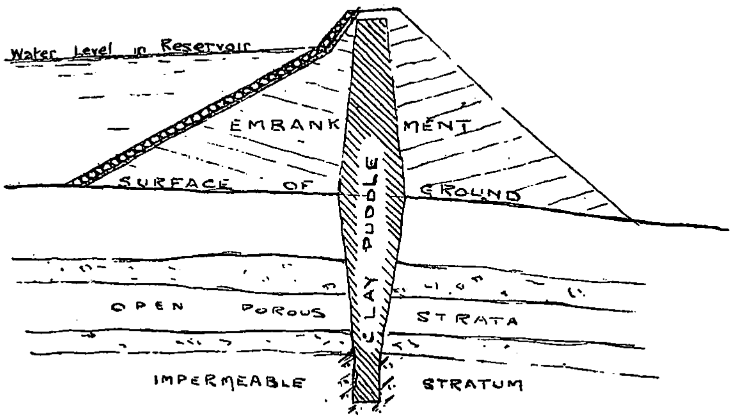
[Read 14th May, 1908.]

I. Introduction.

The section described in this paper has been exposed in the course of construction of a reservoir for the Grangemouth Town Council, near North Third farm steading, 4½ miles S.W. of Stirling, and about 3 miles W. of Bannockburn. The puddle trench has been excavated in an E.-W. direction along the centre line of a proposed embankment, which, when completed, will dam back the upper waters of the Bannock Burn. The *raison d'être* of a puddle trench may readily be grasped by a glance at Fig. 1. Although the earthwork embankment built across the valley might itself be impervious to water, the pressure due to the water in the reservoir would force the water along the previous subsoil and strata underlying the embankment. To prevent this leakage, which would not only be a source of waste but a positive menace to the stability of the embankment, a trench is sunk along the centre-line of the proposed embankment until a solid, impermeable stratum is reached, or at least to a depth at which no serious leakage from the reservoir is expected. The trench is then packed with "puddled clay," forming an impermeable wall through the opener strata under the embankment. The puddled clay is continued right up through the heart of the embankment, rendering that watertight also. The figure below shows the method of construction.

The North Third puddle trench is about 340 yards long, with a width of about 15 feet, and a maximum depth of about 100 feet. A plan of the trench is shown on Plate XIV. It is excavated up to the present entirely in the upper part of the Calciferous Sandstone volcanic series. The extreme eastern end of the trench cuts through the last lava flow before the oncoming of the overlying cement stones. Although covering a wide extent of country, the volcanic series is the least conspicuous of the igneous rocks to the S.W. of Stirling. It forms a barren upland of rough hill pasture, dotted all over with numerous small lava escarpments, and overlooked by the bold mural escarpment of the great Stirling sill.

Not much has been written concerning the geology of this district. The three chief references are the Geological Survey Memoir of Sheet 31 (1879),* two papers on the geology of the Stirling district by H. Monckton,† and, of course, the area is included in Sir A. Geikie's monumental work on "The Ancient



—Sketch Section of Embankment—

Fig. 1.

Volcanoes of Great Britain" (1897), although few special references are made.

The fieldwork for this paper has been done conjointly by the authors. Mr. Martin is mainly responsible for the descriptive and stratigraphical part of the paper, Mr. Tyrrell for the petrographical. The section in the trench is first described,

* The puddle trench falls in Sh. 39, to which no memoir is attached; but the memoir on Sh. 31 describes the same formations a little to the south of this area.

† Monckton. *Proc. Geol. Assoc.*, vol. xii. (1891-2), p. 242.
,, *Q.J.G.S.* (1895), li. pp. 480-491.

then the geology of the surrounding district, of which the two main features are the Sauchie cliff and the fine section of the Carboniferous Limestone series exposed in the gorge of the Bannock Burn. The history of the river system of the district is dealt with briefly, and the paper closes with a petrological investigation of the volcanic rocks exposed in the trench.

II. The Section in the Puddle Trench.

The rocks exposed in the puddle trench are a series of lavas and tuffs dipping eastward at an angle of 10 degs. These form hard and soft beds alternating regularly, and the latter being known to the workmen as "cutters." A diamond drill boring in the bottom of the trench to a depth of 95 feet reveals a continuation of the same series to that depth. The total thickness of volcanic material examined is about 366 feet. Sir A. Geikie estimates the total thickness of the volcanic series at about 1000 feet in the neighbourhood of Kilsyth, thinning out to nothing at Causewayhead.* The thickness obtained in the trench ought, on this estimate, to be nearly the total thickness of the volcanic material in this neighbourhood.

The rocks exposed are described in the petrographical part of this paper, in which a statement of the average thicknesses of the nineteen beds is given. The thicknesses, however, vary considerably, and the surfaces of the flows are highly irregular. For instance, the lava flow designated (E) varies in thickness from 15 to 28 feet, (C) from 34 to 60 feet, and (O) from 80 to 110 feet.† The latter is the greatest thickness attained by any one flow. The tuffs vary in thickness in like manner, but are inferior in this respect to the lavas, except towards the top of the series.

Some of the "cutters" are undoubtedly merely slaggy portions of lava flows. This fact explains the interleaving of one of the flows (G) by a tongue-like projection of "cutter," which gradually thickens until it joins the underlying slag (F). The interpolated bed is merely a highly vesicular or slaggy portion of (G), which weathers as a soft bed.

* "Ancient Volcanoes of Great Britain" (1897), vol i., p. 393.

† See table on p. 250.

Intercalated between I and H, also in P and R, are thin beds of fine red, muddy tuff ranging up to 2 feet in thickness. This rock is soft and decomposed where the trench water has been flowing over it, but is sometimes hard, splintery, and ringing to the hammer when dry and unweathered. This material probably indicates slow deposition of very fine volcanic dust and sedimentary material in temporary accumulations of water on the irregular surfaces of the lava flows. The abundant iron oxides of the decomposing lavas were also washed down into these temporary lagoons, giving the deposited material its bright red colour.

In blasting, the hard beds, especially the thick flow O, have broken away along remarkable planes of division known to the workmen as "backs." These consist of large, smooth, curved surfaces, of any size from 1 to 20 feet in diameter. A fine example is shown in Plate XIII., Fig. 2. These surfaces are sometimes crowded together, forming a series of concentric spherical shells of rock, from which occasionally large curved plates of rock about ½ inch thick may be broken off. The smooth surfaces of the "backs" are sometimes crossed horizontally by a few blunt, rounded ridges.

These surfaces are not developed by weathering, but only become apparent on fracture. The authors believe they are due to a series of concentric surfaces of weak cohesion developed during cooling, which, while they cannot be detected in the unweathered, unbroken rock, control its fracture when broken by such a violent means as blasting. The structure may perhaps be considered as perlitic structure on a gigantic scale. These "backs" are characteristic of lavas or intrusive rocks which have reached nearly to the surface, and which have consequently been subjected to rapid cooling. These varieties of whinstone are known to the quarrymen as "clinker" rocks, as opposed to the varieties due to the deeper-seated intrusions, which are generally more regularly columnar in structure and weather into spheroidal masses, and which are distinguished by the quarrymen as "liver" rocks.

A vertical zone of crushed and brecciated rock 42 feet wide crosses the west end of the trench in a N. and S. direction. There does not seem, however, to have been any vertical dislocation of the adjacent beds. The brecciation may therefore be due to a lateral wrench. The brecciated rock has been eroded to a depth of 10 feet, and the hollow thus formed filled with boulder clay.

III. Geology of the Surrounding District.

Overlying the volcanic series to the E. of the trench is a thin band of cement stones, followed by the lower beds of the Carboniferous Limestone series, into which is intruded a great sill, or, rather, flat laccolite, of diabase. This sill is found over a N.-S. distance of about 10 miles, and its escarpment forms a magnificent range of vertical cliff stretching with few breaks from the Wallace Monument and Stirling Castle on the north to Myot Hill on the south. At Sauchie the sill is just above the Hurlet Limestone, but to the S. its base rises higher and higher in the series. At the same time the sill becomes thinner. Just opposite the trench is a fine cliff section showing a large mass of sandstones and shales caught up and enveloped by the igneous rock.* The sill is broken by three large E.-W. faults into three main blocks, which have the appearance, owing to denudation, of having been displaced relatively to each other. The rock of the sill is a quartz diabase, or micropegmatitic diabase, of the whin sill type.†

The most complete section, however, between the volcanic series and the Hurlet Limestone occurs in the Bannock Burn about half a mile N. of the trench. Above this point the stream meanders in an alluvial plain, which was probably the site of a glacial lake. At this point, however, begins an abrupt descent, and the stream has cut a deep gorge through the volcanic series, cement stones, and Carboniferous Limestone series, until the northernmost E.-W. fault is reached, when the river makes an abrupt turn to the east, and flows along the fault line.

Following the stream from the trench northwards, the boundary of the hard lavas is fairly well marked by the

* H. W. Monckton. *Proc. Geol. Assoc.*, vol. xii. (1891-2) p. 245.

† H. W. Monckton. *Q.J.G.S.* (1895), li., pp. 480-491.

termination of a deep, vertical-sided, rocky gorge. This is followed by a steep-sided, grassy valley, in which sections are not infrequent in the banks of the stream. The last important lava flow is overlaid by coarse, variegated tuff, of which there is a visible thickness of 5 feet in a small runnel on the E. side of the burn. Seventy yards further down stream is an exposure of stratified blue and red mottled tuff, containing some large ejected blocks of vesicular lava. The tuff is very calcareous in places, and towards the top is interstratified with thin, impersistent bands of brick-red cement stones. This is followed by a bed of decomposed vesicular lava about 6 feet thick, then by a bed of blue tuff with large decomposed felspars, evidently due to the explosive disintegration of a porphyritic magma. Overlying this are red and greyish-green tuffs containing much sedimentary material. The top beds are brick-red cement shales, still containing, however, some volcanic material. A further exposure of higher beds shows typical cement stones with an interstratified band, 6 to 12 inches thick, of coarse tuff or agglomerate, containing pebbles up to 1½ inches in diameter. The dip is about 10 degs. to the N.

The boundary between the cement stones and the Carboniferous Limestone series is not actually seen, but there is only a small break between the last exposure of cement stones and the first limestone. The above account of the section shows that the cement stone group in this area is composed mainly of volcanic material, and proves that volcanic activity did not die out until just before the beginning of the Carboniferous Limestone epoch.

The first exposure of the Carboniferous Limestone series is a bed of hard, black, fossiliferous limestone, forming a small fall in the stream. The section at the waterfall is as follows:—

	Feet.	Inches.
Hard black fossiliferous limestone, -	1	6
Fossiliferous calcareous shales, - -	1	0
Hard limestone, - - - - - - -	0	3
Black shales, - - - - - -	0	6 visible.

Exactly the same succession occurs in the bank 3 feet above the fall, but these beds are not continuous with those forming the fall. Below the waterfall is another ledge of limestone with part of the same succession visible, and overlain by black shales. These appearances are best explained by assuming two small step faults at the waterfall, each of about 4 feet throw.

This limestone is some distance below the Hurlet seam. It is succeeded by at least 20 feet of black shale. Then follows in ascending order—

	Feet.	Inches.
Calcareous shale, with spherical limestone concretions up to 18 inches diameter,	6	0
Black shale with thin rib of limestone,	3	0
Hard fossiliferous limestone,	1	6
Black shale,	thickness undetermined.	

The dip is uniformly about 10 degs. N.

Further down stream occurs a finely-exposed syncline bringing on the first limestone again. The Hurlet Limestone is high up in the bank on both sides, and has been extensively worked.

We had not the opportunity of thoroughly examining this fine section, and of collecting its fossils. It is well worth the combined attention of stratigrapher and palæontologist.

IV. History of the River System.

The drainage of the district affords a good example of the influence of a bar of hard rock athwart the main direction of the streams. The consequent streams in this part of Scotland have a general N.W.-S.E. direction. In this particular district the relief has been developed mainly by a series of subsequent streams running nearly due E. and W., and discharging into the Forth below Stirling. The upper Forth itself above Stirling, the Bannock Burn, Pow Burn, and the Carron River are examples of these. Athwart all these is the great bar of the Stirling sill, running 10 miles from N. to S. The Forth itself, by reason of its size, volume, and erosive power, has been able to cut its channel down through the hard bar, concomitantly with the sculpturing of the escarpment on either side. It is clear that the rock on which the Wallace Monument stands and the Stirling Castle rock were once continuous at the surface, and even now are probably connected underground. At the present time the area between the severed portions of the escarpment, 1½ miles wide, is occupied by a large meander of the river. The original Bannock Burn has been enabled to survive by the fortunate chance of its having found the most northerly E. and W. fault. Then lateral tributaries, cutting back rapidly along the comparatively soft rocks on either side of the sill, have captured the headwaters of the Pow Burn, of which the upper Bannock Burn, the Sauchie, and the Auchenbowie Burns are the remnants. The southern headwater of the Pow Burn, now represented by a part of the Auchenbowie Burn, has been beheaded twice—first by the Bannock Burn cutting southward along the western edge of the sill, and then by a tributary of the Carron working northward along the eastern edge. The northern headwater of the Pow Burn has left a fine windgap in the Sauchie cliff opposite North Third.

It seems probable also that during the glacial period the upper waters of the Bannock Burn were dammed back by a great mass of ice blocking up the narrow gap at Wallstale between the Gillie's and the Sauchie cliff, forming a lake between the Sauchie cliff and the volcanic hills to the west. The reservoir now building will occupy the site of this vanished lake. The processes of erosion were suspended in the upper Bannock Burn during this period, but they were probably still active in the lower reaches. The upper Bannock Burn, therefore, presents some of the characteristics of a hanging valley, connected with the alluvial flats below by a deep, post-glacial gorge.

The authors gratefully acknowledge the facilities for visiting the trench kindly given by Messrs. Warren & Stuart, Glasgow, the engineers for the works.

Petrography of the Volcanic Series at North Third Puddle Trench. By G. W. Tyrrell, A.R.C.Sc.

The rocks occurring in the puddle trench consist of twenty-two beds, of hard and soft rock alternately, the latter termed "cutters" by the workmen. The greater number of the beds are visible in the open cutting, and the remainder were obtained by means of chisel borings in the bottom of the trench. On closer examination some of the soft beds or "cutters" turn out to be merely the slaggy upper or lower surfaces of the adjacent lava flows, but the remaining soft beds are shown to be true tuffs, both by their stratified appearance and by microscopical examination.

When the slags are included with the lavas, of which they are a part, the number of beds is reduced to nineteen. The twenty-two apparently separate beds were lettered from A to U in ascending order before the true nature of some of the softer rocks had been ascertained. In order to avoid confusion, however, the original lettering has not been altered, but the indivisible nature of beds containing both hard lava and slag has been indicated by conjoining the letters assigned to the lava and slag respectively.

The delimitation of the various beds has been a matter of some difficulty, on account of the nature of the exposure and the inaccessibility of parts of the cutting. The rocks are very wet and frequently covered with a red slime consisting mainly of hæmatite leached out of the volcanic rock itself.* The continual trickling of water down the sides of the trench has washed out portions of the softer rocks, so that the junctions between adjacent beds are often obscured by layers of mud.

The hard lavas are easily recognised by their massive appearance and by their peculiar spherical jointing. The slags and tuffs are very much alike in hand specimens, but are fairly easily distinguished, under favourable circumstances, in the cutting—the former by their gradual passage into the hard lavas and lack of stratification, the latter by a distinct stratification and the presence of lapilli and small blocks of lava.

Macroscopic Characters.—The lavas may at once be divided into a lower non-porphyritic and an upper porphyritic group; but, following the upper group, there are two thin, non-porphyritic flows, which are the last of the series in this district, and which show distinct characteristics of their own.

Bed A, the lowermost lava obtained in the bores, is a compact, greyish, non-porphyritic, somewhat porous rock, whose specific gravity, as determined by Walker's steelyard, is 2·57. Although this figure is open to suspicion, on account of the

* The workmen informed us that painful wounds were caused by this substance if allowed to get into cuts or abrasions.

slightly porous nature of the rock, it indicates a lava of the nature of a trachyte. C and E* are dark, hard, compact, non-porphyritic rocks, of specific gravity 2·70 and 2·85 respectively. C has a conchoidal fracture, and frequently shows small vesicles elongated in the direction of flow. Both C and E are stained and veined with hæmatite. E shows a transition to the upper group in containing an occasional porphyritic felspar.

The upper group, consisting of Beds G, I, K, M, O, and Q are all highly porphyritic and amygdaloidal. The phenocrysts are invariably of plagioclase, set in a compact, dark-grey base. The vesicles are filled with calcite, chalcedony, quartz, zeolites, "green-earth," and sometimes with hæmatite and wad. The specific gravity of these rocks varies from 2·79 in I to 2·69 in K, the other four rocks having intermediate values. These figures cannot be relied on, on account of the numerous amygdules. In I, the heaviest of the group, the felspar phenocrysts and the amygdules are least abundant. In all cases the groundmass is similar to that of the rocks C and E, so that the presence of numerous felspar phenocrysts may perhaps be taken to indicate a slight decrease of basicity from the lower to the upper group.

The two last flows, S and U, are of entirely different character, and indicate a return to the type of the lower group. They consist of a very fine-grained, greyish-green rock, whose fracture shows a resinous lustre, and which weathers with a bluish crust. There is occasionally a small porphyritic felspar. It presents a characteristic appearance in the field, close horizontal and vertical joints having broken the rock into small tabular pieces. On account of this mode of jointing and of its susceptibility to extreme weathering, it is very difficult to get even a comparatively fresh specimen.

The slags are soft, highly vesicular rocks, the vesicles of which are usually filled with amygdaloidal secondary minerals similar to those of the lavas above described. Sometimes, however, the vesicles are empty, and the rock is then porous and cellular.

* The intermediate beds, B, D, &c., are tuffs and slags, which are hereafter described.

The tuffs are soft, crumbling, purple, red or green-tinted rocks, usually fine textured and well stratified. True lapilli are sometimes seen, and also occasional small ejected blocks of compact lava. Hand specimens are naturally very difficult to get in the open exposure, but specimens from the bores are hard enough to be sliced.

Microscopic Characters.—The microscopical examination of the lavas shows that they are rocks of a highly felspathic nature, passing on the one hand into rocks of a trachytic type, and on the other to relatively acid felspathic basalts. It will be seen later that they closely resemble the mugearites of Skye and Midlothian. The following table gives the succession of the various beds, with their average thicknesses and, in some cases, their specific gravity:—

Bed.	Thickness.	Name.
U,	12 feet,	Trachytic Mugearite (2·62).*
T,	4 ,,	Tuff.
S,	10 ,,	Trachytic Mugearite (2·56).
R,	17 ,,	Tuff.
Q,	10 ,,	Mugearite, porphyritic.
P,	16 ,,	Tuff.
O,	110 ,,	Mugearite, porphyritic (2·78).
N,	4 ,,	Tuff.
M,	11 ,,	Mugearite, porphyritic.
L,	4 ,,	Tuff.
K,	21 ,,	Mugearite, porphyritic (2·69).
J,	6 ,,	Tuff.
I,	19 ,,	Mugearite, porphyritic (2·79).
H,	6 ,,	Slag.
G,	15 ,,	Mugearite, porphyritic (2·74).
F,	3 ,,	Slag.
E,	19 ,,	Mugearite (2·85).
D,	15 ,,	Slag.
C,	29 ,,	Mugearite (2·70).
B,	8 ,,	Coarse Tuff.
A,	27 + ,,	Trachytic Mugearite (2·57).
Total,	366 feet.	

The flows A, C, and E differ so little from one another materially that it is convenient to describe them together. Under the microscope they are seen to consist essentially of a closely-packed aggregate of small laths of felspar, which show a decided fluxional arrangement, having their longer axes parallel to one another at any given point. The inter-spaces between the felspars are filled with abundant ragged

* The figures within brackets indicate the specific gravity of the rock.

granules of magnetite and reddish flakes of hæmatite. Here and there a minute granule occurs which may perhaps be identified as a pyroxene, but the bulk of the ferro-magnesian element occurs as vague green chloritic material interspersed between the felspars. The proportion of ferro-magnesian minerals is in any case very small, compared to that of the felspar. It increases as the series is passed up from A to E, but even the latter rock is still highly felspathic. Many of the felspar laths are untwinned and give straight extinction. These are probably orthoclase, but the remainder show lamellar twinning, and give an extinction angle of about 5 degs. These are, therefore, to be identified as oligoclase. The proportion of oligoclase is greatest in E and least in A. In C there are a few small green, rectangular pseudomorphs, probably after augite or hypersthene. In E a few calcite pseudomorphs occur, which have the characteristic hexagonal shape of olivine. The iron ore in this rock is more abundant than in A and C, and a conspicuous feature is the occurrence of knots of closely-aggregated, clear, red flakes of hæmatite surrounding a ragged nucleus of magnetite. The hæmatite is obviously secondary, as it surrounds, replaces, and penetrates the felspars by their cleavage and other cracks.

The high proportion of the felspathic constituent allies these rocks with the trachytes. They differ from them, however, in the large content of iron oxides. In the relatively acid nature of the felspathic groundmass, the insignificance of the ferro-magnesian minerals, the abundance of magnetite, and the probable occurrence of orthoclase and olivine, they present considerable affinities with the mugearites of Harker.* Where, as in A, the potash and lime-soda felspars are evenly balanced, the rock may properly be termed trachytic mugearites. Where, as in C, the lime-soda felspar predominates, and the ferro-magnesian element, though still small, is in greater proportion, the rock resembles more closely the typical mugearite of Druim-na-Criche. In E, where the more basic character is indicated by the specific gravity (2·85), by a higher content of iron oxides, and by the occurrence of a few pseudomorphs after olivine, the rock approximates to the

* Harker. "Tert. Ign. Rocks of Skye" (1904), pp. 265-267.

basic mugearite from Huisgill, near Talisker. The three rocks, however, form a quite continuous series of increasing basicity from A to E.

The porphyritic group, consisting of Beds G, I, K, M, O, and Q, is of a homogeneous character, and may be described as a whole. The groundmass is similar to that of the compact rocks described above—closely-packed laths of felspar, with abundant magnetite and hæmatite, but with little or no ferro-magnesian element, except in O. There is occasionally a little irresolvable substance in the groundmass, but no isotropic matter. The phenocrysts are entirely of plagioclase, and are usually perfectly idiomorphic. They are much altered and full of red flakes of hæmatite, which has penetrated the crystals through the channels afforded by the cleavage and other cracks. They are frequently zoned with rod-like inclusions of the ground-mass arranged parallel to the boundaries of the crystals. Both carlsbad and albite twinning is shown. The maximum extinction angle obtainable for the albite lamellæ in sections giving symmetrical extinction varies from 28 degs., indicating a medium labradorite, in G and K, to 17 degs., indicating an andesine-labradorite, in I and O.

In G occur a few microporphyritic pseudomorphs in red serpentine after olivine. In K occurs the only phenocryst of augite discovered in the whole series of slides. It is small and much decomposed. The felspar phenocrysts in this rock have sometimes served as nuclei for aggregations of iron oxides. In K and O are several large crystals of a black, opaque mineral, which, from its form, appears to belong to the hexagonal system. In reflected light these are of an iron-grey tint, and are seen to be striated with black lines crossing in two directions at an angle of about 72 degs. This mineral is most probably a titaniferous iron ore of the ilmenite group.

The vesicles in these rocks are filled with calcite, "green-earth," various zeolites, chalcedonic silica, and sometimes also hæmatite and wad. Frequently there is more than one mineral in the vesicle. The most common appearance is of a thin peripheral shell of hæmatite, the interior being filled with calcite, quartz, or "green-earth."

The last two lavas, S and U, are composed of a mesh of minute laths of felspar, with small intersertal granules of a bright yellow mineral, and ragged specks of black iron ores. The better-preserved felspars are untwinned, and give straight extinction in the greater number of cases. These are probably orthoclase. A few, however, show lamellar twinning, and a maximum extinction angle of 5 degs., and are thus oligoclase. The bright yellow intersertal mineral is structureless in ordinary light, but in polarized light a radial structure is revealed by a series of dark extinction "brushes." It is undoubtedly a form of serpentine. It occurs occasionally as small, roughly rectangular, and hexagonal pseudomorphs, which certainly suggest olivine. There is a little colourless isotropic material in the groundmass. The specific gravities of these rocks are 2·56 and 2·62 respectively. They are, therefore, as indicated by their microscopic characters, slightly more acid than C and E. They resemble A very closely, and are thus to be regarded as transition forms between mugearite and trachyte. The fresh rock would probably contain olivine. The slags in thin section, as, *e.g.*, H, differ from the lavas only in being more highly altered and vesicular.

The tuffs are mugearite tuffs, that is to say, they consist of small lapilli of the compact type of lava, in a base of comminuted felspars, the whole thoroughly impregnated with iron oxides. They are composed almost entirely of volcanic material. Only in the red muddy tuffs before mentioned is there any considerable admixture of sedimentary material.

As before mentioned, these rocks in all probability belong to the mugearites of Harker. They are essentially felspar-magnetite rocks, with comparatively acid felspars and a very small content of ferro-magnesian minerals. From their mineralogical constitution, it may be inferred that with a low silica percentage there is a comparatively high content of alkalies, iron oxides, and alumina, together with a deficiency in lime and magnesia, in the chemical analysis.

Since the type-rocks from Skye were described mugearites have been found in Mull and Eigg,* in East Lothian and Midlothian, and also in the Campsie and Kilpatrick Hills.† The

* *Summ. Progr. Geol. Sur.* (1905), Analyses p. 73.

† *Summ. Progr. Geol. Sur.* (1906), p. 91.

occurrences in the Midland Valley belong to Lower Carboniferous lavas, and are believed to be flows, whereas the type-rocks from Skye are members of composite sills of Tertiary age. Dr. Flett has recently described the mugearites of the Lothians.* They differ from the Skye rocks in being much less fresh, and in containing more orthoclase and less olivine. There are also porphyritic types with phenocrysts of labradorite and decomposed augite. The rocks from North Third agree very well in petrographical characters with those from the Lothians, but do not contain the peculiar hornblende or biotite flakes characteristic of the latter rocks. Like the mugearites of the Campsies and Kilpatricks, they occur towards the top of the Lower Carboniferous lavas.

EXPLANATION OF PLATES.

Plate XIII.

Fig. 1.—Photograph showing the excavation through the escarpment of Bed O. The alternating beds of lava and tuff are well shown. Bed L is three feet thick.

Fig. 2.—Photograph of a very perfect "back" or fracture surface developed by blasting. Numerous other concentric surfaces are visible to the left. A two-foot rule gives the scale.

PLATE XIV.

A longitudinal section from E.W. along the trench, showing the alternations of lava and tuff, the irregular surfaces of the flows, and numerous hollows filled with boulder-clay. A small plan shows the exact location of the trench.

* *Summ. Progr. Geol. Sur.* (1907), pp. 119-126.

Fig. 1.

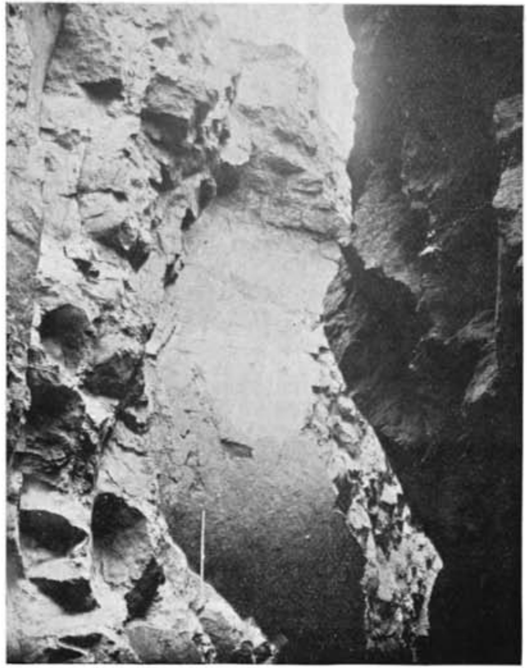


Fig. 2.

LONGITUDINAL SECTION OF PUDDLE-TRENCH