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THE BRIGHTON BASALTS, TASMANIA

By

*IAN MCDOUGALL
Australian National University, Canberra

(With 3 Plates and 1 Figure)

ABSTRACT

The Brighton Basalts consist of but a single flow exceeding 150 feet in thickness which flowed down the pre-existing valley of the Jordan River and flooded back up the valleys of the Bagdad and Strathallern Rivulets. Except where the rivers have breached it the surface has been but little modified by later erosion. The complex system of polygonal jointing indicates that the cooling history of the flow was not simple. The basalt is olivine-bearing and its texture varies from doleritic to an extremely fine-grained porphyritic type. The composition of the magma is intermediate between the olivine and tholeiitic magma-types with closer affinities to the latter. Five volcanic necks of basaltic composition occur within the general region of the Brighton Basalts and are regarded as belonging to the same period of volcanism.

INTRODUCTION

Lewis (1946, p. 191) coined the term Brighton Basalts for the extrusive rocks cropping out over some six square miles of the Pontville and Dromedary squares of the Brighton Army map sheet, Tasmania. The general geology of this region has been described by McDougall (1959). All grid references in the text follow the Army usage. The specimens referred to are in the collection of the Geology Department, University of Tasmania.

Owing to the strongly variable direction and angle of dip of the well-developed columns produced by tension during the cooling of the basalt, Lewis (1946) considered that there were many flows, but careful examination of the well-exposed sections in the sides of the river valleys did not reveal any petrographic or morphological break in the basalt which could be ascribed to a boundary between two flows. No sediments, scoriaceous layers or tuffs were observed interbedded with the basalt. The basalt attains a maximum thickness of 150 feet at 119403, near the southern boundary of the Pontville square, but at this locality neither the top nor the bottom of the flow is exposed, so it is possible that the basalt was 200 feet or more in thickness.

FIELD CHARACTERISTICS AND TOPOGRAPHY

The basalt is scoriaceous, vesicular or massive, but it is commonly inhomogeneous as regards the proportion of vesicles, since in places areas of scoriaceous or vesicular basalt occur within otherwise quite massive rock. In some localities the basalt is coarse and even-grained, with almost a doleritic texture, but in general it is a dark-grey, fine-grained rock with phenocrysts of olivine, 1 mm. to 2 mm. in size, visible to the eye.

The edge of the floor of the pre-basaltic valley is exposed only in a few places. For example, at 121414, an excellent exposure occurs of basalt overlying dolerite. Immediately above the dolerite is a five-foot-thick bed of yellow, friable, coarse-grained tuff dipping off the dolerite at about 25° to the west. It is followed upward by from two to three feet of grey, strongly-weathered tuff, which breaks up into thin columns with sides half an inch across. Above this occurs from zero to ten feet of grey scoria, passing into a vesicular fine-grained basalt and then into a massive, relatively coarse-grained basalt. At 108413, on the flanks of Lodge Hill, scoriaceous basalt overlies the dolerite and passes up into massive hexagonally jointed basalt. The basalt dips off the dolerite at about 10° in a south-westerly direction. In the Bagdad Rivulet, at 126471, and along the Hobart-Launceston Highway, betwen the Broadmarsh and Tea Tree turnoffs, much scoriaceous and vesicular basalt occurs. Pipe amygdules, commonly filled with brown opal, are present in many places. It is considered that the basalt, as exposed at these two localities, is near to the base of the flow.

In this area the only evidence as to the age of the basalt is that the topography, onto which the basalt was extruded, was essentially of the same form as at the present, and hence it is of post-faulting age. The basalt, except where the rivers have breached it, remains relatively undissected, suggesting that it was outpoured in comparatively recent times, possibly in the late Tertiary. A number of volcanic necks occur in the area and these are considered to be of the same age. Spry (1955) suggested a Miocene age for the Tasmanian basalts, but later work (M. R. Banks—personal communication) indicates that there is more than one period of volcanism in the Teritary.

The present surface of the basalt rises gently from south to north, and, apart from the gorges and steep-sided valleys cut by the streams, it is relatively undissected (Plate III, figs. 1, 2). It is considered that this surface in general reflects the configuration of the top of the basalt immediately after outpouring and it is probable that only the upper scoriaceous layers have since partly been

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removed. The altitude of the surface rises from 180 feet or 190 feet at the southern boundary of the Pontville square to about 235 feet at 118482, 600 yards south-east of Mangalore. However, the basalt extending west from the main Hobart-Launceston road rises steadily to attain an altitude of 290 feet at 088432 on the Broadmarsh road at the most westerly point of outcrop of the basalt. These data suggest that the basalt flowed eastwards down the pre-existing Jordan valley and then south to the pre-basaltic Derwent valley with a branch of the flow flooding back up the Bagdad and Strathallern valleys. Lewis (1946, p. 193) was of the opinion that all the basalt originated from a source in the pre-existing Derwent River valley near Bridgewater.

On the hypothesis stated above, the source of the basalt must be further towards Broadmarsh than the most westerly exposure of the basalt. Two plugs of basalt occur in this region, one at the north-western end of Goat Hill and the other at 046436, west of Limekiln Creek, and these are possibly centres of eruption of the Brighton Basalts. However, the composition of the plugs is markedly different from the basalts occurring to the east. The only alternative, then, for the source of the basalts is that the vent up which they found their way to the surface was covered by the lava.

THE PRE-BASALTIC TOPOGRAPHY

The pre-basaltic topography has been contoured from heights obtained at the edge and within the flow by means of an altimeter. The contours (fig. 1) show that the pre-existing Jordan valley which has now been considerably widened by the present Jordan River. When the basalt filled the old valley the river was displaced to the northern edge of the basalt and has continued to migrate northwards ever since. The base of the basalt at the foot of Lodge Hill has a higher altitude than that at the northern edge of the flow and this is most probably due to the pre-existing valley being asymmetrical in outline with steep slopes rising from the north side of the river, much as it is now. A similar profile is reported by Prider (1947, p. 143) for the basalt near Tarraleah, where there is an increase in thickness from west to east, and he considers the asymmetrical valley to be the result of differential erosion of hard dolerite and softer sediments. In the case of the pre-basaltic Jordan valley, the river cut down through dolerite into Triassic sandstone and gradually migrated northwards in the sediments, producing the asymmetrical valley.

Half a mile south of Pontville the pre-basaltic river valley turned south and maintained that general direction, with minor inflexions, until it joined the Derwent valley. The contours show that the river valley in this part of its course was narrow, with relatively steep sides, because the river was cutting down mainly in resistant dolerite. The pre-basaltic Bagdad and Strathallern Rivulets joined the Jordan valley approximately at the same point as they do at the present time and their courses were similar to those they occupy today. For a short distance a small tributary cut back in a north-westerly direction from the pre-basaltic Jordan River from about half a mile south-west of Brighton.

The gradient of the pre-basaltic Jordan River was greater than that of the present river, since the base of the basalt towards its western margin (170 feet) is considerably higher than the floor of the present valley immediately to the north (110 feet), while the base of the basalt at the southern boundary of the Pontville square is below the floor of the River Jordan of today.

JOINTING OF THE BASALT

Good exposure of the basalt in the valley sides gives ample opportunity for the study of the jointing. In general, the cooling of the basalt has resulted in the formation of polygonal joint columns. At 142449, very well developed vertical hexagonal columns occur with sides up to three feet in size (see Plate I, fig. 1), but in most cases the jointing is far less uniform with the number of sides to the columns varying from three to eight feet. Commonly in the few feet immediately below the present surface of th basalt, approximately vertical columnar jointing occurs. However, further down in the basalt, a number of different patterns of jointing have developed. At 142438, 600 yards east of the Jordan River-Bagdad Rivulet meet massive, practically unjointed, rock at a junction, in one portion of the excellent cliff section, vertical columnar jointing extends only ten feet below the present surface of the basalt to sharp contact. This contact does not remain horizontal; westwards it rapidly becomes lower till at least 70 feet of the 90 feet of the section has columnar joints, which are vertical. The massive basalt towards the bottom of the section has a sub-horizontal joint system with a poorly-developed system approximately perpendicular to it, resulting in irregular joint blocks, which are elongated in an horizontal direction. Massive basalt is present at a number of other localities, but it is by no means general.

Commonly, the columnar joints are sub-vertical and grouped together in the form of "fans" up to 20 yards across. The columns diverge from a central, often complexly jointed, zone up to 10° to 20° from the vertical. Good exposures of columns occur in the railway cuttings on the now disused Apsley railway line south of the junction of the Jordan River and the Bagdad Rivulet (Plate I, fig. 2) and also in the 150-feet-high cliffs at 120403.

In the cliffs of the Jordan gorge at the extreme south of the Pontville square and extending outside it, the columnar jointing is most remarkable. Here the direction and angle of dip of the columns changes considerably even in a short distance. One section, at 115399, has exposed in it two rough shallow "synclines" of columns, which are about 120 yards across. In the south-west, the columns dip approximately 30° to the north-east and decrease in dip to nearly zero and then dip south-west in the north-eastern part of the section. One "syncline" has a large, nearly vertical joint, in an axial plane position, the sets of columns on either side of which have different directions and angles of dip (see Plate I, figs. 3 4, 5).

This type of columnar jointing is not uncommon in basalts elsewhere in the world. Iddings (1909, p. 322) figures a quarry at Orange Mountain, New Jersey, which in many respects is similar to the occurrences described here.

Only in local areas is hackly jointing well developed. In a cliff on the Bagdad Rivulet, 50 yards north of the rifle range road at 140456, twelve feet of hackly-jointed basalt is exposed underlying eight feet of massive basalt.

The cooling history of the basalt flow was a very complex process, as shown by the extremely variable manner of jointing, mainly of the columnar type, and it deserves a much more thorough investigation than it has been possible to carry out.

PETROLOGY

Petrology of the Basalts

The Brighton Basalts can be classified as olivine basalts as the term is used by Johannsen (1937, p. 281). They consist of some olivine (3% to 15%), either as phenocrysts or as granules, but commonly as both; abundant plagioclase, constituting between 30% and 50% of the rock; pyroxene, which comprises between a few per cent and 30% of the rock; a variable proportion of mesostasis (10% to 55%); several per cent of iron ore and minor amounts of introduced silica and calcite.

The olivine occurs as colourless euhedral to anhedral crystals, varying downward in size from 3 mm., which are biaxial negative with a very high optic angle, so that the ferrous oxide content of the mineral is greater than 13% and probably is more like 15% to 25%. Alteration of the olivine to serpentine and/or carbonate is not uncommon. Plagioclase (Ab_{30}-Ab_{50}) as lath-shaped crystals ranges up to 1.4 mm. in length. Twinning is very well developed, the albite type being most common, the carlsbad type less so, while pericline twinning is rarely present. Normal zoning is usually present, the difference in composition between the core and the rim of any one crystal being as much as 20% Ab. Pyroxene, generally as anhedral crystals, ranges from 2 mm. in size down to minute granules which commonly occur in the mesostasis. In most thin sections only augite was definitely identified with its moderate optic angle. However, in some, pigeonite, with its characteristically low 2V, was recognised. Iron ore occurs as minute, often euhedral granules, thin rod-like crystals, and as anhedral grains. In rocks which have a high proportion of mesostasis it is found that the iron ore is confined to it. The mesostasis varies in character according to its abundance. When it constitutes one third or more of the rock it is usually opaque, but does contain some skeletal microlites of plagioclase and pyroxene. However, as the proportion of mesostasis in the rock decreases it becomes grey and then pale-brown in colour and the iron ore, which causes the opaqueness because of its finely-divided state, separates out into discrete crystals. Microlites become very common, but in the end product, when the mesostasis constitutes only about 10% of the rock, it consists essentially of pale-brown isotropic glass.

On the basis of the proportions and grain size of the minerals and textures, it has been possible to recognize five distinct types in the basalt flow, three of which have been previously described by Edwards (1950, pp. 102-103). The five types are:—

1. Ouse type.
2. Bridgewater type.
3. Pontville type.
4. Midlands type.
5. Jordan type.

The Ouse, Bridgewater and Midlands types are those previously defined by Edwards, while the two remaining types are included by him in his three groups, but are here proposed and described as separate types. A summary of the salient features of each type are given in Table 1, the proportions of the various minerals being arrived by micrometric analysis using a point counter.

1. *Ouse Type* (Plate II, Figs. 1, 2)

In hand specimen the rock is dense, dark-grey in colour, massive and very fine grained, while in thin section it is hemicrystalline and has a porphyritic texture with an hyaloophitic textured (Johannsen, 1937, p. 147) groundmass. The phenocrysts, which are of fresh, anhedral to subhedral olivine are set in a groundmass consisting of plagioclase (Ab_{30} to Ab_{40}) laths, olivine granules and an abundant opaque mesostasis. The opaqueness of the mesostasis is due to the presence of very abundant, extremely minute, iron ore granules embedded in it. Plagioclase and pyroxene are present in the mesostasis as microlites, the former as skeletal laths and the latter as granules or skeletal prisms commonly arranged in sheaves. Green opal occurs throughout the rock encrusting small vesicles. This Ouse type of basalt was found at the edge of the Brighton Basalt, at 106393, in a quarry beside the Hobart-Launceston Highway.

2. *Bridgewater Type* (Plate II, Fig. 3)

The rock is dark-grey in colour, dense and fine grained, but contains abundant yellowish-green olivine phenocrysts up to 2 mm. in size. In thin section the rock is porphyritic with olivine phenocrysts set in an hyaloophitic textured groundmass of pyroxene, olivine, plagioclase and an abundant opaque mesostasis. This type is coarser grained than the Ouse type and contains pyroxene as a major constituent. The olivine occurs as anhedral, often strongly embayed, fresh crystals. The plagioclase is a pale-grey augite and occurs as anhedral crystals. There is a tendency for a number of granules of pyroxene to crystallize adjacent to one another to form microglomeroporphyritic plates. The opaque mesostasis occupies about 40% of the rock and contains some small plagioclase microlites and pyroxene granules in addition to rather rare thin rod-like crystals of iron ore. Minor amounts of calcite and yellowish-green opal fill small vesicles. The Bridgewater type is very commonly developed and the following specimens belong to this group: 8364, 8369, 8394, 8395, 9412 and 8419.

TABLE 1.—*Comparison of the Five Different Types of Basalt.*

	Ouse Type, Spec. 8378.	Bridgewater Type, Spec. 8373.	Pontville Type, Spec. 8372.	Midlands Type, Spec. 8370.	Jordan Type, Spec. 8421.
Texture.	Porphyritic, Hyaloophitic Groundmass.	Porphyritic, Hyaloophitic Groundmass.	Porphyritic, Sub-ophitic Groundmass, Intersertal mesostasis.	Ophitic.	Inter-granular.
Olivine (%)	13.2	9.8	8.8	6.5 altered to carbonate and serpentine)	3.3 (altered to carbonate)
Max. Size (mm.)	0.8	2.5	2.5	1.5	1.6
Serpentine %	....	...	2.3	..	....
Pyroxene (%)	In mesostasis as microlites	19.1	21.3	28.9	27.9
Augite (A) and/or Pigeonite (P)	....	A	A	A, P	A, P
Max. Size (mm.)	..	0.5	0.9	2.0	0.4
Av. Size (mm.)	0.05	0.2	0.2	0.8	0.1
Plagioclase %	31.8	30.5	38.6	45.9	41.2
Composition	Ab_{31} Ab_{40}	Ab_{30}-Ab_{40}	Ab_{28}-Ab_{51}	Ab_{30}-Ab_{57}	Labradorite
Max. Length (mm.)	0.35	0.2	0.3	0.9	1.4
Av. Length (mm.)	0.1	0.1	0.1	0.4	0.2
Mesostasis %	54.1	40.5	20.5	12.0	14.3
Colour	Opaque to brown	Opaque	Brown to grey	Brown	Brown
Microlites: Abundant (A) Common (B) Rare (R)	C	R	A	C	C
Iron Ore %	In mesostasis (finely disseminated)	In mesostasis	5.4	3.5	3.7
Opal %	0.9	....	1.4	2.5	8.9
Calcite %	...	...	1.7	0.7	0.7

3. *Pontville Type* (Plate II, Fig. 4)

In the hand specimen rocks belonging to this group are very similar to those of the Bridgewater type, but in thin section the phenocrysts of olivine are set in a sub-ophitic groundmass with an abundant intersertal brown mesostasis. The olivine crystals, which are usually euhedral to subhedral are, in some cases, quite strongly embayed and commonly are altered to serpentine and carbonate. Rarely a small plagioclase lath is included in the olivine phenocrysts. Plagioclase of labradoritic composition occurs as laths, which, in a few cases, form microphenocrysts up to 0.8 mm. in size. Pyroxene is present as anhedral crystals, averaging approximately 0.2 mm. in size and rarely as phenocrysts. The pyroxene is generally an augite with a moderate optic angle. However, in specimen 8375 pigeonite with a very low 2V was definitely identified. Plagioclase is commonly ophitically intergrown with the pyroxene. The intersertal mesostasis is usually light-brown in colour and consists of skeletal microlites of plagioclase and pyroxene set in a base of pale-brown glass which is isotropic and has a refractive index less than that of balsam. Iron ore, as minute, commonly euhedral granules, occurs scattered through the mesostasis and also is present as rod-like crystals up to 0.3 mm. in length, which, within a restricted area, are often oriented parallel to one another. Anhedral crystals of iron ore up to 0.2 mm. in size are also present and practically all the iron is restricted to the mesostasis. In specimen 8382 some small prisms of apatite up to 0.25 mm. in length occur in the mesostasis. Minor amounts of olive-green opal and colourless calcite occur as infillings to small vesicles. Specimens 8375, 8376, 8390, 8396 and 8382 fall into this subdivision quite well, but 8396 is considerably coarser than the average, although it has most of the characteristics of the group.

4. *Midlands Type* (Plate II, Fig. 5)

In the hand specimen the rock is dark-grey in colour and has a dolerite texture with green pyroxenes up to 2 mm. in diameter, easily visible to the naked eye. In thin section the rock has a strongly ophitic texture and consists of plagioclase laths and anhedral pyroxene crystals with relatively minor amounts of altered olivine, iron ore, and a grey-to-brown glassy mesostasis. Some calcite and opal occur in small areas as infillings to vesicles. The composition of the plagioclase varies from calcic labradorite into calcic andesine. The greatest range observed in one crystal, from the core to the thin outer rim, was Ab_{32} to Ab_{57}. The pyroxene, which is pale-grey in colour, includes many pragioclase laths ophitically. Both pigeonite and augite are present and they are commonly intergrown, one often partially enclosing the other. In such cases it is seen that the cleavage runs across the boundary between the two pyroxenes without a break, but owing to differences in optical orientation, a sharp boundary can be discerned in the birefringence. The optical angle of the pigeonite is nearly zero, while that of the augite is about 45°. The mesostasis occurs intersertally between the plagioclase and pyroxene. It is brown to grey in colour and commonly is speckled with minute iron ore granules. The mesostasis has a refractive index less than that of balsam and it is isotropic so that it is mainly glass. It contains a number of colourless acicular microlites of apatite up to 0.1 mm. in length. These commonly contain many minute iron ore granules. Microlites of pyroxene and plagioclase also occur in the mesostasis, but rarely. About 3% of the rock consists of iron ore as lath-shaped or anhedral crystals in addition to the minute granules in the mesostasis Olivine occurs as anhedral to subhedral crystals which have been extensively altered to serpentine and carbonate with only small remnants of the olivine remaining. Calcite, commonly crystallized in a spherulitic manner, and green opal occur as infillings to small vesicles. Specimens 8370, 8371, 8400 and 8410 are included in this group. Although the texture of 8376 is very much like that of the Midlands type, it must be considered to be intermediate in position between this type and the Pontville type since the mesostasis constitutes about 15% of the rock and the plagioclase is a little finer grained. No pigeonite was identified in 8376 and the olivine occurs not as phenocrysts but as granules averaging about 0.1 mm. in size .

5. *Jordan Type* (Plate II, Fig. 6)

Specimen 8421 is a massive, grey, fine-grained rock with common pale-green mineral concentrations up to 1 mm. across, which are altered olivine crystals. Vesicles are present but not abundant. In thin section the rock is fine grained with an intergraular texture and consists essentially of lath-shaped labradorite and granular pyroxene. Iron ore, olivine altered to carbonate, and an intersertal isotropic mesostasis are present in lesser proportions. Opal occurs abundantly, along with calcite, in amygdales. The pyroxene is pale-grey in colour and, as far as can be determined, it is mainly augite, although one crystal was positively identified as pigeonite with its characteristically low optic angle. Iron ore is generally present as anhedral elongate crystals. The intersertal mesostasis is brown in colour, but it is, in some cases, nearly opaque. It contains fairly abundant skeletal microlites which are probably of apatite and are speckled with numerous iron ore granules. The brown base is glass. Abundant (about 9%) dark-green massive opal occurs in irregularly-shaped areas up to 0.8 mm. across and calcite is also present, usually with a spherulitic crystal arrangement. This rock can be compared with the Midlands type, as defined above, but it is rather finer grained, particularly as regards the pyroxene, resulting in an interganular compared with an ophitic texture. It was thought to be sufficiently distinctive to raise it as another type and it is probably included in the Midlands type as originally defined by Edwards (1950). Specimens 8367 and 8374 bear close resemblances to 8421 and are therefore included as members of the Jordan type. The form of the pyroxene is the main difference between the Jordan and Midlands types. In the former it occurs as small granules, whereas in the latter it has crystallized as large plates, including plagioclase ophitically. The reason why in the one case crystallization took place about numerous nuclei and in the other about a few is not known.

Intermediate Types

Although the majority of the basalts fall into one or other of the types outlined above, it is to be expected that there will be rocks intermediate in character between them. Thus specimens 8417 and 8418 have textures which lie between those of the Bridgewater and Pontville types; 8365 lies between the Ouse and Bridgewater types and 8411 between the Bridgewater and Midlands types.

Petrogenesis

Mutual Relationships

The various types of basalt are considered to have resulted from different rates of cooling of a single magma, the position within the flow being the major controlling factor of this rate. The fine grain size and the high proportion of mesostasis in the Ouse type indicate a relatively rapid cooling of the magma and, since the specimen was taken from near the edge of the flow, rapid cooling was to be expected. The phenocrysts of olivine probably had an intratelluric origin, while the granules were formed during and after outpouring. The composition of the magma and the physical conditions were such that the plagioclase began to crystallize, but before the composition or temperature of the magma reached a point where pyroxene could form to any extent, the rock was cooled below the temperature of crystallization. However, the cooling was sufficiently slow to allow crystallization of a small amount of pyroxene as microlites. With slower cooling, the pyroxene was able to crystallize into distinct anhedral crystals and the proportion of mesostasis correspondingly decreased so that the Bridgewater type of basalt was formed. The large olivine crystals are in some cases strongly embayed, probably indicating partial resorbtion on cooling which is strongly supported by the fact that there is a marked decrease in the proportion of olivine with increasing grain size, i.e., with slower cooling, more time was available for resorbtion to take place.

The Pontville differs from the Bridgewater type, into which it passes, by having a slightly coarser grain size and a tendency towards an ophitic texture. The proportion of pyroxene increases with a corresponding decrease in the amount of mesostasis present. The mesostasis becomes grey to brown in colour and contains abundant microlites and the iron ore begins to separate out into discrete crystals. These observations indicate that the Pontville type was formed by slower cooling of the magma than in the case of the Bridgewater type. With still slower cooling the Jordan and Midlands types were produced with their relatively coarse grain size and very small proportion of mesostasis.

As mentioned above, the types of basalt grade into one another. For example, in the section on the Bagdad Rivulet, 600 yards east of its junction with the Jordan River, specimens 8370, 8371, 8372 and 8373 were obtained from a cliff about 80 feet high. Specimens 8370 and 8371 were taken five and 17 feet respectively above the base of the cliff; at 27 feet specimen 8372 was obtained, while 8373 was sampled from the 75 feet level. There is no sharp textual change observable in the outcrop but it is gradual. Specimens 8370 and 8371 have a coarse ophitic texture with rather minor amounts of porphyritic or granular olivine and a low proportion of mesostasis, i.e., they are of the Midlands type. Upwards, the texture changes to porphyritic with a sub-ophitic groundmass as represented by 8372 (Pontville type). There is a slight increase in the amounts of olivine and a decrease in the proportions of pyroxene and plagioclase with a corresponding increase in the abundance of mesostasis. The grain size of the constituents, except olivine, is reduced considerably. This trend, the reduction in the proportion of plagioclase and pyroxene, but with little change in grain size, is continued upwards and in 8373 (Bridgewater type) over one-third of the rock is composed of opaque mesostasis and the texture remains porphyritic, but with an hyaloophitic groundmass. The Ouse type results from a more rapid cooling than is the case for the Bridgewater type and is not represented in the section being discussed here. However, it is rather surprising that such strong differences in texture occur in this section as it is within 100 yards of the edge of the pre-basaltic valley.

The fact that the rate of cooling, and hence the resultant texture of the basalt, is controlled by the position within the flow rather than its proximity to the sides or floor of the pre-basaltic valley is amply illustrated in 122414. Here a specimen (8404), taken no more than 20 feet from the side of the pre-basaltic valley, has the coarse Midlands type texture. The altitude of the locality from where this basalt was obtained is 90 feet and the top of the flow at 190 feet plus.

In sections where the polygonal jointing is developed right throughout, much more uniform textures of the basalt are found. For example, at 119403, where the basalt is hexagonally jointed for the full 150 feet of exposure, there is no great difference in texture throughout the whole section.

In the late stages of crystallization some alteration of the olivine to serpentine and/or carbonate took place. Hydrothermal solutions, probably also at this time, introduced opal and calcite, with a little chalcedony, into the rocks and deposited them in vesicles. Their amounts vary considerably from place to place.

The Magma Type

Petrographically, the Brighton Basalts have similarities to both the tholeiitic and olivine-basalt magma-types of Kennedy (1933). The presence of augite rather than a pigeonite as the most abundant pyroxene and the ubiquitous occurrence of olivine suggest affinities with the olivine-basalt magma-type, but the glassy residuum, in many cases, charged with iron ore granules, is more typical of the tholeiitic magma-type. Chemically, the three types of basalt defined by Edwards (1950), which are present in the Brighton area, are very similar to one another (see Table II, Analyses 1, 2 and 3). Comparison with the compositions of the two magma-types of Kennedy (1933) (Table II, Analyses 4 and 5) show that the silica content of the Brighton Basalts is typical of the tholeiitic rather than of the olivine-basalt magma-type, whereas the magnesia and lime contents and the soda/potash ratios are similar to those in the latter. The alumina percentage is intermediate between those of the two types and the iron oxide content is lower than in either type. Edwards (1950) therefore, concluded that the Brighton Basalts are intermediate in composition between the olivine-basalt and tholeiitic magma-types and he also pointed out the strong similarity of the compositions of the basalts with the Newer Volcanic magma-type of Victoria.

TABLE II.

	1	2	3	4	5	6	7	8	
SiO_2	51.48	51.48	50.04	50	45	51.76	50.0	qz	0.18
								or	5.00
Al_2O_3	14.32	14.18	14.47	13	15	12.65	14.3	ab	22.01
Fe_2O_3	2.17	1.56	4.26	13	13	2.37	3.0	an	24.46
FeO	8.98	9.61	7.69			8.88	7.3	di wo	7.66
								di en	4.30
MgO	8.02	8.18	7.89	5	8	8.50	6.6	di fs	3.04
								hy en	16.10
CaO	8.33	8.95	9.35	10	9	9.94	10.9	hy fs	10.56
Na_2O	2.48	2.61	2.47	2.8	2.5	2.19	2.6	mt	2.32
K_2O	0.61	0.82	0.26	1.2	0.5	0.38	0.8	ilm.	3.04
H_2O	0.58	1.00	1.43	....	....	....	0.9	ap	0.67
H_2O-	1.54	0.24	0.52	....	....	....	1.8	H_2O	1.24
CO_2	0.05	tr.	tr.	....	....	....	....	....	100.58
TiO_2	1.45	1.60	1.55	....	....	3.31	1.1	$\frac{(Fe^{2+} + Mn)}{(Fe^{2+} + Mn + Mg)} =$	40.0
P_2O_5	0.21	0.29	0.23	....	....	0.26	0.4	....	....
MnO	0.14	0.15	0.17	....	....	....	0.2	$\frac{\text{(norm. molec. albite)}}{\text{(norm. molec. Ab + An)}} =$	47.4
Cl	nil	tr.	tr.	....	....	....	....	....	....
SO_3	nil	tr.	tr.	....	....	....	....	....	....
	100.36	100.67	100.33	95	93	100.24	99.9	....	....

1. Ouse type from near Ouse township.
2. Bridgewater type, from 400 yards upstream from bridge, Bridgewater township.
3. Midlands type, from Viney's Sugarloaf south of Nile (Analyses 1, 2 and 3 from Edwards, 1950).
4. Tholeiitic magma-type (Kennedy, 1933, p. 241).
5. Olivine-basalt magma-type (Kennedy, 1933, p. 241).
6. Computed composition of historic magma of Mauna Loa (Powers, 1955, p. 85).
7. Average tholeiite of α-middle fractionation stage (Wager, 1956, p. 231).
8. Normative analysis of analysis 2.

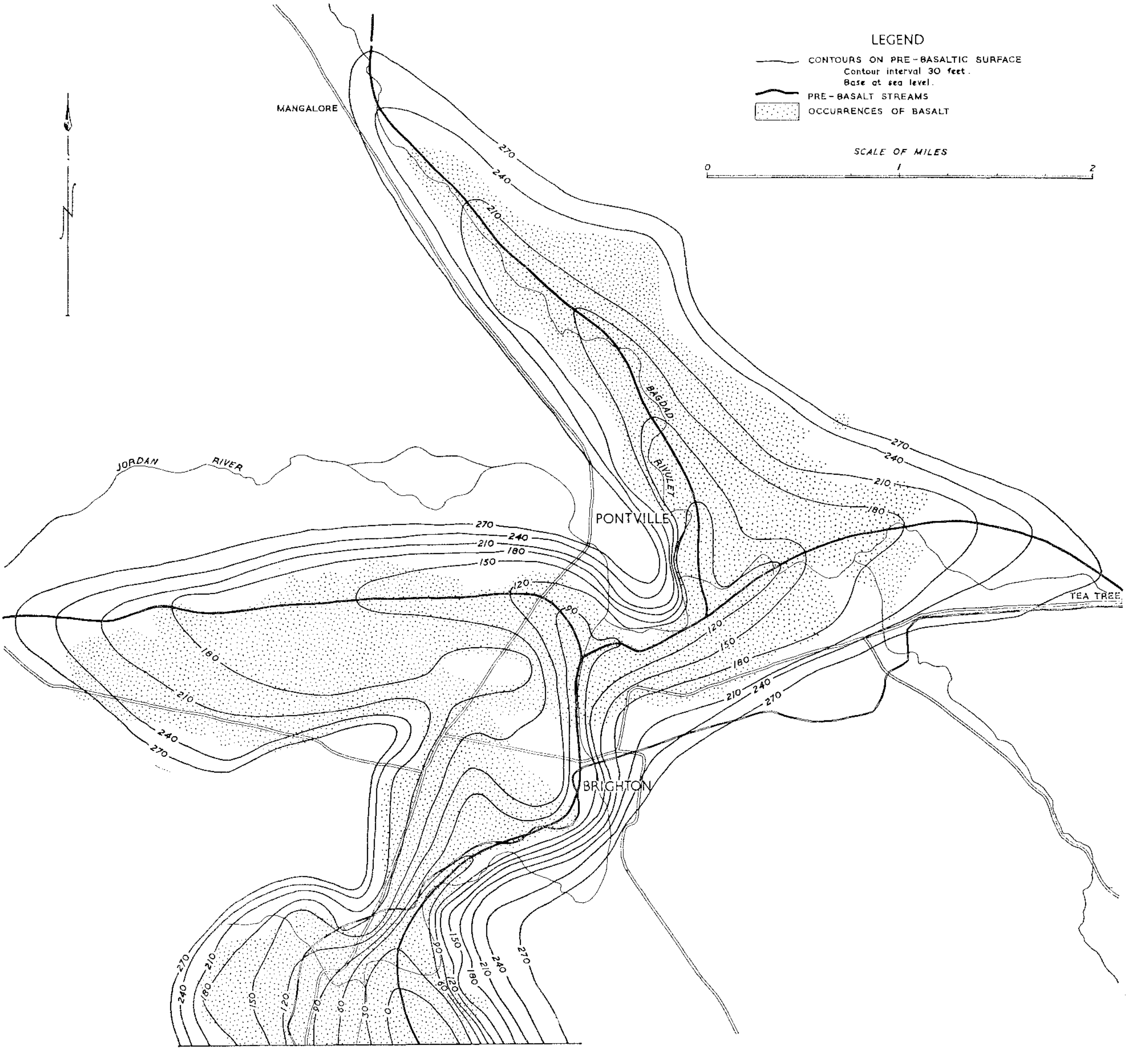

FIG. 1.—Contours on the pre-basaltic surface.

The Brighton Basalts, in many respects, resemble the basalts of the volcanic piles of Kilauea and Mauna Loa in Hawaii. The bulk of the lavas forming these volcanoes are olivine basalts (i.e., contain 5-15% modal olivine), although in the majority of cases the rocks are saturated with silica (Powers, 1955, p. 80) and cannot be included within the olivine-basalt magma-type. The average chemical composition of the magma outpoured in historic times on Mauna Loa (Powers, 1955, p. 80) is quoted in Table II, Analysis 6. The similarity is striking. However, the Brighton Basalts have a slightly higher alumina content and a lower lime and titania content.

The norm calculated for the Bridgewater type (see Table II) indicates that the basalt is just saturated. Yet olivine, an undersaturated mineral, is always present in the basalt. Olivine, when it occurs in basalts, is usually the first mineral to crystallize, but in saturated magmas it is normally resorbed because it becomes out of equilibrium with the magma. This tendency is borne out in the Brighton Basalts by the general decrease in the proportion of olivine in the coarser grained rocks as compared with the more quickly cooled, finer grained basalts.

Wager (1956) has defined successive stages of fractionation of a basic magma by plotting the iron ratios $\frac{Fe^{2+} + Mn}{Fe^{2+} + Mn + Mg}$ and the albite ratios $\frac{\text{(normative molecular albite)}}{\text{(Norm. molec. albite + anorthite)}}$ against each other.

The calculation of these ratios was carried out from the analysis of the Bridgewater type of basalt and, with these values as coödinates, a point is defined on the graphs of Wager, which lies amongst the tholeiitic basalts of the Hebridean province in the α-middle fractionation stage and removed from the plots of the olivine basalts. The average of six analyses of tholeriites plotting in this area is given by Wager (p. 231) and is reproduced above as Analysis 7. Except for a higher lime and lower magnesia content and a slightly lower silica percentage, this average is very similar to the analysis of the Bridgewater type.

It has been pointed out that a number of workers (e.g., Turner and Verhoogen, 1951, p. 181; Green and Poldervaart, 1955, p. 178) that there is a continuous series between the two magma-types rather than a distinct break. The evidence presented above confirms the conclusion of Edwards (1950) that the Brighton Basalts lie in this intermediate zone. However, it has been shown that these basalts have much stronger affinities with the tholeiitic rather than with the olivine-basalt magma-type.

VOLCANIC NECKS

In the same general area as the Brighton Basalts five volcanic necks have been found. Two of them are located in the Dromedary square, one at the north-western end of Goat Hill at 053468, the other 046436, west of Limekiln Creek. North-west of Maiden Early, at 157457, another neck occurs and the other two are located at 195392 in the Back Tea Tree Valley and at 183535, north-east of Butler's Hill. In plan, the necks are circular or sub-circular with diameters from 100 yards to 400 yards. They have been eroded down to the general level of their surroundings, except for the neck in the Back Tea Tree Valley, which rises as a cone-shaped hill to some 300 feet above the valley floor. In every case the necks are situated on, or very close to, a dolerite-sediment intrusive contact or a Tertiary fault, i.e., apparently along lines of weakness. Many of the dolerite intrusive contacts are massive and appear to be anything but lines of weakness. However, at some contacts, both the dolerite and sediments are strongly fractured and jointed.

The necks are considered to be Tertiary in age and belonging to the same volcanic period as the extensive basalts which crop out around Brighton.

The rocks found in the necks are dark-grey in colour, fine-grained and dense, and thin sections show them to vary considerably in composition. Basanites occur in the two vents of the Dromedary square, whereas the neck north-west of Maiden Early and that in the Back Tea Tree Valley are fine-grained olivine basalts. The neck north-east of Butler's Hill is composed of an extremely fine grained olivine basalt.

Thin sections 8423 and 8427, cut from specimens from the Goat Hill and Limekiln Creek necks respectively, consist of phenocrysts of olivine, which in 8427 are altered to and pseudomorphed by reddish-brown iddingsite, abundant very small monoclinic pyroxene prisms and iron ore granules set in a colourless, nearly isotropic base (see Plate III, Fig. 3). The olivine (and its pseudomorph) occurs as anhedral to euhedral phenocrysts averaging about 0.1 mm. in diameter and constitutes some 5% by volume of the thin sections. The pyroxene, comprising about 50% of the rocks, is present as pale-green prisms averaging approximately 0.01 mm. in length in 8423 and 0.035 mm. in 8427. Rare phenocrysts of pyroxene occur in both specimens, one of which in 8427 is 0.7 mm. in size. Iron ore, comprising some 10% of the thin sections, occurs as anhedral or well-formed crystals averaging about 0.005 mm. in diameter in 8423 and 0.02 mm. in 8427 and attains a maximum size of 0.04 mm. in the former and 0.2 mm. in the latter. The above constituents are set in a clear, colourless, low birefringent base, which has a refractive index less than that of balsam and is present to the extent of about 35% in 8423 and 25% in 8427. In both thin sections several per cent of colourless or yellow opal occurs in addition to chalcedony in 8423.

Spry (1955) described similar basanites from Sandy Bay and they also occur at New Norfolk. From the analysis made by Aurousseau (1926), Spry calculated the norm which shows a high orthoclase, albite and nepheline content and therefore considered that this indicates that the base is composed of a mixture of these minerals. The basanites occurring at Sandy Bay are considerably coarser grained and contain a lower proportion of iron ore than in the rocks found in the Dromedary square.

The volcanic neck north-west of Maiden Early is a dark-grey, dense and fine-grained rock containing fairly common phenocrysts which are mainly of olivine, although pyroxene and feldspar are also present. In thin section (8424) the rock contains phenocrysts of large euhedral to subhedral crystals of olivine, several subhedral pyroxenes, and plagioclase laths set in a fine-grained groundmass consisting of plagioclase laths, pyroxene granules and prisms of iron ore. The plagioclase laths, both large and small, are aligned to give a very distinct flow texture to the rock (Plate III, Fig. 4). The olivine, comprising some 10% of the rock, occurs as phenocrysts up to 2 mm. in size and granules down to 0.1 mm. or less in diameter are not uncommon. The $n\gamma$ was found to be 1.688, indicating that the olivine contains about 12% of the fayalite molecule which agrees with the very high optic angle of the mineral. The several phenocrysts of pyroxene, which appear to be augite, are pale-green in colour and occur up to 1.4 mm. in size. Within the groundmass abundant (40%) small granules and prisms of pale-yellow clinopyroxene occur, averaging about 0.025 mm. in diameter. Plagioclase feldspar, invariably in lath-shaped crystals, is present as phenocrysts as well as in the groundmass, there being all gradations in size. The phenocrysts are up to 0.7 mm. in length, but average around 0.3 mm., while those in the groundmass average about 0.05 mm. in size. The plagioclase, a labradorite, comprises about 40% of the rock, of which nearly one-quarter occcurs as phenocrysts. Iron ore makes up some 5% of the rock and is present as granules averaging 0.015 mm. in diameter which are commonly euhedral, although crystals occur up to 0.6 mm. in size and these are anhedral in form.

A plagioclase crystal 1.1 mm. long and 0.6 mm. in width occurs in thin section 8424, surrounded by a distinct corona up to 0.9 mm. in width and is shown in Plate III, Fig. 5. From the slightly off-centre X bisectrix figure the angle between the Y direction and the 010 cleavage was measured as 5°, indicating that the mineral is oligoclase. The corona surrounding the plagioclase consists of two zones, which have a sharp but irregular boundary between them, an inner one, 0.2 mm. to 0.35 mm. wide, which is extremely fine grained, and an outer, rather coarser grained zone 0.2 mm. to 0.5 mm. wide. The inner fine-grained zone consists of minute crystals which are light-grey in colour, have moderate relief and show upper first order to lower second order interference colours, suggesting that it is a pyoxene. The outer, relatively coarse-grained zone consists of crystals averaging between 0.05 mm. and 0.1 mm. in size but occur up to 0.4 mm. The granules are colourless; they have a high relief and strong birefringence with colours up to upper second order. The crystals are generally anhedral, but several well-formed prisms occur with cleavage, on which there is straight extinction, developed either parallel or transverse to the prisms. The properties indicate that the mineral is olivine. The contact between the feldspar and its corona is sharp and is step-like since it follows the two cleavages of the plagioclase. The inner zone is undoubtedly a replacement of the plagioclase since the cleavages and cracks can be readily traced into it. However, they do not pass into the outer zone. It is considered that the feldspar is a xenocryst caught up in the almost completely fluid magma as it ascended from below. Olivine had begun to crystallize, but plagioclase probably had not and, since the xenocryst was oligoclase it certainly must have been out of equilibrium with the magma. The physical conditions were such that the crystal, instead of being dissolved by the magma reacted with it and was replaced by what is possibly pyroxene, presumably by movement outward of soda and alumina and inwards of ferrous iron, lime and magnesia, by solid diffusion. The coarse outer zone of olivine granules was precipitated around the plagioclase and its corona, which together acted as a centre of crystallization. However, if the inner zone is in fact pyroxene and the outer one olivine, this is a reversal of the normal crystallization sequence, perhaps due to a local lowering in temperature in the vicinity of the xenocryst, followed by a re-establishment of equilibrium. Within the same thin section there is another similar occurrence, but in this case there is no feldspar core preserved. The rock is an olivine basalt and bears some resemblance to the Brighton Basalts. However, the fine grain size, the flow texture, the abundant phenocrysts of olivine and plagioclase are important differences.

In hand specimen the rock (8425) obtained from the volcanic neck north-east of Butler's Hill is dark-grey in colour, fine grained, dense, has common olivine phenocrysts, and contains several xenoliths. Some specimens have large angular olivine aggregates up to 20 mm. across. In thin section the rock is seen to consist of phenocrysts of olivine set in an extremely fine grained base of plagioclase laths, iron ore granules and much opaque indeterminable material. The olivine, which constitutes about 10% of the rock, is present as phenocrysts (up to 1 mm. in size) and microphenocrysts, though the former are not very common whereas the latter, averaging about 0.04 mm. in diameter, are abundant. The greater part of the rock (about 80%) consists of an almost opaque groundmass in which abundant iron ore granules 0.01 mm. or less in size occur in addition to laths of plagioclase averaging about 0.02 mm. in length. Amygdales, usually elongate in section and up to 2 mm. in size, contain calcite, chalcedony, opal and a zeolite, probably analcite and, in most cases, at least two of these minerals are associated in the one amygdale.

A roughly circular xenolith of medium-grained dolerite 3 mm. in diameter, occurs in the thin section completely surrounded by the fine-grained basalt; the contact between it and the basalt is sharp. Also a plagioclase crystal 1.5 mm. long and 0.5 mm. in width is present surrounded by a corona, 0. mm. wide, of a similar type to that described above. However, the inner fine-grained zone is much narrower than that in specimen 8424 and passes into a coarser zone without a distinct break and there is no doubt that both zones are replacements of plagioclase in this case since the traces of twin lamellae of the plagioclase are clearly visible in the whole of the corona. The grey colour, the relief, the birefringence and the prismatic form of some of the crystals suggests that the mineral constituting the corona is pyroxene. The plagioclase is an oligoclase with composition about Ab_{80}. A similar crystal occurs in the thin section which has been completely replaced by granules of pyroxene, no plagioclase remaining.

Several other large plagioclase crystals, also considered to be xenocrysts, occur in the thin section but these do not have coronas.

The rock is an olivine basalt which has been rapidly cooled. During its ascent from below the basalt picked up plagioclase crystals from the rocks up through which it passed and also included dolerite fragments as xenoliths. In some respects this rock is similar to 8424 but it is much finer grained and there is no pyroxene except perhaps in the corona of the plagioclase. However, both the rocks contain plagioclase xenocrysts with the same type of reaction rims suggesting that the magma in both cases passed through similar rock types as it ascended. It is possible that the plagioclase xenocrysts were derived from Triassic sediments since they commonly contain feldspar, but the presence of well-formed crystal faces on at least one of the crystals suggests that these xenocrysts were derived from crystalline rocks.

The volcanic neck in the Back Tea Tree Valley is composed of a dark, dense, very-fine-grained olivine basalt which in thin section is seen to be holocrystalline and porphyritic. Olivine, along with some pyroxene, occurs is phenocrysts which are set in a fine-grained groundmass consisting of pyroxene prisms, plagioclase laths and euhedral iron ore crystals. The plagioclase laths have a preferred orientation giving the rock a distinct flow texture. The olivine, making up about 10% of the rock, is present as fresh or slightly-altered phenocrysts which vary from euhedral to anhedral in form. Pyroxene, which is light-grey in colour and is all probably augite, occurs in two generations; those which are phenocrysts and those in the groundmass. The phenocrysts average between 0.1 mm. and 0.2 mm. in size, but occur up to 0.5 mm., whereas the well-formed prisms in the groundmass average about 0.06 mm. in length. The phenocrysts of pyroxene, which commonly are euhedral, constitute only about 2% of the rock, whereas the pyroxene in the groundmass comprises approximately 55% of the rock. The plagioclase is present as common (25%) colourless laths averaging 0.09 mm. in length. However, there are several crystals which reach 0.4 mm. in length. Iron ore occurs as relatively abundant (10%), often euhedral, granules averaging about 0.02 mm. in size and they are distributed evenly throughout the rock. The rock could have crystallized from a magma of very similar composition to that from which the Brighton Basalts were formed.

These five necks show great diversity in the textures developed within them, probably because of differences in composition and rate of cooling of the magma. Three of the necks appear to have a composition similar to that of the Brighton Basalts and they probably originated in the same magma chamber. There is no evidence to suggest that these necks are infilling vents from which the Brighton Basalts were extruded. The two necks occurring in the Dromedary square are basanites which are considerably more basic than the Brighton Basalts. Their position would allow them to be sources for the Brighton Basalts but the difference in composition does not support this hypothesis.

SUMMARY

A single flow of basalt, over 150 feet in thickness, was extruded in the Tertiary Period onto a topography which was rather similar to that of the present day. It is considered that the basalt flowed down the pre-existing Jordan River valley to the Derwent River valley, flooding back up the valleys of the Bagdad and Strathallern Rivulets. Except where the rivers have cut down into the basalt, the original surface of the flow, minus the upper scoriaceous layer, has been preserved. The cooling history of the basalt was complex, as shown by the unusually variable form of the contraction jointing pattern within the flow.

The basalt is an olivine bearing type which varies from an extremely fine-grained but porphyritic rock to a relatively coarse-grained rock with a dolerite texture, the rate of cooling being the controlling factor in the production of these textures. A decrease in the proportion of olivine down through the flow suggests that resorbtion by the magma of this mineral took place in the slower cooling parts of the lava. The magma is intermediate in composition between the olivine-type and the tholeiitic magma-type, but it has closer affinities to the latter.

Five volcanic necks occur in the area adjacent to the Brighton Basalts and these are believed to have been intruded during the same volcanic period.

ACKNOWLEDGMENTS

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PLATE I.

FIG. 1.—Well developed hexagonal columns in basalt at 142449 in a cliff beside the Bagdad Rivulet.

FIG. 2.—Fan-shaped collection of columns of basalt in a railway cutting at 134437.

FIG. 3.—" Syncline " of columns in basalt at 114399. Note the large vertical joint a little left of centre. At the right the columns are nearly vertical.

FIG. 4.—Closer view of the large vertical joint noted in the previous figure in the " axial plane " position of the " syncline ".

FIG. 5.—Second " syncline " of columns at 115399 in a cliff beside the River Jordan. At mid left the columns are pointing directly towards the observer.

PLATE II.

(All photomicrographs taken under ordinary light.)

FIG. 1.—Ouse type of basalt. Greyish granules of olivine with moderate relief and colourless plagioclase laths set in an abundant opaque base. X50.

FIG. 2.—Ouse Type; same as above but with phenocryst of olivine. Thin elongate microlites of pyroxene in the mesostasis at lower left. X50.

FIG. 3.—Bridgewater Type. Phenocryst of olivine, granules of pyroxene and plagioclase laths in an abundant opaque mesostasis. X30.

FIG. 4.—Pontville Type. Partially resorbed olivine intergrown as phenocrysts set in a groundmass of plagioclase laths and pyroxene intergrown subophitically and an intersertal, almost opaque, mesostasis. X30.

FIG. 5.—Midlands Tpe. Coarse ophitic basalt—colourless plagioclase laths included ophitically in large anhedral pyroxene crystals. X30.

FIG. 6.—Jordan Type. Basalt with an intergranular texture and consisting of plagioclase laths and granules of greyish pyroxene. At lower right an iron ore crystal; at centre dark-coloured opal, and at top centre brown (dark) intersertal mesostasis of small microlites embedded in glass. X65.

PLATE III.

FIG. 1.—View from half a mile east of Summerville looking north up the Bagdad Rivulet valley across the well-preserved surface of the basalt.

FIG. 2.—View east up the Stratballern Rivulet valley from near Summerville across the flat surface of the basalt.

FIG. 3.—Basanite from volcanic neck at 040436, west of Limekiln Creek. Phenocrysts of olivine, pseudomorphed by iddingsite, set in a very fine grained groundmass of pyroxene prisms, iron ore granules and a colourless, nearly isotropic, base. Ordinary light, X65.

FIG. 4.—Olivine basalt from volcanic neck north-west of Maiden Early. Well developed flow texture due to alignment of plagioclase laths. Large phenocryst and a number of smaller crystals of olivine an phenocrysts of plagioclase set in a fine-grained groundmass, which is dark in the photomicrograph, consisting of plagioclase laths, pyroxene granules and prisms, and iron ore. Ordinary light, X65.

FIG. 5.—Xenocryst of plagioclase in same rock as previous figure. Colourless crystal of oligoclase surrounded by a fine-grained corona of pyroxene (dark in photomicrograph) followed by a coarser zone of granules of olivine. Ordinary light, X30.

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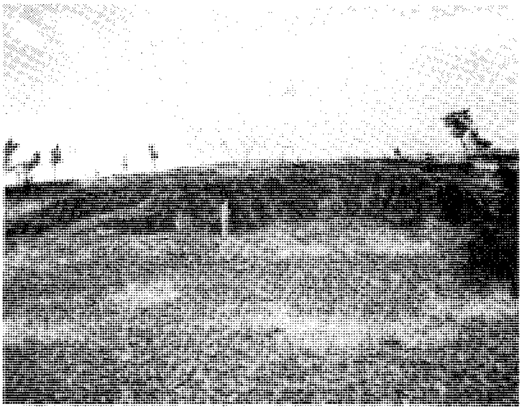

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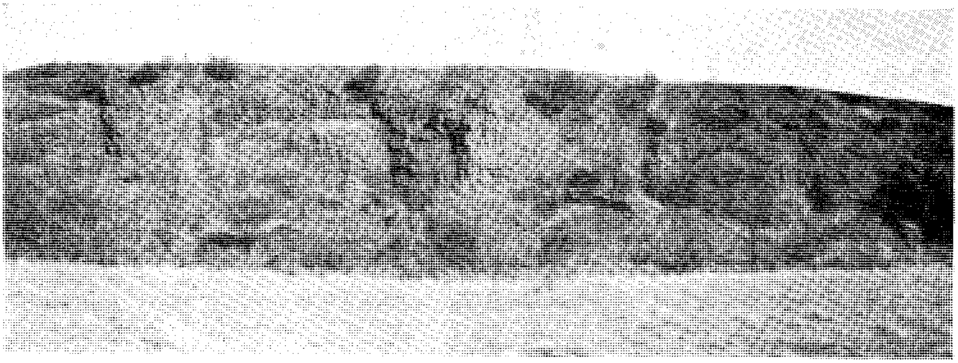

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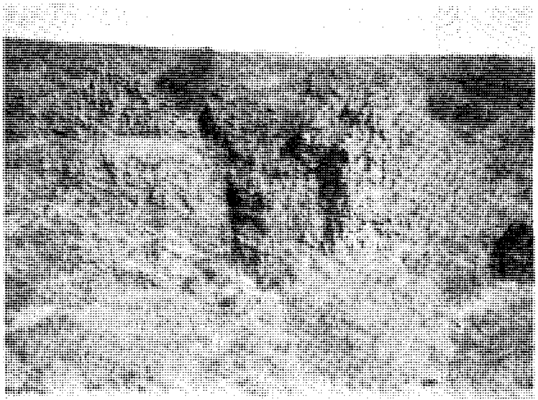

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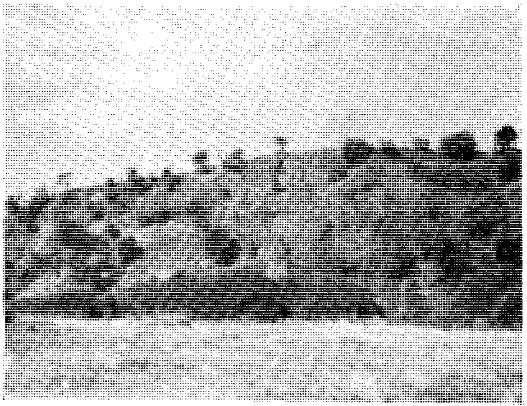

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PLATE I.

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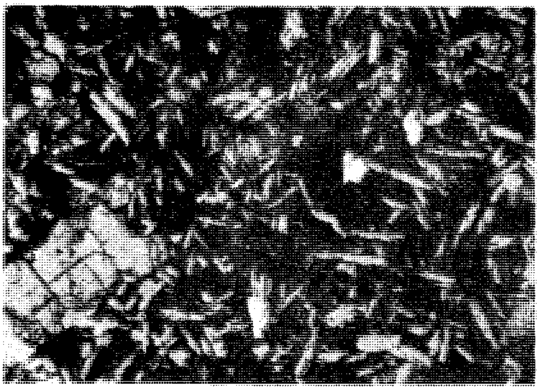

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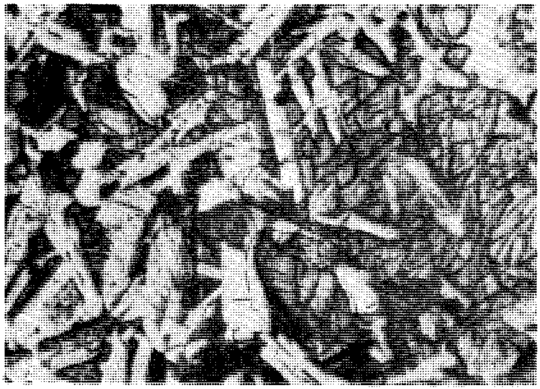

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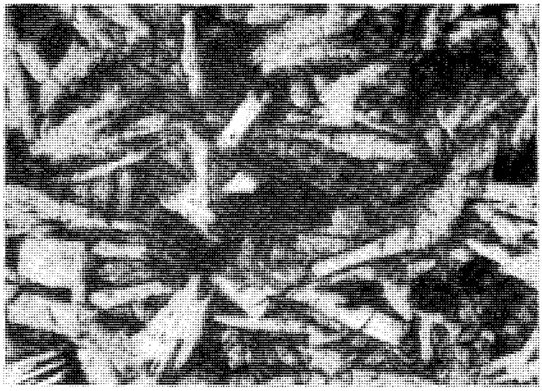

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PLATE II.


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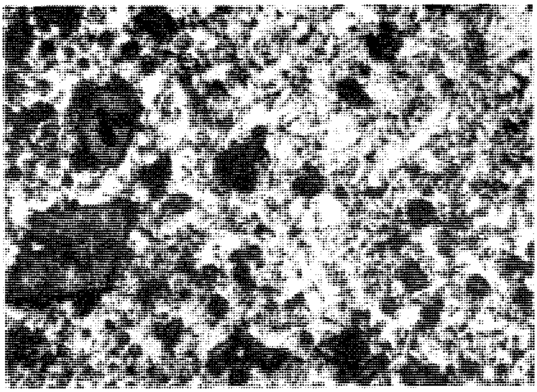
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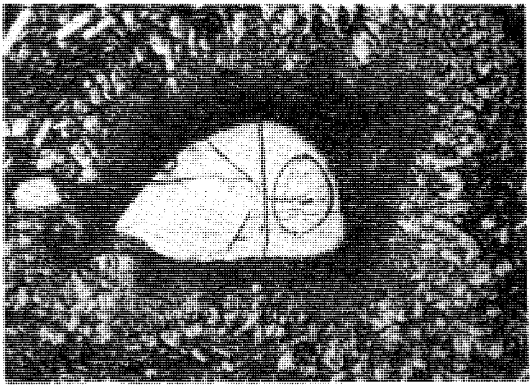
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PLATE III.