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THE GEOLOGY OF UBEKENDT EJLAND, WEST GREENLAND

PART II

THE PICRITIC SHEETS AND DYKES OF THE EAST COAST

BY

H. I. DREVER

WITH 9 FIGURES IN THE TEXT AND 12 PLATES

KØBENHAVN
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BIANCO LUNOS BOGTRYKKERI A/S
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PREFACE

The broader aspects of the geology of Ubekendt Ejland were published in 1948 (Drever and Game). This account was largely based on the field work of two pre-war expeditions. As part of the programme of another expedition in 1950 (Drever and Wyllie, 1951), more data and specimens were obtained.

Delay in completing and publishing more detailed results of field and laboratory work is due to the claims of other obligations, one of which was to pursue in the Shiant Isles and in Skye the enquiry, of which this paper is part, into the origin of picritic rocks. The remaining parts of this series of publications on the geology of Ubekendt Ejland will follow in relatively quicker succession.

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29th April, 1955.

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INTRODUCTION

Ever since Bowen (1927, 1928), in particular, very convincingly demonstrated that picritic (and dunitic) rocks, with special reference to their development in Skye (Harker, 1904), were not derived from a liquid of their bulk composition, this view has been accepted by the majority of geologists as well-founded; and later work, both petrological and experimental, has tended to confirm rather than to invalidate it. So much is this true in fact, that it has become almost axiomatic that picritic (olivine-rich basaltic) rocks are the result of crystal accumulation. Such rocks are regarded as the result of the final congelation of a mixture of liquid and crystals, usually olivine. This olivine, according to the field evidence in any particular case, settled in the liquid before, during or after emplacement as an intrusion or eruption as a lava flow. This view the writer accepted up to the time when he examined the rocks of Ubekendt Ejland. That all picritic rocks on this island were formed by accumulation of olivine seemed to him too facile an explanation to invoke; and this opinion he expressed in a lecture in Copenhagen (Drever, 1952), and to Section C of the British Association for the Advancement of Science at its Meeting in Oxford in 1954.

The chief purpose of the present paper is to continue to test, with some of the evidence from Ubekendt Ejland, the complete adequacy of Bowen's well-established hypothesis. With this in mind, three dykes and four sheets were chosen as sufficiently representative of the picritic intrusions of the east coast. The writer has been unable to confirm that some of the dykes are markedly composite (Drever and Game, 1948). Relatively to the dykes, the sheets have been examined in greater detail; for they are more continuously accessible¹) and thus afford a more complete and satisfying study. But only one of these sheets (Sheet 2) was considered to possess such critical and significant evidence as to justify a thorough petrographical investigation based on a large number of specimens. A major feature of this sheet was thought to be unique until the writer found, in March 1954, an identical feature in a picrite

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¹) It would certainly be worthwhile, however, to make a determined attempt to ascend the coastal cliff along the line of one of the dykes.

sill on the island of Soay (Clough and Harker, 1904). As the writer, in collaboration with two colleagues, is now comparing this Soay sill with Sheet 2, detailed but incomplete optical and chemical data which forms part of this comparative study is, to avoid unnecessary duplication, not yet published.

The origin of picritic rocks is here regarded as still a vital problem which will repay constant attention and re-investigation in the light of new evidence. This paper attempts to achieve its main purpose by recording significant new evidence in the best possible way. At the same time the writer trusts that his Danish colleagues will also accept it as a small contribution to the Geology of Greenland and of some relevance to their own work on similar problems.

FIELD OCCURRENCE AND ASSOCIATED ROCKS

Regional Setting and General Relations.

The East Coast Group of dykes and sheets are intruded only into the Lower Lava Group (DREVER and GAME, 1948), which is predominantly vesicular picritic lava. The picritic dykes and sheets were intruded before the tholeiitic dykes and sheets of the same area, and their geographical distribution is more restricted. All of them are practically non-vesicular, in striking contrast to the picritic lavas into which they are intruded. At least two of the dykes (including Dyke 2 in Fig. 1), when followed by eye up the crumbling, inaccessible cliffs north of Igdlorssuit, are seen to die out at about 100 metres above sea level. All the intrusions selected as representative outcrop along the coast to the north and south of the native village of Igdlorssuit (Fig. 1) and, with the exception of Sheet 3, are more easily accessible from the sea.

All the picritic dykes are nearly vertical and all the picritic sheets tend to be sill-like and concordant in relation to surfaces and vesicular banding of the lava flows.

Local Relations.

Dyke 1.

As seen from the sea, this is the third dyke immediately north of Naqerdloq. It is about three metres thick. Specimens were collected in 1938, and there has been no further opportunity to revisit it. Unfortunately, recent detailed examination in the laboratory has established it as petrologically the most interesting. The lower part is very rich in olivine.

Dyke 2.

This dyke occurs about four kilometres north of Igdlorssuit from which one can reach it at low tide by walking along the shore at the base of the cliffs. It is approximately three metres thick and appears to die out in the lavas on the cliff face at about a hundred metres above sea-level.

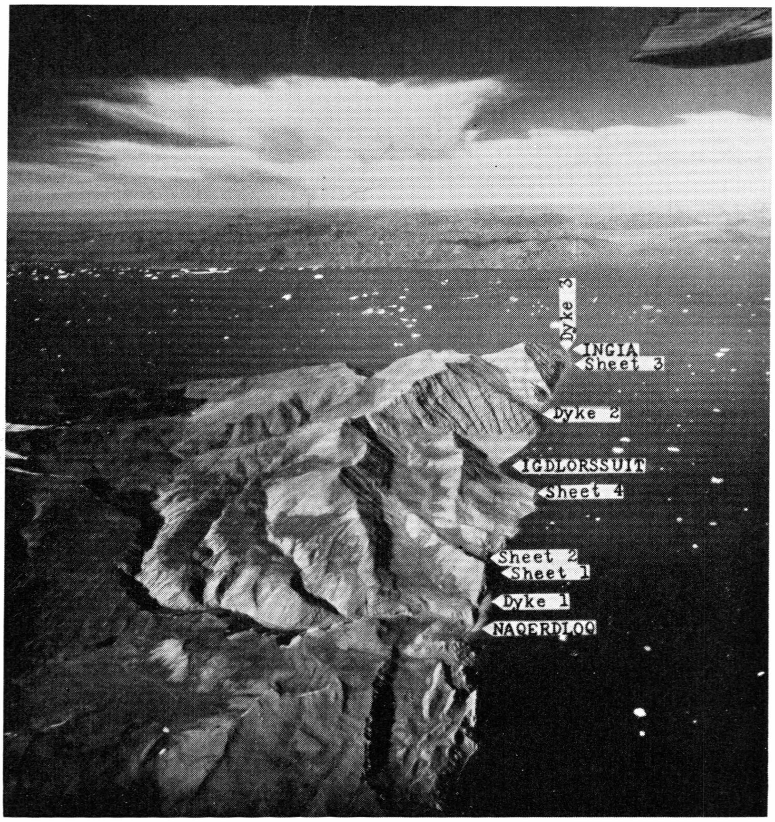

Fig. 1. The east coast of Ubekendt Ejland (reproduced from an aerial photograph by kind permission of the Danish Geodetic Survey) along part of which there has been large scale slumping of the lavas which has increased their degree of inclination to the south-west. Inserted are the locations of the sheets and dykes described in this paper. Distance from Naqerdloq to Ingia is about 17 kilometres.

Dyke 3.

This most northerly dyke is about nine metres thick and strikes north-west to south-east, unlike the average trend of the picritic dykes which is roughly east to west. It is also relatively thick, not so rich in olivine as the average picritic type and represents a link (or an intermediate type) between picritic and normal olivine-dolerite dykes.

Sheet 1.

This is a small, irregular sheet up to seven metres thick, north of Naqerdloq and accessible only from the sea. Its most distinctive feature is a remarkable vein-like, tapering branch, the final metre of which is only two centimetres in average width (Fig. 2).

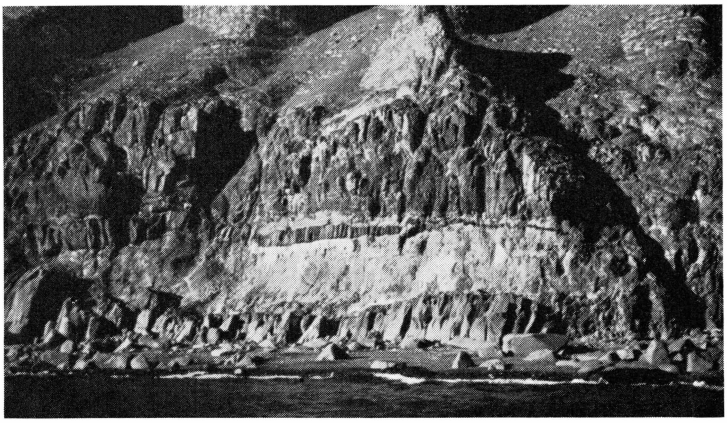

Fig. 2. (from a Kodachrome transparency). Branching picritic sheet intrusive into lava flow (highly vesicular below and massive above). The maximum visible thickness on the left is seven metres, and the attenuated branch tapers to two centimetres on the right.

Sheet 2.

This sheet is exceptionally olivine-rich and from the sea appears to follow a zig-zag course across the face of the cliffs. The zig-zag course is due to spectacular step faulting associated with the coastal slumping. The general strike of this faulted sheet follows the strike of the lavas. Although it can be examined in detail only at sea-level and for about ten metres upward, it can be seen to retain a remarkably uniform thickness of about 1.8 metres along a course, of about ninety metres, obliquely across the cliffs of vesicular-banded lava (Fig. 3). From a level of about seven to ten centimetres below the upper contact there is a twenty to thirty centimetres thick layer of dolerite; but the bulk of the sheet is very fresh, green picrite or picrite-basalt with large olivines. This sheet is probably the most interesting and important of all the picritic intrusions and has been examined in great detail.

Sheet 3.

This sheet is exposed immediately above the coastal cliff about half a kilometre south of the most southerly house in the village of Igdlorssuit. It occurs over a short distance as two parallel, adjacent sheets, rather less than one metre thick; but these sheets are so closely similar in every respect as to suggest that they are merely branches of a single sheet.

Sheet 4.

This sheet, the largest on Ubekendt Ejland, is about thirty metres in maximum thickness and extends along the shore just south of Ingia

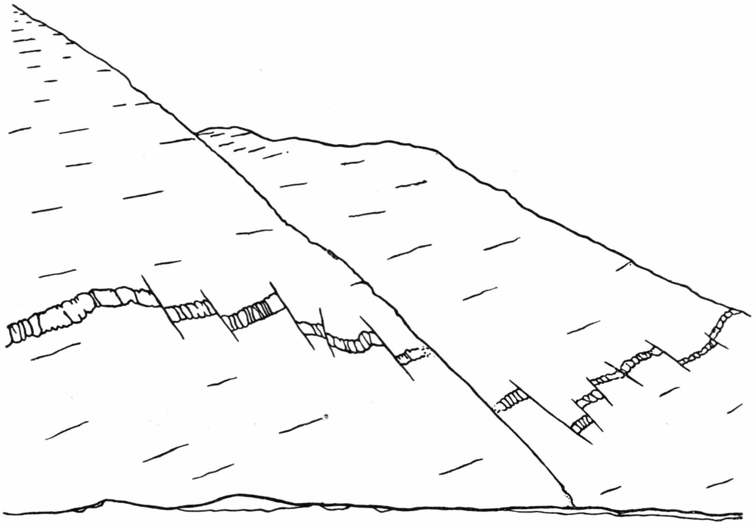

Fig. 3. (sketched from a Kodachrome transparency). Step-faulted, picritic sheet, about 1.8 metres thick, traversing the coastal cliffs of inclined, highly vesicular, olivine-rich lava flows.

for almost half a kilometre. The lower two thirds represents the only example on Ubekendt Ejland of an intrusive picritic rock with zeolite-rich veins. The majority of these veins are parallel to the top and bottom of the sheet and vary in dimensions from a little less than a metre in thickness (and extending laterally about ten metres) to five centimetres or less in thickness (and traceable laterally for only two or three metres). Vertical veins, extending upward for not more than two metres, are rare and the largest observed was only five centimetres in width. Toward the top this sheet changes to dolerite, and inconspicuous thin horizontal layering is revealed on weathered surfaces. Although quite easily located, the bottom contact is vesicular, friable and stained with iron oxide, and no coherent specimens of the sheet in actual contact with lava could be collected. The dolerite becomes fine-grained near the top contact but, very unfortunately, the actual line of junction with lava was not attained. A more fully representative collection of specimens will be obtained from this sheet at the earliest opportunity.

FIELD AND LABORATORY METHODS

In picritic rocks, the variation in relative sizes and amounts, and in the shapes and textural relations, of the olivines (and to some extent the feldspars and pyroxenes) is of critical importance. If one could transport to the laboratory a complete series of specimens across a dyke or sheet at any one locality the petrological evidence would be assured of the soundest foundation from the very start. From such a series of specimens, about sixty thin sections of normal size would be completely representative (at one locality) of the cross-section of a sheet, 1.8 metres thick. But thin sections of such small area do not accurately reveal continuous variations over much larger areas. An almost complete series of specimens was collected from Sheet 2; only where the rock showed no apparent variation were they neither large nor contiguous. The laboratory problem was to make as large thin sections as possible from the large specimens.

Certain variations can of course be seen on polished surfaces; but for detailed examination, modal determinations, photographic recording and for vivid illumination of some important factual evidence in petrological problems of this kind, the making of a really large thin section is here regarded as obligatory. It is also the writer's opinion that his research on the origin of picritic rocks, to be recorded satisfactorily, must be illustrated to the fullest extent possible. Measurements on a series of normal thin sections, of dimensions and amounts of olivine, can have nothing like the convincing impact, or indeed the intrinsic precision, of a good photograph of a large thin section. The days of superficial scratching at a petrological problem (of the kind exemplified by Sheet 2), with the aid of a few small specimens and normal thin sections, should be regarded as past. Detailed petrography, however careful and accurate, can be largely a waste of time if not preceded by comprehensive collecting; the research is crippled from the start. And if outcrops are poor, the research, from a purely petrological standpoint, can rarely be significant. Indeed, the writer looks forward to the day when the equipment of a geological field party, engaged in the investigation of problems of fundamental importance, will include some form of drilling rig by means of which a continuous series of drill-cores are obtained to considerable depths (cf. Tyrrell, 1948). Only in this way, in many cases, can purely petrological studies hope to start on a footing commensurate in precision with experimental work. And such a basis, at the same time, will help in the aim of the majority of petrologists to reduce the large area in petrogenesis at present occupied by interpolation, extrapolation, speculation or pure guess-work.

To make a really large thin section with standard equipment is certainly not easy. The surfaces of the large section of rock and of the glass plate on which it is mounted must be uniformly flat. "Lakeside 70" seems to be the best plastic mounting medium. With the section held firmly on a magnetic chuck, a vertically mounted, diamond-impregnated peripheral grinding wheel, driven at high speed, is passed along the length of the mounted section in a series of parallel traverses many times repeated. When no more traverses are possible without damaging the section, any faint corrugations that remain are smoothed out by a final polish on fine carborundum powder. By careful and patient work, a uniform thinness of 0.035 millimetres (or even less) can be achieved without losing any rock from the edges of the section.

Since in many cases the dimensions, shape and relative abundance of olivine in the picritic rocks were regarded as primarily significant, the majority of photographs could be made by the simple method of projection through a suitable enlarger. Only the choice, and the development, of the photographic emulsion to be used (for both negatives and prints) requires experience.

PETROGRAPHY

Dykes.

Several major aspects of the occurrence of olivine in dyke 1 are illustrated in Fig. 4. There is a marked tendency for many of the olivines to be elongated in habit and to lie parallel to the margin of the dyke. Close to the actual contact the average size of the olivines increases; apart from this, there is a general increase inward (upward in Fig. 4) in the average size of the olivines. There is no significant variation in the amount of olivine from the contact end to the inward end of the specimen. A specimen from the centre of the dyke at the same level has also about the same amount of olivine.

The contact and inward ends of the same specimen (Fig. 4) are illustrated with greater magnification and detail in Pl. 1, Figs. 1 and 3 respectively. The central photograph (Pl. 1, Fig. 2) is of a thin section 8 centimetres from the contact (i. e. from bottom of Fig. 4). The only mineral which shows a marked increase in relative size, from the contact to the innermost end of the specimen, is the plagioclase. For two or three millimetres from the contact it forms a very fine sub-variolitic (or radiating microlitic) intergrowth with pyroxene. The plagioclase then develops as little laths in random orientation, defining a texture which passes insensibly (for a distance of 10 to 11 centimetres) through what could be called a doleritic texture (Pl. 1, Fig. 2) to a more positively variolitic texture in which radiating intergrowths of plagioclase and pyroxene are characteristic (Pl. 1, Fig. 3).

In any single thin section from this specimen, the forsteritic olivine ($2V = 90^\circ$ approx.) is always found to have developed over a considerable range in size. All the elongated olivines are length slow with the optic axial plane perpendicular to the length. Thin sections cut from the same specimen, but at right angles to one another, reveal that the elongated olivines are actually thinly tabular, sometimes almost lamellar, in habit; the largest face developed must be 010. Many of the phenocrysts and microphenocrysts assume a variety of distinctive shapes. In the contact selvage (Pl. 1, Fig. 1) there are olivines that entirely enclose portions of the groundmass indistinguishable from the groundmass surrounding these olivines. One or two olivines enclose rounded inclusions with thread-like pyroxene intergrowths. Other inclusions are iron ore and minute, rounded, deep brown chrome spinel.

Fig. 4. Scale: × 1. Dyke 1. Photograph of a thin section from a specimen of picrite-basalt extending from the chilled contact (lower end of above thin section) inward toward centre of dyke. All white crystals are olivine.

The groundmass pyroxene near the contact is greyish pink in colour and in sub-ophitic relation to the plagioclase. In the variolitic groundmass developed toward the centre of the dyke, the pyroxene may assume a radiating or plumose character and may develop, characteristically, as thin lamellae between the feldspar laths (extinguishing under crossed nicols with neighbouring lamellae) or, apparently, dividing single feldspar laths down the centre (Pl. 1, Fig. 3).

There is also no marked difference in character and occurrence of olivine in the centre of the dyke (Pl. 2, Fig. 3) at the same level as the specimen already described. The groundmass is only slightly coarser and the variolitic texture is at the same time a little less typical. The optic axial angle of the olivine is near 90° and that of the pyroxene is greater than 40°. Thread-like intergrowths of pyroxene, occasionally associated with a little brown amphibole (cf. DREVER and LIVINGSTONE, 1948) occur as rounded inclusions in the olivine. These intergrowths are finer-grained than the groundmass but coarser-grained in comparison with analogous inclusions in olivines near the contact. In general, there is a progressive increase in the coarseness in grain of these intergrowths from the margin of the dyke to the centre.

Thin sections from specimens collected above those already described are illustrated in Pl. 2, Figs. 1 and 2. They have relatively much less olivine and thus establish the fact that there is a marked vertical variation in olivine distribution in this dyke. The olivine is forsteritic with much in common with olivines lower in the dyke and no noteworthy differences. The pyroxene is also an augite and has a sub-ophitic relation to plagioclase; but here also it has a tendency to occur as thin lamellae between the feldspar laths, typical of the variolitic or sub-variolitic texture already described in the rocks collected from a lower position in the dyke.

In Dyke 2 (Pl. 3) there is no significant variation, from the contact inward, in the size or amount of olivine. In a specimen collected halfway between the centre and the margin of this dyke (Pl. 3, Fig. 2) there is (under crossed nicols) round many of the olivine crystals, a thin veneer with a quite conspicuously higher interference colour, indicating a late but notable increase in the relative amount of iron in the olivine. Although the olivines are very fresh there is no sign whatever of this veneer in the olivines of the contact rock (Pl. 3, Fig. 1). In this dyke, in general, many of the olivines occur in rather irregular grains with a considerable range in relative size.

In the rock at the contact, the pyroxene shows no tendency to enclose ophitically the minute plagioclase laths. In the coarser-grained groundmass of the rock from the centre of the dyke (Pl. 3, Fig. 2) the plagioclase laths tend to lie with their long axes parallel to the margin of the dyke and the few elongated olivines are also similarly orientated. The thin vertical layering noted in the field is due to thin layers relatively deficient in olivine (Pl. 3, Fig. 2). The pyroxene of the coarser rock occurs in irregular grains between, and in rather indefinable relation to, the feldspar laths. Grains of iron ore are fairly abundant throughout the rock.

Dyke 3 (Pl. 4), which is relatively thick, exhibits a very considerable degree of difference when one compares the rock at the contact with that near the centre. All the olivines of the chilled contact rock are very thin and elongated (Pl. 4, Fig. 1); in the centre they are irregular or rounded equidimensional grains. The only feature all the olivines of this dyke have in common is that they are partly or wholly replaced by a saponitic serpentine. Saponitic pseudomorphs may completely replace the olivine as single green to greenish yellow, pleochroic, uniformly extinguishing crystals of fairly high birefringence. In the thin section illustrated in Pl. 4, Fig. 2, the saponitic alteration is quite unlike the normal serpentinisation of olivine: the appearance is often as if the centre of the olivine was partly corroded or eaten away as it was being replaced. The writer has not previously seen a replacement of olivine quite like this.

The plagioclase in the contact rock occurs as a plexus of very small laths in sub-ophitic relation to the pyroxene. The plagioclase of the rock from the centre of the dyke (Pl. 4, Fig. 2) has developed as much larger crystals but still in sub-ophitic relation to the brownish augite ($2V = 40°—60°$.

Sheets 1, 3 and 4.

The chilled contact rock from the upper margin of the main portion of Sheet 1 is illustrated in Fig. 5. Phenocrysts and microphenocrysts of forsteritic olivine (the optic axial angle is approximately 90°) occur as irregular crystals, or idiomorphic crystals with deep embayments, or as angular crystals of great dimensional range. Fig. 5 illustrates an extreme case in which angularity is a major characteristic, a fact which strongly suggests an origin by micro-brecciation of larger crystals. Surprisingly, however, many grains, in close proximity but separated in thin section by some of the groundmass, are in optical continuity. Microphenocrysts of plagioclase occur in the groundmass, but not in dark, rounded, semi-translucent inclusions in some of the olivines. Pyroxene has an indefinable textural relation to plagioclase in the groundmass in which dusty iron ore is very abundant. Iron ore is also common as inclusions in olivine.

By a marked increase in crystallinity of the groundmass, in a specimen collected as far as possible from the chilled contact, the rock becomes an almost even-grained picrodolerite. The olivine tends mainly to be xenomorphic and equidimensional but there are occasional examples

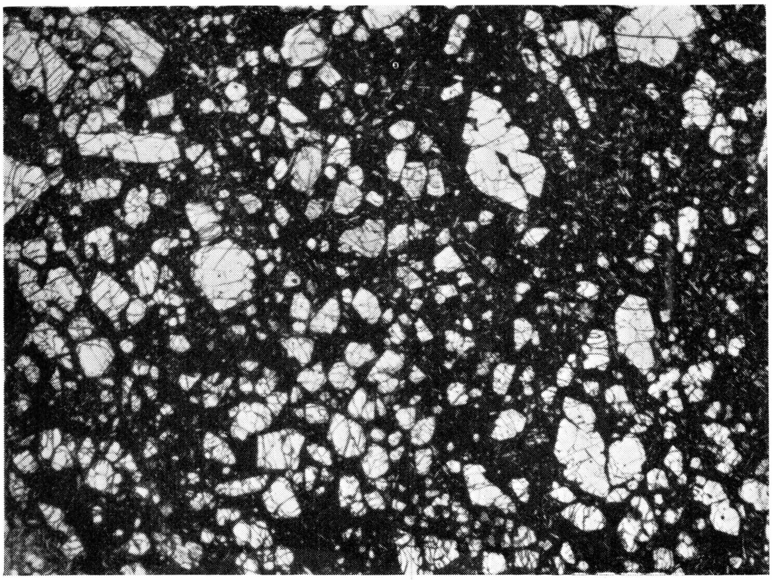

Fig. 5. Scale: × 6. Sheet 1. Thin section from the top contact (Fig. 3) of the main portion of the intrusive picrite-basalt. Phenocrysts and microphenocrysts of olivine which may be idiomorphic, sub-idiomorphic or irregular. Note large idiomorphic crystal with deep embayments. Small microphenocrysts of short plagioclase laths are discernible in the dark groundmass of iron ore, plagioclase and pyroxene.

of idiomorphism or elongated habit. Some of the inclusions in the olivine consist of pyroxene-amphibole (brown) intergrowths (cf. Drever and Livingstone, 1948). The olivines exhibit peripheral zoning and the plagioclase is strongly zoned. In sub-ophitic relation to this plagioclase is pale brown augite (the optic axial is approximately 40°—60°). Iron ore also occurs in relatively large crystals.

There is no significant increase or decrease in the amount of olivine in the tapering branch of Sheet 1 (Fig. 3) or in its chilled contacts; only the degree of serpentinisation increases. There is no decrease in the size of the largest olivines and some grains, discontinuous in thin section, may yet be seen in optical continuity under crossed nicols. In general, the olivine grains again tend to be irregular or angular, the plagioclase occurs as stumpy laths with ragged terminations and the groundmass is dark with dusty iron ore.

The picrite-basalt of Sheet 3 is a beautifully fresh rock characterised by abundant, elongated and often idiomorphic, olivines, all of which are length slow (tabular parallel to (010)). There is no marked difference in amount or size of the olivines from the contact to the centre of this sheet.

In the contact rock (Pl. 5, Fig. 1) some of the olivines contain rounded sub-translucent, partly glassy inclusions in which only crystallites have developed, but analogous rounded inclusions in a specimen from the centre of the sheet contain relatively coarse thread-like pyroxene intergrowths. One or two olivines also contain small, rounded inclusions of brown chrome spinel. In the groundmass of the contact rock there are a few microphenocrysts of plagioclase in the very fine-grained plexus of feldspar laths and pyroxenes.

In the specimen from the centre of the sheet (Pl. 5, Fig. 2) there are many elongated, tabular olivines, but this feature is not so well developed as in the contact rock; and the average size of the olivines is slightly larger. No zoning, of the type described in the case of dyke 2, was detected. In the relatively coarse-grained groundmass the texture is sub-ophitic to sub-variolitic, thin pyroxene laminae occurring in intimate association with the feldspar laths. The pyroxene is a pinkish brown augite with an optic axial angle of 40°—60°.

Apart from its relatively large size, Sheet 4 differs from other sheets described in this paper in the occurrence of veins (Pl. 6) and of a uniformly coarse-grained picrite with relatively large plagioclase and pyroxene crystals (Pl. 8, Fig. 2). In the occurrence of an upper olivine-poor zone (Pl. 8, Fig. 1) it resembles Sheet 2, which has yet to be described.

In the lower contact selvage (Pl. 7, Fig. 2), and the rock at approximately 30 centimetres above this contact (Pl. 7, Fig. 1), the amount and crystal habit of the olivine is comparable with olivines in rocks already described. Near the contact this olivine tends to be entirely replaced by bright-green to yellow, pleochroic, saponite pseudomorphs which perfectly retain the integrity of the original olivine shapes, and under crossed nicols extinguish as a unit (single crystal of saponite). Characteristically, the original olivine shapes are thin, skeletal lamellae (Pl. 7, Fig. 2). Thin sections of this contact rock are difficult to make owing to the intumescence of the saponite with water; the sections had to be ground in oil. Very small, partly altered plagioclase laths are the only crystals distinguishable in the very dark groundmass. The saponitic alteration of olivine is confined to the neighbourhood of the contact. About 30 centimetres above the contact the olivine is practically unaltered, the groundmass is well-crystallized (Pl. 7, Fig. 1), and the amount of olivine is no more or less than at the chilled lower contact selvage. Many of these olivines are skeletal and very fragile, and they are sometimes as much as forty times as long as broad; but they remain perfectly intact in spite of the high degree of crystallinity in the groundmass, and many apparently isolated and irregular grains of olivine are in optical continuity. The pyroxene is an augite in ophitic relation to the plagioclase. There is a considerable development of dusty iron ore.

The massive picrite at the base of this sheet must be at least ten metres thick. As no complete series of specimens was collected in the field, the relations of this picrite to the rocks immediately above and below (which appear gradational in the field) has not yet been established. The pale greyish yellow augite (the optic axial angle is approximately in the 40°—60° range) may poikilitically enclose well-rounded olivine grains (Pl. 8, Fig. 2) whereas the olivine enclosed in large plagioclase (An 80—85) crystals is often idiomorphic and of equant crystal habit. None of the minerals are zoned. Only very occasional, rounded inclusions of fine pyroxene intergrowths occur within the olivines. There is a little sporadically distributed iron ore and some interstitial zeolites.

Toward the top of the sheet the picritic rocks are succeeded by an even grained olivine dolerite (Pl. 8, Fig. 1) in which the augite once more becomes ophitic in relation to plagioclase laths, which are zoned. The olivine occurs mainly as irregular grains and there is a little interstitial serpentine rich in acicular iron ore.

The veins intruding the picrite tend to be rich in zeolites. In the thickest horizontal vein (Pl. 6, Fig. 1) the plagioclase has been entirely converted to an aggregate of prehnite and milky-white material which is probably finely divided albite. Patches of prehnite are common throughout this rock. The augite remains unaffected in spite of the fact that in places it has crystallised in an intimate graphic intergrowth with the altered plagioclase. This augite may also be intimately intergrown with iron ore. In a specimen from a thin vertical vein (Pl. 6, Fig. 2) the plagioclase is almost unaltered and there is a prolific development of acicular ilmenite. In this vein also the augite tends to be intergrown with the plagioclase. There are only a few zeolite patches and some accessory needles of apatite.

Sheet 2.

It could fairly be asserted that the series of photographs reproduced in Pl. 9 (*a* to *g*) is an almost completely representative cross-section of this remarkable little intrusion.

The main component is picrite or picrite-basalt very rich in large phenocrysts of fresh, greenish yellow olivine (Pl. 9, *e*) set in a fine-grained, sub-variolitic groundmass composed largely of pyroxene intergrown with plagioclase (Pl. 11, Fig. 2).

The most distinctive characteristics of this sheet are toward the top and bottom margins. At the top (and bottom) of the sheet a slightly translucent brownish black glass is the result of quick chilling at the actual contact with lava. But in this contact selvage (and contiguous with the actual contact) are olivines which, relatively to those immediately below, tend to be larger in size and appear to be equant in habit.

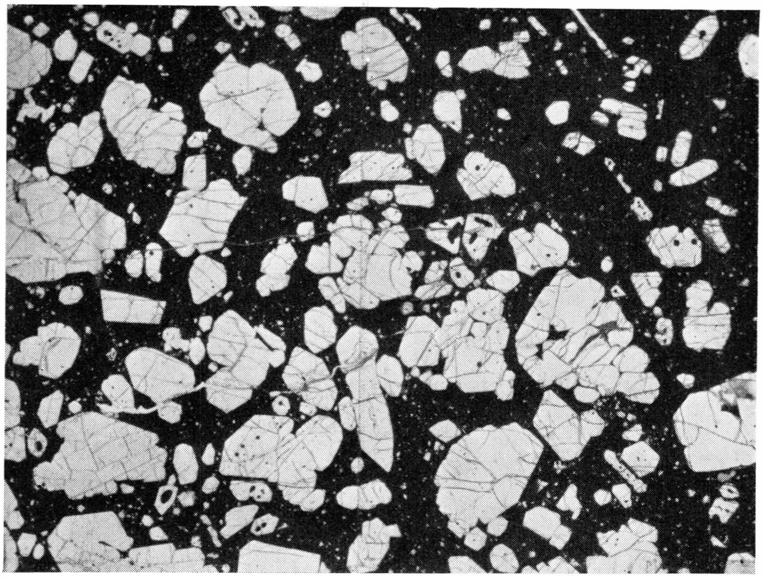

Fig. 6. Scale: × 6. Sheet 2. Area in upper chilled selvage with a concentration of olivines in two main generations—one relatively very large and the other relatively very small (white dots). Almost all the olivines tend to develop crystal faces. Brown chrome spinel occurs as rounded inclusions in some of the olivines, and it also occurs as microphenocrysts. Elongated olivines are atypical of this selvage.

They also tend to occur in two generations in both of which many of the crystals are idiomorphic (Fig. 6). The microphenocrysts tend to be equant in habit. The smallest crystals (or crystallites), which are typically diamond-shaped, are a component of the groundmass. In this groundmass some fine, radiating spherulites may occur before it becomes evenly crystalline throughout as the degree of crystallinity increases downward; the most mature crystallisation is represented by minute feldspar laths of random orientation. Brown chrome spinel occurs as rounded inclusions in olivine and occasionally as idiomorphic microphenocrysts set in the groundmass.

There is an abrupt increase in crystallinity in the groundmass at a plane of discontinuity which can be discriminated as such only in sections cut perpendicular to it (Fig. 7 and Pl. 10, Fig. 1). At the same place there is an abrupt decrease in the amount of olivine and some decrease in average size. Relatively common below this discontinuity are skeletal crystals and length slow, elongated sections of tabular or lamellar crystals, lying approximately parallel to the margins of the sheet (Pl. 9, *b*). In this zone also, olivine occurs in a second generation. The discontinuity is not apparent in Pl. 9, *a* and there is very little evidence of an increase in size and amount of olivine contiguous with the contact.

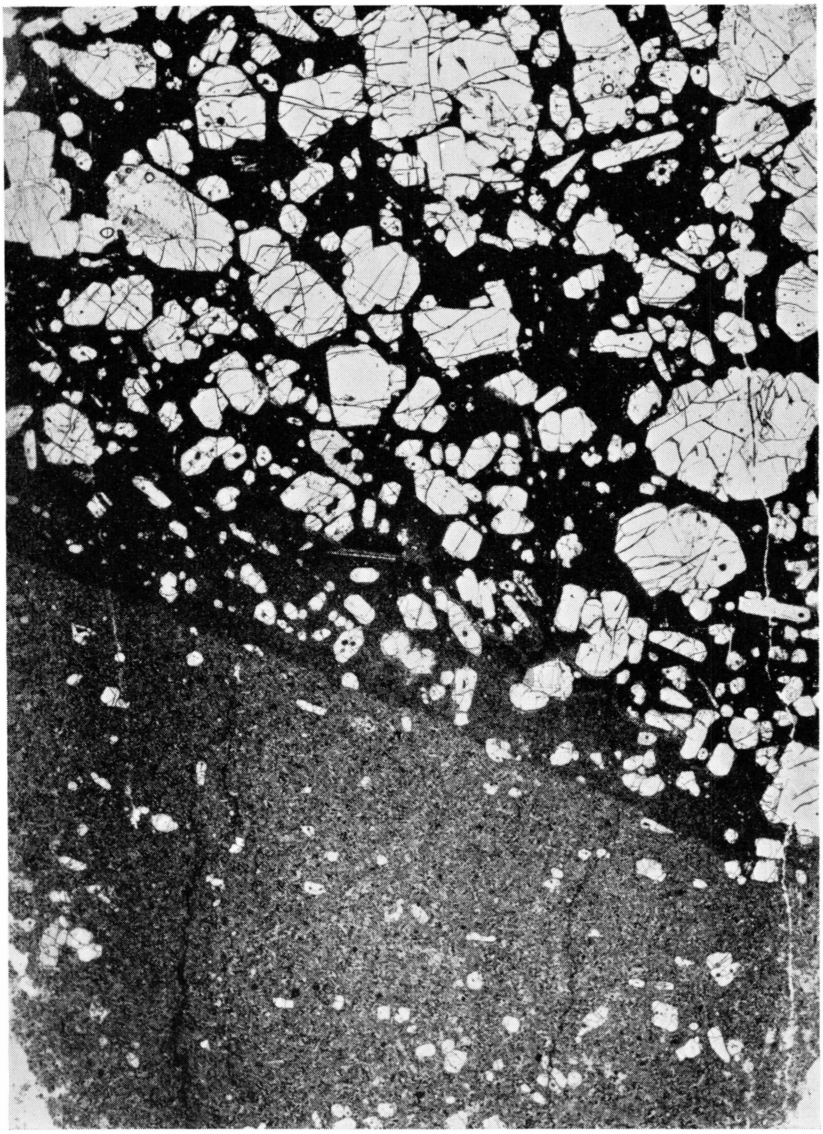

Fig. 7. Scale: × 5. Sheet 2. Small area of the upper contact selvage (and the rock immediately below it) in which there is a concentration of olivine crystals separated below by an abrupt discontinuity from a rather olivine-poor part of the normal rock of the upper margin of the sheet (see Pl. 9, *b*). The groundmass in the dark fine-grained material just above this discontinuity are delicate, radiating, microlitic intergrowths of pyroxene and feldspar (see also Pl. 10, Fig. 1).

Another discontinuity occurs at a slightly lower level in the sheet (Pl. 9, *b* and Pl. 10, Fig. 2). In Pl. 9, *b* the degree of crystallinity in the groundmass gradually increases downward. But immediately below this further discontinuity an abrupt decrease in grain size is accompanied by an almost complete disappearance of olivine.

There are now no phenocrysts and the degree of crystallinity once again increases downward. For a vertical distance of approximately twenty-five centimetres the rock is an olivine-poor even-grained basalt or dolerite. In this zone there is a beautifully preserved natural downward variation (Pl. 9, *c* and *d*): gradually the olivine begins to increase both in amount and average size until the rock becomes a picrite with large olivines (associated with a coarse-grained, sub-ophitic intergrowth of augite and plagioclase (Pl. 11, Fig. 1)) which tend to be equidimensional and xenomorphic; only a few are elongated and lamellar. In the olivine-poor rock, the groundmass is essentially doleritic with relatively short plagioclase laths although there is a tendency for the pyroxene to occur as thin lamellae intergrown with the plagioclase. Gradually as the olivine increases in amount and average size, there is a concomitant increase in the average size of the plagioclase (zoned) and pyroxene ($2\,V > 40°$). The doleritic texture persists, and it must be admitted that exactly how and where the transition takes place to a markedly porphyritic texture and variolitic groundmass (Pl. 11, Fig. 2) has not been established. In the field, the main central portion of the sheet appeared perfectly uniform. It thus seems likely that the change in size and relation of the plagioclase and pyroxene is a gradual one, as it is in the case of the finer doleritic and variolitic textures at the bottom margin of the sheet (p. 25).

Finally, at the bottom of this sheet, the direction of the variation in the amount and average size of the olivine is the reverse (Pl. 9, *f*) of that already recorded (Pl. 9, *c* and *d*). This upward increase in amount and size of the olivines is continuous and gradual; only very close to the actual contact is there, like the upper margin, a thin, unevenly developed, chilled selvage with relatively large crystals of olivine. If there is a plane of discontinuity separating this more porphyritic selvage from the rock above, it must be of very variable orientation. Elongated crystals (tabular or lamellar) and skeletal crystals are very common toward the bottom and the degree of idiomorphism also increases in this direction (Pl. 9, *f* and Fig. 8, *a* and *b*). The marginal rock between 0.5 and 2.5 centimetres above the contact selvage was chemically analysed (p. 27).

As the size of the olivine phenocrysts increases upward, a smaller generation of olivines persists, the size of which remains more or less uniform in spite of, in addition, an increase in the crystallinity of the groundmass. In the groundmass immediately above the chilled selvage, minute laths of plagioclase, and relatively larger but irregular pyroxenes, can be discerned. The size of the plagioclase increases gradually upward

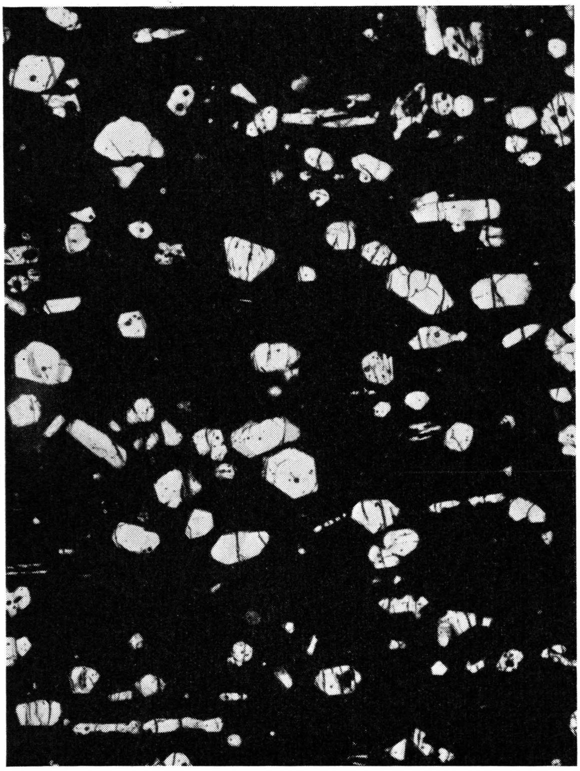

Fig. 8 *a*. Scale: × 8. Sheet 2. Immediately above lower contact selvage. All white crystals are idiomorphic, sub-idiomorphic or skeletal microphenocrysts of olivine. For a chemical analysis of this rock see p. 27.

unaccompanied by any noticeable increase in the size of the pyroxenes. At four to five centimetres above the chilled selvage the fine doleritic texture gives place upward to a sub-variolitic texture which passes rapidly, a few centimetres higher up, into a texture which can be generally defined as a variolitic texture in which fine, plumose intergrowths of pyroxene and feldspar are characteristic. These intergrowths are finer than those developed at a similar distance from the contact in dyke 1 (Pl. 1, Fig. 3).

In the parts of the sheet in which the groundmass is very fine-grained, the inclusions in olivine tend also to be very fine-grained. These inclusions increase in crystallinity at the same time as the associated groundmass and become the characteristic thread-like intergrowths. When the groundmass becomes still coarser, the crystallinity of these inclusions is very noticeably less than that of the groundmass. No cases were observed in which the degree of crystallinity of these inclusions exceeded that of the associated groundmass.

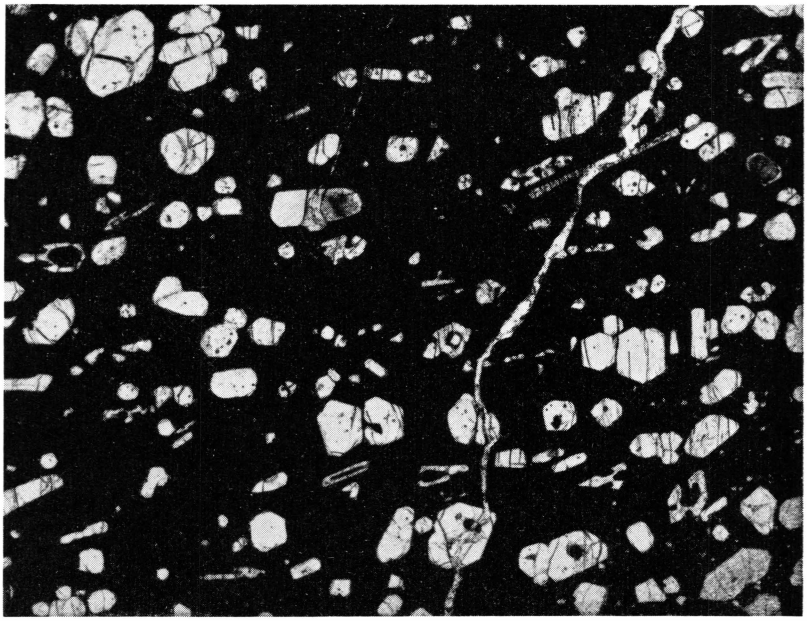

Fig. 8 *b*. Scale: ×8. Location and explanation as in Fig. 8 *a*. For a chemical analysis of this rock see p. 27.

Only a small fragment of the lava immediately above (and in actual contact with) Sheet 2 was brought back (Pl. 9, *a*). A small but more satisfactory specimen was obtained of the lava contiguous with the lower contact (Pl. 9, *g* and Pl. 12, Figs. 1 and 2). In both cases the lava is zeolite-rich, picritic basalt.

The small fragment of lava preserved in contact with the top of the sheet contains fresh olivine, including elongated crystals, right up to the contact. These olivine crystals are margined by dark, semi-opaque material like that of the glassy selvage, and there is a patchy distribution of the dark material throughout this lava fragment. Apart from this, there is little evidence of thermal metamorphism or recrystallisation.

In the part of the specimen of lava nearest the lower chilled selvage the olivine is absent. But in one or two other fragments of lava also in visible contact with the chilled selvage, the olivine of the lava does occur right up to the selvage. There is evidence here of some refusion of the lava, particularly round vesicles containing mainly thomsonite (Pl. 12, Figs. 1 and 2). Some thomsonite has been resorbed, but there no apparent conversion to plagioclase (cf. McLintock, 1915).

CHEMICAL ANALYSIS

SiO_2	44.32
Al_2O_3	10.29
Fe_2O_3	1.88
FeO	8.93
MgO	22.07
CaO	8.06
Na_2O	0.94
K_2O	0.10
$H_2O +$	1.41
$H_2O —$	0.92
TiO_2	0.78
MnO	0.11
P_2O_5	0.12
CO_2	0.15
Total	100.08

Norm		
Or		0.56
Ab		7.96
An		23.63
Neph		—
Di	6.15	11.71
	4.50	
	1.06	
Hyp	11.10	13.87
	2.77	
Ol	27.72	35.27
	7.55	
Mt		2.76
Ilm		1.32
Ap		0.34
Cal		0.30
H_2O		2.33
Plag	$Ab_{25}An_{75}$	
Hyp	$En_{80}Fs_{20}$	
Diop	$Wo_{53}En_{39}Fs_8$	
Oliv	$Fo_{79}Fa_{21}$	

0.5 to 2.5 centimetres above bottom contact of Picritic Sheet (Sheet 2), east coast of Ubekendt Ejland, West Greenland. Analyst: W. H. Herdsman (New Series).

Comparisons.

	1	2	3	4	5
SiO_2	44.61	41.65	42.16	43.68	46.74
Al_2O_3	10.86	12.95	8.32	9.72	8.19
Fe_2O_3	2.31	1.62	1.70	2.19	2.77
FeO	7.46	10.70	9.85	8.95	9.60
MgO	21.06	21.98	24.23	17.81	20.47
CaO	9.01	6.51	7.62	9.22	7.47
Na_2O	1.15	1.32	0.38	1.64	1.74
K_2O	0.19	0.16	0.36	0.37	0.35
H_2O+	1.17	1.60	2.56	2.38	—
$H_2O—$	0.05	0.53	0.90	1.60	—
TiO_2	2.25	0.62	1.48	2.02	2.12
MnO	0.16	0.18	0.18	0.13	0.14
P_2O_5	0.10	0.05	0.14	0.16	0.22
Total	100.38	99.87	99.88	99.87	99.81

Norms.

	1	2	3	4	5
Or	1.11	1.11	2.22	2.22	2.22
Ab	9.43	9.96	3.14	13.62	14.67
An	24.20	28.63	19.74	18.07	13.34
Neph	—	0.57	—	—	—
Di	15.44	2.22	13.71	21.46	18.09
Hyp.....	10.06	—	10.51	1.36	13.94
Ol.......	31.02	51.36	41.47	31.78	29.05
Mt	3.10	2.32	2.55	3.25	4.18
Ilm	3.70	1.22	2.89	3.80	3.95
Ap	0.34	0.34	0.33	0.34	0.34
H_2O	1.22	2.13	3.46	3.98	—
Plag.	$Ab_{28}An_{72}$	$Ab_{26}An_{74}$	$Ab_{14}An_{86}$	$Ab_{43}An_{57}$	$Ab_{52}An_{48}$
Hyp.	$En_{86}Fs_{14}$	—	$En_{80}Fs_{20}$	$En_{81}Fs_{19}$	$En_{76}Fs_{24}$
Diop.	$Wo_{53}En_{41}Fs_{6}$	$Wo_{52}En_{36}Fs_{12}$	$Wo_{52}En_{38}Fs_{10}$	$Wo_{52}En_{38}Fs_{10}$	$Wo_{53}En_{33}Fs_{14}$
Oliv.	$Fo_{85}Fa_{15}$	$Fo_{74}Fa_{26}$	$Fo_{79}Fa_{21}$	$Fo_{78}Fa_{22}$	$Fo_{79}Fa_{21}$

1. Picrite-dolerite dyke, Coire Labain, Skye (BOWEN, 1928). Analyst: M. G. KEYES.
2. Picrodolerite immediately above discontinuity, 38 feet above sea-level, eastern cliffs of Garbh Eilean, Shiant Isles.
   Analyst: R. J. MURRAY.
3. Picrite-basalt lava, Igdlorssuit, Ubekendt Ejland, West Greenland.
   Analyst: W. H. HERDSMAN.
4. Picrite-basalt dyke, approximately 15 kilometres south of Nûgssuaq, Nûgssuaq Peninsula, West Greenland (DREVER and LIVINGSTONE, 1948).
   Analyst: W. H. HERDSMAN.
5. Picrite-basalt, oceanite type; average of 9 analyses (MACDONALD, 1949).

Every care was taken to ensure that the material analysed, from the bottom margin of Sheet 2, did not include any part of the selvage, thin and inconstant in width, which contains a slight, relative concentration of olivine together with an increase in average size. The analysis thus expresses accurately the composition of the rock representing the starting point of the gradational upward variation in size and amount of olivine (Pl. 9, *f*). The olivines in the analysed rock were all relatively small, many skeletal, and many elongated and thinly tabular.

The natural relations of this analysed rock are clearly established by comparison with the other analyses here tabulated. Analyses 2 and 3 have not previously been published. Apart from the relative amount of titanium, the closest equivalent is a dyke in Skye (Analysis 1) which has been discussed in some detail by BOWEN (1928). The lower rocks of the well-known sill of the Shiant Isles (JOHNSTON, 1953) will always represent important standards of comparison in any investigation of picritic rocks. The picrodolerite (Analysis 2) immediately above the discontinuity is the nearest equivalent. The true picrite of the Shiant

Isles, with large plagioclase crystals, is considerably more ultrabasic, as also is a lava from Igdlorssuit (Analysis 3). Why this latter rock should be, for a lava, so exceptionally ultrabasic is at present obscure. The results of a detailed investigation of the picritic lavas of Ubekendt Ejland will be published in the following paper of this series (i. e. Part III). The picrite-basalt from The Nûgssuaq Peninsula (Analysis 4) and the average oceanite of the Hawaiian Islands (Analysis 5) are less ultrabasic than the marginal rock from Sheet 2 or any of the other three rocks (analysis 1—3). An analysed oceanite from Svartenhuk (NOE-NYGAARD, 1942) is much richer in lime (approx. 13 $^0/_0$).

PETROGENESIS

Summary of Critical Data.

In relation to the picritic intrusions of Ubekendt Ejland, the following are believed to be the six most important aspects:

1. Variation in size and amount of olivine.
2. Variation in groundmass textures and, in general, the textural relations of plagioclase and pyroxene.
3. Crystal growth, skeletal crystallisation and compositional range (if any) of olivine.
4. Compositional range of plagioclase.
5. Contact metamorphism.
6. Little or no zeolites, in marked contrast to the associated picritic lavas.

Critical petrographical data, mainly relating to phenomena in 1 and 2, and obtained from Sheet 2, are summarised in the form of a diagram (Fig. 9). Data relating to 3, 4 and 5 will be the major basis of a comparison between Sheet 2 and some picritic sills in Scotland. This comparative study is likely to be completed and published fairly soon. The investigation of what might be called the 'zeolitic problem' (6) must clearly await a detailed account (also partly completed) of the picritic lavas.

Thinly tabular and skeletal olivines, with their longest axis orientated parallel to the contacts, occur in both sheets (e. g. 2 and 3) and dykes. Dyke 1, in particular, is closely similar in this respect to Sheet 2, but the orientation of the olivines is in an approximately vertical plane. Also at the margins of both sheets and dykes (e. g. Sheet 4 and Dyke 3) the very numerous olivines may occur entirely in skeletal and lamellar form.

In Dyke 1, the textures and textural variation of the marginal rock (Fig. 4) are remarkably similar to those of the bottom marginal rock of Sheet 2 (Pl. 9, *f*). Relatively coarse doleritic textures are developed

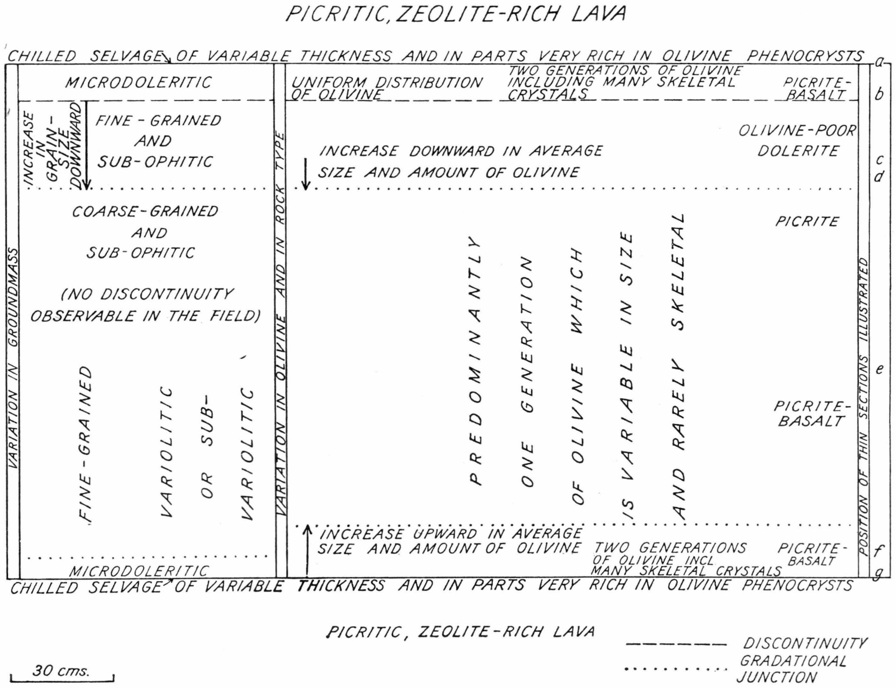

Fig. 9. Sheet 2. Major zones and rock-types; major variations in relative size and crystal habit of olivine; and major textural variations. Only vertical relations are expressed on this diagram. (a, b, c, d, e, f, g refer to Plate 9, Figs. a to g).

in the upper picrite and transitional picrodolerite of Sheet 2 (Pl. 11, Fig. 1), and the picrodolerite forming the centre of Dyke 3. In the picrite of the largest sheet (Sheet 4), the texture is similar to one of the characteristic textures of the Shiant Isles picrite (Johnston, 1953), in which very large plagioclase crystals poikilitically enclose olivines. In these two picrites the plagioclase shares the following contrasts in relation to that of the other rocks (with which they are associated in these two relatively large intrusions):

1. Average size is more than twice as large. The disparity in size may be much greater than this.
2. Much less zoned or entirely unzoned.
3. At least ten per cent richer in Anorthite (An).

An account of the Shiant Isles picrite will shortly be ready for publication. The olivine-rich dolerite (picrodolerite) of the Palisade Sill (Walker, 1940) shows the same general tendencies.

The study of some inclusions in olivines of another West Greenland picrite-basalt (Drever and Livingstone, 1948) led to the discovery of similar inclusions in the picrite of the Shiant Isles (Johnston, 1953) and in the picrites or picrodolerites of Trotternish in Skye, and of Soay. Similar inclusions were found in many of the olivines in picrites and picrite-basalts of Ubekendt Ejland, but here they tend on the whole to be finer-grained and rarely contain any brown amphibole. They are best developed in Dyke 1, Sheet 2 and Sheet 3. In the marginal rocks of these intrusions they are usually quite indistinguishable from the groundmass with which one can confidently identify them. The tentative theory advanced in 1948 (Drever and Livingstone) that they represent liquid enclosed during growth of the olivine crystals is now amply supported by, literally, hundreds of examples of this phenomenon at various stages of development.

Preliminary Interpretation of new Evidence in relation to the Origin of Picritic Rocks.

As a key-stone for his theory of crystal accumulation Bowen (1927, 1928) has adduced, with particular reference to picritic rocks in Skye and Soay, the persistent porphyritic texture and very different degree of crystallinity of phenocrysts of olivine and the groundmass surrounding them. Such a relation of olivine to groundmass also widely prevails in the picritic intrusions of Ubekendt Ejland; but it is not an invariable relation. In two parts of a single intrusive sheet (Sheet 2) the olivine, in amount far exceeding that of a normal olivine basalt, does not occur as typical phenocrysts. In the upper part (Pl. 9, *d*) a downward increase in average size and amount is accompanied by an almost equal increase in the size of the plagioclase and pyroxene (which lower down decrease in size in relation to olivine and the texture becomes porphyritic). In the lower part (Pl. 9, *f* and Fig. 8), which has been chemically analysed, skeletal crystallisation of olivine is very common and all the olivines are small. The first generation of crystals, it must be admitted, are relatively larger than the plagioclase and pyroxene of the groundmass, but they are often so thin and fragile that it seems certain that their crystallisation was not before but after intrusion.

The range in the crystallinity and mutual textural relation of plagioclase and pyroxene in picritic rocks is quite astounding. This variation introduces, into what has tended to be an oversimplified picture, a complexity for which there is no ready-made explanation, and for which we must find a satisfactory explanation if we are properly to understand the origin of picritic rocks. There are not only major differences to be discovered when different picritic intrusions are compared but there are also major variations within a single picritic sheet less than two metres in thickness. The detailed comparative study of these and other phenomena which the writer and his colleagues are attempting is based not only on evidence assembled from Ubekendt Ejland but also from many other localities. In the meantime it has been firmly established that there are in Sheet 2 complete gradations in texture from—using the nomenclature of VUAGNAT (1946)—"intersertal" (doleritic), "intersertal divergent" (sub-variolitic), to "arborescent" (variolitic). The term "doleritic" in this paper has been employed in a general sense and has included both sub-ophitic and ophitic relations of plagioclase and pyroxene. It is thus used in a different sense from that of KROKSTRÖM (1932). The terms "sub-variolitic" and "variolitic" have been used with the meaning generally understood by petrologists. The writer is inclined to interpret all of the very intimate pyroxene-plagioclase intergrowths as due to approximately simultaneous subliquidus crystallisation rather than to overlap during the normal course of crystallisation down a liquidus surface.

The occurence of rounded or embayed phenocrysts, or of phenocrysts full of inclusions of glassy or fine-grained material like the groundmass of the rocks in which they occur, was a subject of some importance to petrologists in the late nineteenth century. Had the interpretation of these phenomena remained as healthily controversial as it was then,¹) these phenomena would not have been regarded by many petrologists, with such uncritical acceptance, as due to "resorption" or "corrosion". It is conceivable that any doubts, they may have harboured, have been lulled by BOWEN's emphasis on the reaction relation of olivine to liquid together with the oft-repeated assertion (or implication) by petrologists, such as MACDONALD (1949) and others, that almost any rounding or embayment of olivine spells "resorption" or "corrosion". On the other hand, NIGGLI (1954) remained unaffected by this facile convention: "Corrosion shapes", he writes, "often strongly resemble dendritic growth shapes—there is hardly a single type which can be produced by one process exclusively". So the present writer has, it would seem, no reason to apologise for resurrecting an old controversy.

The proper interpretation of the very great variety of shapes assumed by both natural, and artificially crystallised, olivine is of vital importance. On the crystallisation of olivine and its reaction, or failure to react, with the liquid, may depend the whole course of crystallisation and fractionation of basaltic magma. For the permanent establishment of this as a central fact in igneous petrognesis every petrologist is indebted to Dr. BOWEN. Clearly, the more we know about olivine the better.

There are many descriptions of very irregular or elongated olivines.

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¹) Refer for example to the discussion on the paper by Judd in Quart. Journ. Geol. Soc., London, Vol. XXXIX, 1883, pp. 464—465 and HEDDLE (1896), pp. 87—91.

Some of these olivines can be closely matched with olivines in picritic rocks from Ubekendt Ejland. DANA (1889) interpreted the phenomena as due to magmatic corrosion, and noticed that "some of the corroded forms take very fantastic shapes".

HEDDLE (1896) was an early advocate of the alternative view that the embayment of many phenocrysts and the enclosure of the groundmass and its isolation in minerals as rounded inclusions were phenomena of crystal growth. The crystals interpreted by DANA as corroded were re-interpreted by IDDINGS (1911) as original growth shapes. BUERGER (1947) has pointed out that rounded crystals and irregular crystals without faces are to be expected when growth takes place in a medium of similar surface tension to that of the growing crystal. DREVER and LIVINGSTONE (1948) incorrectly interpreted elongated olivines as due partly to resorption, but regarded inclusions in olivine as, originally, liquid caught up by the growing crystals.

DANA (1889) was probably the first to recognise that many elongated, often very thin, olivines in Hawaiian lavas were tabular parallel to (010). LACROIX (1936) and MACDONALD (1944) have also described elongated olivines and have interpreted them in some cases as microlitic. LACROIX goes so far as to affirm that, in spite of the relatively large dimensions of these crystals, they should be referred to the microlitic period of crystallisation. Inclusions of the groundmass have also been noted in all these described cases of elongated olivines. It would appear that MACDONALD (1944) has found, in the same rock, some crystals of olivine he would regard as immature and others he would regard as partly resorbed; but for unambiguous evidence on which such inferences are based, the reader will search in vain. The present writer does not deny the validity of resorption of olivine especially as it is precisely what would be expected in basaltic magma of tholeiitic type (as defined by TILLEY, 1951); but certain natural phenomena ascribed to resorption are open to at least one other interpretation. In no cases known to the writer of melting or resorption of olivine under artificial conditions (e. g. PONTEVIN, 1928) are typical embayments formed. Examples of undoubted skeletal crystals of olivine have also been described and figured by KREUTZ (1885), DOSS (1886), RINNE (1891), BODMER-BEDER (1898), CLOUGH and HARKER (1898), KUNO (1950) and by others. Both equant and elongated skeletal olivines, with inclusions of glass, crystallise during the cooling of artificially melted olivine basalt (e. g. PONTEVIN, 1928). A fuller account of this work will be given in a later paper.

Highly magnesian melts, which have a high liquidity, cannot be congealed to yield a glass (at low temperatures); the tendency to crystallise is too great. In addition, forsteritic olivine is a mineral with a high specific tendency to grow rapidly. Its precipitation would leave the magma much less magnesian and hence, owing to increased viscosity, less liable to crystallise. A later crystallisation of small olivines might follow. The occurrence of relatively large skeletal olivines, associated in the same rock with a second generation of much smaller olivines and immature crystal intergrowths of plagioclase and pyroxene, suggests two distinct periods of rapid crystallisation in situ. Skeletal and microlitic crystals are likely to form during labile crystallisation under conditions of considerable undercooling (cf. Drever, 1952).

But these brief observations though strictly relevant are to be regarded as tentative only. Very little in fact is known concerning factors conducive to much undercooling in magmas, and more than one factor may contribute to rapid crystallisation of olivine. It is even conceivable that some of its crystallisation may postdate a high temperature congelation of most of the liquid. The occurrence of large phenocrysts in chilled contact selvages (e. g. in Sheet 2), and the apparent microbrecciation of olivines as in Sheet 1, seem to indicate the presence in some cases of olivine crystals in the magma prior to intrusion. This fact is in perfect accord with Bowen's hypothesis. Some gravitative settling of olivine appears to have occured in Dyke 1, Sheet 2 and Sheet 4.

Optical and chemical analyses of the minerals, as mentioned earlier in this paper, will be published later. But it is clear, in general, that the olivines are forsteritic (Game, 1942), the pyroxenes are augites and the average composition of most of the plagioclases, is fairly near An_{60}. The picrites or picrite-basalts cannot be classified as tholeiitic (Tilley, 1951). Nor have they all clearly an affinity with alkaline basalts; they appear in fact to occupy a position somewhere between these two fundamental types.

The distribution of olivine in Sheet 2 is probably as important as it is spectacular. Have we here a natural demonstration of the size-selective winnowing of olivines during a downward gravitative accumulation? Or does this phenomenon mainly express an original chemical gradient that can be interpreted in terms of water distribution and thermodiffusion? A very similar downward gradational increase in size and amount of olivine (or upward gradational increase in relative amount of plagioclase and pyroxene) the writer discovered in a picritic sill on the island of Soay in Scotland. A systematic comparative study is now being made of the development of this phenomenon in these two intrusions. In the bottom marginal zone of Sheet 2 there is an upward increase in size and amount of olivine which would be unexceptional were it not for the fact that the rock, even at the bottom (analysed), is picritic and the fact that the olivines tend to be skeletal. Detailed discussion of the distribution, in general, of olivine must await the determination of more optical and chemical data.

Conclusions.

Olivine is a key mineral in magmatic theory, but the characteristics of its growth in magmas have not, within recent years, received the attention they are due. If picritic rocks owe their origin simply to an accumulation of olivines in basaltic liquids, there should be no relation between their special richness in olivine and the composition or textural relation of the plagioclase and pyroxene.

It seems to the writer, on the basis of evidence presented in this paper, that there is an alternative or collateral working hypothesis which is worthy of careful examination in the light of further evidence of the kind to which this paper has drawn attention. The complete adequacy of Dr. BOWEN's concept of crystal accumulation is challenged but the existence of truly ultrabasic magma finds no place in this hypothesis. Instead, it is suggested that the possibility should be considered of an extension of true magmatic liquids beyond BOWEN's (1928) compositional limits. The present writer believes that magma from which at least twenty-five per cent of olivine can crystallise is a widespread and important type and that one of its characteristics is a tendency to crystallise relatively rapidly.

The writer and his colleagues are continuing their investigation of this problem, and much illumination it is hoped will be shed on it by the results of Dr. YODER's present research on the system diopside-anorthite-forsterite-water (ABELSON, 1955).

ACKNOWLEDGMENTS

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The large thin sections—an invaluable contribution—were made by Mr. C. Methven in the Department of Geology, University of St. Andrews. Mr. R. Johnston kindly checked the manuscript and Miss D. Moncrieff typed it and drew Figure 9. Dr. R. J. Murray permitted the publication of his analysis of the Shiant Isles picrodolerite and the Director of the Danish Geodetic Institute the publication of one of their aerial photographs.

The expeditions received much help and consideration from the Greenland Department in Copenhagen and from Greenlanders such as Johan and Anna Zeeb in Igdlorssuit.

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Færdig fra trykkeriet den 22. juni 1956.

PLATES

Plate 1.

Fig. 1. Scale: × 6. Dyke 1. Contact selvage (Specimen illustrated in Fig. 4 of text). Phenocrysts and microphenocrysts of olivine in a very fine-grained, crystalline groundmass of pyroxene and plagioclase (in very fine sub-variolitic intergrowth immediately adjacent to the contact) together with some grains of iron ore. Picrite-basalt.

Fig. 2. Scale: × 6. Dyke 1. 8 centimetres from contact selvage (Specimen illustrated in Fig. 4 of text). Phenocrysts and microphenocrysts of olivine in a fine-grained groundmass composed of very small, short plagioclase laths with pyroxene between them, together with some grains of iron ore. Picrite-basalt.

Fig. 3. Scale: × 6. Dyke 1. 12 to 14 centimetres from contact. (Specimen illustrated in Fig. 4 of text). Phenocrysts and microphenocrysts of olivine in a sub-variolitic to variolitic groundmass composed of elongated, often radiating, intergrowths of pyroxene and plagioclase, together with some grains of iron ore. Picrite-basalt.

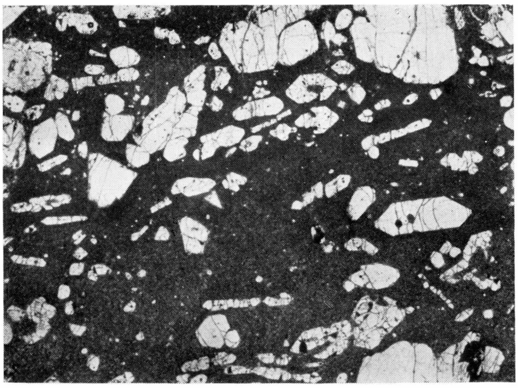
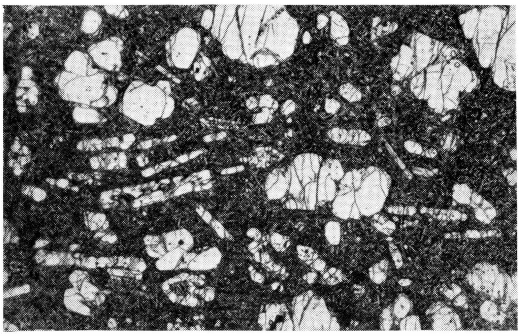


Fig. 1.



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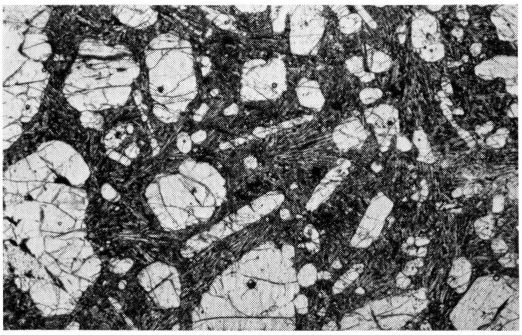


Fig. 3.

Plate 2.

Fig. 1. Scale: × 6. Dyke 1. Near centre and higher in dyke than any other specimens. Phenocrysts and microphenocrysts of olivine in micro-ophitic to sub-variolitic groundmass of augite and plagioclase. Some iron ore. Olivine-basalt.

Fig. 2. Scale: × 6. Dyke 1. Near centre and higher than specimens represented by Fig. 4 of text and Plate 2, Fig. 3 (below). Phenocrysts and microphenocrysts of olivine in micro-ophitic to sub-variolitic groundmass of augite and plagioclase. Some iron ore and intersertal serpentine. Olivine-basalt.

Fig. 3. Scale: × 6. Dyke 1. Near centre. Phenocrysts and microphenocrysts of olivine in a sub-variolitic groundmass of augite and plagioclase, together with some grains of iron ore. Picrite-basalt.

Fig. 1.

Fig. 2.

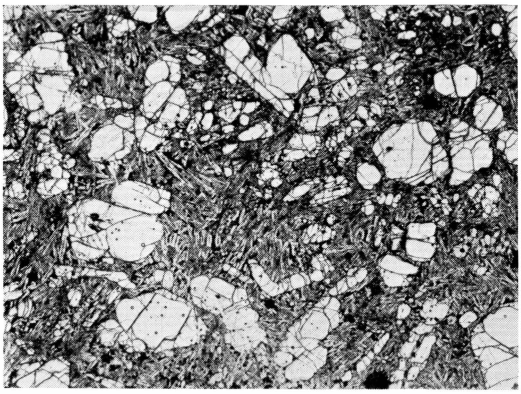
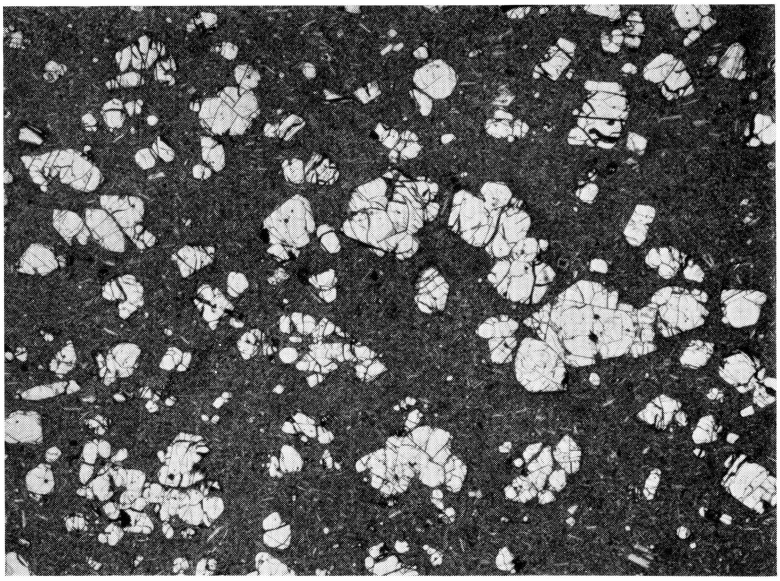


Fig. 3.

Plate 3.

Fig. 1. Scale: × 9. Dyke 2. Contact selvage, Phenocrysts and microphenocrysts of olivine in a groundmass composed of a felt of minute, short laths of plagioclase separated by granular pyroxene. Some iron ore. Picritic basalt.

Fig. 2. Scale: × 9. Dyke 2. Half-way between centre and contact selvage. Phenocrysts and microphenocrysts of olivine in a fine-grained groundmass of short laths of plagioclase many of which, together with some elongated olivines, are orientated parallel to the margin of the dyke. The pyroxene occurs as irregular grains between the plagioclase laths. Small grains of iron ore are an important constituent. There is a dark, irregular, approximately vertical line of shearing to the right of which an olivine-poor zone corresponds to a thin vertical layer observable in the field. Picritic basalt.



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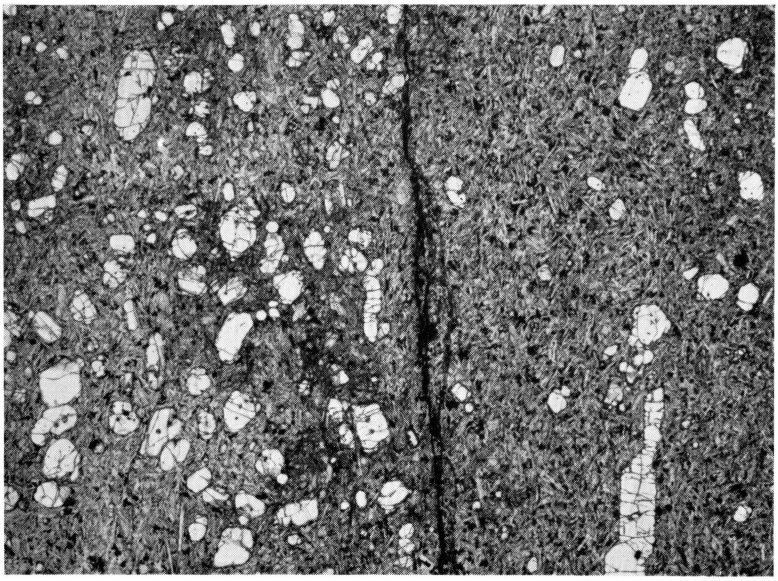


Fig. 2.

Plate 4.

Fig. 1. Scale: × 6. Dyke 3. Contact selvage. Phenocrysts and microphenocrysts of olivine, largely or wholly represented by saponitic pseudomorphs. Groundmass composed of a very fine-grained plexus of plagioclase laths and sub-ophitic pyroxene. Some iron ore grains. Irregular white patches are holes in the thin section. Picritic basalt.

Fig. 2. Scale: × 6. Dyke 3. Near centre. Equidimensional grains of olivine partly replaced (often centrally) by saponitic serpentine. Also smaller olivine grains. Brownish augite in sub-ophitic relation to plagioclase of equant habit. Some iron ore. Picrodolerite.

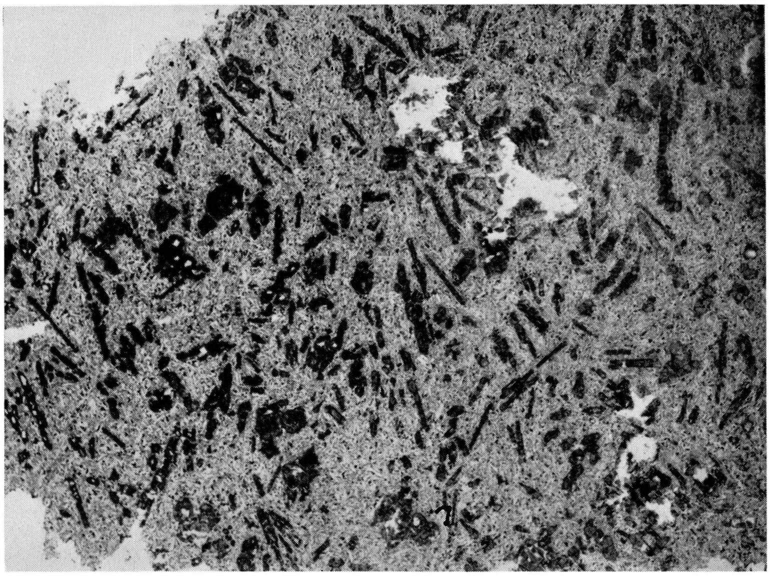


Fig. 1.

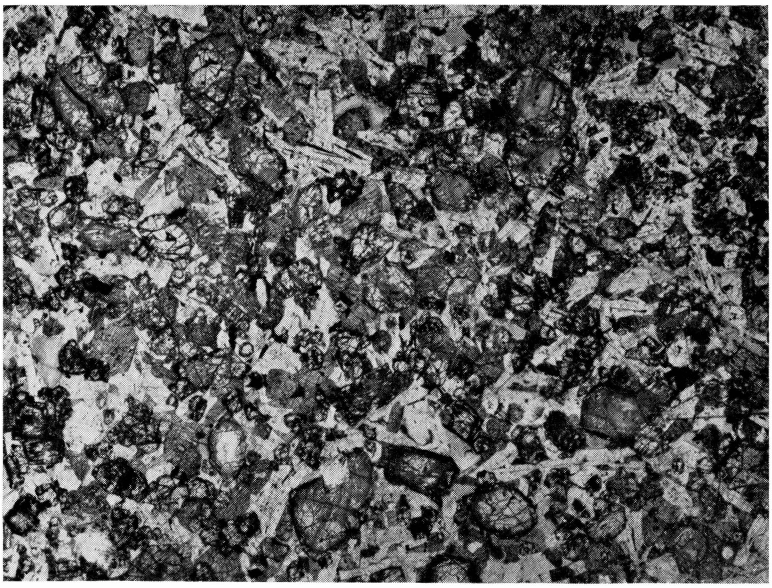
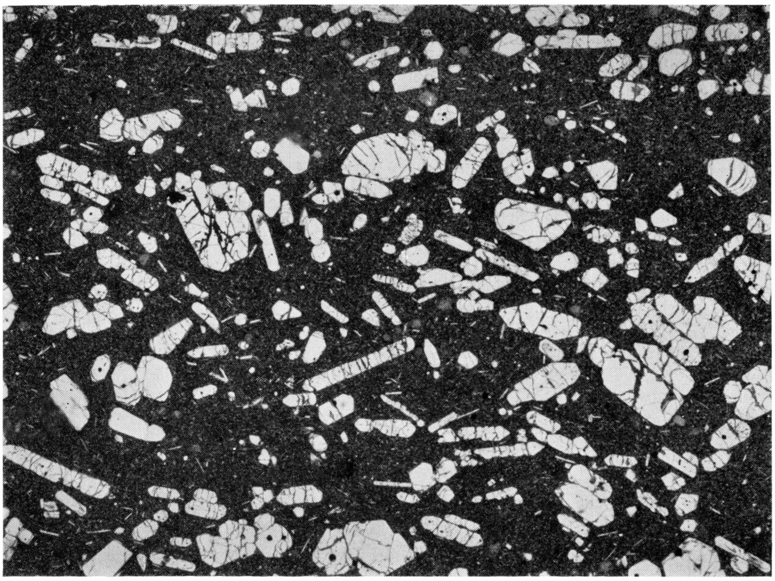


Fig. 2.

Plate 5.

Fig. 1. Scale: × 7. Sheet 3. Contact selvage. Sub-parallel phenocrysts, microphenoe crysts and parallel growths of idiomorphic olivine. Occasional microphenocrysts of plagioclase. Plexus of short plagioclase laths together with pyroxenin a very fine-grained groundmass. Some iron ore. Picrite-basalt.

Fig. 2. Scale: × 7. Sheet 3. Near centre. Phenocrysts of olivine (less distinct idiomorphism than in Fig. 1 above). Augite in sub-ophitic to sub-variolitic relation to plagioclase laths. Some iron ore. Picrite-basalt.



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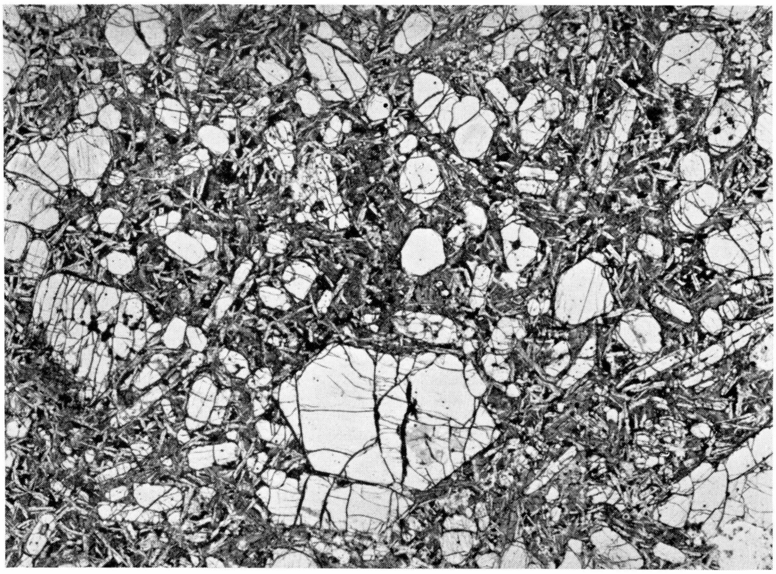

Fig. 2.

Plate 6.

Fig. 1. Scale: × 6. Sheet 4. Large zeolite-rich horizontal vein in picrite. Prehnitised plagioclase (dark in photograph) is intimately intergrown with unaltered augite (light grey in photograph). White patches are zeolites.

Fig. 2. Scale: × 6. Sheet 4. Small vertical vein in picrite. The plagioclase (lightest in photograph) is almost unaltered and partly intergrown with augite. Acicular ilmenite is an important constituent. A few small zeolite patches.

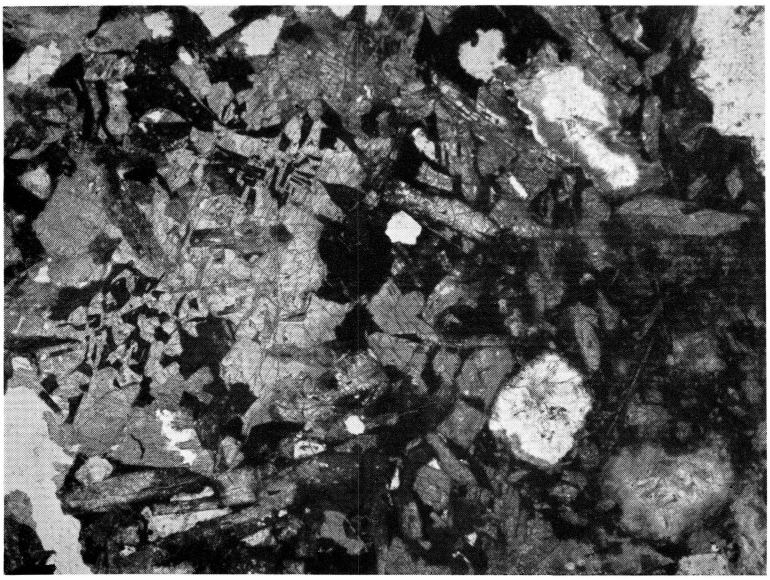

Fig. 1.

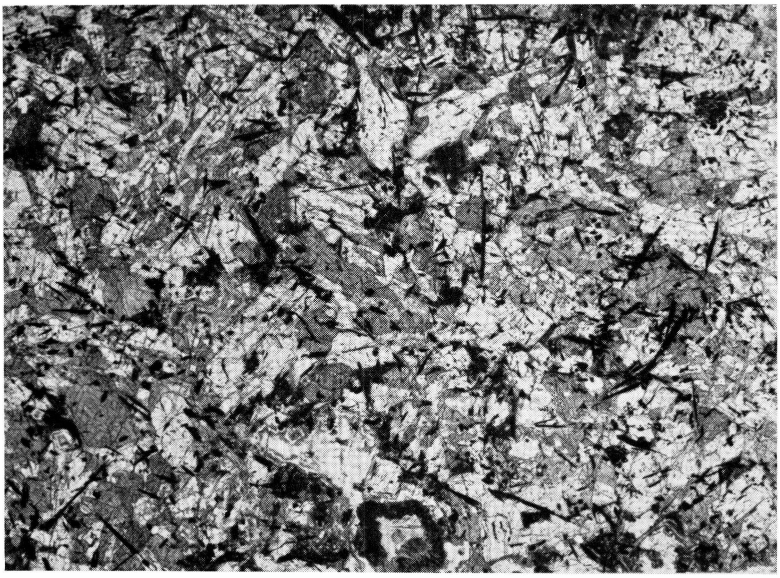

Fig. 2.

Plate 7.

Fig. 1. Scale: × 11. Sheet 4. Approximately 30 centimetres above lower contact. Elongated, lamellar, skeletal olivines in well-crystallised groundmass of augite in ophitic relation to plagioclase laths. Dusty iron ore. Picritic basalt.

Fig. 2. Scale: × 11. Sheet 4. Lower contact. Microphenocrysts of skeletal olivines pseudomorphed by green saponite. Semi-translucent groundmass with minute plagioclase laths. Picritic basalt.

Fig. 1.

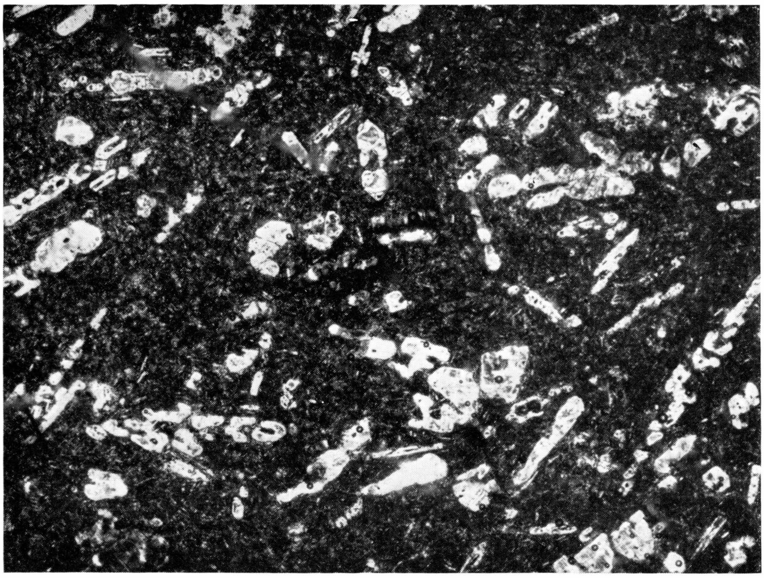

Fig. 2.

Plate 8.

Fig. 1. Scale: × 8. Sheet 4. About three or four metres from the top. Small amount of irregular grains of olivine. Augite in ophitic relation to zoned plagioclase. Interstitial serpentine (black in photograph) rich in acicular iron ore. Olivine-basalt (or fine-grained dolerite).

Fig. 2. Scale: × 25. Crossed nicols. Sheet 4. Middle of lower half. Large pyroxenes (P) enclosing rounded olivines poikilitically. Large twinned plagioclase crystal on the right is also enclosing olivine. The remainder of the thin section is mainly occupied by irregular or rounded olivines. Picrite.

Fig. 1.

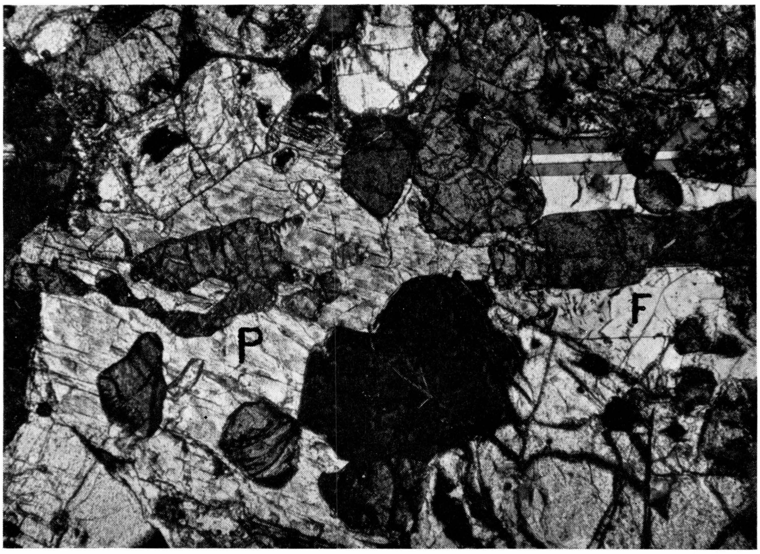

Fig. 2.

Plate 9.

Scale: × 1. Thin sections from top to bottom (*a* to *g*) of Sheet 2.

(*a*) Upper contact with olivine-rich lava. All white crystals are olivine (see also Fig. 6 and 7).

(*b*) Upper marginal rock with vertical joints (see also Pl. 10). Abrupt discontinuity with olivine-poor basalt. All white crystals are olivine.

(*c*) Lowest and relatively coarse-grained part of basalt zone and the top of the main olivine-rich part of the sheet. Downward and gradational increase in size and amount of olivine.

(*d*) As above (*c*) with slight overlap, but showing to a lower level in the sheet the gradational downward increase in size and amount of olivine (see also Pl. 11, Fig. 1). All white crystals are olivine.

(*e*) The main (central) part of the sheet. All white crystals are olivines (see Pl. 11, Fig. 2).

(*f*) Bottom margin of the sheet. All white crystals are olivine (see also Fig. 8, *a* and *b*).

(*g*) Chilled contact selvage (above) containing olivine phenocrysts (white) and vesicular picritic lava flow (below). (See also Pl. 12, Figs. 1 and 2).

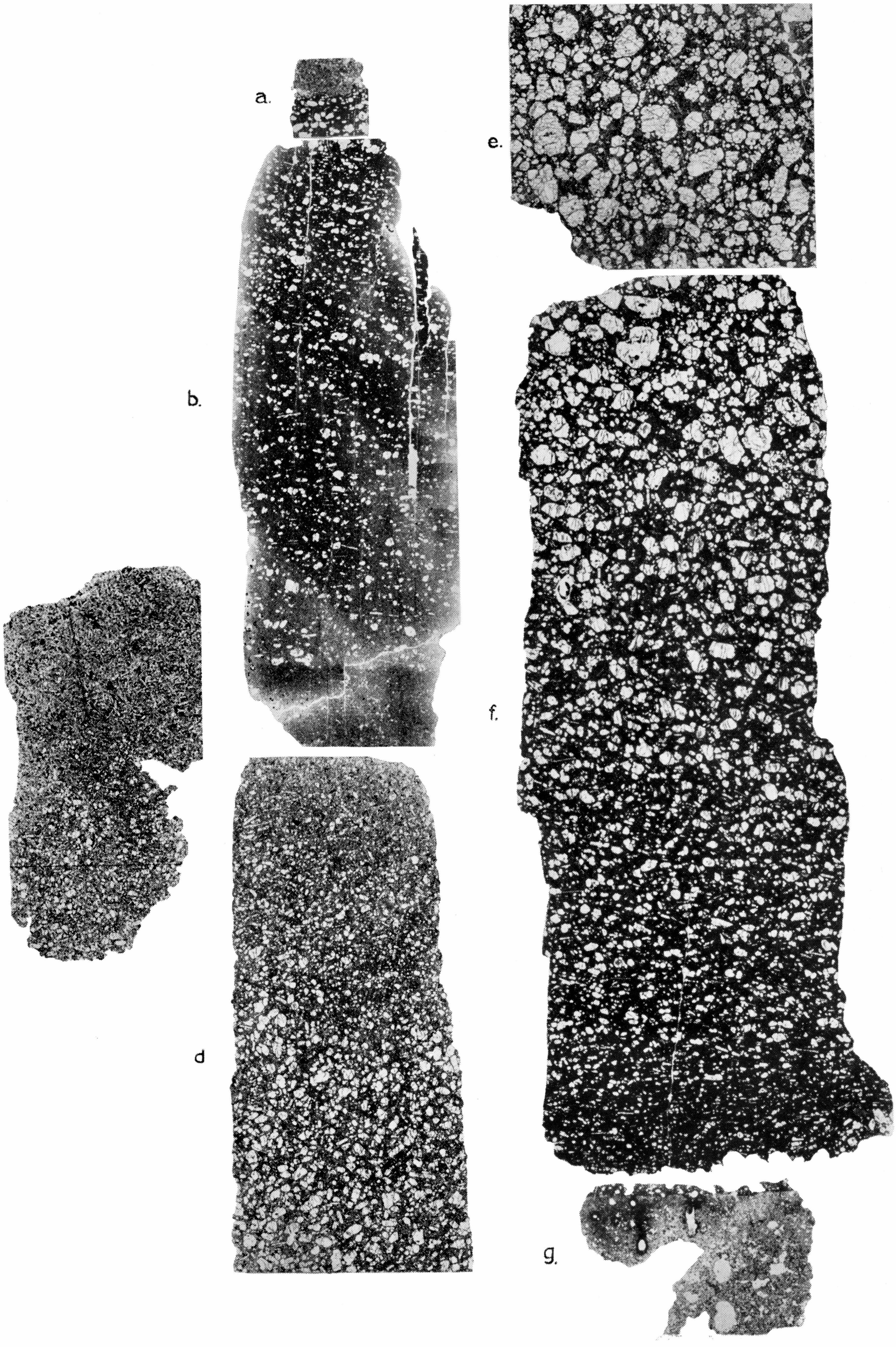
a.
b.
c.
d
e.
f.
g.

Plate 10.

Fig. 1. Scale: × 8. Sheet 2. Discontinuity between the upper marginal rock and an olivine-rich facies of the upper chilled contact selvage. One olivine lies athwart the plane of this discontinuity. The difference in groundmass on either side is due to a difference in degree of crystallinity. Little veinlets also with a relatively higher degree of crystallinity traverse the relatively finer grained groundmass.

Fig. 2. Scale: × 8. Sheet 2. Enlargement of lower discontinuity (in Pl. 9, *b*) between upper marginal rock and the top of the olivine-poor basaltic zone. The degree of crystallinity of the groundmass above the discontinuity is slightly the greater.

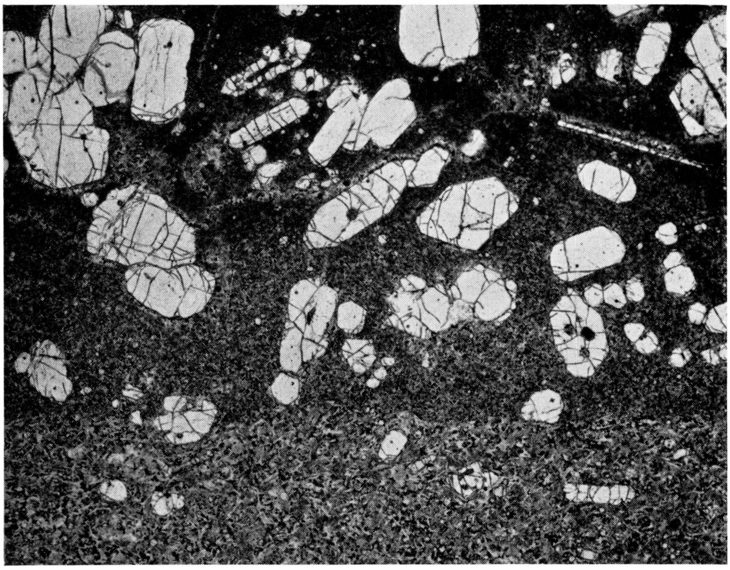

Fig. 1.

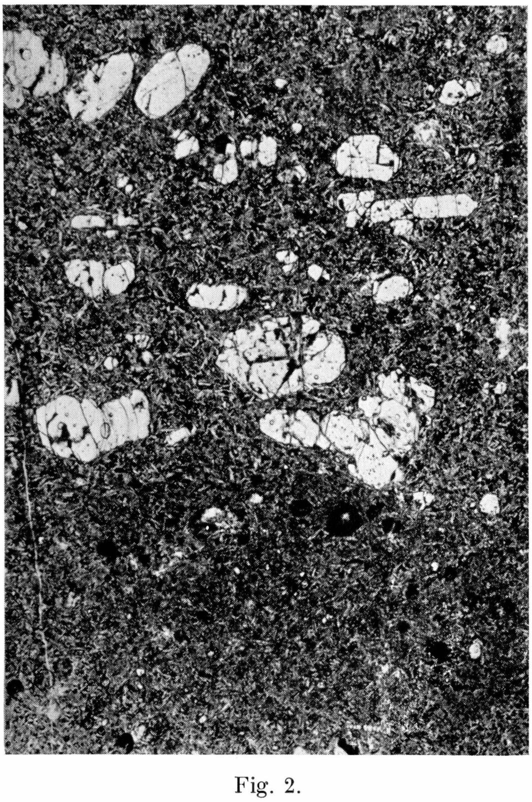

Fig. 2.

Plate 11.

Fig. 1. Scale: × 9. Sheet 2. About 35 cms. from upper margin (just below the thin section illustrated in Pl. 9, *d*). Olivine with augite and plagioclase in subophitic relation. Accessory iron ore. Relatively coarse-grained picrite.

Fig. 2. Scale: × 9. Sheet 2. About 60 cms. from lower margin (from same specimen as illustrated in Pl. 9, *e*). Phenocrysts and microphenocrysts of olivine in a sub-variolitic groundmass of augite and plagioclase, together with some grains of iron ore. Picrite-basalt.

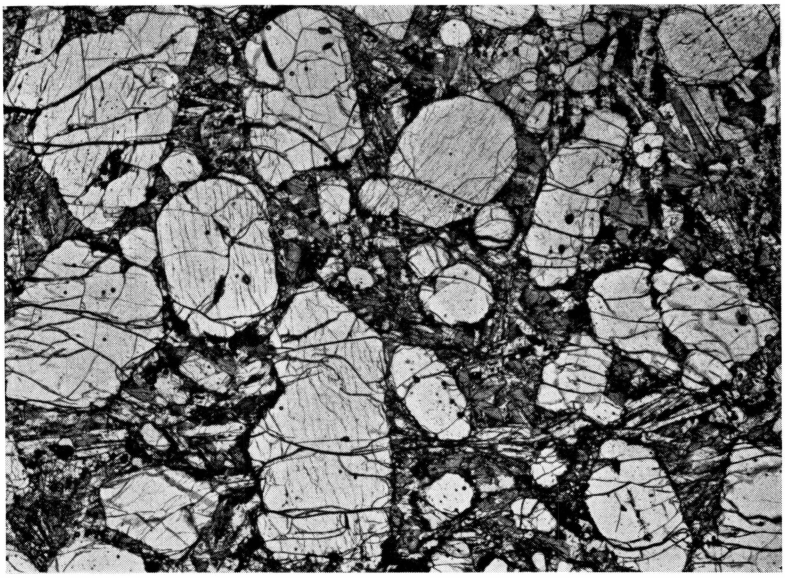

Fig. 1.

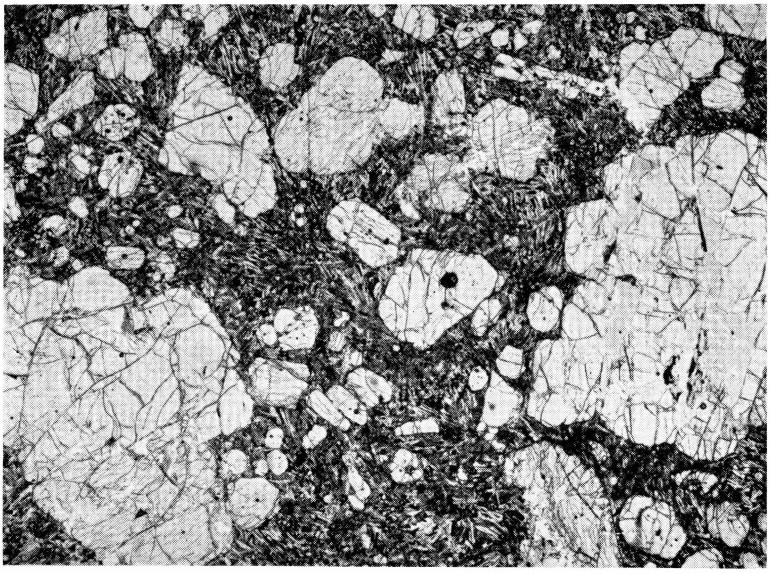

Fig. 2.

Plate 12.

Fig. 1. Scale: × 6. Sheet 2. Lower chilled contact (Pl. 9, *g*) with vesicular, picritic lava. Above is the chilled glassy selvage (black) with phenocrysts of olivine (white). The chilled glassy material has partly invaded and replaced the thomsonite of the vesicle on the right, but the black (partly glassy) material down the centre of the photograph is not in continuity with the chilled selvage. Contiguous with the chilled selvage, the lava appears to have been partly vitrified and recrystallised. The thomsonite, here represented by rounded relicts, has obviously participated in the vitrifaction.

Fig. 2. Scale: × 6. Sheet 2. Only a small portion of the lower chilled contact is visible in the top right-hand corner. The rest of the photograph is vesicular picritic lava. The vesicles are mainly filled with thomsonite. The centre of one vesicle is occupied by analcite. Olivine, which is abundant as grains of rather short elongated crystals, tends to disappear toward the junction with Sheet 2 and at the same time the plagioclase appears to have recrystallised in radiating groups. As in Fig. 1 above there has been some vitrifaction associated with the zeolite in the vesicles.

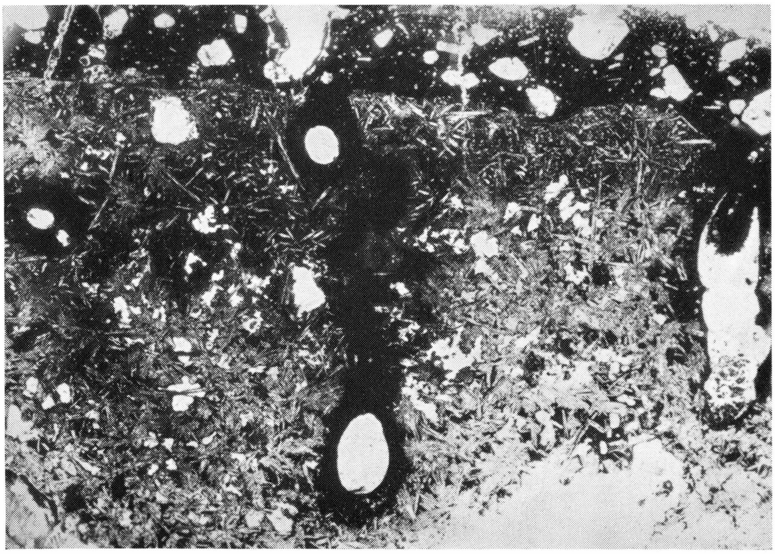

Fig. 1.

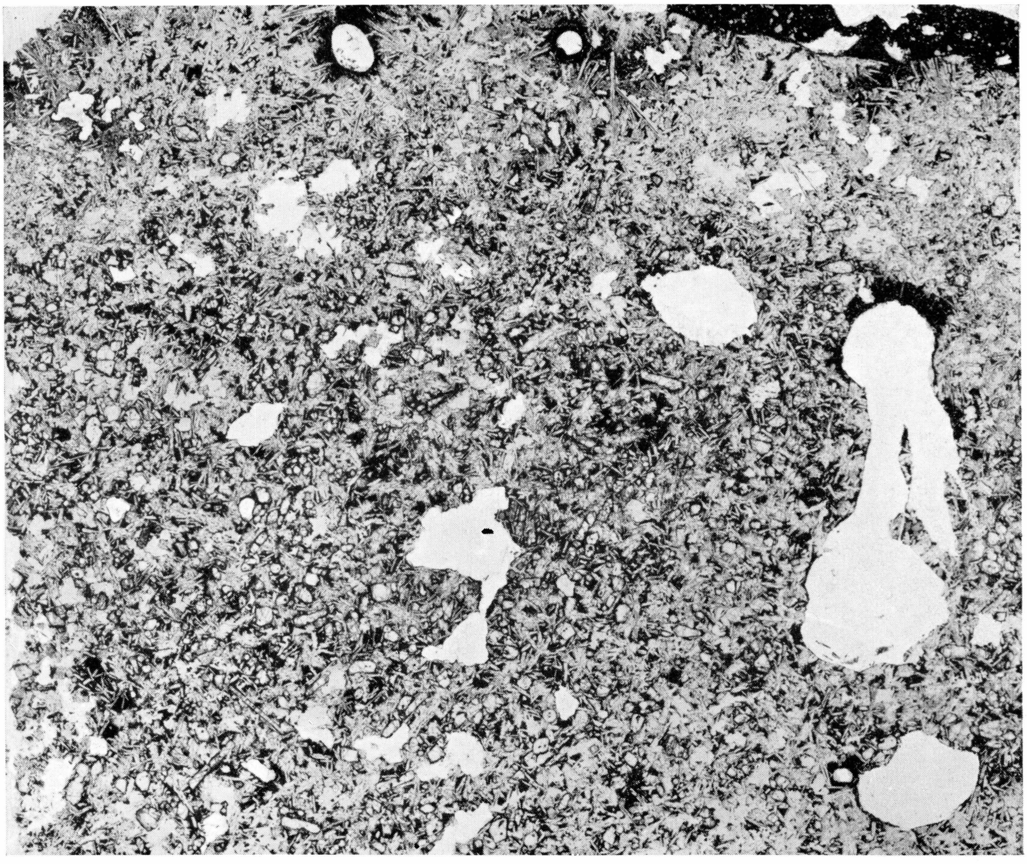

Fig. 2.