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THE ANKARAMITES OF HVAMMSMÚLI, EYJAFJÖLL, SOUTHERN ICELAND

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WITH 8 PLATES
AND 6 FIGURES IN THE TEXT

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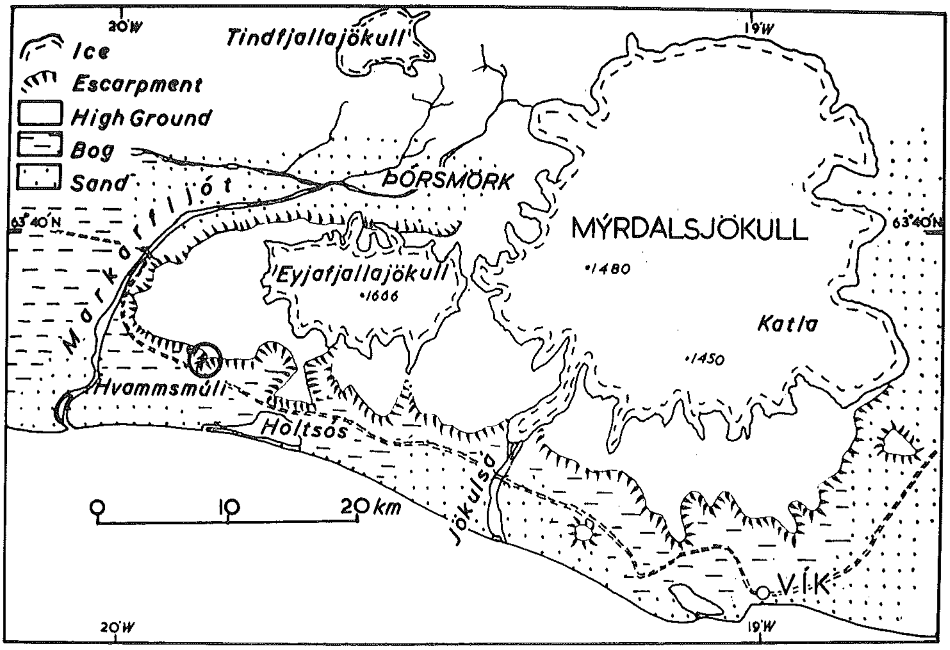


Fig. 1. Topograpic sketch of the Eyjafjöll area. Hvammsmúli encircled.

ABSTRACT

The occurrence of an ultrabasic rock of Quaternary age is described from Hvammsmúli, Eyjafjöll, S.-Iceland. A study of structures and field relations indicates that the rocks represent a case of multiple intrusion, the main masses being sills. Phenocrysts of olivine and clinopyroxene, which usually carry a mantle of lower temperature composition, constitute about a third of the rock. Some of the olivines described show iron exsolution of unusual intensity. Two types of textures, granular and subophitic, were recognized. The main minerals were studied optically and found to be of similar composition throughout the rocks. The various rocks are therefore thought to be closely related in time.

INTRODUCTION

The Eyjafjöll mountain range (Fig. 1), is an igneous Quaternary formation in the central south of Iceland. The range is capped with two separate ice sheets, Eyjafjallajökull to the west. Mýrdalsjökull to the east. It belongs to the Palagonite or „Móberg Formation" of Iceland.

I quote Kjartansson (1959): „The móberg (palagonite tuff and breccia) consists chiefly of brownish basaltic glass that has been subjected to palagonitization, a process of hydration and alteration. In addition, this rock usually contains fragments, globules and irregular lumps of more or less crystalline, vesicular basalt, and it ranges in coarseness from fine tuffs to coarse breccias. Some of these tuffs are regularly stratified and even the coarse varieties may show rough stratification. In some places numerous veins, dykes or more voluminous irregularly shaped masses of crystalline basalt are intercalated in the móberg. These basalts are usually tightly jointed into prismatic columns trending irregularly in all directions or roughly radiating from different centres. A typical pillow structure is common.

Most students of the Móberg Formation assume that the reason why basaltic magma consolidated into móberg and its attendant varieties of basalt instead of into normal lava flows was that it was extruded under water or thick ice, and consequently they assume a subglacial origin of these rocks".

Indeed, the forces which built these mountains are still active: Katla, the well known subglacial volcano in Mýrdalsjökull, erupts at fairly regular intervals, and Eyjafjallajökull has erupted at least once in history. That eruption started in December 1821, and lasted until the 26th of June 1823, on which date a Katla eruption started. The eruption has left a record in a thin light-coloured ash band of acid composition which is well seen in Thórsmörk. All Katla eruptions, however, are basic (Thorarinsson: pers. comm., Thoroddsen 1925, Loftsson 1880).

Towards the end of the Pleistocene glaciation, marine erosion moulded the high south cliffs of Eyjafjöll. The broad piedmont plain of sands and gravels is still being formed. Glacial rivers, draining Mt. Eyjafjöll and the highlands

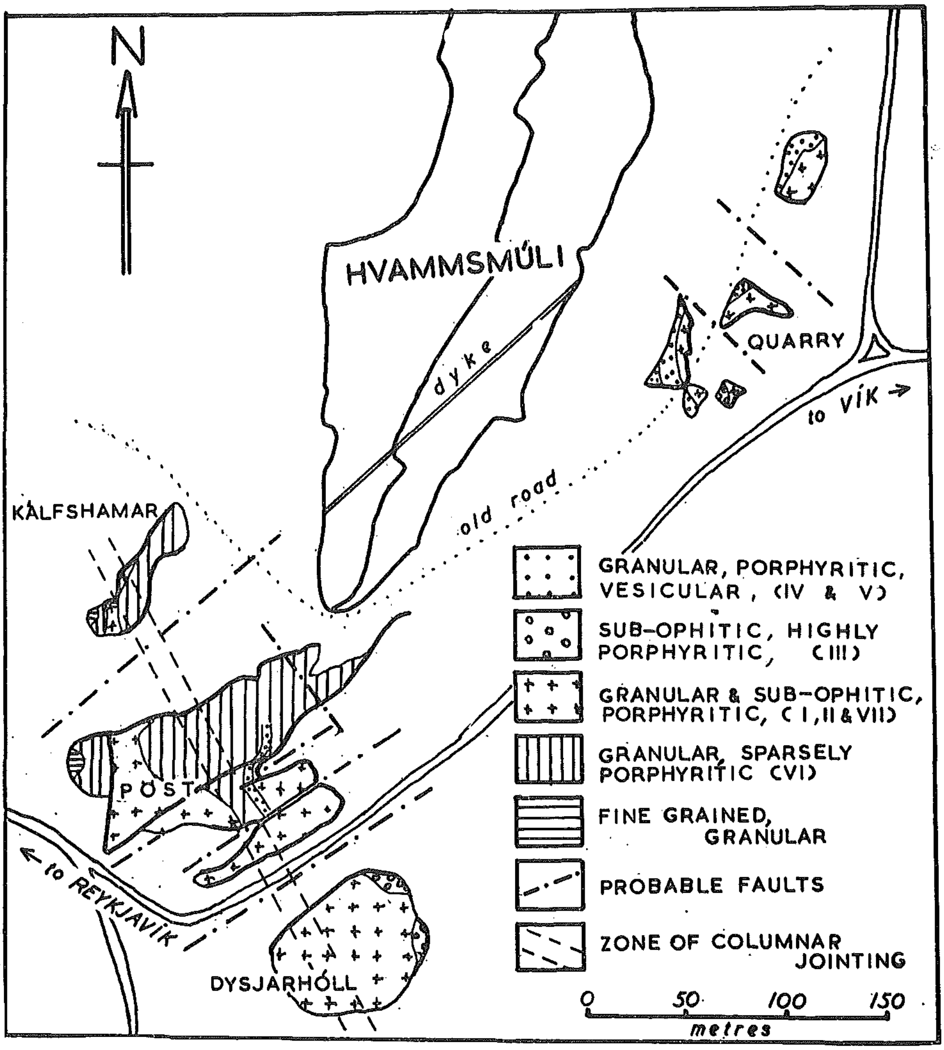


Fig. 2. Map of Hvammsmúli and the ankaramite outcrops. For description of the rocks see pp. 20—25.

farther north, carry abundant sediments which build up and evtend the land southwards. But the rivers are unstable. They meander and spread over wide areas, eroding here, depositing there. Thus the river Markarfljót, which drains the Thórsmörk side of Eyjafjöll, flowed eastwards along the south cliffs of the mountains into the tidal lagoon or „haff" Holtsós, until the 17th century, when it changed to its present course. Then the road, which now runs between Pöst and Dysjarhóll, lay above Pöst (Figs. 2 and 3).

Hvammsmúli is a small promontory extending south of Eyjafjöll (Fig. 2). At its base occur the ultrabasic rocks which form the main subject of this thesis. Then follows a thin succession of basic lavas, and lastly a pile of palagonite tuffs and breccias, which sometimes show conspicuous bedding. The palagonite is intruded by basic sills and veins showing close columnar jointing. The extrusive nature of the lower basaltic sequence is indicated by the scoriaceous top of at least one flow, which is followed by a thickish layer of scoriae. A dyke (1.5 m wide), cuts both the lavas and the palagonite trending NE—SW.

The ankaramites at the base of Hvammsmúli occur in well defined outcrops, bounded by vertical cliffs which at one time were washed and eroded by the sea, and later by the river Markarfljót (cf. above). The cliffs run parallel to the dyke mentioned (i. e. NE—SW). Presumably, therefore, the gaps between the outcrops are sea-eroded zones of weakness which may or may not have been occupied by dykes. (See Fig. 2).

Whether the main masses be thick lava flows or sills remains uncertain, because the top is concealed by scree and the bottom by alluvium. But certain structural considerations as well as the fact that the rock is distinct and different from the succession above, but has certain features in common with the intrusive veins in the tuffs, seem to be rather in favour of the latter.

Recently one of the cliffs was quarried for road material. The quarry, of course, provides 100% exposure and a good opportunity to study the more delicate structures of the rock. Its marvels will be described in some detail on a later page.

The rocks are generally highly porphyritic with phenocrysts of clinopyroxene and olivine up to 6 mm across. Feldspar phenocrysts occur as well but in minor amounts. Other minerals are iron ore in the groundmass and as exsolutions in olivine and inclusions in feldspar, serpentine and iddingsite as alteration products of olivine, and occasional spinel in olivine. Aragonite occurs as late stage filling of vesicles, and biotite was seen in one thin section associated with aragonite. Apatite was not noted. Neither analcite, pigeonite nor titan-augite were found. There is therefore no evidence as to the affinity of the magma, whether it was tholeiitic or alkalic-olivine basalt — proably in between the two.

Two distinct textural types are present in the groundmass, sub-ophitic and granular. Usually one rock mass is characterized by only one textural type, but both types may occur in the same rock. The rocks occur in 6 well defined outcrops (Fig. 2), Kálfshamar, Pöst and Dysjarhóll to the south west and the

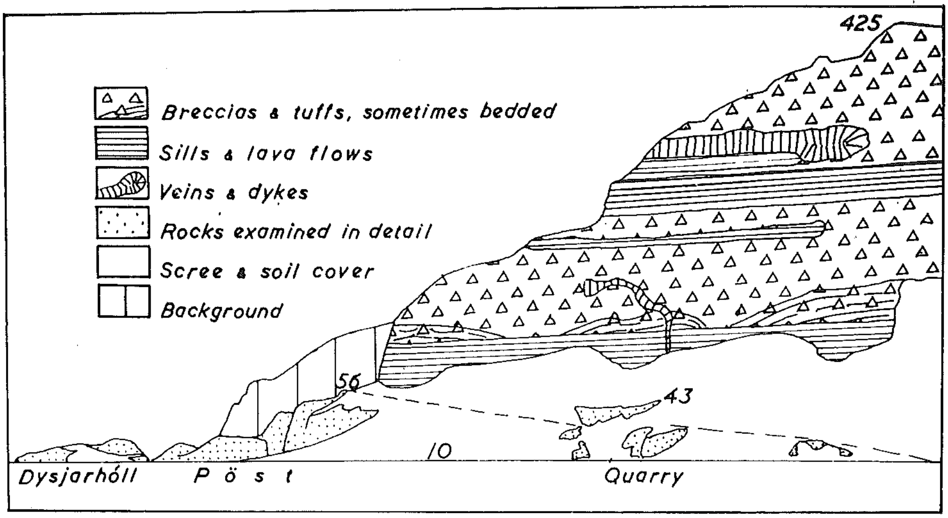


Fig. 3. Geological cross-section of Hvammsmúli from the east. Ankaramite outcrops, Dysjarhóll and the quarry group. The dashed line represents the old travellers' route (cf. text). Heights in metres.

3 quarry outcrops to the north east. They have no proper names and are conveniently decribed as the quarry, SW of the quarry, and NE of the quarry.

Four or more phases of intrusion can be distinguished, some of which at least are divided by only a short time span.

METHODS AND MINERALOGY

The rocks are composed of 4 primary minerals: plagioclase, clinopyroxene, olivine and iron ore. The pyroxene and olivine occur abundantly both as phenocrysts and as constituents of the groundmass, whereas the feldspar occurs mainly, and the magnetite exclusively, in the groundmass. Deuteric alteration of olivine to serpentine and iddingsite is common, but on the whole, the phenocrysts are extremely fresh.

A representative specimen of the rocks might contain 21% feldspar, 37% pyroxene, 33% olivine, and 9% ore. The phenocrysts often constitute about 30% of the rock, of which 60% may be olivine, 40% pyroxene. The rock is therefore ankaramite or ankaramite type of picritic basalt (Johannsen vol. III; Macdonald 1949).

A four-axes Universal stage was employed to determine the angle 2H of olivines, pyroxenes and few plagioclase crystals. The maximum extinction angle of pyroxene, and the parallel (max.) extinction angles of plagioclase were also determined by this means. It was attempted to use the methods of Köhler and Reinhard to determine the An-content of the plagioclase, but too much zoning rendered the methods impracticable. The cores of the phenocrysts, however, could be determined in this way giving (a) the composition, (b) the nature (high temperature) and (c) the twin law. For the groundmass plagioclase the zone method of Rittmann was employed in conjunction with refractive index. The rock was ground down, the feldspars separated in heavy liquid (bromoform) and maximum and minimum R.I. found in sodium light by the immersion method and a Leitz-Jelley refractometer. The accuracy is estimated as $\pm$ 0.003, but might be less in certain cases because of the possiblity that the actual maximum or minimum values were not obtained from the randomly orientated grains. By comparing the R.I. values with the ones obtained fram the extinction angles the groundmass crystals were found to be high temperature plagioclase as well.

Direct measurements of 2V of olivines and pyroxenes were made whenever possible. They were corrected for difference in R.I. between hemispheres and the mineral according to the formula β sinV = n sinH. The measurements were orthoscopic. The R.I. of the hemispheres used was n = 1.557 in all cases. The R.I. of the central plate is n = 1.560. The majority of the measurements was made with U.M. 2 objective and fully open diaphragm (Munro 1963).

The maximum possible error in actual reading of 2H is estimated $\pm$ 1° (0.5° on each side), but the accuracy may be as small as $\pm$ 3° in the case of olivine corresponding to 6% Fa. The pyroxene measurements are more accurate due their smaller optic axial angles, or $\pm$ 1.5°.

Measurements of R.I. of olivine and pyroxene were made on orientated sections giving nβ. The accuracy in estimated $\pm$ 0.003. The values thus obtained correspond reasonably well with those obtained from the 2Vs.

The carbonate present in the rock was determined by X-ray powder method as aragonite. One olivine crystal was determined in this way as well, and was found to be Fo 83%, Fa 17%. (Yoder 1957).

Modal analysis was made of representative sections. About 1000 points were counted in each section. A fine interval counter was used in most cases (10 points per mm), but a coarser one (3 points per mm) was used to count some of the coarser grained sections. The modes were determined for (a) composition of the groundmass, (b) phenocrysts, and (c) overall composition.

The density of numerous specimens was measured by means of a Walker's steel yard. The unaltered rocks showed a variation in density about the mean of 3.06.

The plagioclase occurs mainly as an important constituent of the groundmass. Phenocrysts do occur in some of the rocks, and may then reach up to 3 mm in length. Albite and Carlsbad twinning is the rule but pericline twinning occurs as well. Both phenocrysts and groundmass crystals show zoning. The phenocrysts have a central portion of fairly uniform sodic bytownite, which, however, shows a certain amount of direct continuous zoning. Then follows a sharp break and an outer strongly zoned rim of more albitic composition. The core is rounded by resorption. The groundmass crystals show zoning from An_{77} (bytownite) to An_{40} (andesine). They vary greatly in size according to the rock types, but in the coarsest grained varieties their average length is about 0,4 mm.

The plagioclase phenocrysts commonly contain a number of magnetite crystals in the core. These inclusions are not seen in the groundmass plagioclase or in the outer zone of the phenocrysts. The inclusions, which are small but euhedral with rectangular outline, are orientated in the phenocryst with their faces parallel to a cleavage (001), (010), (cf. Pl. IIa). These inclusions seem to indicate parallel growth of plagioclase and magnetite in the magma prior to emplacement to the present position.

Diopsidic augite occupies the greatest modal volume in these rocks, both as phenocrysts, (where it, however, is frequently subordinate to olivine), and in the groundmass. The phenocrysts are variable in size, commonly 3—4 mm across and may reach up to 6 mm. Occasional crystals, 2—3 cm in diameter, were seen. The size of a crystal in thin section depends of course on two factors, i. e. the actual sizt, and the way in which the crystal was cut. The shape of the crystal in thin section is also dependent on this second factor.

The phenocrysts are composed of two discontinuous zones; the core, which is sligthly zoned, is clear and colourless and devoid of inclusions. The composition is that of diopsidic augite ($+ 2V = 50$—$54°$, extinction angle $Z \Lambda c = 46$—$48°$, and average $n = 1.675$ giving 52% $MgSiO_3$, 41% $CaSiO_3$, 7% $FeSiO_3$.) (Tröger; Hess 1949, Muir 1951). The outer zone shows a distinctly darker brownish tint than does the core, that of the groundmass pyroxene. Both zones are unpleochroic. The boundary between the two is further emphasized by the presence of abundant small, rounded inclusions, mainly plagioclase. The outer zone shows sieve structure and may exhibit ophitic intergrowth with the plagioclases of the groundmass. The two zones, however, show physical (cleavage and crystal faces) and optical continuity, but he rim extinguishes at a slightly greater angle than the core.

The two zones represent two phases of crystallization. The core crystallized in a magma chamber at depth or under way to the present site. Subsequently, the mush, liquid with phenocrysts, was emplaced and the crystallization of the outer rim took place.

The pyroxene phenocrysts show usually some sort of crystal faces. Signs of resorption are not always evident, but blunt edges of the core suggest some resorption between the two phases of crystallization. In certain of the rocks, however, the crystals are highly rounded. A number of times the outer rim was seen to follow embayments in the crystal indicating that the embayment was there prior to the emplacement of the magma. Embayments, which are quite common in the phenocrysts, may be due to either rapid or faulty crystallization, „accidents" during flow, or resorption. A probable instance of „skeletal growth" is seen in the pyroxene in Pl. II b. Cavities in the crystals, filled with groundmass, occur as well.

Olivine is the most abundant phenocryst of these rocks but subordinate to pyroxene and plagioclase in the groundmass. The phenocrysts range in size up to 6—7 mm in diameter; the average size is similar to that of the pyroxenes. They are usually extremely fresh but show some deuteric alteration to serpentine or iddingsite on the edges and in cracks. The olivine phenocrysts show discontinuous zoning in the same way as the pyroxenes. The rim is, however, not easily distinguished because there is no change in colour or extinction angle. Inclusions sometimes emphasize the boundary line, but the outer zone is most conclusively seen when selective alteration has taken place, i. e. the crystals of the groundmass and the rim are altered while the core is fresh and unaltered (Pl. III a). Finally the rim may be defined by a curved crack.

A considerable variation of 2V and R.I. was found in the olivines, or from $+ 2V = 93$, $n = 1.663$ (Fa_7) to $+ 2V = 87$, $n = 1.687$ (Fa_{20}). An X-ray measurement of a fresh and clear crystal obtained Fa_{17}. The most forsteritic values are those of the „black olivines" (cf. below). Suitable sections showed slight zoning of the core.

In many sections the olivine crystals are euhedral. Their habit is then short-columnar with elongation parallel to the „c" crystallographic axis. More commonly, however, the crystals are more or less rounded or irregular in shape. The roundness would generally be due to resorption, but attrition may play some part too. Cataclastic effects are, however, not evident.

Holes and embayments in the phenocrysts provide evidence of rapid or imperfect crystal growth. In certain rock types a circular or semi-circular cavity, fulled with groundmass, is commonly seen in the middle of the olivine phenocrysts. Indeed, in some sections the presence of such cavities is as much the rule as is their absence. Such cavities may in certain rocks be explained by a rapid or incomplete growth *in situ* (Drever and Johnston 1957), and in the case at hand the earlier phase of crystallization may have occured in this way, fallowed later by the crystallization of the rim and the cavity fillings. We are therefore compelled to postulate either that these cavities represent a transverse section of a „tunnel" which in fact is open to the groundmass, or the crystallization of the inclusion from liquid trapped by the crystallizing olivine earlier on.

Most of the olivine crystals are very clear and free of inclusions, but exsolutions of magnetite are present in some. They form small, circular dendritic growths orientated parallel to a cleavage or they may form apparently irregular pattern of trails of inclusions winding about the crystal. The distribution pattern is partly dependent on the orientation of the crystal in the thin section. An extreme case of this type is seen in the top zone of the outcrop just SW of the quarry. Here the olivines are filled with „inclusions" almost to such an extent as to make the host opaque in thin section (Pl. IV a and b). The „black olivines" are completely fresh and unaltered save for the ore exsolutions. Usually they are euhedral, whereas the accompanying pyroxene is rounded in shape. The margin is always bordered by a dense growth of ore which may extend into the groundmass as well. Then follows a narrow zone clear of inclusions. The main central area is crowded with ore. The magnetite occurs in irregular clots, or branching streaks ramifying the surface of the crystal section. The occasional parallelism of the streaks suggests that the distribution of ore is in fact not random, but is governed by the crystal structure to some extent. Some crystals are completely blackened, or light may penetrate through the crystal as through a thick cloth. The clear marginal zone is, however, present in most cases. Where the degree of exsolution is less intense, the crystal may be comparatively clear in the centre, and grow blacker towards the margin. The probable course of the process of exsolution may be deduced from the apparently various stages or degrees seen in the section:

First the margin becomes crowded with magnetite (Pl. IV a), which appears to be rather *on* the crystal than inside it. Then, (and probably simultaneously), exsolutions of rods or clots of magnetite start to form within the crystal, most intensely nearest to the margin (but leaving the clear zone at the margin) and decreasing in intensity inwards. The clots join up to form streaks, which in turn connect to form a dense net of ore. Finally the speces of the „net" are filled up.

The black olivines are more forsteritic than normal olivine lower down in the same rock. (Black olivine n = 1.663 giving 93% Fo as opposed to n = 1.682 giving 85% Fo for the normal olivine).

Bartrum (1942) has described olivines similar to these from New Zealand. He contributes the ore exolutions to a reaction between early formed crystals and liquid. In the process the olivine was converted to a more forsteritic variety; the conversion took place at a very late stage in a volcanic cycle.

We may note the following facts in connection with the black olivines of Hvammsmúli and their environment: They occur in the uppermost zone of a thin sill (or lava flow), the thickness of which is about 10 m from the contact at the base to the top of the exposure. The top is very vesicular, so that one may assume that the top of the exposure is in fact close to the original top of the sill. There is an apparently continuous gradation from the medium-grained granular base, upwards through a fine-grained zone with normal olivines, into the top zone, which is vesicular and very fine-grained. The top zone is red coloured (hematite); there is a ca. 50 cm wide transition zone with irregular red and grey patches between the vesicular red above, and the massive grey below. The base too is marked by a vesicular zone 50—70 cm wide, with the vesicles drawn out as a result of flow. The central portion of the sill is massive. All the olivines of the red rock are black; immediately below the transition zone the olivines are normal. Otherwise similar rock in Pöst has normal olivines.

The main difference between the red and the grey types of groundmass is the distribution of iron ore. In the gray rock magnetite occurs in small but discrete grains; in the red it is disseminated all over the mass, mainly as hematite. On Pl. IV a the red area is seen to be considerably more vesicular than the grey one. It is noted too, that the olivine crystal in the grey area is less blackened than the other one. Even in the hematite (red) rock the olivine exsolutions are mainly magnetite. Only an occasional crystal is red in reflected light. This suggests greater amount of oxidation of the groundmass than of the crystals.

The geological setting suggests that this feature of the olivines was acquired more or less *in situ*, otherwise black olivines would be found all over the rock, not merely at the top. The freshness of the olivines seems to exclude the possibility of weathering.

It has been shown recently (Hamilton, Burnham and Osborn 1964) that basic magmas contain considerably more volatiles than had previously been thought. Furthermore, the great number of vesicles in the red zone is an indication of the presence of much volatiles, presumably mostly water vapour.

It is thought that the conditions in this vesicular zone were such as to cause the exsolution of iron from the olivine, which was then oxidized to magnetite.

It appears that the magnetite rim is actually *on* the crystal rather than inside it. In that case the clear zone seems to represent a mantle of composition different from that of the core, which did not suffer exsolution. A later phase of crystallization would, however, not be expected, considering the very fine grained groundmass. In all the other rocks the pyroxene shows greater tendency than the olivine to develop a mantle, but as seen in Pl. IVa the pyroxene does not carry any such rim here. This problem must await further research and methods allowing the exact analysis of the various parts of the crystals.

As stated, some of the crystals are almost completely blackened with ore. It seems that all this great quantity of iron cannot be accounted for by exsolution alone, because the change from Fo_{85} to Fo_{93} (i. e. 8% Fo) would not give rise to all that much magnetite. This fact, and the presence of a magnetite rim on the crystals, appears to indicate the introduction of certain amount of iron which may have been concentrated by the volatiles (to account for the absence of all these phenomena further down).

Magnetite forms the fourth primary constituent of the rocks. It usually occurs in discrete grains, clusters or „streaks" in the groundmass, and frequently shows poikilitic intergrowth with plagioclase; occasionally it is seen enclosing pyroxene or olivine. Pl. Va shows magnetite with a dense core and a poikilitic margin. The magnetite started to crystallize fairly early on and later proceeded to do so, together with the plagioclase, to form the intergrowth. In the finer-grained rocks, the ore forms small euhedral grains of rectangular outline (crystals). In weathered rocks it is partly oxidized to hematite. Magnetite also occurs as inclusions and exsolutions in plagioclase and olivine (above).

Aragonite is found in some of the rocks, filling vesicles. A large well formed crystal from a vesicle, and a tiny carbonate spot from a thin section, were determined by means of X-ray analysis. Both proved to be aragonite.

Small biotite crystals were seen in the aragonite in one thin section. Both the aragonite and the biotite are late stage products, deuteric or post-crystallization. The aragonite occurs both in the dark and the light coloured rock types (cf. G. P. L. Walker 1960).

PETROGRAPHY

a. Field criteria.

A few rock types, which sometimes show clear contacts, were recognized in the field. The characteristic feature of them all, distinctive from the overlying sequence, is their highly porphyritic nature. Phenocrysts of olivine and pyroxene constitute 10 to 60% of the volume of the rock. On average the phenocrysts make up about 30%. Gradations are seen, but generally one rock type is rich in phenocrysts and another relatively poor. On this basis the rocks were arbitrarily divided into highly porphyritic, porphyritic, sparsely prophyritic and non-porphyritic groups. The non-porphyritic forms thin bands or „veins" and inclusions in the porphyritic rocks.

An important field criterion is the colour of the rock. The rocks fall into two broad groups: light and dark coloured. The dark colour is believed to be in most cases due to deuteric alteration of the original light coloured rocks (G. P. L. Walker 1960). Therefore, each dark rock type may have its light coloured counterpart and vice versa. The dark colour is due to alteration of the olivine, especially in the groundmass, and to the dissemination of iron ore. The primary coloration depends, however, much on the relative abundance and grain size of the minerals in the groundmass (feldspar versus pyroxene).

The relationship between the light and dark rocks is well seen in the quarry. Dark rocks occupy the lower region of the quarry face, light ones the upper levels. A definite boundary is seen, often accentuated by a narrow zone of brown rock. But there is no actual junction between the two, and no change in mineral content or texture across the boundary. What most conclusively shows the later origin of the dark colour is the fact that the dark zone is seen to traverse non-porphyritic veins and inclusions, leaving the other end unaffected. In other exposures the relationships are quite different, as the light porphyritic rock is underlying and intrusive into the dark rock.

The various rock types show different and distinctive weathering. The highly porphyritic rock, which seldom takes on a dark coloration, because plagioclase laths predominate in the groundmass, weathers with an even surface when massive but becomes progressively more pitted when the rock is vesicular. The porphyritic, in most cases dark, weathers to rounded boulders with a brown surface. The phenocrysts weather better than the groundmass and stand out. This type of weathering may be a reflection of crude columnar jointing in the rock.

The sparsely porphyritic rock weathers very well. It is hard and tough to hammer. The groundmass is granular, rich in pyroxene, and in thin section the rock is similar to the other rocks but for the relative paucity of phenocrysts. In this rock a distinctive type of columnar jointing is developed in a ca. 10 m wide zone running NW—SE (See Pöst, Fig. 2). The columns are commonly bounded by 3 faces, which meet in sharp, acute edges. This zone grades on both sides into softer rock with less well defined columns.

The non-porhyritic rock occurs as „veins" or inclusions in the porphyritic type. The veins show contact with the surrounding rock, the only difference being the absence of phenocrysts in the vein. The non-porphyritic weathers slightly better than the host (Pl. VIb).

A suggestion of columnar jointing is fairly common in these rocks. Usually the columns are fat and ill defined, with rounded and blunt edges. The jointing of the hard, sparsely porphyritic rock mentioned above is an exception; here the individual units are roughly triangular in cross section, bounded by sigmoidal surfaces, and lens out towards both ends. This type of jointing is believed to be a reflection of some special conditions of cooling, probably accompained by movement. It is of note that a trace of this NW—SE zone of sigmoidal jointing, which grades into normal rock on either side, is seen to affect other rock types in direct continuation NW and SE of the type cliff. The extension of the zone is indicated on Fig. 2.

There is no obvious evidence of movement to be seen in the field, and the only difference between the types is slightly coarser grain outside the zone. But the fact remains that inside the zone the columns are more sharply defined than outside it, and the zone extends through two rock types.

b. Textures.

Two apparently well defined types of texture are recognized in the groundmass, the overall texture being porphyritic, viz:- (a) granular, and (b) subophitic. (Pl. Vb).

The granular groundmass is characterized by a high proportion of pyroxene, which forms small subhedral grains embedded in the mass of small plagioclase grains or laths. The plagioclases exceed the pyroxene grains in length, and govern the form of them. The olivines of the groundmass are of larger size than the other two. Their rounded outline seems to be independent of the surroundings, suggesting earlier crystallization. The ore shows poikilitic intergrowth with the other minerals of the groundmass, and commonly encloses many entire plagioclase and pyroxene grains, or it may occur as discrete crystals.

Even on a microscopic scale the pyroxene grains are fairly evenly distributed over the groundmass. The pyroxene phenocrysts, however, are sometimes surrounded by a narrow zone rich in plagioclase and free of pyroxene grains. (See e. g. Pl. II b). The plagioclases are then orientated parallel to the edges of the phenocryst. It appears that in this zone the liquid was empoverished in pyroxene, which was being concentrated to precipitate on the already formed phenocryst nucleus. This effect is hardly seen at all around the olivine phenocrysts, nor would it be expected there anyway, because olivine is much sparser in the groundmass, and crystallizes quickly to form discrete grains of fair size.

In some sections the plagioclase laths are aligned in parallelism. The granular texture may then be due to movement: the mush of already crystallized olivines and plagioclases was still flowing whilst the pyroxene was crystallizing. Against this cataclastic hypothesis appears to be the fact that the granular groundmass is sometimes seen sitting in a cavity of phenocrysts (Pl. III b). It is hard to visualize how the granular mass came to be inside the phenocryst, for there is no reason why the crystals forming in the cavity should not be precipitated from the liquid already there, instead of being brought in from the turmoil outside. (It is assumed that the cavity was present in the phenocryst when the groundmass began to crystallize).

Macdonald (1944) has described picritic basalt from Hawaii with hornfels-like groundmass of augite, hypersthene, labradorite and iron ore. The texture is attributed to recrystallization of the groundmass in response to thermal metamorphism. This explanation is hardly applicable for the Hvammsmúli rocks, because the two textures, granular and ophitic, are frequently seen associated in the same thin section, and showing no intrusive relationships (Pl. V b). It is conceivable in such cases that the two types represent some sort of banding governed by the movement of the crystallizing magma during emplacement. As shown elsewhere, (next section), the flow was laminar, and flow units may have formed where relatively unaffected units were bounded by planes of movement (the granular bands). Such relationship would be expected to be confused: an irregular pressure from behind would soon break up the banded relationship, fold the mass and chew it about causing partial remixing of the two units.

Composition seems to play a very important role as well in this connection, because the granularity increases with pyroxene content (F. Walker 1957).

The sub-ophitic texture is characterized by optically continous pyroxene areas, partly enclosing plagioclase laths of greater average length than that of the pyroxenes themselves (F. Walker 1957). More or less rounded grains of olivine are enclosed by the pyroxene as well. The form of the pyroxene is completely governed by the other minerals, and plagioclase laths are seen to extend into olivines too. The form of the olivine is, however, relatively unaffected by the surroundings.

Flow structure is common, where the plagioclase laths, which dominate the groundmass, are orientated in parallelism and bend round obstacles such as phenocrysts. The sub-ophitic rocks are coarser than the granular ones, which may reflect more rapid cooling of the latter, or, what is more likely, more intense movement resulting in smaller and more numerous crystals. Both types show gradation in grain size. The grain size of the granular rocks seems to be inversely proportional to the amount of pyroxene in the groundmass.

The magnetite forms patches of similar size and habit as the pyroxene in the sub-ophitic rock.

There seem to be two factors which govern the resulting texture of the rock, viz:- chemical composition, and amount and timing of movement with respect to crystallization. In both types the plagioclases are aligned in parallelism (seen in suitable sections) indicating flow. In the case of the ophitic rocks, the movement of the mass, which consists mainly of plagioclase laths, seems to have come to a halt when the crystallization of the pyroxene took place, whereas the magma was still moving while the granular pyroxene was crystallizing, and hence the texture. It is possible in the case of the plagioclase-rich liquid that movement ceased before all the plagioclase had crystallized out. The remaining liquid crystallized on already formed smaller needles which were aligned in parallelism due to the flow. Hence the relatively large and well

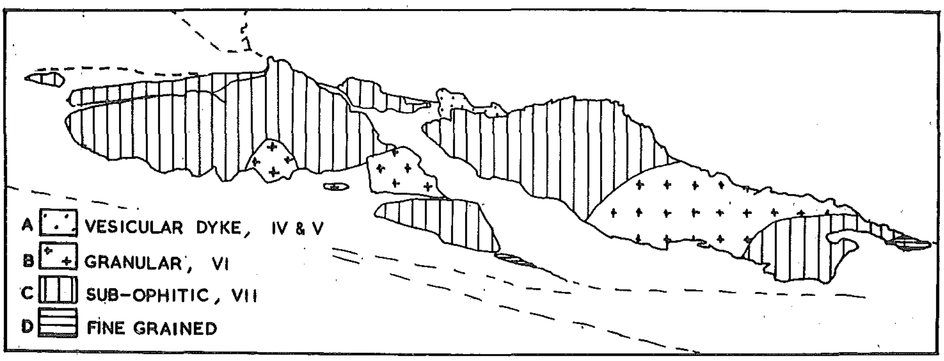


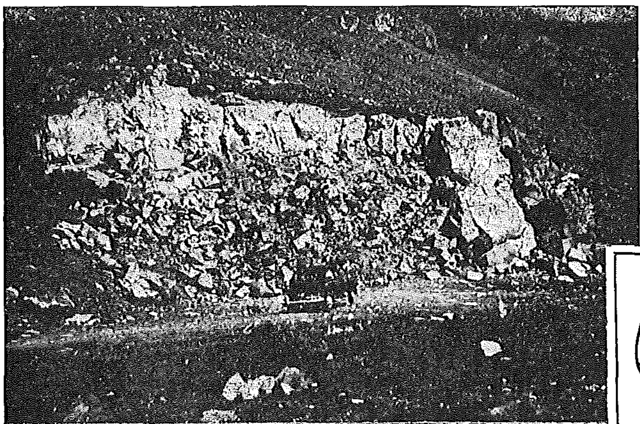
Fig. 4. Kálfshamar (left) and Pöst (right) seen from northwest.

formed laths, as opposed to the small and numerous plagioclases of the granular rocks.

c. Distribution and description of the various rock types.

Figs. 2 and 4 show the distribution of the outcrops and rock types. The outcrop NE of the quarry is an extension of the quarry rock, with the vesicular rock (IV) on top of the combined granular and subophitic rock (I & II) underneath. The same relationships are present in the quarry, and in the outcrop S of it. The highly porphyritic type (III) is intrusive into the main rock of the quarry. SW and above the quarry, Rock IV is sitting on top of the quarry-group, showing a sharp contact. At the contact the rock is light coloured and vesicular, with definite elongation of vesicles parallel to the contact. Upwards it becomes finer grained, and the rock is dark and massive in the hand specimen (V). The last 2 m or so are occupied by a vesicular slaggy rock, red in colour and heavily weathered. It is in this rock that the black olivines are found. Thin sections of the rock types seem to indicate that the red rock is an oxidized derivative of the dark massive rock below.

Dark, hard, granular and sparsely porphyritic rock occupies much of the



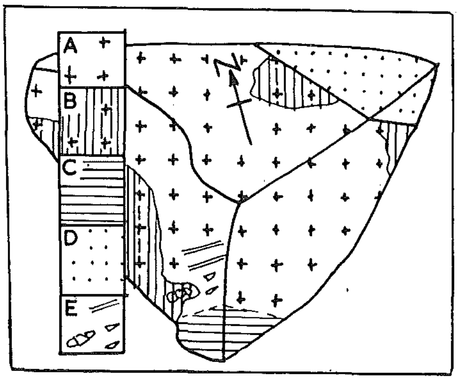


Fig. 5. The quarry face viewed from south (Volkswagen for scale) and a block diagram of the quarry showing the distribution of rock types. A: The main rock of the quarry (I & II). B: The dark variety of same. C: Finer grained granular. D: The vesicular rock (IV). E: Inclusions and bands. The quarry face is ca. 10 m. high.

northern block of Pöst (VI), (Fig. 4). It is intruded by a black sub-ophitic rock (VII). The lowest and westernmost outcrop is a dense, very fine-grained, light-coloured and porphyritic rock, similar to that seen in the lowest levels of the puarry (See later). These relationships are repeated in Kálfshamar. In Dysjarhóll the black sub-ophitic rock (VII) is underlain and intruded by light coloured rock. The same relationship is seen in the SE cliffs of Pöst. The „dyke" of Type V in Pöst is thought to be the same rock as that seen in the quarry-group.

The tops of Pöst and Kálfshamar are covered by a layer of slaggy, weathered product of the underlying rocks. As stated earlier, the main mass of the quarry rock consists of two types which are closely intercalated, one granular (I), the other sub-ophitic (II).

The various types will now be briefly described, mainly with reference to thin sections. The modes are tabulated in Table I.

TABLE I.

Rock	Minerals	Groundmass %	Phenocrysts %	Overall %
	plagioclase	30.2	—	20.9
I	pyroxene	45.1	20	37.4
	olivine	12.5	80	33.3
	ore	12.2	—	8.4
	plagioclase	55.4	6.8	38.0
II	pyroxene	21.1	41.7	28.5
	olivine	13.3	51.5	27.0
	ore	10.2	—	6.5
	plagioclase	76.6	0.7	29.4
III	pyroxene	6.2	56.6	37.6
	olivine	8.6	42.7	29.8
	ore	8.6	—	3.2
	plagioclase	36.7	—	26.8
IV	pyroxene	40.3	30	37.2
	olivine	15.4	70	30.5
	ore	7.6	—	5.5
V*				
	plagioclase	28.0	—	23.5
VI	pyroxene	49.9	45	50.7
	olivine	14.1	55	19.0
	ore	8.0	—	6.8
	plagioclase	50.3	6	42.8
VII	pyroxene	26.6	57	31.7
	olivine	15.6	37	19.2
	ore	7.5	—	6.3

* Type V is too fine grained for modal analysis. Distribution of phenocrysts is similar to that of Type IV.

Rock I. The granular rock in the quarry (See Table I).
Phenocrysts occupy 30% of the volume.

The rock is dense, light grey or dark in colour in the hand specimen, depending on which side of the colour boundary it was taken. The groundmass is granular, medium- to fine-grained. It is of note that with increasing modal pyroxene content in the groundmass the rock becomes (a) more granular and (b) finer grained.

The plagioclases are aligned in parallelism, suggesting movement during crystallization. The olivines in the groundmass are rounded; in the dark variety they are heavily serpentinized, but completely unaltered in the light variety. The ore occurs in discrete grains or clusters, showing sieve structure. Massive core with poikilitic margins is common. (Pl. Va is taken from this rock). In the dark variety, a halo of hematite staining is present around the magnetite grains.

Phenocrysts of olivine and pyroxene carry a discontinuous outer zone. It is conceivable that some resorption took place before the rim was deposited, because the outline of the core is slightly rounded. Otherwise both olivines and pyroxenes have good outline. The pyroxene rim is granular in appearance, but shows perfect optical continuity with the core. A few olivine crystals show exsolution of dendritic magnetite. A plagioclase-rich zone is often seen around the pyroxene phenocrysts (Pl. II b is from this rock).

A few small plagioclase phenocrysts occur. They are very rounded in shape due to resorption. A broad outer margin shows sieve structure due to numerous small and rounded pyroxene grains. The feldspar phenocrysts are surrounded by a zone enriched in pyroxene, which presumably is a mirror image of the feldspar zone round the pyroxene phenocrysts. Occasional aragonite crystals are present filling vesicles.

Rock II. The sub-ophitic rock in the quarry.

Phenocrysts occupy about 30% of the volume. Feldspar laths, up to 0.5 mm long form the main substance of the groundmass. The crystallization of the plagioclase seems to have been well under way when the pyroxene started to crystallize, because quite large laths of plagioclase are incorporated in the outer rim of the pyroxene phenocrysts. The magnetite may incorporate all three, plagioclase, olivine and pyroxene in ophitic intergrowth. The phenocrysts have poor outline. They may reach large size (Max. olivine 7.5 mm, average size about 2—2.5 mm. The pyroxenes are generally smaller).

Reaction rim (outer discontinuous zone) is pronounced in the pyroxene, but in the olivine it is hardly visible though probably present. A few of the olivine phenocrysts show dendritic magnetite exsolutions, and may contain minute needles of spinel.

Pl. VIa shows a large phenocryst of olivine, sitting in the groundmass of feldspar laths, but containing granular groundmass in an embayment. This phenomenon seems to be a further evidence of the close genetic relationship between the two textural types in the quarry. The phenocryst was carried about by the moving magma. The groundmass in the embayment shows that the phenocryst came at one stage into touch with the granular mass. Protected by the phenocryst, the granular substance remained in its hole in spite of the change of enviroment.

The olivines are slightly altered to iddingsite. The occasional plagioclase phenocrysts (up to 2.5 mm long) contain small magnetite crystals in the core.

Rock III. The highly porphyritic rock in the quarry.

Phenocrysts occupy over 60% of the volume. The rock is the coarsest grained type at Hvammsmúli; the groundmass is dominated by plagioclase laths ca. 0.4—0.5 mm long. The texture is ophitic, since the optically continuous pyroxene areas are large enough to enclose entire plagioclase laths (F. Walker 1957).

The olivine phenocrysts are rounded in outline and fresh, the pyroxenes irregular. Reaction rims are not obvious, except by the ophitic intergrowth of the margins with feldspar laths of the groundmass. Some of the olivines possess a curious conchoidal fracture round the rim but are unfractured in the centre. The fracture may define a compositional break. A few of the olivines show dendritic magnetite exsolutions. The phenocrysts are similar in size as those of Type II but much more numerous.

The ore occurs in largish poikilitic areas defined by and including feldspars. The rock was intruded into the other rock types of the quarry (See later).

Rock IV. The granular rock above the quarry.

Phenocrysts occupy less than 30% of the volume. The rock is very similar to Type I: the groundmass is granular, relatively coarse at the base, and grows finer upwards. The phenocrysts are rather well formed and carry a reaction rim. A sharp, almost vertical, junction is seen between the light coloured Type IV and the dark quarry rock. Type IV is thought to be later. Next to the contact the (otherwise) light coloured Type IV has a narrow zone, 10—15 cm wide, which is dark, due to the alteration of olivine and ore. Neither rock is chilled at the margin. Rock IV has average density of 3.1 as opposed to all the others, which have a specific gravity about 3.04.

Rock V. The finest grained rocks above the quarry and in Pöst.

The groundmass is granular, too fine-grained for modal analysis, but pyroxene is vastly predominant. Olivine occurs in larger rounded grains in the groundmass. Tabular crystals of ore are numerous, scattered all over the groundmass. They vary in size from place to place and may in some cases form minute and extremely numerous rounded grains in the groundmass.

Phenocrysts of pyroxene and olivine constitute ca. 30% by volume. Plagioclase phenocrysts are present as well but few. Gradations in grain size are seen; in the finest grained rock the phenocrysts carry no reaction rim, or a very thin one, presumably indicating rapid cooling with crystallization about many centres. The phenocrysts sometimes are rounded in shape. The pyroxenes in particular have embayments filled with groundmass, and a rounded, groundmass-filled cavity in the middle of the olivines is rather the rule than the opposite (Pl. III b).

The few feldspar phenocrysts show clear signs of unstable relation to the groundmass, by their rounded outline, occasional embayments and numerous inclusions of various kinds.

The crystals are, however, very fresh. The edges of the olivines are slightly indented (jagged) and serpentinized, and the rounded conchoidal fractures parallel to the margins are characteristic.

With coarser grain size the outer zone of the phenocrysts becomes more pronounced, and alteration generally more advanced. The pyroxene carries a reaction rim in the coarser grained types of this rock, but in the more fine-grained varieties the pyroxenes are rounded and have no rim, (Pl. VIa).

It is thought that this rock represents a variant of Rock IV. The relationships have been discussed on an earlier page.

Rock VI. The sparsely porphyritic rock in Pöst.

Phenocrysts constitute ca. 15% of the rock. In the field it is dark, massive, and tough to hammer. Columnar jointing is pronounced; the columns are sigmoidal with the faces meeting in sharp edges. The main characteristic of the rock is the jointing and the relative paucity of phenocrysts. A very marked increase in the amount of phenocrysts is, however, seen from SW to NE along the NW cliffs of both Pöst and Kálfshamar.

The groundmass is granular, of the same type as that of Rocks I and IV. Olivine and pyroxene phenocrysts may reach 3.2 mm in diameter. Some are euhedral, others rounded or irregular in shape. They sometimes include plagioclase laths and aragonite in cavities. A reaction rim is present but relatively thin.

The contact between Rocks VI and VII is sharp and marked by a vein of light coloured rock of Type II, (i. e. groundmass with subophitic texture; largish plagioclase laths predominant). Towards the contact the groundmass of Rock VI becomes coarser grained, but is still distinctly granular, with increased amounts of both plagioclase and magnetite, which occurs in very numerous euhedral grains. This corresponds to the general picture: as stated earlier the strictly sigmoidal jointing only occurs in a zone which marges into a softer and coarser grained rock on both sides. The junction between Rocks VI and VII is in the marginal region of the jointed zone.

Rock VII. The crystalline, sub-ophitic rock of Pöst.

Phenocrysts constitute about 20% of the volume. In the field the rock is black coloured if fresh, but has a brown weathering surface. It forms poorly shaped columns with blunt edges, very distinct from the sigmoidal columns of Rock VI.

The groundmass is crystalline, similar to that of Rock II. The modes are similar as well. The plagioclases of the groundmass (0.3—0.5 mm long) are aligned in parallelism. The plagioclase phenocrysts have the central portion occupied by numerous crystals of ore, which are orientated and commonly show cubic form. The marginal portion is free of these inclusions. The two portions are separated by a compositional break: the core, which is of almost uniform composition (An_{75}), is rounded in shape, whereas the marginal zone has good crystal faces and shows continuous zoning comparable with that of the groundmass-feldspars. The olivines in the groundmass and the margins of the phenocrysts are altered to seprentine, and magnetite is abundant — hence the black colour.

STRUCTURES

It seems appropriate to describe the quarry in some detail because owing to the superior exposure on the newly broken rock face, various relationships are seen which do not show in the ordinary weathered rocks. The SE corner of the quarry face is occupied by a light coloured rock with a very fine-grained granular groundmass. No contact was observed between this rock and the coarser one higher up. It is therefore thought to be a slightly chilled variety of same. Similar rock occurs in both the westernmost outcrops of Pöst and Kálfshamar (Figs. 2 and 4), where it occupies the lowest levels of the exposure, but here the overlying rocks are of a completely different type and show a definite contact. The light coloured rock may in that case represent an upper chilled zone of a rock mass deeper down.

Moving upwards we encounter the main rock of the quarry. It is partly dark in colour due to deuteric alteration, the dark variety occupying the lower levels of the quarry face. The dark rock reappears on the top face of the block, and in a small spot on the NE face. Overlying the main mass is the vesicular Rock IV, which shows a definite flow structure in the field, due to the parallel elongation of the vesicles.

A small area is occupied by a hard, non-porphyritic rock, grey in colour. The only other place where similar rock is seen is in the Kálfshamar outcrop. It is suggested that in both cases it is a xenolith and not an authentic member of the rock series.

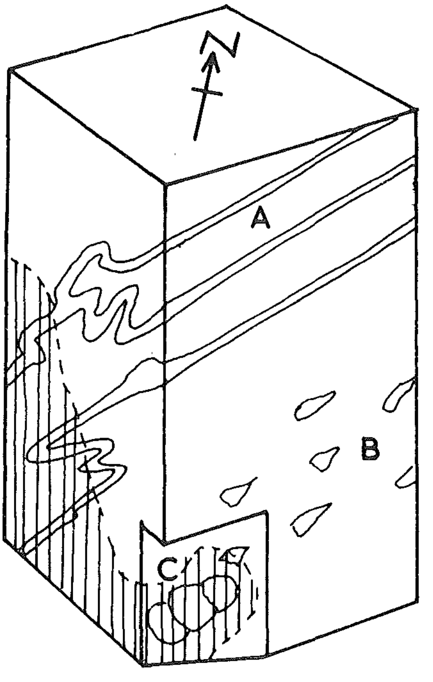


Fig. 6. Block diagram showing bands (A), "fish" (B) and the column (C). Dark rock to the left affecting the bands and half "fish". Not to scale.

In the SE corner of the quarry a number of non-porphyritic bands and inclusions were observed. (Pl. VI b and Fig. 6). The inclusions are 15—30 cm long, fish-like in shape, with one end rounded and the other one acute. They all run parallel to each other, dipping ca. 30° with their blunt end towards SW. Parallel to these inclusions, but occupying upper levels on the quarry face, the bands or „veins" occur. In 3-D their symmetry seems to be monoclinic, because, seen from SE they are straight and parallel to the „fish", but on a perpendicular plane they wind about in an irregular fashion, (Fig. 6).

A unique object in these rocks, aligned parallel to the bands and the „fish", is a complete basaltic column with 3 segments (Pl. VIIa). A thin section of its contact with the host rock shows that a certain amount of fusion has taken place, because the contact is by no means clear. In the field, however, the even surface of the column is very distinct from the uneven surface of the porphyritic host. The lower end of the column sticks into the dark area, and the dark zone swings round it. Probably fusion of the basalt provided some iron ore for the darkening of the rock.

These structures must be explained as mesoscopic flow structures. The non-porphyritic bands are considered to be contemporaneous structures formed in the magma *in situ* by the removal of phenocrysts by some agency, whereas, the „fish" and the column are inclusions *in sensu stricto.*

The magma liquid carried the phenocrysts and inclusions in suspension. Its flow was laminar, as reflected by the parallelism of the elements.

The inclusions, „fish" and column, occupy the lower levels of the rock face, and the bands the upper. The shape and orientation of the „fish", which all lie with their narrow end pointing in the same direction, seems to indicate a flow from right to left, i. e. the narrow end facing the flow direction. Inclusions of this shape (but different composition) are quite common outside the quarry. The main rock masses seem to represent gently dipping sheets of rock, most likely sills. One would hardly expect such uniform laminar flow in a lava.

The non-porphyritic „veins" possess very delicate banding or lamination (ca. 10 per cm) running parallel to their edges. In thin section the minunte feldspar laths show very marked orientation parallel to the lamination. The groundmass is granular. The laminae, which do not show well in thin section, appear to be due to a slight concentration of magnetite grains in the darker bands as compared with the lighter ones.

The „veins" are composed of the groundmass material of the rock on each side, the only difference between the two being the absence of phenocrysts in the bands.

It seems to be difficult to reconcile the structure of the „veins" and the flow direction obtained for the inclusions (Fig. 6). A possible explanation is that the „veins" were originally more or less planar sheets caused by the laminar flow. While still in the plastic state a new phase of intrusion took place disturbing the earlier mass locally, pushing it about and producing the folding.

A second intrusive phase is clearly indicated by an apparently composite xenolith seen in the rock immediately east of the non-porphyritic „veins" (Pl. VII b). One half of it is a non-porphyritic rock, the other half porphyritic, grey in colour. The porphyritic portion is ramified by non-porphyritic „veins" which are cut short by the margins of the inclusion. The surrounding rock is highly porphyritic of Type III (p. 23). The edges of the xenolith are fused, especially towards the top, which obscures the relationships there. An approximately 20 cm thick band of the intrusive rock separates the xenolith from the normal porphyritic rock below. The intrusive rock is more porphyritic underneath the xenolith than on the sides, possibly representing an instance of filter-pressing. The fact that the xenolith is more fused on the sides and round the top than at the lower margin may be a reflection of this: the liquid was squeezed out from underneath the xenolith, leaving the phenocrysts, and hence could not react at the lower margin.

The porphyritic part of the xenolith at least has not been carried far. In fact, it might be disturbed by the intrusion but otherwise more or less *in situ,* because it is the same rock as is seen other places in the quarry. The non-porphyritic portion is harder to place, but it is certainly a proper xenolith floating in the magma. Pl. VIIIa is taken much farther west on the quarry face. The highly porphyritic rock is clearly intrusive. In the outcrop just SW of the quarry the same relationship is seen again where differential weathering helps to bring out the two types, (Pl. VIIIb).

Small inclusions or clusters of a more or less pure feldspar rock occur in the quarry. The composition and size of the feldspar crystals is similar to that of the feldspar phenocrysts in the rock, but the magnetite inclusions (cf. Pl. II a) are missing.

A last feature to note in the quarry is the occurrence of aragonite crystals filling some vesicles but not others. No systematic distribution of filled and empty vesicles was discovered.

CORRELATION

In Dysjarhóll light porphyritic rock is seen to underlie and intrude the main rock, which is black in colour. The same light, porhpyritic rock appears in the S and SE cliffs of Pöst as coatings on the main rock, 3—5 cm thick. The magma has been squeezed up joints and solidified there. Where the joint units have weathered away the veins are seen as coatings on the joint face.

On the top face of the rock these veins may sometimes be seen as honeycomb structures: i. e. the black rock has been weathered out leaving ridges of the intruding veins. The vein between Rocks VI and VII is of this type.

Inclusions in the rock may give some clue as to the relative ages of the rocks. The black sub-ophitic rock of Pöst and Dysjarhóll (Type VII) contains granular inclusions which are conceivably derived from the sparsely porphyritic, hard rock of Pöst (Type VI). A light grey, fine-grained and granular inclusion, which might be derived from the similar rock underneath, was, furthermore, found in the black rock of Pöst. All these inclusions are fish-like in shape and orientated parallel to each other, dipping slightly towards S or SW. The reason for the uniform shape of the inclusions is not clear, but it seems likely that the „raw material" was tabular jointed, such as is seen some places in Pöst, the tabulae giving rise to the fish-shape upon resorption or melting.

We are now in a position to try and correlate the intrusions, for it seems clear that we are dealing with more than one magma injection. In the three quarry outcrops there seems to be the minimum of three phases, two penecontemporaneous and a third later. The main mass of the quarry (Rocks I and II) was emplaced first, and followed by the highly porphyritic rock (Rock III) while not yet fully solidified. Later, and showing clear contacts, is the overlying vesicular rock with its flow structure at the base and the slaggy top (Types IV and V).

The three SW outcrops Kálfshamar, Pöst and Dysjarhóll, must represent at least five phases: 1) Granular, fine-grained rock outcropping on the westernmost tips of Pöst and Kálfshamar. 2) The granular, sparsely porphyritic rock with sigmoidal jointing (Rock VI). 3) The sub-ophitic black rock (VII) intruded into (2) (and (1)?). 4) The sub-ophitic light coloured vein phase. 5) The granular, vesicular dyke, the same as the vesicular rock above the quarry.

The overall relationship is then probably as follows, equating the similar rock types of the various outcrops:

1) The fine-grained granular rock at the base of Pöst and Kálfshamar.
2) The sparsely porphyritic rock of Pöst and Kálfshamar.
3) The black rock of Pöst and Dysjarhóll (Type VII) and the main mass of the quarry (I and II).
4) The vein phase, seen at the base of Dysjarhóll, as coatings and veins in Pöst, and as the highly porphyritic rock in the quarry.
5) The granular, partly vesicular rock seen both in Pöst and in the quarry group.

Members 2 to 4 are, most likely, closely related in time. The other two may or may not be contemporaneous, but the uniform composition of the rocks seems to indicate rather that the various intrusions were not far removed from each other in time.

It appears that the whole group has been tilted towards the SW as evidenced by the dip of the inclusions. A certain amount of faulting has taken place as well. Probable faults are drawn on the map in Fig. 2.

EPILOGUE AND ACKNOWLEDGEMENTS

The Hvammsmúli ankaramites are by no means the only rocks of this type in the Eyjafjöll area. The writer has found boulders of apparently similar rock in Thórsmörk north of Eyjafjöll, and Dr. T. Tryggvason, geologist in Iceland, presented him with a boulder from the river Jökulsá, south of Eyjafjöll. It is therefore evident that the rocks are widespread here. They add a new paragraph to the splendid textbook of igneous geology which the Eyjafjöll area undoubtedly is.

The field work for this thesis was carried out during the summer of 1963. The laboratory work was started in the University Research Institute, Reykjavik, where the writer worked during the summer, and carried to its conclusion in St. Andrews.

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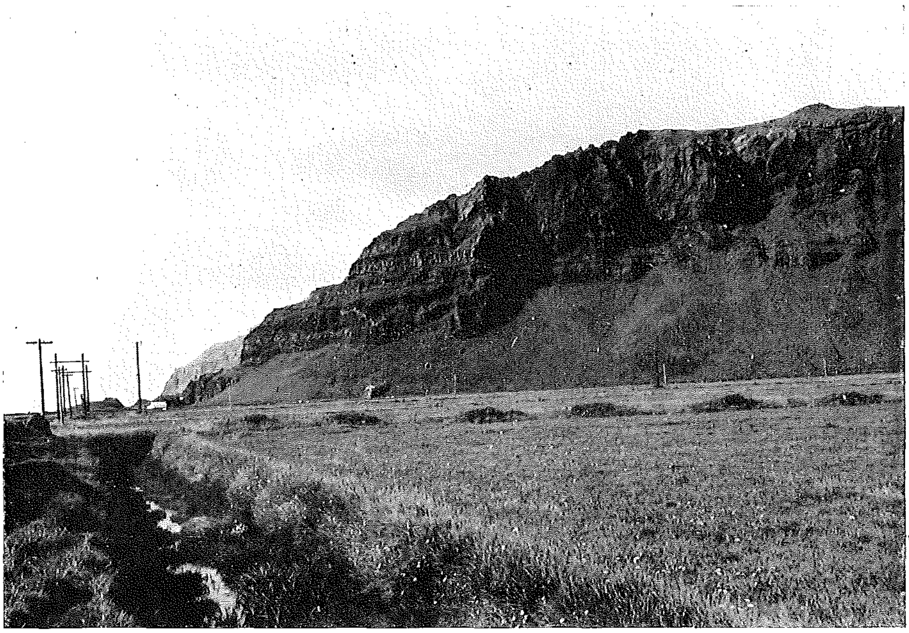
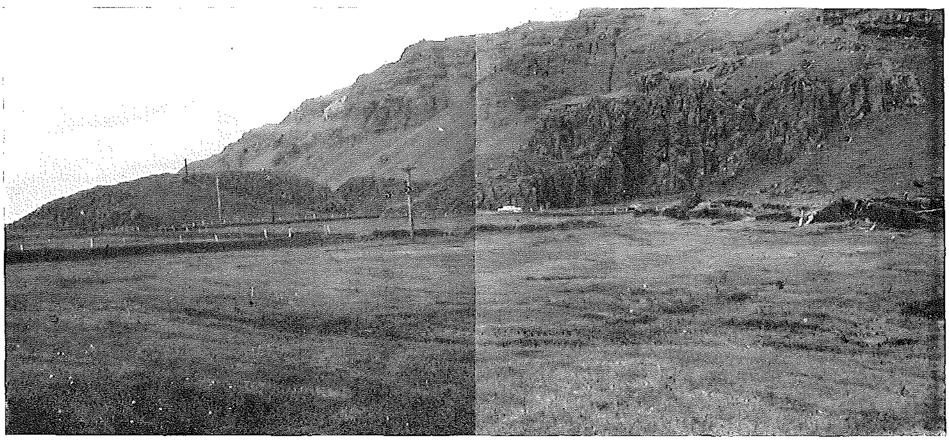
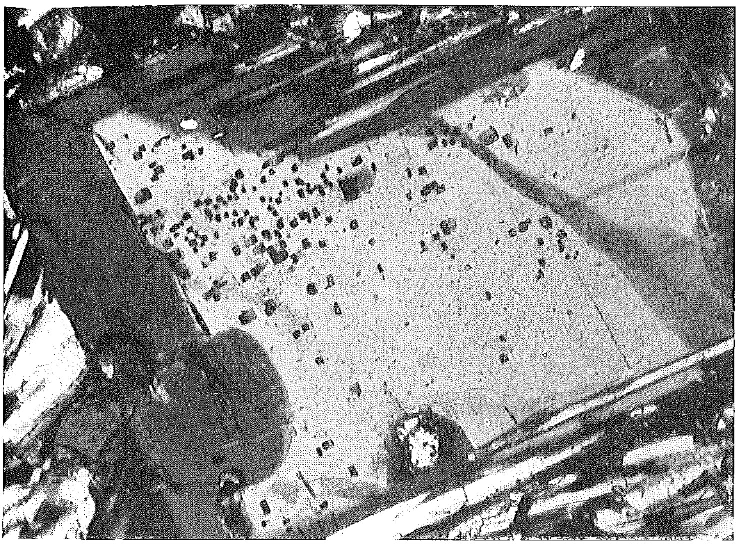
PLATE I.



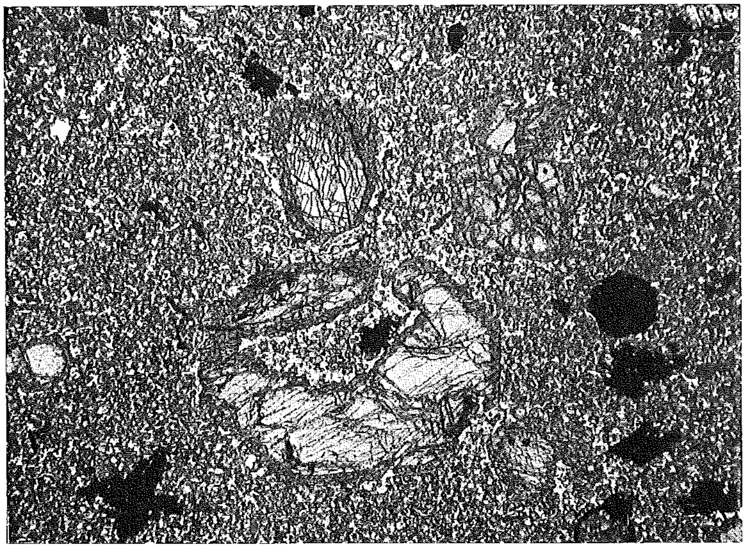
Pl. I a. Hvammsmúli from the east.



Pl. I b. Dysjarhóll (left) and Pöst from the east.

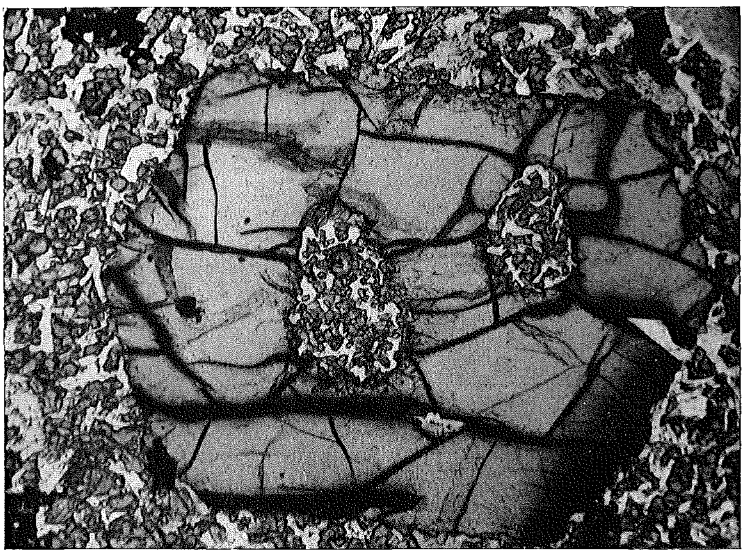


Pl. II a. Plagioclase phenocryst with a core of uniform composition and a zoned mantle. The core is occupied by cubes of magnetite. Crossed nicols x 50.



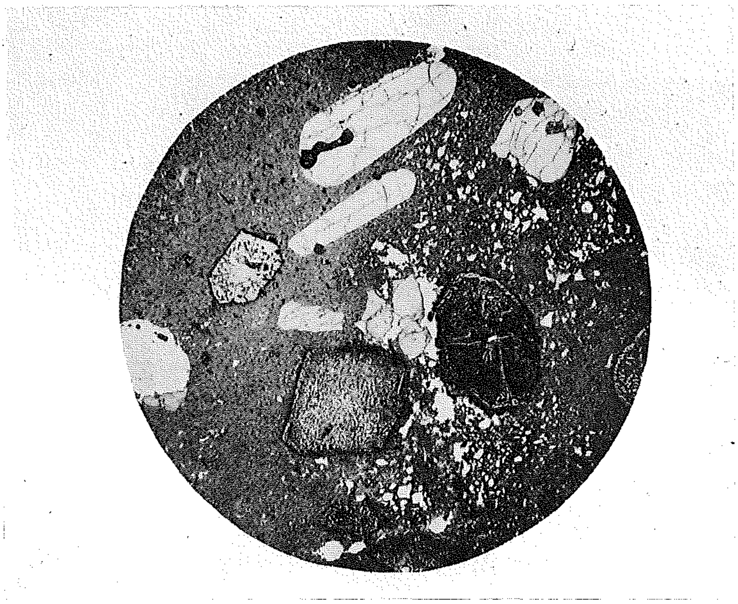
Pl. II b. Pyroxene phenocrysts in a granular groundmass. The large phenocryst shows an open cavity thought to be due to skeletal growth. The outer rim is well seen and the plagioclase zone next to the phenocryst. The black spots are iron ore. Plane polarized light x 15.

Pl. III a. Mantled olivine and pyroxene phenocrysts in granular groundmass. The rim of the olivine is emphasized by the selective alternation of the second phase of crystallization (mantle and groundmass crystals). Plane polarized light x 15.

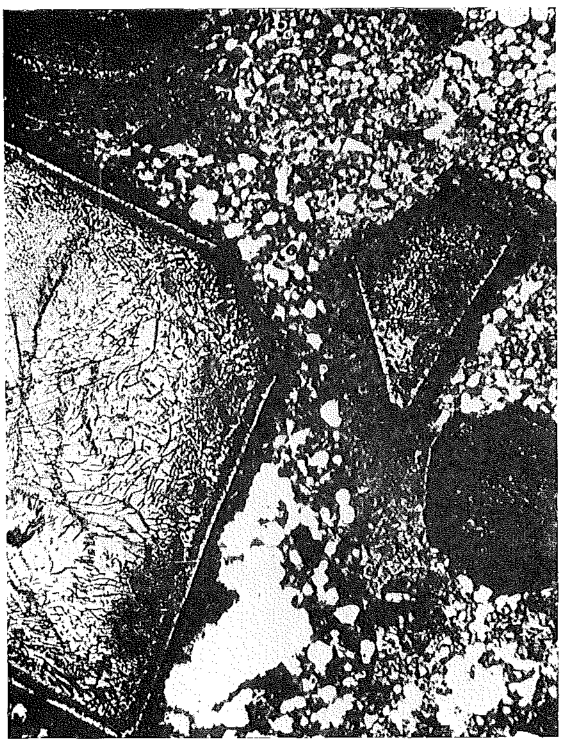


Pl. III b. Olivine phenocryst containing granular groundmass in cavities. Plane polarized light x 50.

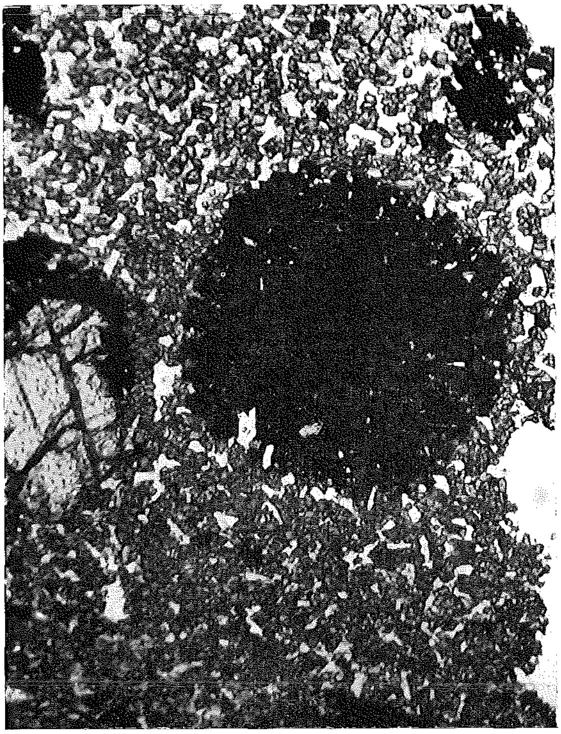
PLATE IV.



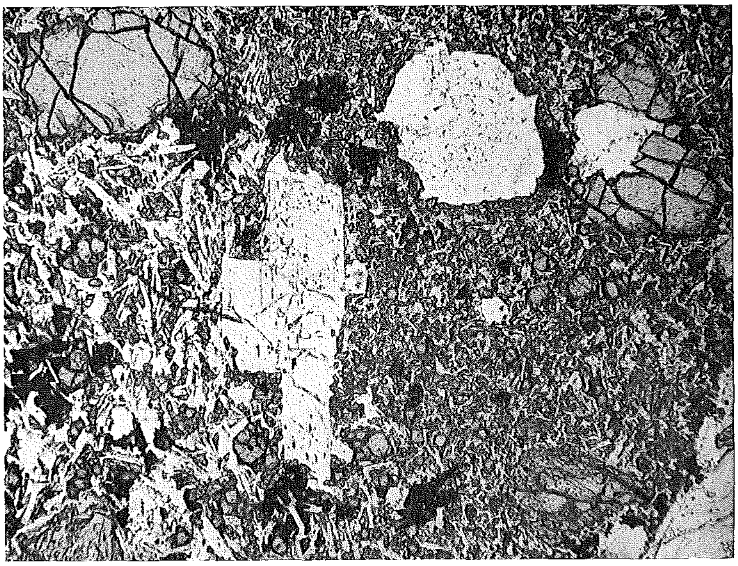
Pl. IV a. Photomicrograph of the transition between normal grey and oxidized red rocks above the quarry. The olivines are euhedral, the pyroxenes rounded. The olivines are blacker in the red vesicular type than in the grey massive one showing various degrees of exsolution. Plane polarized light x 10.



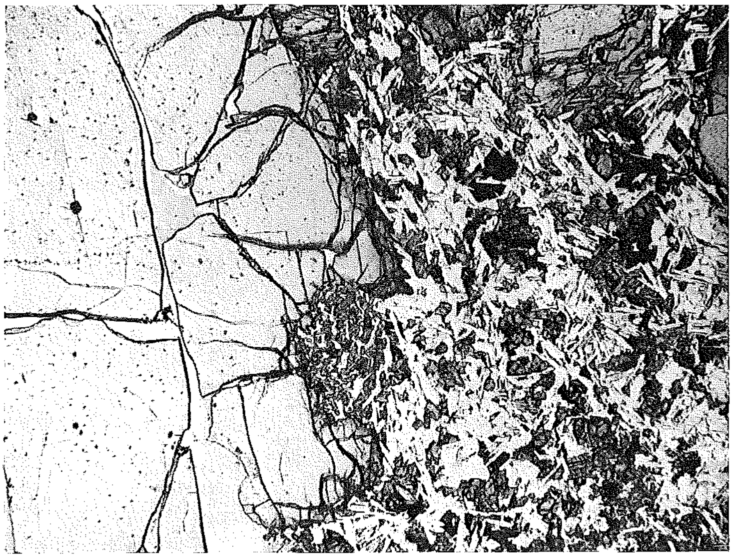
Pl. IV b. "Black olivine". The clear zone between the rim and the core is well seen. Note the fine-grained groundmass, and the good crystal faces of the olivine. Plane polarized light x 15.



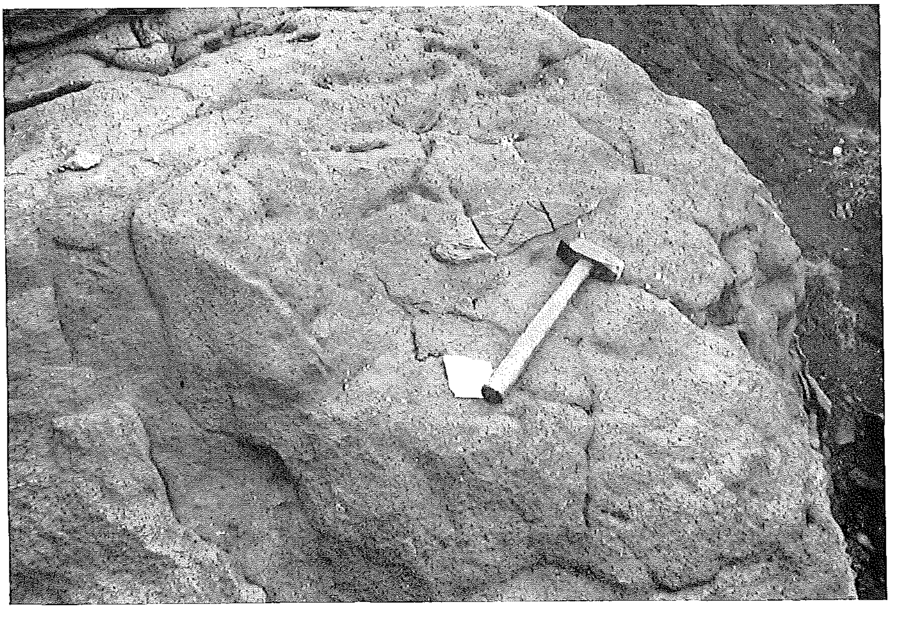
Pl. V a. Magnetite with massive core and poikilitic margin. The groundmass is granular. Plane polarized light x 50.



Pl. V b. Photomicrograph to illustrate two types of texture occurring together without any signs of intrusive relationships between the two. The plagioclase phenocryst contains inclusions of magnetite. Plane polarized light x 15.



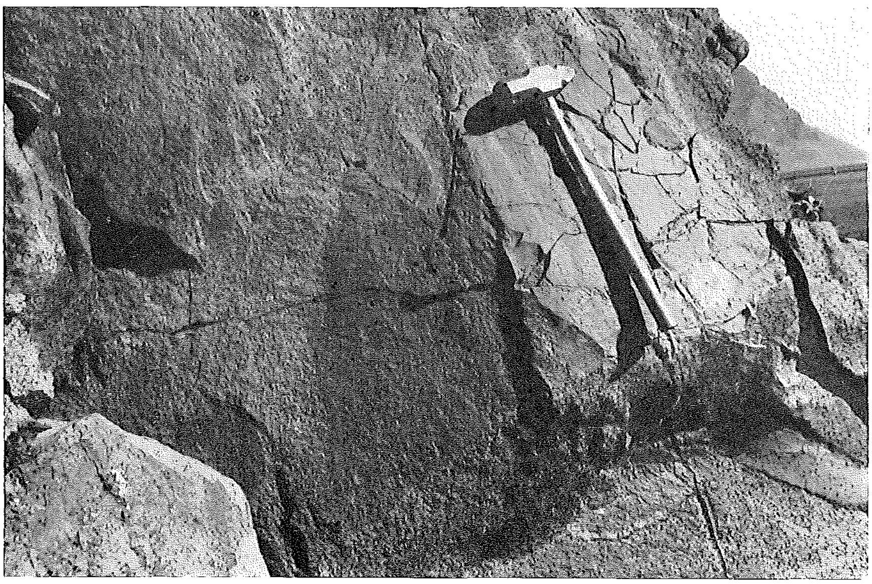
Pl. VI a. Detail of an olivine phenocryst sitting in subophitic groundmass but containing granular mass in an embayment. Plane polarized light x 15.



Pl. VI b. A non-porphyritic „fish“ in porphyritic host. All the fish are orientated parallel to each other and with their blunt end pointing the same way. Hammer is 40 cm.

PLATE VII.

Pl. VII a. The column. Three segments are seen, connected by ball joints. The „fish" occupy the face in the upper right corner. Dark rock to the left affects half „fish" just above the hammer. Hammer is 54 cm.



Pl. VII b. Composite xenolith in the quarry. The hammer (54 cm) sits on the non-porphyritic portion, the other half being porphyritic. The porphyritic part is ramified by „veins", which are cut short by the edges of the xenolith. The body is surrounded by light-coloured, highly porphyritic rock. Note non-porphyritic band in the lower left corner.

Pl. VIII a. Highly porphyritic rock intruded into the normal rock in the quarry. Note non-porphyritic band in upper left corner. Head of hammer 16 cm.

Pl. VIII b. Outcrops SW of the quarry. Weathering helps to bring out the two types of rock. Hammer 40 cm.