MARSCOITE AND RELATED ROCKS OF THE WESTERN RED HILLS COMPLEX, ISLE OF SKYE

By L. R. WAGER, F.R.S., E. A. VINCENT,* G. M. BROWN AND J. D. BELL
Department of Geology and Mineralogy, University Museum, Oxford

(*Received* 11 *December* 1963)

[Plates 9 to 14]

CONTENTS

The rock from Skye which Harker called marscoite was recognized by him to be hybrid in origin because of the close association in the rock of basic plagioclase, quartz and orthoclase. The position of marscoite in the sequence of rocks forming the Western Red Hills Tertiary complex has now been defined, and evidence for its parentage and the mechanics of its formation obtained.

The Western Red Hills intrusive centre, developed after the Cuillin and before the Broadford centres, as suggested by J. E. Richey, consists of five different, high-level granitic intrusions which were followed by a southern and northern series of late intrusions, including marscoites, ferrodiorites, and various additional granitic rocks. The high-level granitic rocks of Skye, which have so far been loosely termed granophyres, cannot all properly be described as such, and the term epigranite is proposed as a general name for them.

The earliest rocks belonging to the southern late intrusions are porphyritic epigranites and felsites, having quartz and potash felspar phenocrysts resembling the xenocrysts of these minerals in the marscoite. Then came marscoite, somewhat chilled against the felsite but also back-veined by it. The marscoite in Harker's Gully, and in other places on Marsco, passes gradually into ferrodiorite which sometimes contains basic andesine phenocrysts similar to the xenocrysts of the marscoite. The ferrodiorite has a composition suggesting that it was derived by extreme fractional crystallization of basic magma†. The xenocrysts of the marscoite are highly characteristic and indicate that

* Present address: Department of Geology, The University, Manchester 13.
† But see footnote, p. 304.

marscoite was formed by the mixing of a porphyritic acid magma, like that which produced the Southern Porphyritic Felsite, and a porphyritic basic magma, like that which produced the porphyritic ferrodiorite of Marsco. The chemical compositions of the presumed parent materials and marscoite support this view. Because of the even distribution of the xenocrysts in marscoite, the mixing must have been largely effected by the mechanical stirring together of two liquids, in both of which were suspended crystals. Diffusion within the liquid phase must also have contributed in some degree to the ultimate homogeneity of the liquid part of the mixture.

The origin of the marscoite of the northern late intrusions is presumably similar to that of the southern, except that the basic parent is believed to be represented by the porphyritic hawaiite blocks in the northern marscoite. The northern marscoite cuts through, and is chilled against, the Glamaig, Eas Mòr, and Maol na Gainmhich epigranites. Inwards from the contacts, the marscoite gives place, in a distance of 30 to 50 yd., to a rock here called glamaigite, which consists of rounded, dark patches, usually an inch or so across, and a less dark matrix, in approximately equal amounts. In both dark and light material there are xenocrysts of andesine, potash felspar and quartz, as in the marscoite. The difference in composition of the darker and lighter parts of the rock is not great, but is such as to suggest that the darker would have had a slightly higher temperature range of crystallization. The glamaigite is believed to have originated from a less well-homogenized mixture of basic and acid porphyritic magmas. From the mixture, the slightly more basic parts solidified first, and then flow movements of the magma resulted in rounding of the early semi-solid clots of hybrid material.

The central parts of the composite, northern, late intrusions consist of a rock resembling glamaigite but tending to be more uniform and acid in composition. The greater homogeneity of this rock, distinguished as dioritic glamaigite, may be due to its central position within the intrusions, where slower cooling would allow more time for diffusion.

It is suggested that the epigranites of the Hebridean igneous province originated by melting of crustal rocks of broadly granitic composition. The heat to produce the melting is believed to have been derived from basic magma intruded into the earth's crust, the upward transfer of heat being aided by convection in the magma and bottom accumulation of early formed crystals. At some stage, a residual layer of ferrodiorite or hawaiite liquid, produced by fractionation, may have underlain a granitic liquid produced by melting. Two separate systems of convection currents are envisaged in the two liquids, because of the differing densities. At the junction of the two systems of currents, where they would be flowing in opposite directions, there would be an opportunity for mechanical mixing. Ultimately, a mass of hybrid magma may have developed, annular in form and with a forced circulation, which was the source of the marscoite and related rocks.

1. Introduction

Alfred Harker mapped central Skye for the Geological Survey during field seasons from 1895 to 1901 and his classic account, *The Tertiary igneous rocks of Skye*, was published in 1904. The six-inch maps and the memoir present a wealth of data, but the great significance of his work for igneous petrology lies in the masterly way in which he effected a grand synthesis of the Tertiary igneous events in Skye. This has appeared so final to generations of geologists, that any considerable re-investigation of the area has not been undertaken until recently.

During the investigation of the Western Red Hills, Harker found small amounts of a rock which he recognized as hybrid in origin, and named marscoite (1904, pp. 175 and 186) after Marsco, a mountain in central Skye. The rock consists of a sprinkling of well-shaped crystals, or glomeroporphyritic groups, of fairly calcic plagioclase a few millimetres in length, and a lesser sprinkling of quartz and potash felspar crystals of smaller size, and usually rounded, all set in a uniform groundmass of plagioclase, potash felspar, quartz, augite, hornblende, apatite and iron ore. The association of rather calcic plagioclase, characteristic of basic rocks, and of quartz and orthoclase characteristic of acid rocks, together with the intermediate composition of the groundmass, led Harker to infer a hybrid origin for the rock. Other rocks in Skye were recognized by Harker (1904, pp. 170–186) as showing an arrested stage in the digestion of basic rock by acid magma but he considered marscoite to be basic magma modified by inclusion of granitic material (1904, pp. 186, 192). Harker's clear realization of marscoite as a hybrid rock seems to the present authors a remarkable achievement for that time.

Harker, however, did not succeed in giving a convincing account of the relation of marscoite to the associated rocks, some of which he considered also to be hybrid in origin. This could not have been achieved without more detailed mapping of the different units of granite and granophyre which he knew to exist (Harker, pp. 130–1) in the Western Red Hills, but did not separately map; furthermore, he did not have chemical analyses of marscoite and the related rocks to aid him in an interpretation. The present account is based on more detailed mapping and petrological investigation, carried out at intervals over the last seventeen years, and on chemical analysis of the chief rock types.

The present study forms part of a re-investigation of the geology of central Skye begun in 1946 by Dr J. E. Richey, Professor F. H. Stewart, and the first-named author. At an early stage, two separate acid intrusions, designated G_1 and G_2, were distinguished by Dr Richey, whose skill in detecting the small but significant differences in the mineralogy and texture of granites was of great value in the preliminary part of our work (Richey, Stewart & Wager 1946, 1947). At that time it was also realized that marscoite was chilled against the granophyre G_1 and was later than it. Thus Harker's generalization that the time of marscoite emplacement was between the early stage of basic intrusions and the later stage of granitic intrusions was invalid. Richey (1930) had earlier suggested a revision of Harker's sequence of igneous events; in particular, he had suggested that there were three independent centres of activity: the Cuillins, the Western Red Hills and the Eastern Red Hills, probably developed in that order. As the mapping of the different intrusions continued, it became apparent that a Western Red Hills centre undoubtedly existed as a separate entity with a complex history, and that the marscoite and related rocks belonged to it.

The acid rocks vary in texture from granitic and granophyric to felsitic. The microgranites and granophyres are liable to be miarolitic and to have well-shaped felspar and quartz crystals lining the cavities. Pegmatites are not found and aplites only rarely. There is general recognition that these Skye acid rocks are distinctly different from deep-seated granites, such as those of Caledonian age in Scotland, and the habit has grown of calling them all granophyres. The distinguishing features of the Skye granitic rocks which are most general, and probably of most significance, are the miarolitic cavities and the absence of pegmatites, rather than the granophyric texture. In producing these textural characteristics, rate of cooling is only one factor, and probably not the most significant. It seems that, in the case of the Skye granitic rocks, their chief peculiarities are due to crystallization at a high level in the crust, that is, under low hydrostatic pressure. A true gas phase apparently formed, as a result of the low external hydrostatic pressures, when the magma was still only about three-quarters crystallized, and thus were formed the innumerable miarolitic cavities. The conditions for the formation of pegmatites were normally not attained. Tuttle & Keith (1954) and Tuttle & Bowen (1958) have shown that the mineralogy of the

Beinn an Dubhaich granite, belonging to the Broadford centre, shows certain features to be expected in a high level, and thus relatively quickly cooled, intrusion.

The term epigranite* is here proposed as a group name for the high-level type of granite of non-orogenic regions such as Skye and Mull, in order to distinguish it from the deep-seated, non-miarolitic type with associated pegmatites. Although, perhaps, transitional types occur in the British Tertiary province, it is suggested that there is a distinction between these two types which is of sufficient importance to be recognized in the nomenclature, and this cannot reasonably be done by describing the high-level granites simply as granophyres when, in many cases, they show a microgranitic texture.

2. The early epigranites

Mapping in the Western Red Hills has established that, within Harker's area of undivided granophyre, at least five early acid intrusions were emplaced before the various intrusions associated with the marscoite episode (see map, figure 1). The identification of the different epigranites was established by field mapping. The significance of the minor differences becomes apparent only when the observer has visited exposure after exposure and realized that one type exists confined to one area, and another type to another area; eventually it is possible to draw a line where one type abruptly, rather than gradually, gives place to the other. In some cases the differences between the types are slight, and the observer finds himself using differences in texture, particularly those related to the phenocrysts. Other features, such as the common presence of xenoliths, weathering characteristics, etc., have also proved helpful in the field. The mapping is complicated by extensive belts of crushing, often near, or along, the boundaries of the different granites, and this has made it difficult to establish age relations. In the end, however, any one granite usually proves to be surprisingly constant in many of its characteristics although others, such as the abundance of miarolitic cavities, may vary. The several different epigranites distinguished in the field, proved to have mineralogical, textural and chemical differences when examined in the laboratory, but these would not generally have been deemed significant had not the field mapping previously shown this to be the case.

The Western Red Hills epigranites usually have steep outer contacts where they are visible, and their emplacement was presumably by a ring dyke mechanism, involving the sinking of a central block, or by piecemeal stoping. The epigranites cut into the Cuillin gabbro complex and are not intruded by the very abundant cone sheets which characteristically intrude the latter. Harker was aware of this and suggested that the cone sheets penetrated the gabbro more easily than the granitic rocks. Richey (1930) later pointed out the improbability of this explanation and suggested that the period of cone sheet intrusion preceded emplacement of the Western Red Hills complex; this has been made very clear by the mapping of one of us at the northern end of the Blaven range (Bell 1959).

The five different epigranites which preceded the intrusion of marscoite and related rocks in the Western Red Hills complex are grouped together as the early Western Red Hills intrusions. Of these, one of the earlier, if not the earliest, is the *Glamaig Epigranite*, GE (previously called G_1 in Richey, Stewart & Wager 1946, and Wager, Stewart & Kennedy

* 'Epi', a Greek preposition roughly meaning 'upon', is used here in the sense of high level. For the deep-seated granites, the term katagranite might be used (cf. Buddington's conception of catazone granites, 1959).

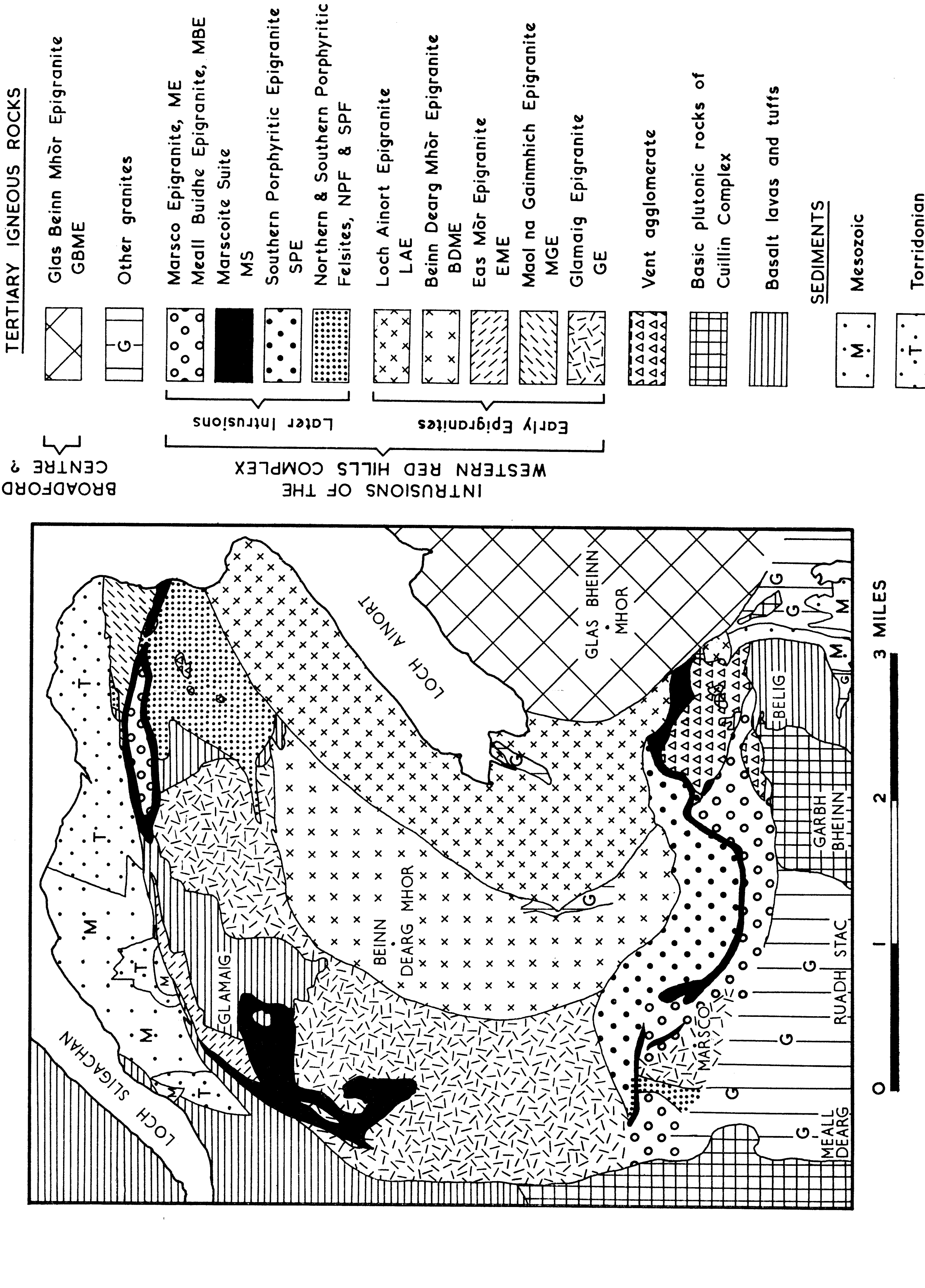


FIGURE 1. Outline geological map of the Western Red Hills Complex, Isle of Skye.

1948), which cuts across, and partly underlies, the basalt on Glamaig (see map, figure 36, p. 307). It is a medium-grained, hornblende- and biotite-bearing rock with miarolitic cavities, and contains about 15% of sodic plagioclase as early crystals surrounded by quartz and potash felspar (figure 4, plate 10). Another of its characteristics is the presence of shadowy dark patches, usually a centimetre or so across, but occasionally larger, probably representing partially digested xenoliths. There is such an even distribution of these patches, presumably the result of some highly effective stirring process, that most areas even if only a few square inches in size show them. The analysis, C.I.P.W. norm and mode of the Glamaig Epigranite are given in table 1.

Table 1. Chemical analyses of the early epigranites

	1	2	3
SiO_2	69·62	74·31	71·68
Al_2O_3	13·91	11·71	12·55
Fe_2O_3	1·18	1·63	2·29
FeO	3·01	1·67	2·40
MgO	0·46	0·04	0·24
CaO	1·73	0·61	0·92
Na_2O	4·27	4·11	4·28
K_2O	4·92	5·22	4·37
$H_2O^{+110°}$	0·53	0·39	0·64
$H_2O^{-110°}$	0·12	0·05	0·25
TiO_2	0·49	0·36	0·38
P_2O_5	0·14	0·03	0·03
MnO	0·03	0·06	0·05
total	100·41	100·19	100·08

C.I.P.W. norms

	1		2		3	
Qz		21·0		29·6		27·4
Or	29·1		30·8		25·8	
Ab	36·1	69·5	31·2	62·0	36·2	64·1
An	4·3		—		2·1	
Ac		—		3·2		—
Di *Wo*	1·4		1·2		0·9	
Di *En*	0·4	2·9	0·1	2·6	0·2	1·9
Di *Fs*	1·1		1·3		0·8	
Hy *En*	0·8	3·5	—	0·9	0·4	1·6
Hy *Fs*	2·7		0·9		1·2	
Mt		1·7		0·8		3·3
Ilm		0·9		0·7		0·7
Ap		0·3		0·1		0·1
water		0·7		0·4		0·9
total		100·5		100·3		100·0

Approximate modes (vol. %)

	1	2	3
Quartz	18·6	28·1	
Plagioclase	14·3	67·3	94·1
Potash felspar	59·3		
Hornblende	3·3	2·4	—
Pyroxene	—	—	2·1
Biotite	2·9	—	—
Chlorite	—	1·5	2·7
Accessories (including iron ore, zircon, etc.)	1·6	0·9	1·1

1, Glamaig Epigranite, H857, from top of waterfall, Allt an Fhuar-choire. (Anal. E. A. Vincent.)
2, Maol na Gainmhich Epigranite, H984, from roadside north of Moll. (Anal. E. A. Vincent.)
3, Beinn Dearg Mhòr Epigranite, H932, from waterworn gully on east face of Beinn Dearg Mhòr, at about 1400 ft. (Anal. E. A. Vincent.)

Another early acid intrusion is the rather coarse, one-felspar rock with alkali amphibole, called the *Maol na Gainmhich Epigranite*, MGE (previously called Coarse Granite) (figure 5, plate 10). So far, its known distribution is confined to the northern part of the complex, but an epigranite on the neighbouring island of Scalpay, only cursorily examined, may prove to be the same. The age of MGE relative to GE is not definitely established but, like GE, it was certainly emplaced before the marscoite suite. The analysed rock (table 1) has 67 % of coarse microperthite, 28 % of quartz, and a few per cent of alkali amphibole (strongly pleochroic, dark greenish blue to yellow). Chlorite is also present and probably some patches of this represent former olivine. Granophyric intergrowth of quartz and felspar has not been found, except in the chilled contact rock.

Yet another early intrusion is the *Eas Mòr Epigranite*, EME (figure 6, plate 10), found on the northern face of Glamaig. Like MGE, this rock contains only microperthitic felspar, but the ferromagnesian mineral is green hornblende, and is fairly abundant. The chilled margin against basalt contains quartz and microperthite phenocrysts in a fine-grained groundmass.

Beinn Dearg Mhòr and associated summits are composed of a pyroxene granite called the *Beinn Dearg Mhòr Epigranite*, BDME (previously called G_2). Near the contact with the BDME the Glamaig Epigranite is much crushed, whereas BDME is less affected. Basic rock seems to have been dragged up along the junction of the two intrusions along the northern contact (see map, figure 36). The difference in degree of crushing is regarded as evidence of the emplacement of BDME after GE.

Another granite, very similar to BDME, forms the lower ground between Beinn Dearg Mhòr and Loch Ainort, and is called the *Loch Ainort Epigranite*, LAE (previously G_2'). Mapping in the southern part of the area suggests that these two granites were emplaced before the marscoite suite and related rocks, and this is assumed in the present account.

Both the Beinn Dearg Mhòr (figure 7, plate 10) and Loch Ainort Epigranites contain phenocrysts of perthite surrounded by a coarse granophyric intergrowth of quartz and potash felspar. The chief ferromagnesian mineral is green hedenbergitic pyroxene while iron-rich olivine, either fresh or replaced by dark brown serpentine, is not rare. Green hornblende occurs, added to, or replacing, the pyroxene crystals in some specimens. Harker noted that, among the plutonic acid rocks, good development of the granophyric texture usually occurred in the pyroxene-bearing types and not in the others having dominant hornblende or biotite. Although there are exceptions, e.g. the Marsco Epigranite, ME, described later, this rule holds generally for Skye. In the BDME, iron-rich olivine was not recorded by Harker, presumably because in miarolitic rocks of this kind weathering is so deep that olivine has been totally replaced in the usual material collected; the old road cuttings have not often provided fresh material but it is to be found in the roadworks now in progress (1963).

3. The Southern Late Intrusions of the Western Red Hills

Following the five epigranites so far considered, there came a group of intrusions, including the marscoite suite, which were emplaced within a narrow time interval; these are distinguished as the late intrusions of the Western Red Hills (figure 1). The first intrusions of the group were certain porphyritic epigranites and felsites; then came the intrusion of the marscoite suite, followed immediately by two other epigranites. A southern group of the later intrusions is here distinguished from a northern group, although they show great similarities and both include marscoite. The age relations between the southern and northern groups are not known but it is convenient to treat the southern group first.

(a) *The Southern Porphyritic Epigranite and Felsite*

A porphyritic epigranite, the first of the southern late intrusions and called the *Southern Porphyritic Epigranite* (SPE), is found on the north and north-east slopes of Marsco and the ground to the east. It cuts across three of the early epigranites in a way that indicates its later age, though actual contacts are poor and badly crushed. The SPE contains quartz and cloudy potash felspar as phenocrysts (figure 8, plate 10) the typical, figured specimen having 7 and 18% by volume, respectively. Around the phenocrysts is a beautifully granophyric base which becomes markedly coarser away from the centres of the granophyric texture. The only ferromagnesian mineral is chlorite, which is associated with the coarse, outer part of the radiating granophyric material where miarolitic cavities tend to occur. Over much of its outcrop on Marsco, the SPE is crushed; in places the rock has been shattered, giving angular blocks of uncrushed granite surrounded by finely comminuted material, while in other places pulverized material is in the form of mylonite veins. No material other than that from the granite itself has been found in the crushed rocks. The rock types produced resemble the classic crush breccias of Parys Mountain, Orange Free State. They are probably the result of explosions, due to high water vapour pressure developed during the later stages of solidification of part of the magma (see p. 281–2).

A porphyritic felsite is found widely, injecting the SPE; it can be well seen forming a strip adjacent to the marscoite intrusion on the northern side of Harker's Gully on Marsco (see figure 2, plate 10, figure 11, plate 11, and figure 10). A similar, but not identical porphyritic felsite crosses the western face of Marsco below the Glamaig Epigranite of the summit (figure 2). The *Southern Porphyritic Felsite* (SPF) is not chilled against the SPE and is believed to have been injected into the latter after it had been crushed, but while it was still hot.

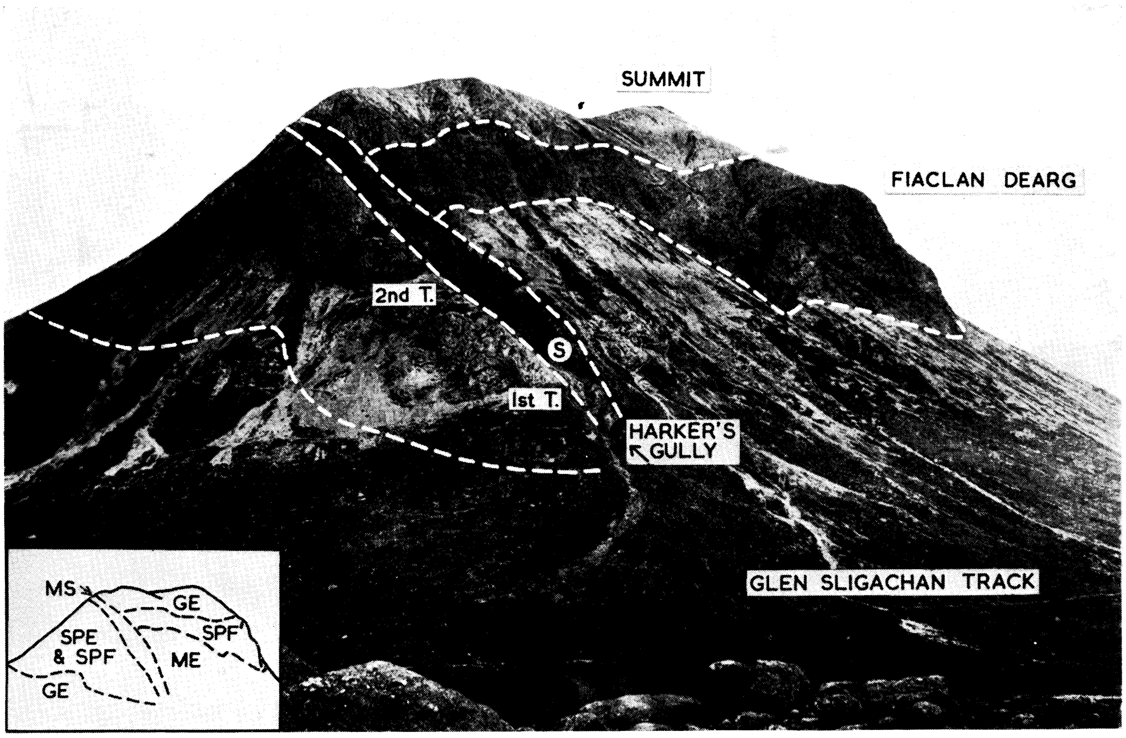
The SPF contains quartz and potash felspar phenocrysts, similar to those of the SPE, around which is a felsitic or microgranitic base (figure 9, plate 10). The analysed rock from Harker's Gully at the level of the First Terrace (see figure 2) contains about 10% of

---

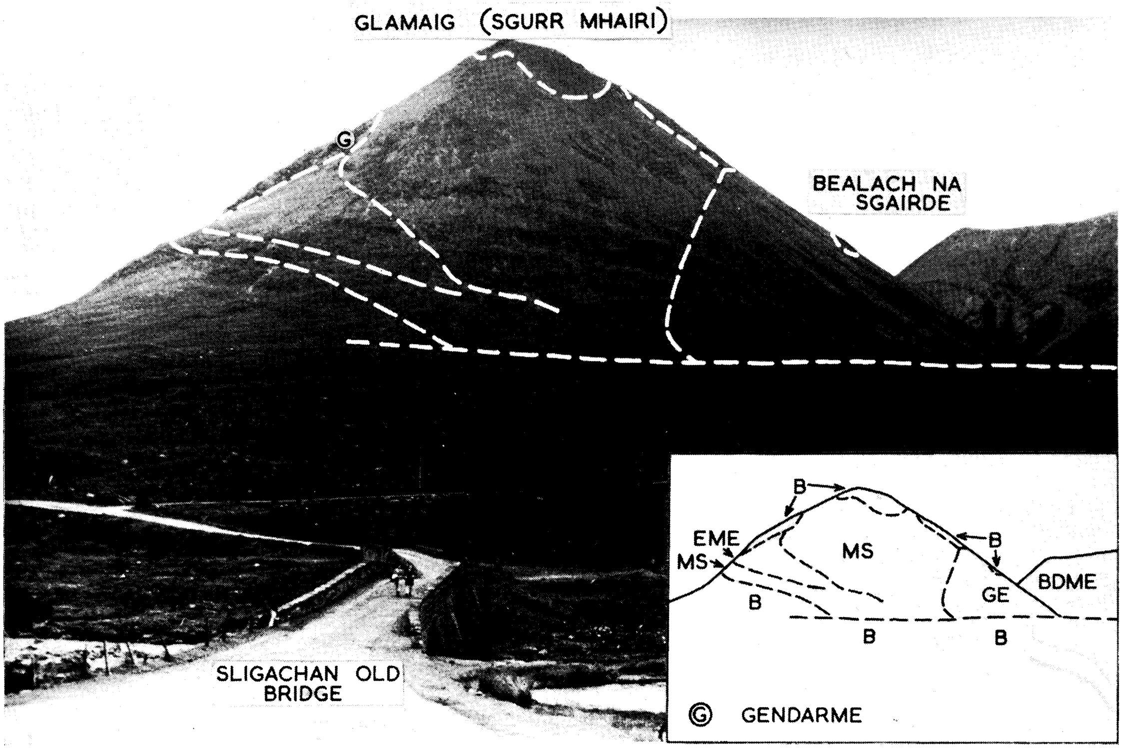
Description of plate 9

Figure 2. Marsco, from the north-west, showing the distribution of the main rock units (photograph from Harker 1904, plate VIII). GE, Glamaig Epigranite; on the north-west flanks, crushed in places; on the summit, mainly uncrushed with some other more basic rocks; SPE, Southern Porphyritic Epigranite and SPF, Southern Porphyritic Felsite (much crushed in places). SPF′, Special type of Porphyritic Felsite, uncrushed. MS, Marscoite Suite of Harker's Gully, marscoite and ferrodiorite; ME, Marsco Epigranite; S, Shelter Stone; 1st T, 2nd T: First Terrace and Second Terrace.

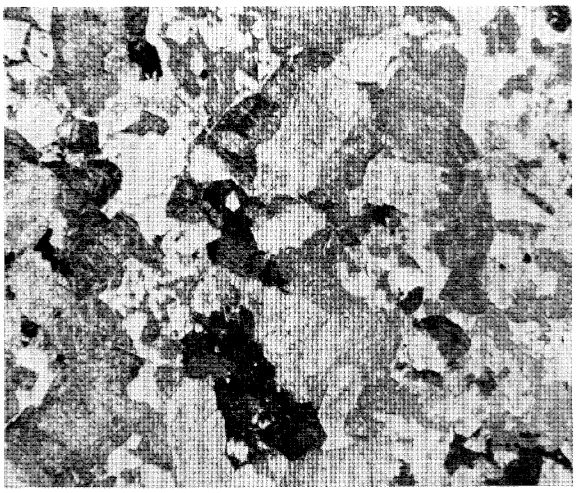
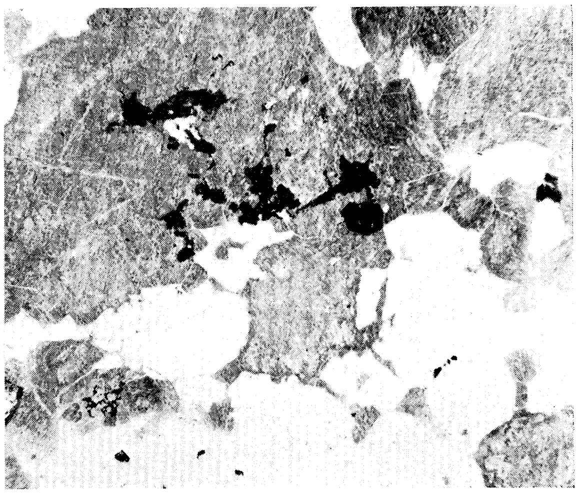
Figure 3. Glamaig, from the west, showing the distribution of the main rock units. GE, Glamaig Epigranite; EME, Eas Mòr Epigranite; BDME, Beinn Dearg Mhòr Epigranite; MS, Marscoite Suite—marscoite, glamaigite, and dioritic glamaigite; B, Basalt.

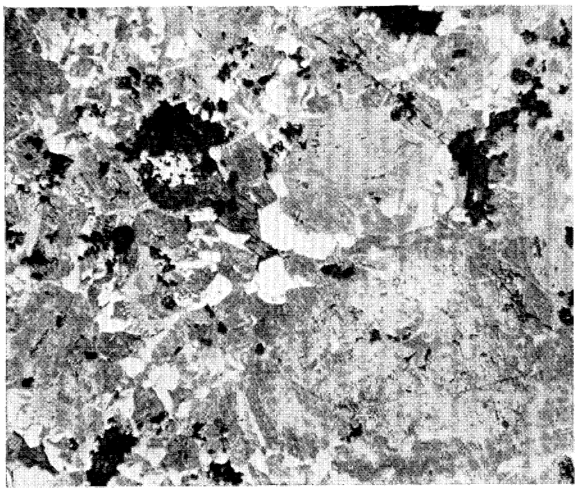
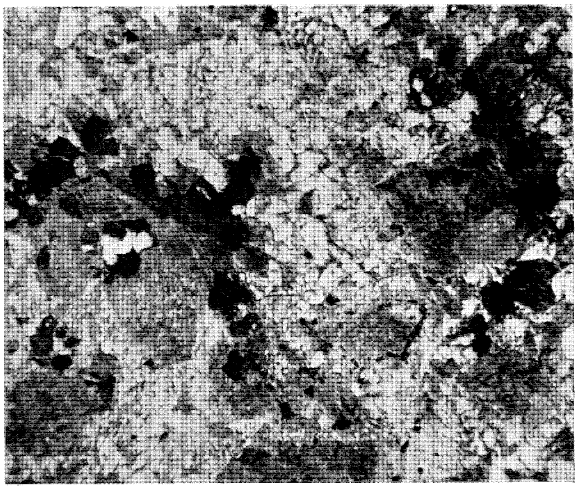

SUMMIT
FIACLAN DEARG
2nd T.
S
Ist T.
HARKER'S GULLY
GLEN SLIGACHAN TRACK
MS
GE
SPE & SPF
SPF
ME
GE

2

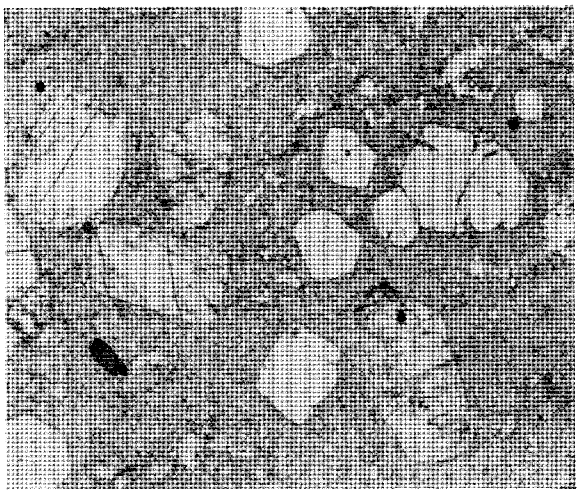

GLAMAIG (SGURR MHAIRI)
G
BEALACH NA SGAIRDE
SLIGACHAN OLD BRIDGE
B
EME
MS
MS
B
GE
BDME
B
B
B
B
G GENDARME

3

4


5

6


7

8


9

well-shaped potash felspar* phenocrysts with $2V$ varying from 60 to 70°, 4% of quartz phenocrysts, which retain the bipyramidal habit of the original high-temperature form, and occasional green pyroxene and ore phenocrysts. These are set in a mainly felsitic groundmass.

The close similarity in the size and form of the quartz and felspar phenocrysts in SPE and SPF indicates that both rocks were derived from essentially the same magma, the former, however, being rich in water as evidenced by the miarolitic cavities, and the latter probably relatively dry. Perhaps the felsite, which was emplaced just after the shattering

---

Description of plate 10

Figure 4. Glamaig Epigranite, H857, from top of waterfall, Allt an Fhuar-choire (analysed). Just above the centre of the photomicrograph is an early formed, clear plagioclase rimmed with turbid potash felspar; several others occur in other parts of the photomicrograph. The ferromagnesian minerals occur typically in clusters and are hornblende (lighter in shade), and biotite (darker). Some opaque minerals are also present. The groundmass quartz and felspar show some degree of micropegmatitic intergrowth. (Magn. × 9.)

Figure 5. Maol na Gainmhich Epigranite, H984, from roadside north of Moll (analysed). Turbid potash felspar, large patches of quartz containing dusty inclusions, and iron ore and dark sodic amphibole are present. About one-quarter of the black mineral in the photomicrograph is opaque oxide and the rest is amphibole. (Magn. × 9.)

Figure 6. Eas Mòr Epigranite, H960, 30 ft. upstream from Eas Mòr on northern slopes of Glamaig. A large potash felspar phenocryst occupies most of the lower right-hand quarter of the photomicrograph. Above the phenocryst, to right and left, are clusters of chlorite and opaque minerals, and crystals of hornblende. Outside the larger potash felspar crystals there is micropegmatite. (Magn. × 9.)

Figure 7. Beinn Dearg Mhòr Epigranite, H932, from waterworn gully on south-east face of Beinn Dearg Mhòr, at about 1400 ft. (analysed). Turbid phenocrysts of potash felspar, fringed with micropegmatitic intergrowth of quartz and felspar, which becomes coarser away from the phenocrysts. Rounded serpentine pseudomorphs after iron-rich olivine, and crystals of hedenbergitic pyroxene (prism and basal sections), and opaque minerals are also present. (Magn. × 9.)

Figure 8. Southern Porphyritic Epigranite, H707, from northern slopes of Marsco. The phenocrysts are of embayed quartz and turbid, subhedral potash felspar rimmed with a fringe of granophyric intergrowth of quartz and felspar. The granophyric groundmass increases in coarseness away from the centres of the granophyric texture. Small amounts of opaque minerals and chlorite are the only dark minerals present. (Magn. × 9.)

Figure 9. Southern Porphyritic Felsite, H868, from the northern side of Harker's Gully, Marsco, at the First Terrace level (analysed). The phenocrysts are the same size and shape as in the Southern Porphyritic Epigranite (figure 8) but appear more distinct when set in the finer grained, generally felsitic groundmass. Small phenocrysts of hedenbergite pyroxene (bottom left) and an opaque mineral are sparingly present. (Magn. × 9.)

* The term potash felspar is used in this paper as a general term describing those felspars which are not plagioclase. In the case of SPE, chemical analyses and optical measurements ($2V$) carried out by one of us (Bell 1959) show the majority of the felspar phenocrysts to be perthites or cryptoperthites lying between the low sanidine–anorthoclase and orthoclase–low albite series as defined by Tuttle (1952), with *Or* in excess of *Ab*. Similar detailed measurements have not yet been performed on the alkali felspars of the other epigranites and, although some may turn out to have more sodium than potassium, they are described under the overall term potash felspar.

of the epigranite, represents a portion of magma from which the volatile constituents were able to stream off after the explosive shattering of the roof. The analysis of SPF from Harker's Gully (table 2) shows that the rock is the richest in silica and poorest in iron and magnesium of all the Skye acid rocks so far analysed. The normative anorthite content is only 1·2 %, which is lower than that for all the other Skye acid rocks so far analysed except MGE.

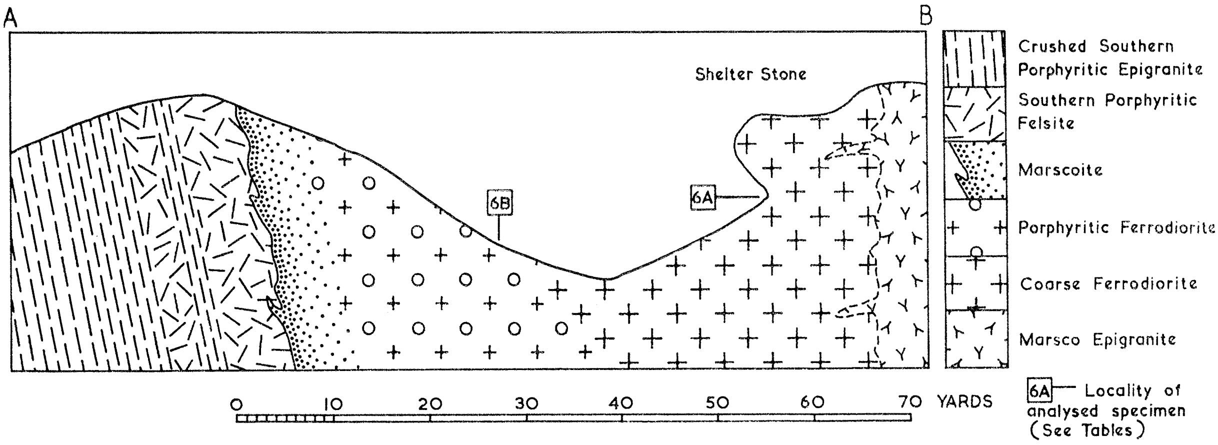


FIGURE 10. Diagrammatic cross-section of Harker's Gully, Marsco, at Shelter Stone level. (For position see figure 11, plate 11).

(b) *The marscoite and ferrodiorite of the southern area*

(i) *Field relations*

The most accessible locality for study of the southern marscoite suite is the gully at the north-west corner of Marsco, which has been called, for some time now, Harker's Gully (see Wager *et al.* 1948, pp. 10–11). The disposition of the rocks is indicated on the photograph of the mountain from the north-west (figure 2), the photograph of the gully (figure 11, plate 11) and the diagrammatic section across the gully (figure 10); the latter should be compared with Harker's section (1904, figure 35).

In Harker's Gully the marscoite suite forms a thin, steeply inclined, complex sheet, dipping away from the centre of the Western Red Hills complex at a high angle. Other similar sheets on Marsco have the same general disposition, so that they are regarded as being of ring dyke form, resulting from slight downward movement of the central part of the Western Red Hills complex, relative to the peripheral. From the First Terrace to the Second Terrace and beyond (see figure 11, plate 11, and figure 2, plate 9), typical marscoite may be seen somewhat chilled against SPF on its northern side, and yet in places the marscoite has apparently pushed into the still viscous SPF (figure 13, plate 11). This is particularly well seen at the lowest exposure in the gully and on the Second Terrace level. The final consolidation of the SPF, however, was later than that of the marscoite as thin veins of SPF are found extending a yard or so into the marscoite.

The typical chilled marscoite (figure 12, plate 11), with its characteristic plagioclase, quartz, and potash felspar xenocrysts, and fine-grained base, persists for a few yards from the junction with the SPF and then passes gradually into a more quickly weathering rock containing scarce, large crystals of plagioclase, but no potash felspar or quartz xenocrysts (figure 14, plate 11). This porphyritic rock passes into a slightly coarser and uniform-

TABLE 2. CHEMICAL ANALYSES OF MARSCOITE AND RELATED ROCKS OF THE SOUTHERN LATE INTRUSIONS OF THE WESTERN RED HILLS COMPLEX

	4	5	6A	6B	7
SiO_2	76·41	60·07	54·18	53·43	71·14
Al_2O_3	11·71	14·22	13·74	13·88	12·82
Fe_2O_3	1·68	3·71	1·88	3·27	1·17
FeO	0·77	6·65	10·79	10·32	3·48
MgO	0·17	1·39	2·42	2·56	0·29
CaO	0·42	4·35	6·34	6·45	1·36
Na_2O	3·62	4·02	3·46	3·69	4·24
K_2O	4·92	2·75	1·85	1·84	4·19
$H_2O^{+110°}$	0·50	0·67	1·40	0·93	0·57
$H_2O^{-110°}$	0·12	0·06	0·26	0·38	0·13
TiO_2	0·14	1·53	1·97	2·25	0·44
P_2O_5	0·04	0·60	1·30	1·10	0·09
MnO	0·002	0·26	0·30	0·32	0·02
total	100·50	100·28	99·89	100·42	99·94

C.I.P.W. norms

	4		5		6A		6B		7	
Qz		35·6		14·3		7·8		6·3		25·7
Or	29·1		16·3		10·9		10·9		24·8	
Ab	30·6	60·9	34·0	62·9	29·3	56·7	31·2	58·0	35·9	64·3
An	1·2		12·6		16·5		15·9		3·6	
Di *Wo*	0·3		2·1		2·7		3·8		1·1	
Di *En*	0·2	0·5	0·7	4·3	0·8	5·5	1·3	7·7	0·2	2·3
Di *Fs*	—		1·5		2·0		2·6		1·0	
Hy *En*	0·2	0·2	2·8	8·5	5·2	18·7	5·1	15·6	0·6	4·3
Hy *Fs*	—		5·7		13·5		10·5		3·7	
Mt		2·1		5·4		2·7		4·7		1·7
Hm		0·3		—		—		—		—
Ilm		0·3		2·9		3·8		4·3		0·8
Ap		0·1		1·3		3·1		2·6		0·2
water		0·6		0·7		1·7		1·3		0·7
total		100·6		100·3		100·0		100·5		100·0

Approximate modes (vol. %)

	4	5
Phenocrysts or Xenocrysts: Plagioclase	—	4·9
Potash felspar	9·7	3·0
Quartz	4·1	1·2
Pyroxene	0·1	0·3
Groundmass	86·2	90·6

	6A	6B	7
Felspar	53	50·6	65·2
Quartz	8	8	25·7
Ortho-pyroxene	11	12	—
Clino-pyroxene	8	9	1
Opaque oxide	4·5	6·2	1
Apatite	2·5	present	—
Olivine	1	—	0·4
Hornblende	12 (Hornblende + Biotite + Chlorite)	9·3	6·7 (Hornblende + Biotite + Chlorite)
Biotite		3·5	
Chlorite		1·4	

4, Southern Porphyritic Felsite, H868, North side of Harker's Gully, Marsco, at First Terrace level. (Anal. E. A. Vincent.)

5, Marscoite, H871, 10 in. from contact with SPF, north side of Harker's Gully, Marsco, at First Terrace level. (Anal. E. A. Vincent.)

6A, Ferrodiorite, H344, from Shelter Stone, Harker's Gully, Marsco. (Anal. E. A. Vincent.)

6B, Porphyritic Ferrodiorite, H870, 30 yd. north of Shelter Stone, Harker's Gully, Marsco. (Anal. E. A. Vincent and B. A. Collett.)

7, Marsco Epigranite, H817, from lowest continuous exposure in stream south of Harker's Gully, Marsco, 200 ft. below First Terrace level. (Anal. E. A. Vincent.)

textured ferrodiorite already described (Wager & Vincent 1962). The type ferrodiorite (figure 15, plate 12) was collected at the Shelter Stone (figure 2, plate 9) between the First and Second Terrace levels. The chilled marscoite tends to have fractures, now healed, inclined at a considerable angle to the margin, and these may be seen in the field and also in thin section (figure 12, plate 11). The porphyritic marscoite, on surfaces exposed in the stream, sometimes shows slight banding parallel to the walls of the intrusion. The porphyritic ferrodiorite shows striking spheroidal weathering, the kernels of fresh rock being extremely tough; the non-porphyritic ferrodiorite of the Shelter Stone weathers more slowly and into larger, rounded blocks.

On the south side of Harker's Gully the ferrodiorite gives place to the Marsco Epigranite (ME) in a transition zone about a yard wide. There is no chilling and the time sequence is not obvious. However, rare, unchilled veins from ME cut some way into the ferrodiorite. At the present stage of our investigations, these are not considered to be the result of rheomorphism but to be ordinary veins of ME injecting the ferrodiorite and implying later emplacement of the epigranite at a time when the ferrodiorite was still hot. Such an explanation makes the mechanism of intrusion of ME difficult to envisage, and when the other occurrences of the marscoite suite of Marsco have been examined in detail the suggested time sequence may require modification.

A long, curving tail of the marscoite suite of rocks extends eastwards from Marsco as far as the col between Glas Bheinn Mhòr and Belig (see figure 1). Particularly good exposures are found in a gully on the east side of Druim Eadar Da' Choire, in the deep gorge of Eas a' Chail and in Allt a' Mheadhoin. Here, as on Marsco, the marscoite suite is bordered on the north by SPE or SPF, and on the south by ME, except in Coire Choinnich, where the vent agglomerate of Belig is found to the south and the Loch Ainort Epigranite to the north, showing that both predate the marscoite suite. The Glas Bheinn Mhòr Epigranite cuts off the marscoite suite of rocks and is considered to belong to the later, Eastern Red Hills Complex.

(ii) *Petrology*

The analysed specimen of marscoite from Harker's Gully on Marsco (H871)*, was collected 10 in. from the SPF at the Second Terrace in Harker's Gully; it is rather fine-grained but otherwise is typical; it is illustrated in figure 12, plate 11, and will be described in detail. Xenocrysts† of andesine, potash felspar, and quartz are present and tend to be bounded by crystal faces, especially in the case of andesine. The proportion by volume of the observed xenocrysts is as follows: plagioclase 4·9 %, potash felspar 3·0 %, quartz 1·2 %, pyroxene 0·3 %, iron ore 0·05 %. The plagioclase xenocrysts, often glomeroporphyritic, have a composition of about An_{50} and are virtually unzoned except for a narrow, more sodic margin. The potash felspar xenocrysts show a fringe of intergrowth of two felspars due, apparently, to exsolution, while the centres are optically homogeneous. The limited corrosion of the

* All such numbers refer to the collection of Hebridean rocks in the Department of Geology and Mineralogy at Oxford.

† The term xenocryst normally refers to crystals which are foreign to, and generally not in equilibrium with, the groundmass or magma in which they are found. In the case of marscoite, as will be shown later (p. 288), the xenocrysts are not to be considered entirely foreign but yet they are not in equilibrium with the magma because the latter is a new liquid, produced by mixing.

quartz and microperthite contrasts with the state of these minerals in the marscoite of the northern intrusions (p. 296). The groundmass, about 90% by volume, consists of plagioclase, quartz and potash felspar, with greenish-brown hornblende and ore, but no pyroxene. The composition of the rock is given in table 2.

The ferrodiorites of Harker's Gully vary slightly, but significantly. A variety with porphyritic andesine occurs in the centre of the gully at the Shelter Stone level, and this passes into a coarser type without phenocrysts which forms the Shelter Stone and thence extends to the southern margin with ME. This arrangement of types persists for the whole length of Harker's Gully and is, in general, the relationship found on the north-east face of Marsco.

Since the ferrodiorites have already been described (Wager & Vincent 1962), only a summary of their petrology need be given here. The Shelter Stone rock (figure 15, plate 4) is taken as the type example of the non-porphyritic ferrodiorite. Its composition and mode are given in table 2. The plagioclase, average length 1·5 mm, has large cores of An_{49} with strong marginal zoning leading to about An_{30}; the potash felspar beyond this is untwinned and turbid. The central part of the plagioclase was, no doubt, one of the earlier minerals to crystallize. Quartz occurs with interstitial habit. Apatite is strikingly abundant in small, euhedral, prismatic crystals. Orthopyroxene is of two kinds: one contains exsolution lamellae indicative of formation by inversion of pigeonite, and the other, free from this type of exsolution, was presumably directly precipitated from the magma. The optics of both indicate a composition close to En_{31}. Augite, pinkish-brown in colour, occurs in clusters of zoned crystals. Olivine, although in only small amounts, was an early mineral to crystallize. It is pale yellow in colour and its $2V$ is 59°, indicating a ferrohortonolite, Fo_{22}. It has been altered considerably to a dark-brown serpentine. In polished section, about three-quarters of the iron oxide material is seen to be ilmenite, generally in euhedral crystals, and one-quarter titaniferous magnetite, showing very fine-scale exsolution networks of ulvöspinel and occasional lamellae of ilmenite. Pyrrhotite, in globular form, is a noteworthy accessory and is frequently partly or completely altered to marcasite.

The second analysed ferrodiorite, H870, collected 30 yd. north of the Shelter Stone, is similar to H344 but is more easily weathered and has rather large, scattered, porphyritic plagioclase crystals (figure 14, plate 11), while the rest of the rock is slightly finer-grained.

Enclosed in the ferrodiorites, particularly the porphyritic types, are raft-like masses of coarse andesinite measuring a few inches to a few feet in length. Rather similar but smaller masses also occur in the neighbouring marscoite. The andesinite has the appearance of being the result of an accumulation of plagioclase crystals similar to the larger crystals of the porphyritic ferrodiorite. The andesinites occur as blocks with sharp margins towards the enclosing ferrodiorite and they must be regarded as cognate xenoliths rather than aggregations of crystals formed in the position in which they now occur.

Chemically, both the porphyritic and non-porphyritic ferrodiorites from Marsco are very similar (table 2). The main difference lies in the state of oxidation of the iron. The An_{49} composition of the extensive plagioclase cores is sufficiently different from the plagioclase molecular ratio of the norm, An_{35}, to indicate that the rims and outer alkali felspar must be poor in lime. The iron-rich nature of the ferromagnesian minerals is reflected in the high value for $Fe^{2+} \times 100 \div (Fe^{2+} + Mg)$, which is 72. The reduced state of the rock is indicated by the high value of $Fe^{2+} \times 100 \div (Fe^{2+} + Fe^{3+})$, which is 86. The high ferrous iron and phosphorus, and low magnesium values are all characteristic of ferrodiorites. It has been suggested (Wager & Vincent 1962) that the ferrodiorites of the southern marscoite suite represent a residual liquid produced by considerable fractionation of a rather reduced basic magma. The rocks formed from this magma bear resemblances both to the Skaergaard ferrodiorites and to the Hebridean mugearites (but see footnote, p. 304).

(*c*) *The Marsco Epigranite* (*ME*)

Immediately succeeding the marscoite suite on Marsco, the non-porphyritic *Marsco Epigranite* (ME) (previously called G_4) was intruded, as described above (p. 284). This granite type occurs extensively on Marsco and extends eastwards as far as Belig. The spatial relations of ME to the marscoite suite should become clearer when work now in progress, by Mr R. N. Thompson, is completed.

The type Marsco Epigranite, which has been analysed (table 2), was collected on the

---

Description of plate 11

Figure 11. Harker's Gully, Marsco, photographed from just below the First Terrace level, looking east. The Shelter Stone is to the right of the middle of the photograph and to the right (south) of this is the contact of the ferrodiorites with Marsco Epigranite (see figure 10). The deep part of the gully, left of the Shelter Stone, is cut into ferrodiorites which become porphyritic, and weather spheroidally, further to the north. The northern grassy slope of the gully shows knobbly exposures of porphyritic ferrodiorite and marscoite. The sharp line marking off this grassy area from the slabs of light-coloured rock further north is the contact with SPF and crushed SPE. Higher up the gully may be seen the 'Upper Amphitheatre' and above and to the left the marscoite and ferrodiorite cut the skyline.

Figure 12. Marscoite, H871, 10 in. from contact with SPF on northern side of Harker's Gully, Marsco, at the Second Terrace level (analysed). A cluster of well-shaped andesine xenocrysts is seen on the left of the photomicrograph. Near the lower right corner are grey-looking potash felspar xenocrysts showing the effects of corrosion. Two clear and somewhat rounded quartz xenocrysts are seen above and to the left of the two potash felspars. The groundmass consists of quartz, felspar, hornblende and apatite, and is notably coarser in the interstices of the andesine crystals. Dark shear lines, marked by clustering of hornblende grains, run diagonally from bottom left to top right of the picture and continue through the andesine crystals as dusty lines. (The more prominent dark line running across these shears is a crack in the slice.) (Magn. × 9.)

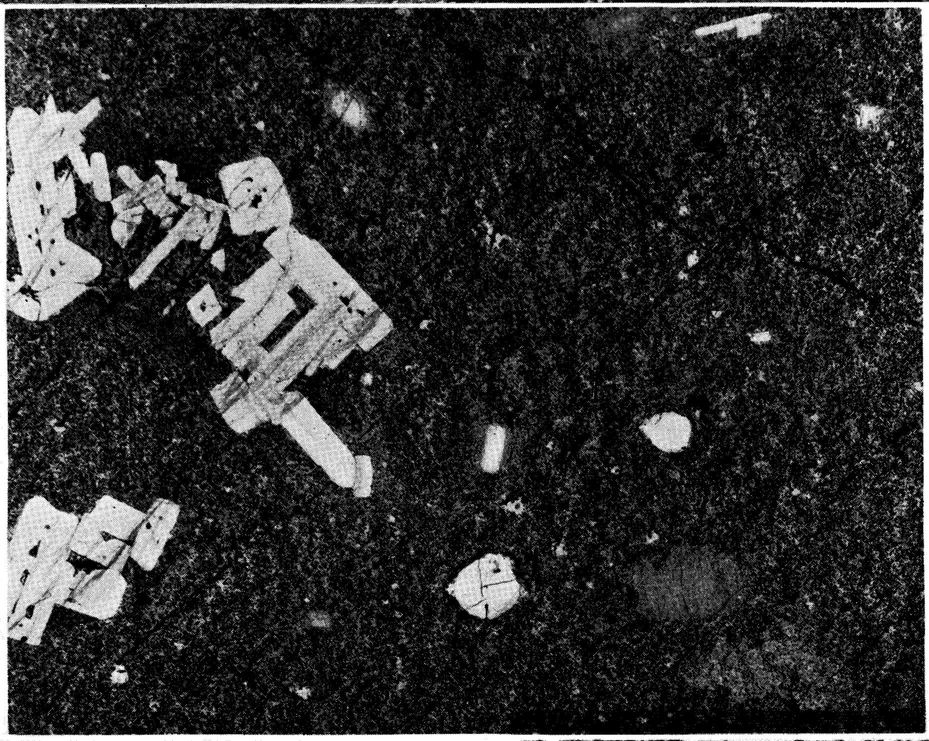
Figure 13. Polished hand-specimen, H177, of the contact of marscoite and SPF from northern side of Harker's Gully, Marsco, at the Second Terrace level. Dark, fine-grained marscoite containing xenocrysts of andesine (faint prismatic crystals), potash felspar (white crystals) and rounded quartz is seen penetrating the lighter porphyritic felsite. The marscoite has the appearance of having been pushed into SPF while the latter was still a viscous liquid. (The grey patch at the bottom left-hand corner is an unpolished, inclined surface of marscoite.) ($\frac{3}{4}$ × natural size.)

Figure 14. Porphyritic ferrodiorite, H870, approximately 25 yd. from the contact with SPF and 30 yd. north of Shelter Stone, Harker's Gully, Marsco (analysed). The phenocrysts on the left are andesine, zoned only at the margins. The ferromagnesian minerals are orthopyroxene, small grains of clinopyroxene, hornblende (the uniform dark areas), ilmenite and magnetite. A considerable amount of quartz occurs with the felspar of the groundmass. Needles of apatite are abundant in the rock but too small to be seen in the photomicrograph. (Magn. × 9.)

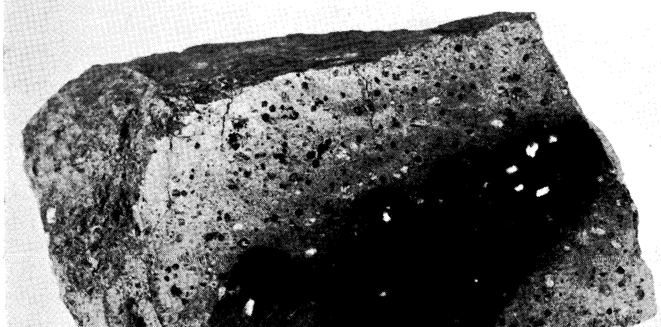
A B

11

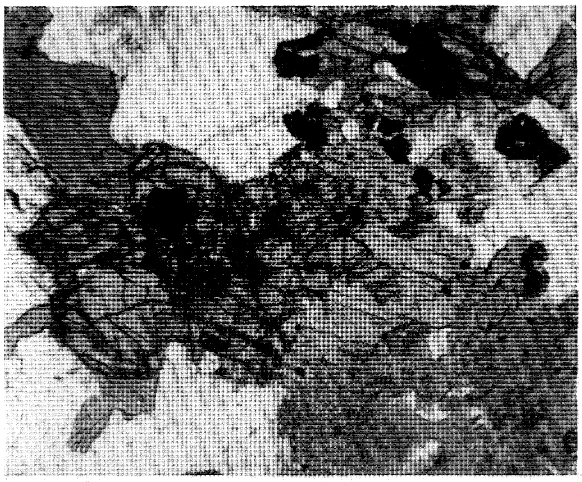
12

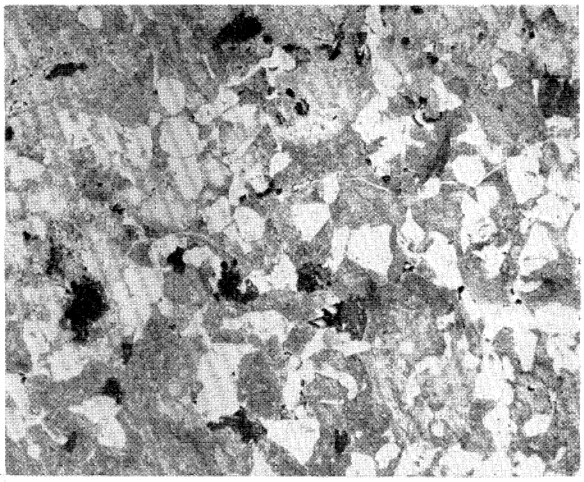


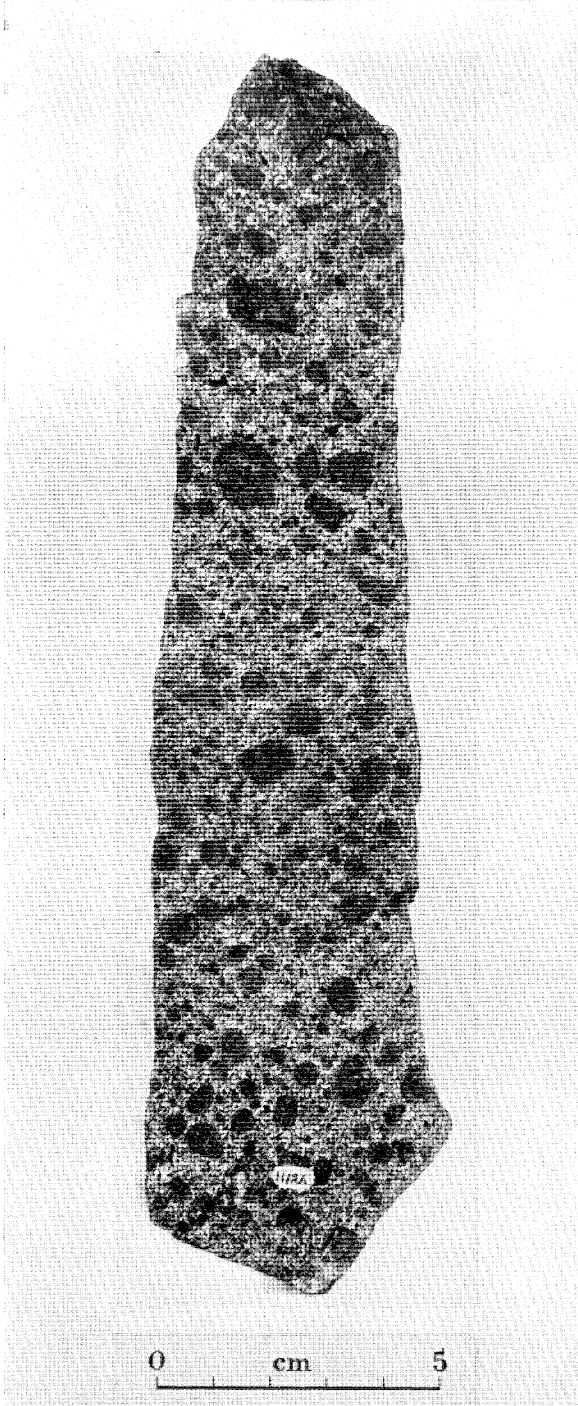
13

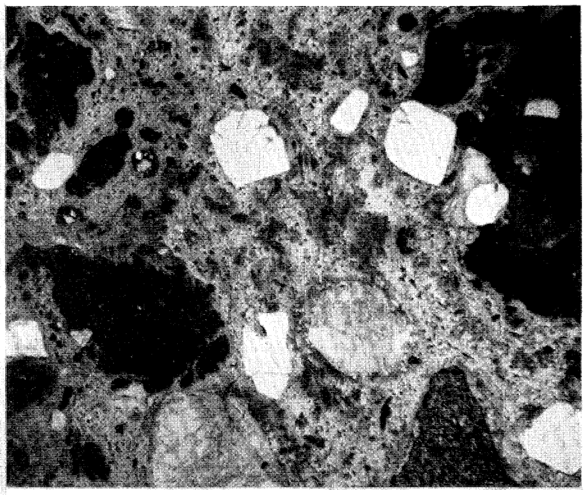


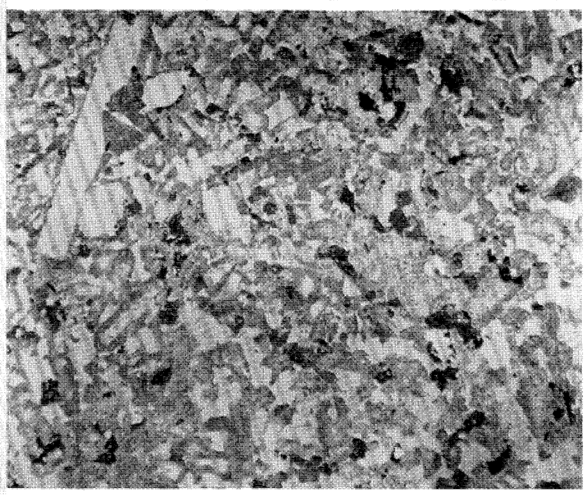
14

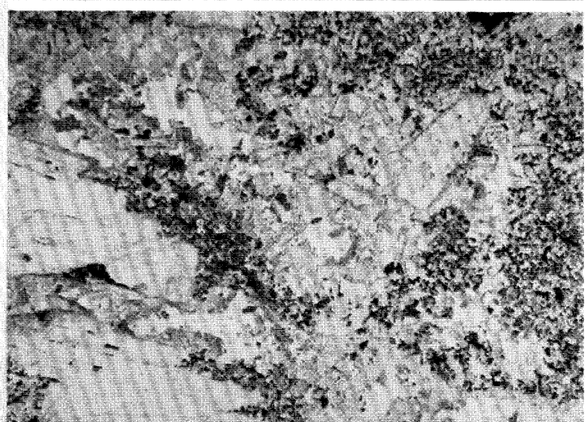
15


16


17


18


19


20


Description of plate 12

Figure 15. Coarse ferrodiorite, H 344. At Shelter Stone, Second Terrace level, Harker's Gully, Marsco (analysed). An irregular-shaped, iron-rich olivine crystal occupies the centre of the photomicrograph. To the right and extending upwards is an orthopyroxene crystal, part of which is inverted pigeonite. Clinopyroxene crystals are attached to the bottom left-hand edge of the olivine and also form a cluster round a hornblende crystal in the bottom right corner of the photomicrograph. Hornblende is also seen in the top left corner. Opaque minerals are fairly abundant. The leucocratic minerals are plagioclase, quartz (cuspate grain in the clinopyroxene cluster) and apatite (needle in plagioclase crystal above the olivine, and hexagonal basal sections in various places). The photomicrograph represents a more melanocratic part of the section than the average. A more extensive area is covered by the photograph in the earlier paper (Wager & Vincent 1962, figure 2). (Magn. × 34.)

Figure 16. Marsco Epigranite, H 817, from lowest continuous exposure in stream south of Harker's Gully, Marsco, about 200 ft. below First Terrace level (analysed). The bulk of the rock consists of quartz and a turbid potash felspar. The inner parts of some areas of felspar are less turbid and these are of plagioclase mantled by the potash felspar. The mafic minerals are hedenbergitic pyroxene (light-grey crystal, in middle of left side of photomicrograph), fayalitic olivine often serpentinized (below clinopyroxene mentioned above), hornblende, occasional biotite, and opaque minerals. (Magn. × 9.)

Figure 17. Weathered block of Glamaigite, H 121, from scree at about 1700 ft. and W.N.W. of Glamaig summit. This specimen shows how weathering emphasizes the heterogeneous texture of glamaigite. White plagioclase xenocrysts can be seen in the leucocratic area in the lower left corner of the specimen. Much of the scree on the west face of Glamaig is composed of this kind of material. ($\frac{3}{4}$ × natural size).

Figure 18. Inhomogeneous xenolithic hybrid, H 851, from west face of Sròn a' Bhealain, approximately west of the summit. The dark fine-grained patches are considered to be the basic parent of marscoite already modified by the acid magma; a small crystal of andesine is to be seen in the patch at the top right corner of the photomicrograph and larger examples are seen in other patches. The lighter rock is porphyritic felsite containing the characteristic phenocrysts of embayed quartz and somewhat turbid potash felspar rimmed by a fine granophyric intergrowth. Some mixing has produced the material seen on the left-hand side of the photomicrograph. Near the bottom right corner, part of a medium-grained basic xenolith, such as is found in the Northern Porphyritic Felsite, is seen. This specimen is believed to show an arrested stage in the production of marscoite. (Magn. × 9.)

Figure 19. Meall Buidhe Epigranite, H 4351, Allt a Bhealaich Bhric (analysed). At the top left of the photomicrograph is a large plagioclase phenocryst, rimmed by potash felspar and penetrated by a crystal of clinopyroxene itself partly replaced by amphibole. Other plagioclases mantled by potash felspar are to be seen. The bulk of the rock consists of quartz and turbid potash felspar. Amphibole is the predominant ferromagnesian mineral. (Magn. × 9.)

Figure 20. Contemporaneous leucocratic vein cutting glamaigite, H 4547, from west face of Sròn a' Bhealain. The vein runs from bottom right to middle left, and cuts through a cluster of andesine xenocrysts. It is composed of clear quartz and turbid potash felspar, the former being concentrated in the central parts of the vein. Hornblende crystals and patches of very fine granophyric intergrowth of quartz and potash felspar are also present. The central leucocratic area of the photomicrograph is not part of the vein but is the usual leucocratic material of glamaigite; the darker patches of the glamaigite occupy about one-third of the area shown. Two large andesine xenocrysts are to be seen towards the bottom left of the photomicrograph. (Magn. × 9.)

face of Marsco south of Harker's Gully, about 200 ft. below the First Terrace level. The rock (figure 16, plate 12) is typically non-porphyritic and miarolitic. There is a little sodic plagioclase mantled by potash felspar, and this is surrounded by abundant potash felspar and quartz. The dark minerals are light green, hedenbergitic pyroxene, hornblende, biotite, iron ore, and iron-rich olivine (either fresh or pseudomorphed by serpentine). The texture of the groundmass is predominantly micro-granitic, but some micropegmatitic intergrowth also occurs.

(*d*) *The suggested origin of marscoite*

As Harker pointed out in the Skye Memoir (1904, chap. XI), orthoclase and quartz phenocrysts would not be expected to have crystallized from a magma of the composition indicated by the groundmass minerals of marscoite, nor would they have crystallized in equilibrium with the calcic plagioclase phenocrysts. Harker (p. 186) called the plagioclase phenocrysts 'medium labradorite'. We have found them to be less anorthite-rich than this, averaging An_{50}, but Harker's argument is still valid. Harker also pointed out that the rounding of both the quartz and 'orthoclase' phenocrysts, and the reaction rims of augite round the quartz (a prominent feature of the northern marscoites), indicate that the quartz and 'orthoclase' were not in equilibrium with the magma surrounding them, but were reacting with it. The conclusion was reached, therefore, that marscoite was a hybrid rock representing 'an originally basic magma modified by the inclusion of granitic material' (Harker 1904, p. 192). Harker was never explicit as to whether the marscoite was the result of the mixing of two magmas or whether it was the result of a basic magma becoming acidified by the incorporation of fragments of a solid acid rock. We believe that an origin by mechanical mixing of two liquids, each of which contained phenocrysts, is clearly indicated by the evidence now available. It is suggested that an intermediate magma, containing andesine phenocrysts, and an acid magma, containing potash felspar and quartz phenocrysts, were the parents of marscoite. The quartz and potash felspar phenocrysts were, presumably, in the acid magma in approximately the ratio of 2·5:1, as now found in the marscoite. The proportions of these to the andesine crystals would be dependent on the amount of phenocrysts in the two magmas and the proportions in which these magmas were mixed. The mixing, to produce the uniform distribution of the phenocrysts, must have been a vigorous mechanical stirring. Stirring would also produce a mixing of the liquid parts of the parent magmas, but homogenization to produce the apparently almost uniform groundmass would also have been aided, but to an unknown extent, by diffusion.

In considering whether any of the rocks at present exposed might represent samples of the parent magmas, it is at once evident that the Southern Porphyritic Felsite fits the requirements for the acid parent since it contains the right kind of phenocrysts in the right proportions. Moreover, the field evidence (p. 282 and figure 13, plate 11), indicating that some material of this kind was still not completely solidified at the time of the injection of the marscoite, suggests that SPF magma was available at the postulated time of formation of the marscoite. The intermediate parent, with andesine phenocrysts, has not been so readily identified. Harker's account does not make it clear what material he envisaged as this more basic parent, but he appears to have considered that a residuum of the Cuillin basic magma was involved (Harker 1904, p. 193). The latter hypothesis is not likely to be correct because the marscoite belongs to the Western Red Hills centre, the time of development of which is separated from the activity at the Cuillin centre by at least the time required for the cooling of the Cuillin gabbros and the injection of the cone sheets and most of the N.N.W.–S.S.E. dyke swarm. When it was realized, during the present investigation, that the ferrodiorite was a rock type of the marscoite suite, and when its mineralogy and chemistry were investigated, it became clear that ferrodiorite magma, particularly the porphyritic variety, was appropriate as the more basic parent of marscoite in respect of both composition and availability.

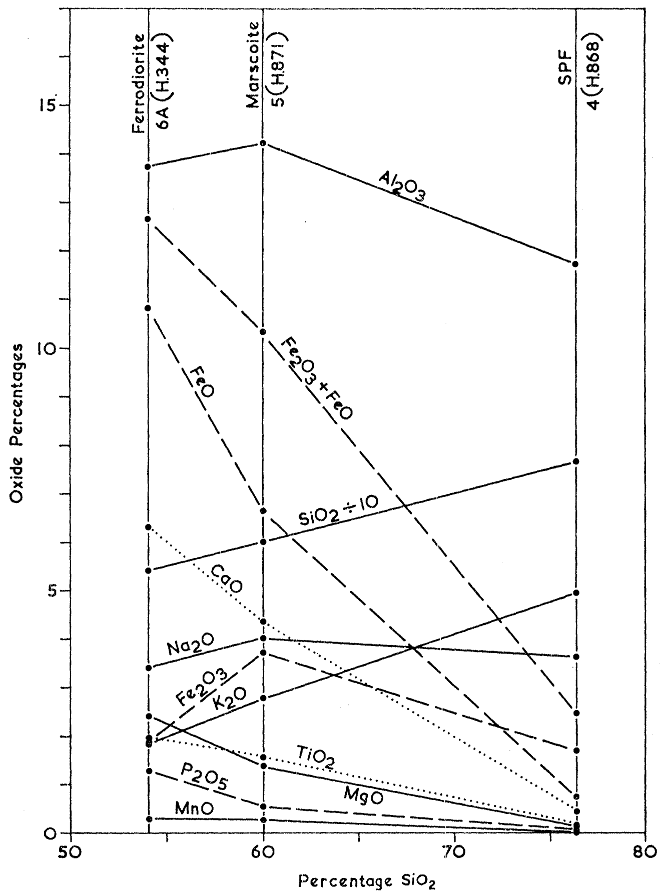


FIGURE 21. Variation diagram showing weight percentages of oxides plotted against silica percentages for ferrodiorite, marscoite and Southern Porphyritic Felsite. On the whole, the composition of the marscoite is intermediate between the hypothetical parents. On the basis of silica percentage as the criterion, marscoite represents a mixture of 26·7 % SPF and 73·3 % ferrodiorite. The figures 4, 5, and 6A refer to column numbers of the analysed specimens (tables 2 and 3).

The hypothesis that marscoite is a mixture of southern porphyritic felsite and ferrodiorite magmas receives strong support from the chemical composition of the rocks. A plot of the compositions of the three relevant rocks against silica percentage is presented in figure 21 and shows, in a general way, that the composition of marscoite from Harker's Gully lies close to a mixture of the two postulated parents in the proportion of about two-thirds of ferrodiorite to one-third of porphyritic felsite. In table 3 are set out the compositions of the two hypothetical parents and of two mixtures of which that having 65 % of ferrodiorite and 35 % of SPF gives perhaps the closest approach to the composition of marscoite. Harker (1904, pp. 231–2, 1909, pp. 235–9) discussed the use of variation diagrams in considering theoretical mixtures of two end-products and pointed out that if the process of mixing were by diffusion of one material into the other, then the composition of the mixtures would not lie on straight line graphs because of the differing rates of diffusion of the different components. If, however, the mixtures be produced by mechanical mixing of two liquids, the compositions of all possible mixtures should, of course, lie on straight-line graphs. Although the amounts of some of the oxides in the marscoite are some way off the straight-line graphs for mechanical mixing, we do not think this implies the effect of diffusion but rather that the particular porphyritic felsite and ferrodiorite analysed do not represent exactly the compositions of the co-mingling magmas.

Table 3. A comparison between the chemical analysis of the marscoite of Marsco and calculated compositions of SPF and ferrodiorite mixtures

	4	6A	A	5	B
SiO_2	76·41	54·18	61·96	60·07	60·85
Al_2O_3	11·71	13·74	13·03	14·22	13·13
Fe_2O_3	1·68	1·88	1·81	3·71	1·82
FeO	0·77	10·79	7·28	6·65	7·78
MgO	0·17	2·42	1·63	1·39	1·74
CaO	0·42	6·34	4·27	4·35	4·57
Na_2O	3·62	3·46	3·52	4·02	3·51
K_2O	4·92	1·85	2·93	2·75	2·78
$H_2O^{+110°}$	0·50	1·40	1·09	0·67	1·13
$H_2O^{-110°}$	0·12	0·26	0·22	0·06	0·22
TiO_2	0·14	1·97	1·33	1·53	1·42
P_2O_5	0·04	1·30	0·86	0·60	0·92
MnO	0·002	0·30	0·20	0·26	0·211

4, Southern Porphyritic Felsite, SPF, H868, Harker's Gully.
6A, Ferrodiorite, H344, Harker's Gully.
A, Composition of mixture of 35 % SPF and 65 % ferrodiorite.
5, Marscoite, H871, Harker's Gully.
B, Composition of mixture of 30 % SPF and 70 % ferrodiorite.

It might, perhaps, be thought that the mixture of porphyritic felsite with more-or-less any basic magma available in the Hebrides might give a reasonably close approach to the composition of marscoite. However, mixtures of average tholeiitic and alkali olivine basalt of the Hebrides with porphyritic felsite do not give anything like so close an approach to the composition of marscoite as mixtures of porphyritic felsite and ferrodiorite. Furthermore, early plagioclase crystals formed in alkali olivine basalt, tholeiitic, or porphyritic central type basalt would be bytownite or labradorite, rather than andesine, and so do not provide the required andesine xenocrysts.

The mechanical events leading to the observed relationships of the rocks of Harker's Gully are not easy to picture. Perhaps the marscoite can be thought of as having been formed in depth by mechanical mixing and then injected into the porphyritic epigranite and felsite, which had intruded a short time before. Then, without a break, the injecting magma changed from the hybrid marscoite to ferrodiorite, which may be supposed to have lain beneath the hybrid marscoite liquid in a small magma reservoir. Bailey & McCallien

(1956) have suggested an origin for certain rocks of composite intrusions which should be compared with this hypothesis.

While not claiming that the ferrodiorite of Harker's Gully represents exactly the more basic parent of marscoite, or that the analysed SPF represents exactly the acid parent, we believe that they closely approach the composition and nature of the parents. The most significant supporting evidence lies in the similarity between the porphyritic components of the proposed parents and the xenocrysts of the hybrid. The bulk analyses of marscoite and the presumed parent rock give further support to the hypothesis. Finally, the close association in space and time of marscoite, ferrodiorite, and SPF means that both parent magmas were available at just the time when the postulated mixing, to produce the marscoite, is believed to have taken place.

4. The Northern Late Intrusions of the Western Red Hills

The northern late intrusions comprise a sequence of rocks paralleling, but not identical with, the southern series. The sequence begins, as in the south, with an intrusion of porphyritic felsite magma. This is succeeded by marscoite intrusions which, however, have no associated ferrodiorite. Instead, they pass inwards into a highly characteristic variant of marscoite which we have named glamaigite (see p. 292). In one of the northern intrusions, the final injection was of epigranite bearing a resemblance to the Marsco Epigranite both in its field relations and composition.

(a) *The Northern Porphyritic Felsite*

The porphyritic felsites of the northern and southern areas are similar, but not identical. The *Northern Porphyritic Felsite* (NPF) has an outcrop of about one square mile, north-west of Moll (see figure 36, pull-out facing p. 306), within which are blocks of vent agglomerate and, at the northern end of the Moll marscoite intrusion, a mass of basalt. In the western part of its outcrop, NPF is in contact with basalt, or crushed Glamaig Epigranite, which it intrudes. The presence in NPF of agglomerate blocks suggests that it is an intrusion filling a wide vent, opening out to high levels where volcanic agglomerates were forming. No epigranite of the composition of NPF exists at the present level of erosion in the northern area.

The NPF has the same phenocrysts of quartz and potash felspar, and in the same proportion, as SPF, but it has a greater total amount of phenocrysts (cf. figure 9, plate 10 and figure 23, plate 13). There are also rather more phenocrysts of pyroxene and iron ore. Small angular pieces, up to a millimetre or so across, of fine-grained basic rocks—presumably basalt or dolerite—are frequent, and one is shown in figure 23 (plate 13). Similar inclusions occur in the felsite of the Southern Mountains Complex of Rhum (Hughes 1960). The small size and wide dispersion of these inclusions is remarkable and they deserve more detailed investigation.

(b) *The northern marscoite–glamaigite intrusions and the Meall Buidhe Epigranite*

(i) *Field relations*

There are three independent intrusions of the northern marscoite suite, at the present level of erosion, which are here called the Glamaig, Meall Buidhe, and Moll Shore intrusions (figure 36). The first of these, on Glamaig (figure 3, plate 9), is seen to be a rather irregular, wide gash through the granites and basalts, with a southerly apophysis, on Sròn a' Bhealain, having the form of an inclined sheet dipping away from the Western Red Hills centre. In the Allt Daraich, the south-east margin of the marscoite–glamaigite intrusion dips north-west at 45°, and the southern margin on Glamaig dips steeply in the same general direction. The upper contact, on the north-west ridge running down from the summit of Glamaig (Sgùrr Mhairi), dips north or north-west at about 40° under basalts, but the lie of the outer boundary on the lower ground is not clear; it may be similarly outward dipping or perhaps be an arcuate vertical boundary. On Sròn a' Bhealain, the sheet-like intrusion has a lower contact dipping north-west at about 7°. There were probably two successive injections of the marscoite as there is evidence on the west face of Glamaig of an inner one being chilled against an outer (see figure 3, plate 9).

The form of the Meall Buidhe intrusion is that of a lenticular gash through earlier rocks, with contacts probably steep or vertical. The smaller, Moll Shore intrusion is clearly a near-vertical sided mass. It is because these other two intrusions are apparently vertical that it is suggested that the outer, northern margin of the Glamaig intrusion is more or less vertical, also. The form of the northern marscoite intrusions, as of the southern, is ring dyke in style with an upper, near-horizontal, inward extension in one place. The general tectonic conditions at the time of intrusion were apparently the result of downward sagging of the central part of the complex.

At the margins of the three northern intrusions there is always chilled marscoite (figure 24, plate 13), passing, in a yard or so, into typical marscoite of normal grain size (figure 25, plate 13). After a variable width of the normal marscoite, usually 10 or 20 yd. (see sections, figure 22), the inner rocks may develop a streaky or net-veined character resulting in some degree of heterogeneity (figure 26, plate 13), and this passes inwards, in another 10 yd. or so, into a remarkable patchy rock (figure 27, plate 13 and figure 17, plate 12; see also Harker 1904, figure 41). The rounded, darker patches, usually 1 to 4 cm across, contain the characteristic xenocrysts of marscoite (figure 27, plate 13), and some xenocrysts are often to be seen, although less obviously, in the surrounding lighter material. This rock type, which we propose to call *glamaigite*, is abundantly present in all three of the northern intrusions. Harker described it as xenolithic granophyre, believing it to have been produced by granophyric magma intimately invading marscoite, probably while the latter was still hot. Thus, from Glamaig and Sròn a' Bhealain he described a marscoite sheet, the base of which had been invaded by granophyre (Harker 1904, figure 38 and pp. 188–91). Re-examination, however, shows that along the Sròn a' Bhealain contact marscoite is chilled against the Glamaig Epigranite. The numerous dark inclusions of the latter were wrongly equated by Harker with the dark patches in the glamaigite which forms the top of the ridge. The nature of the contact was also not correctly appreciated by McIntyre & Reynolds (1947). The rock we propose to call glamaigite is more than a local accident, since it is present in all three northern intrusions and, indeed, forms a major part of them.

The glamaigite tends to become homogeneous and coarser in texture towards the centre of the intrusions, and this type is distinguished as dioritic glamaigite (figure 28, plate 13). This material still shows clear indications of its relation to marscoite; thus xenocrysts of plagioclase, potash felspar and quartz can be detected in it, although they are not so conspicuous as in glamaigite.

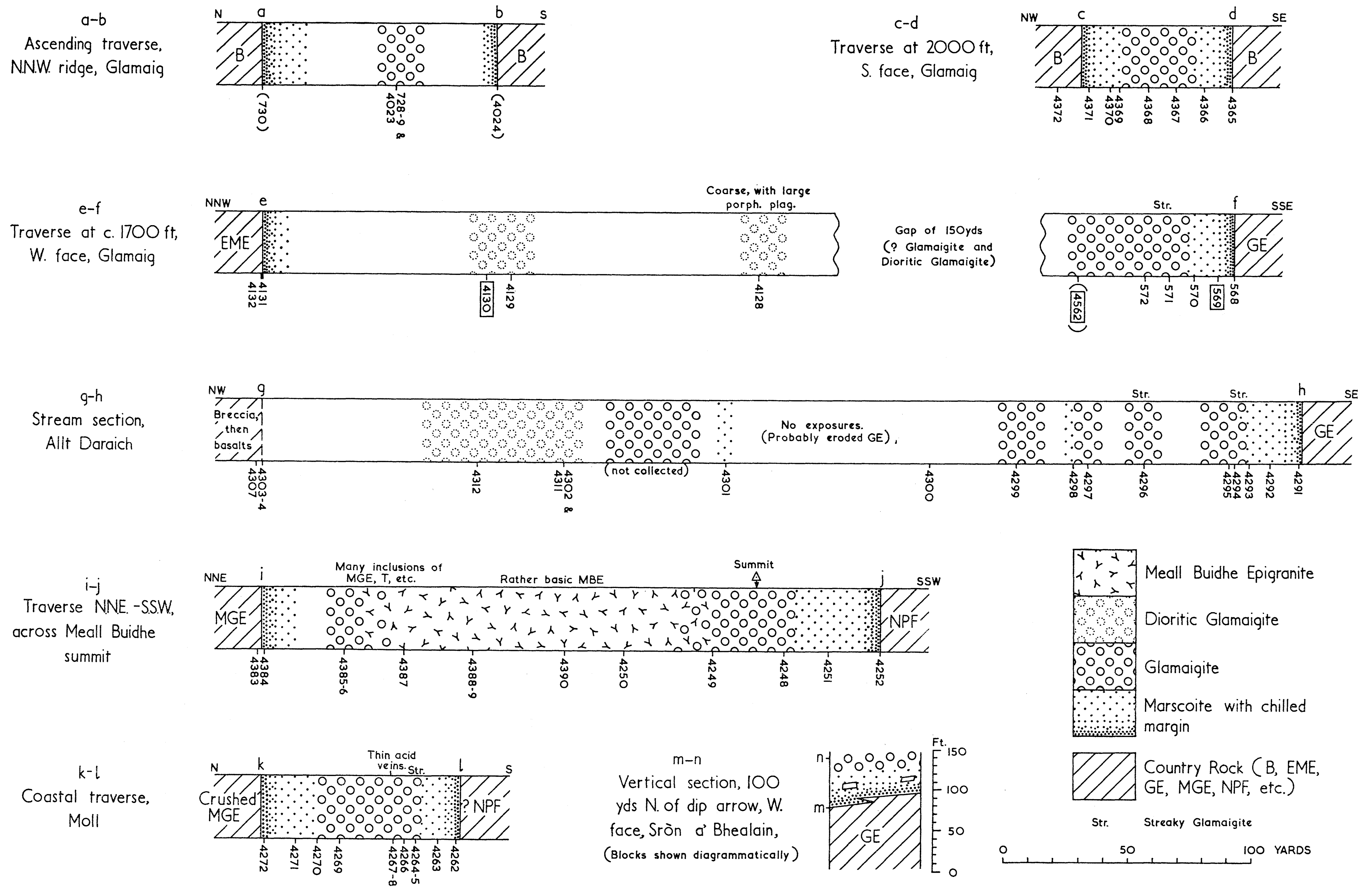


FIGURE 22. Diagrammatic representation of the rocks of the Northern Marscoite suite along various traverses; *ab*, *cd*, etc., shown on the map, figure 36, p. 307. The position of the important specimens is indicated. Analysed specimens shown boxed. Certain specimens collected near traverses are bracketed.

An epigranite of rather variable composition forms the central part of the Meall Buidhe intrusion. Its contact with the marscoite–glamaigite material seems to be steep and approximately parallel to the contacts of the latter with the country rocks. There is no chilling of the *Meall Buidhe Epigranite* (MBE) at the contact, but instead there is a transition

Description of plate 13

Figure 23. Northern Porphyritic Felsite, H 828, about 1100 yards W. 30° S. of Meall a' Mhaoil. Abundant phenocrysts of well-shaped potash felspar (considerably altered) and of quartz are set in a fine-grained matrix of quartz, potash felspar and iron ore. Large dark patches with ragged outlines are composed of reddish serpentine and opaque oxide and are probably pseudomorphs after iron-rich olivine. The elongated black crystals (bottom centre) are small phenocrysts probably of ilmenite. Just above the xenolith in the bottom right corner is a phenocryst of hedenbergitic pyroxene. The xenolith is basalt and around it the felsite groundmass is darkened. (Magn. × 9.)

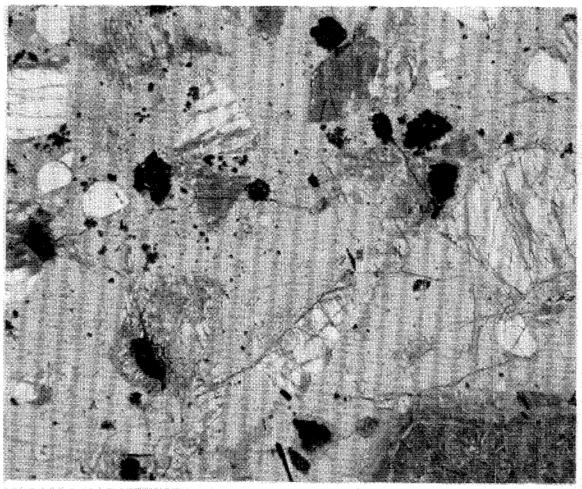
Figure 24. Contact of chilled marscoite and Glamaig Epigranite, H 568, on west face of Glamaig at a height of about 1700 ft. The marscoite shows signs of flow structure parallel to the contact and contains detached, small pieces of the epigranite. The conspicuous large crystals in the marscoite are andesine xenocrysts; quartz xenocrysts appear as small, dark, rounded grains while the potash felspar xenocrysts are not detectable in the photograph. This figure and also figures 25 to 28 are of polished rock specimens and all are either from traverse *e–f* at 1700 ft. or nearby (see figures 22 and 36). ($\frac{3}{4}$ × natural size.)

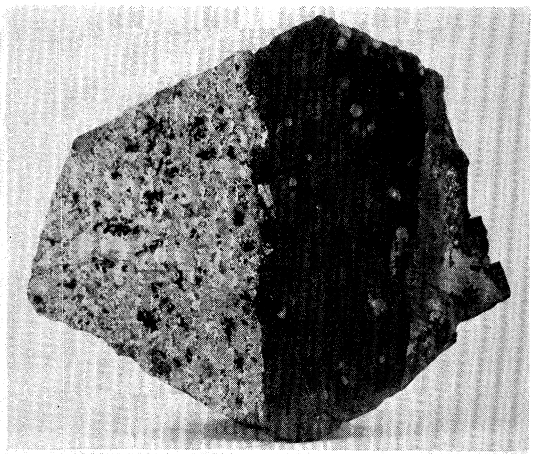
Figure 25. Marscoite, H 569, 7 yd. from contact of marscoite suite intrusion with GE on Glamaig at about 1700 ft. (analysed). The marscoite is coarser than that of the previous figure. Clustering of the andesine xenocrysts into glomeroporphyritic groups is well shown. Quartz xenocrysts appear as small, rounded, almost black grains while the potash felspar xenocrysts are light grey and can scarcely be detected in the photograph. The rounded, dark xenolithic patches (e.g. centre of photograph and top right) are believed to be modified hawaiite inclusions. ($\frac{3}{4}$ × natural size.)

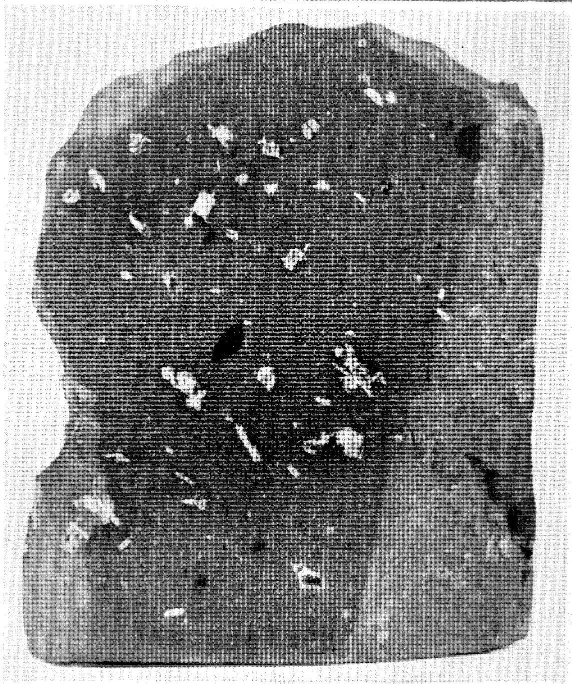
Figure 26. Streaky marscoite, H 571, 30 yd. from contact with GE figure 24. Structurally, this type is often found between the typical marscoite and the inner glamaigite. The groundmass is heterogeneous with leucocratic streaks and a tendency towards rounding of the more mafic patches. Glomeroporphyritic clusters of andesine crystals are conspicuous. The rounded quartz xenocrysts are light in colour with neat rims of augite and are clearly visible (e.g. bottom right). The dark, fine-grained patches are again considered to be modified hawaiite inclusions as in figure 25. ($\frac{3}{4}$ × natural size.)

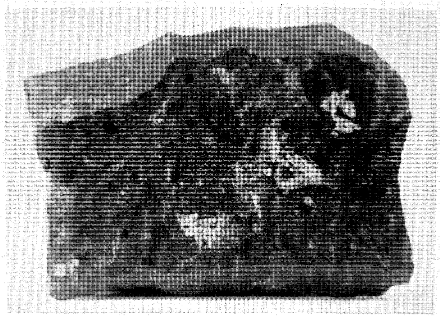
Figure 27. Glamaigite, H 4562, 50 yd. from the contact of marscoite suite intrusion with GE on Glamaig at about 1700 ft. (analysed). Typical glamaigite showing rounded darker patches set in a lighter base. Both light and dark material contains andesine xenocrysts and also quartz and orthoclase xenocrysts but the two latter are scarcely visible. ($\frac{3}{4}$ × natural size).

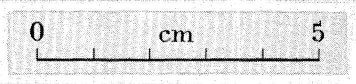
Figure 28. Dioritic glamaigite, H 4128 A, west face of Glamaig at about 1700 ft. and 100 yd. S.S.W. of analysed H 4130 (see figure 22 and map, figure 36). This rock is characteristic of the inner parts of the Marscoite–Glamaigite intrusions. It is more homogeneous than glamaigite but it still retains features which point to its relationship with other marscoite-suite types. Thus there are glomeroporphyritic groups of andesine crystals (not conspicuous because the whole rock is coarser), augite clusters resulting from replacement of quartz xenocrysts (base of specimen), and potash felspar xenocrysts (but these are not distinguishable in the photograph). Occasional rounded dark xenoliths (two near the bottom of the specimen photograph) are apparently modified hawaiite inclusions. ($\frac{3}{4}$ × natural size.)

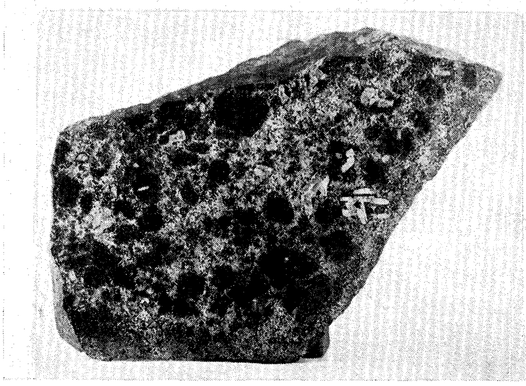

23

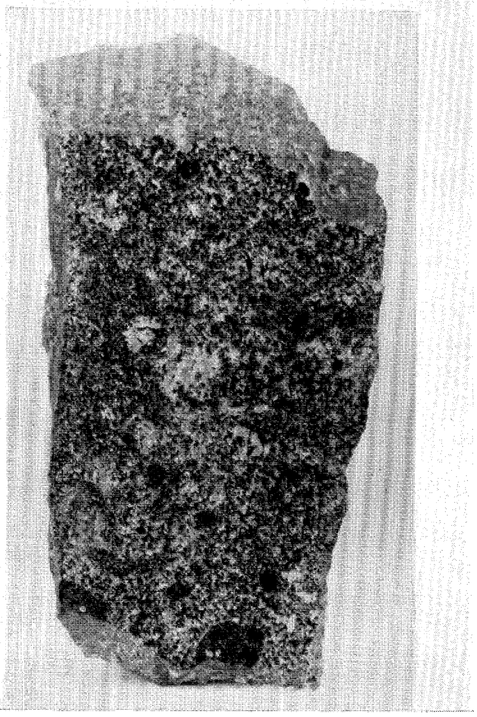

24


25

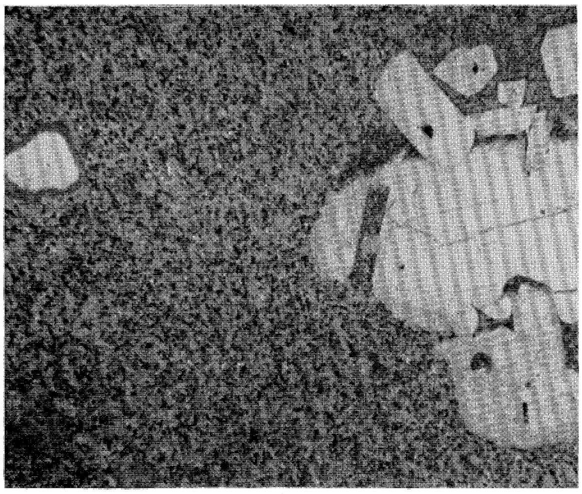

26



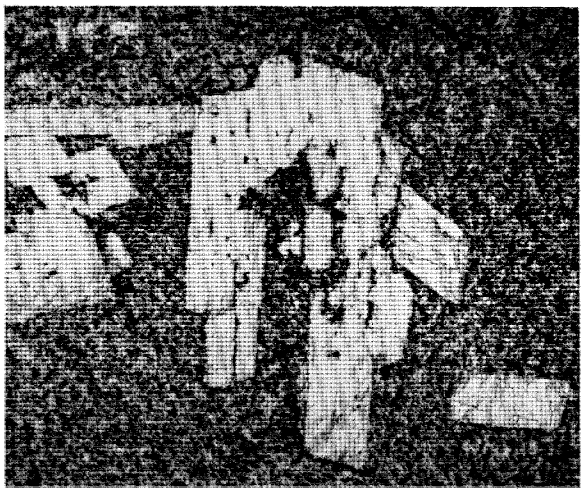

27


28

(*Facing p.* 294)

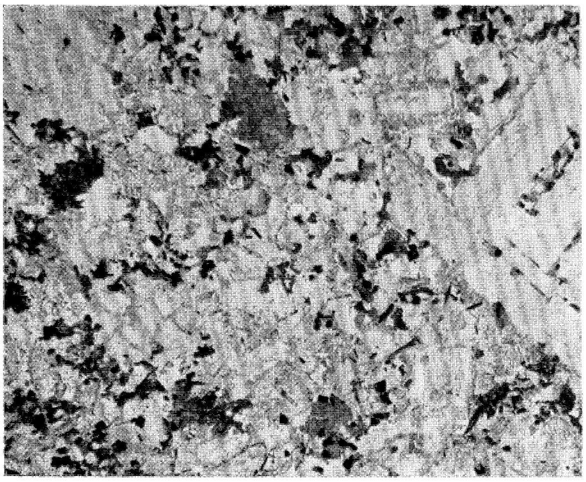


29

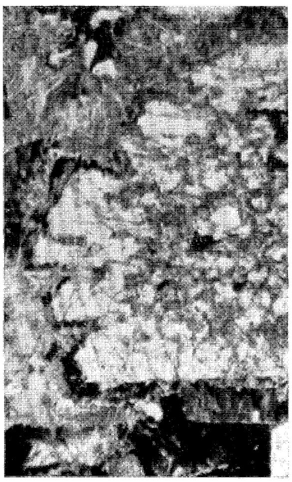


30

31



32



33

34

over a few feet in Allt a Bhealaich Bhric (the stream shown on the map (figure 36) east of Abhuinn Torra-mhichaig) and a still more gradual transition on Meall Buidhe. Apparently, the epigranite was intruded into the marscoite–glamaigite rocks while they were still hot, making it comparable with the Marsco Epigranite in its relative time of emplacement, as it is also in composition (see p. 301).

Description of plate 14

Figure 29. Marscoite, H 569, 7 yd. from southern contact with GE at 1700 ft., west face of Glamaig (analysed). On the right is a typical cluster of andesine xenocrysts. A quartz xenocryst rimmed with granular augite crystals occurs at the left-hand edge of the figure and two turbid potash felspar xenocrysts can just be distinguished in the bottom left-hand corner. The texture of the groundmass is markedly finer in the interstices between the andesine xenocrysts in contrast with the coarser material between the plagioclase xenocrysts of the marscoite of Harker's Gully (figure 12, plate 11). (Magn. × 9.)

Figure 30. Part of hawaiite inclusion in glamaigite, H 4516, from west face of Sròn a' Bhealain, about 250 yd. S.E. of analysed specimen H 4540 (see map, figure 36). Andesine phenocrysts are set in a groundmass of plagioclase, hornblende, pyroxene and iron ore. Occasional small patches of interstitial quartz can be seen (centre of andesine cluster and top left corner). (Magn. × 9.)

Figure 31. Glamaigite, H 4562 A, 50 yd. from the southern contact with GE at 1700 ft. on west face of Glamaig (analysed). Clusters of andesine xenocrysts appear in the top centre and right-hand corner of the figure: the individual crystals have lost the sharp outlines characteristic of marscoite. Andesine also occurs in the dark, fine-grained hawaiite inclusion seen left of centre. A rounded quartz xenocryst, partly replaced by augite, can be seen in the lower right-hand corner. No potash felspar xenocrysts are present in this photomicrograph. The heterogeneous nature of the groundmass is well seen, with leucocratic areas particularly below and to the left of the centre, and more melanocratic areas particularly in the bottom left and the upper part of the photomicrograph. The vague rounding of some of the melanocratic patches can be seen. (Magn. × 9.)

Figure 32. Dioritic glamaigite, H 4128 B, west face of Glamaig at about 1700 ft. and 100 yd. southwest of analysed H 4130 (see figure 22 and map, figure 36). On the right side of the picture is a cluster of andesine xenocrysts. In the top left corner is a potash felspar xenocryst outlined by chlorite flakes. Between these two is a cluster of augite grains, the result of replacement of a quartz xenocryst. Conspicuous in the groundmass is plagioclase with turbid rims crowded with chlorite. The other minerals in the groundmass are augite, hornblende (the more elongated dark crystals), opaque minerals, and quartz and potash felspar in granophyric intergrowth. (Magn. × 9.)

Figure 33. Potash felspar with fingerprint texture in dioritic glamaigite, H 4130, from northern slopes of Glamaig (see figure 22 and map, figure 36). The patchily turbid central part of the felspar crystal is a coarse variety of the fingerprint textures developed in potash felspar xenocrysts. Growing out from this is clear plagioclase, in the outer rim of which is a concentration of chlorite flakes and grains of iron ore, as in the rims of the groundmass plagioclases. (Magn. × 34.)

Figure 34. Part of quartz xenocryst in glamaigite, H 4562 (see figure 22). The quartz xenocryst is partly replaced by a rim of small clinopyroxene crystals of no preferred orientation, with some small areas of green amphibole, quartz, and turbid potash felspar among them. In the centre of the xenocryst, as cut, there is a patch mainly of turbid potash felspar, probably an extension of groundmass felspars in an embayment of the xenocryst. (Magn. × 34).

The relationship between the marscoite–glamaigite rock types and the Meall Buidhe Epigranite in the northern late intrusions is shown diagrammatically in the sections (figure 22), on which, also, the positions of specimens described in the petrological section below are indicated. The sections represent horizontal traverses across these composite intrusions except in the case of Sròn a' Bhealain, where the section is a vertical one from the contact upwards, and in the case of Sgùrr Mhairi (first section) which represents a traverse along the steep northern ridge. The sections illustrate the symmetry which exists in all these intrusions.

Many inclusions, some probably of related rocks and others of extraneous origin, are common in the northern marscoite–glamaigite intrusions. Blocks of andesinite are found resembling the material from the southern marscoite–ferrodiorite intrusions. In addition, there are glomeroporphyritic patches of xenocrystic plagioclase, of considerable size; these seem to have a mode of origin somewhat different from that of the andesinite even though they are composed of similar andesine felspars. In the lower part of the Sròn a' Bhealain sheet, above the marginal few feet of chilled rock, inclusions of many kinds are particularly abundant and have, presumably, accumulated by sinking. A common type consists of a dark, fine-grained rock having boundaries with the enclosing marscoite of a sort which suggest that the included material was of doughy consistency* when incorporated. The smaller, rounded patches scattered thinly through all the rocks of the marscoite suite (e.g. figures 25 to 27, plate 13) are, apparently, of the same material and are described more fully in the next section. They have a mineralogical and chemical composition intermediate between alkali olivine basalt and mugearite and, following MacDonald (1960), they are described as hawaiite. Other inclusions are of banded gneisses, presumably Lewisian, and epigranites of Eas Mòr or Glamaig type. The inclusions of presumed Lewisian have been found frequently within the marscoite–glamaigite intrusions, and also in the marscoite–ferrodiorite intrusions of the southern sector; some special, but undetermined significance is probably to be attached to them. It is worthy of comment that inclusions of Lewisian have never been found in the Western Red Hills granitic intrusions.

(ii) *Petrology of the northern marscoite and the hawaiite inclusions*

The analysed marscoite, H 569, collected 20 ft. from the contact with GE on the west face of Glamaig, will be described as a typical example (figure 25, plate 13 and figure 29, plate 14). The rock is lighter in colour, and coarser, than the marscoite immediately adjacent to SPF in Harker's Gully, but there are the same well-shaped plagioclases, often in glomeroporphyritic groups, the same quartz xenocrysts, but with wider reaction rims of augite crystals, and similar, but more corroded, potash felspar xenocrysts. Xenoliths of a dark, fine-grained rock, presumably hawaiite, are widely spread through the marscoite but are not shown in the photomicrograph. The potash felspar xenocrysts show exsolution of a fingerprint type. The groundmass is even-grained, as in the Marsco rock, and is not obviously heterogeneous. It consists of sodic plagioclase, potash felspar and quartz, with augite, hornblende, chlorite, iron ore and apatite. Augite is a normal mineral in the groundmass of the northern marscoite, while it is absent or rare in the southern type.

* Similar 'doughy' inclusions are described from the composite sills near Broadford in a thesis by R. R. Skelhorn (1959).

Between the plagioclases of the glomeroporphyritic groups the groundmass is usually different, and in the case illustrated is finer-grained and of slightly different composition. This contrasts with the coarse groundmass between the glomeroporphyritic crystals of the Harker's Gully marscoite (figure 12, plate 11). Towards the contact, the marscoite has a finer-grained groundmass but the xenocrysts remain the same, except that they are less corroded and the reaction rims, of augite round the quartz, are narrower.

It is clear that the marscoite of the northern sector of the Western Red Hills Complex, like that of the southern sector, was formed by the mixing of a porphyritic acid magma with a porphyritic intermediate magma. In the northern area, on Meall Buidhe, there is porphyritic felsite which could represent the acid parent, but there are no ferrodiorite intrusions which can be considered as providing a sample of the more basic parent, as there are in the southern sector. However, there are the hawaiite inclusions in the marscoite, often containing porphyritic plagioclase of about An_{50}, and these, it seems, might represent samples of the more basic parent which have been caught up and preserved in the hybrid magma.

The hawaiite inclusions, varying in size from a few millimetres up to half a metre, are liable to occur in all the rocks of the marscoite–glamaigite suite. The margins of the inclusions tend to be rather sharp against the surrounding marscoite or glamaigite. The inclusions may contain numerous unzoned andesine crystals, *ca.* An_{50}, closely similar to those in the marscoite, or they may be free from phenocrysts. Occasionally, smaller andesine phenocrysts are found which have a core of An_{46} and, unlike the larger andesines, are normally zoned. The groundmass of the hawaiite inclusions is composed of plagioclase, clinopyroxene, hornblende, ore, abundant apatite, and a little quartz. No doubt their situation, as inclusions in the hybrid material, has resulted in the presence of hornblende, and in other differences from the hawaiite lava flows of the Skye basalt plateau. In some of the inclusions, acidic ocelli up to 5 mm in diameter are present; these are composed of quartz and potash felspar, often in micrographic intergrowth, with some chlorite and biotite, and their origin is unknown. The phenocrysts of An_{50} help to distinguish the material of the hawaiite inclusions from ordinary basalt. Phenocrysts of plagioclase of about this composition occur, in the porphyritic mugearites of Roineval, five miles to the north-west (see Kennedy 1931).

The analysis of one of the hawaiite inclusions (table 4) shows it to resemble closely the hawaiites of Hawaii and some of the mugearites from the British Tertiary igneous province, especially one from Rhum (table 5). There is also some resemblance to the composition of the estimated Middle Zone liquid of the Skaergaard intrusion. The sodic nature of the normative plagioclase (An_{43}), the high ratio of iron to magnesium, and the relatively high total alkalis and phosphorus suggest that the inclusions are material belonging to a middle or later fractionation stage of basalt.

The Northern Porphyritic Felsite has not been analysed but its composition is, no doubt, fairly similar to the analysed felsite from Harker's Gully. The composition of mixtures, in various proportions, of the SPF of Harker's Gully and of the analysed hawaiite inclusion have been estimated (table 6). The one fitting most closely the composition of the analysed northern marscoite consists of 40 % of SPF and 60 % of the hawaiite inclusions. The general fit is even closer than was obtained for the Harker's Gully marscoite, using the

Table 4. Chemical analyses of marscoite and related rocks of the Northern Late Intrusions of the Western Red Hills Complex

	8	9	10A	10B	11	12
SiO_2	48·84	58·08	58·35	56·21	61·22	68·60
Al_2O_3	13·17	12·44	11·62	12·09	13·24	13·51
Fe_2O_3	5·24	2·65	3·31	3·73	2·85	1·59
FeO	9·88	8·12	7·32	8·29	6·61	3·83
MgO	4·60	2·09	3·40	3·24	1·70	0·63
CaO	7·58	4·80	4·73	5·55	4·12	1·89
Na_2O	2·97	3·61	3·50	2·95	3·75	4·07
K_2O	1·23	2·61	2·81	2·20	2·65	3·99
$H_2O^{+110°}$	2·25	2·33	1·99	2·01	0·86	0·81
$H_2O^{-110°}$	0·46	0·23	0·21	0·44	0·47	0·43
TiO_2	3·38	1·86	2·12	2·45	1·56	0·61
P_2O_5	0·77	0·99	0·91	0·85	0·89	0·15
MnO	0·30	0·17	0·25	0·26	0·21	0·16
total	100·67	99·98	100·52	100·27	100·13	100·27

C.I.P.W. norms

	8		9		10A		10B		11		12	
Qz		4·9		13·5		13·2		14·3		17·6		23·1
Or	7·3		15·4		16·6		13·0		15·7		23·6	
Ab	25·1	51·4	30·5	55·9	29·6	53·9	25·0	51·3	31·7	58·9	34·4	64·8
An	19·0		10·0		7·7		13·3		11·5		6·8	
Di *Wo*	5·7		3·1		4·1		3·7		1·3		0·7	
Di *En*	3·1	11·2	1·1	6·3	2·1	8·1	1·8	7·4	0·5	2·6	0·2	1·4
Di *Fs*	2·4		2·1		1·9		1·9		0·8		0·5	
Hy *En*	8·3	14·7	4·1	12·0	6·4	12·2	6·3	13·0	3·8	10·5	1·4	5·9
Hy *Fs*	6·4		7·9		5·8		6·7		6·7		4·5	
Mt		7·6		3·8		4·8		5·4		4·1		2·3
Ilm		6·4		3·5		4·0		4·7		3·0		1·2
Ap		1·8		2·3		2·1		2·0		2·1		0·4
water		2·7		2·5		2·2		2·4		1·3		1·2
total		100·7		99·8		100·5		100·5		100·1		100·3

Approximate Modes (vol. %)

Colourless minerals (mainly plagioclase	47	Plagioclase	3·8	Xenocrysts	Plagioclase	41·4	Potash felspar	51·5
Green ferromagnesian minerals	45	Potash felspar	0·6		Micropegmatite	29·8	Plagioclase	20·6
Opaque minerals	8	Quartz	0·6		Quartz	2·4	Quartz	20·6
		Felspar and quartz	59·0	Groundmass	Opaque minerals	2·3	Opaque minerals	0·8
		Pyroxene, hornblende and chlorite	32·5		Clinopyroxene	5·0	Hornblende, Chlorite, Epidote, Biotite	12·8
		Opaque minerals	3·5		Hornblende	13·0		
					Chlorite	6·1		

8, Hawaiite inclusion, H4540, from marscoite sheet of Sròn a' Bhealain. (Anal. E. A. Vincent.)

9, Marscoite, H569, 7 yd. from southern contact of marscoite suite intrusion with GE at 1700 ft. on west face of Glama (Anal. E. A. Vincent.)

10A, Glamaigite, H4562A, 50 yd. from south-east contact of marscoite suite intrusion with GE, Glamaig. (Anal. E. Vincent.)

10B, Dark patches, H4562B, in Glamaigite, H4562A, at about 1700 ft. (Anal. E. A. Vincent.)

11, Dioritic glamaigite, H4130, at *ca.* 1700 ft. on the slopes of Glamaig, 200 yd. west of, and 100 ft. below, the 'gendarm (See figure 3, plate 9). (Anal. E. A. Vincent.)

12, Meall Buidhe Epigranite, H4351, Allt a Bhealaich Bhric. (Anal. E. A. Vincent.)

The localities are marked on the map, figure 36, and some are indicated on figure 22.

SPF and ferrodiorite as the parents (see table 3). The evidence available for the northern late intrusions is regarded as satisfactorily confirming the postulated origin of the marscoite through a mixing process.

A fine-grained layer of marscoite near the base of the Sròn a' Bhealain sheet contains a few thin streaks of porphyritic felsite and an associated basic rock with porphyritic andesine crystals. The rock (figure 18, plate 4) apparently shows an arrested stage of

TABLE 5. CHEMICAL ANALYSIS OF HAWAIITE INCLUSION WITH COMPARISONS

	8	D	E
SiO_2	48·84	50·70	48·76
Al_2O_3	13·17	14·60	15·82
Fe_2O_3	5·24	5·23	4·10
FeO	9·88	7·68	7·53
MgO	4·60	4·15	4·74
CaO	7·58	7·20	7·99
Na_2O	2·97	3·71	4·50
K_2O	1·23	1·33	1·58
$H_2O^{+110°}$	2·25	1·15	—
$H_2O^{-110°}$	0·46	2·08	—
TiO_2	3·38	1·89	3·29
P_2O_5	0·77	0·49	0·72
MnO	0·30	0·42	0·17
total	100·67	100·63	99·20

8, Hawaiite inclusion, H4540, from marscoite sheet of Sròn a' Bhealain (from table 4).
D, Mugearite sill, southern base of Fionn-Chro, Rhum. (Anal. E. G. Radley) (Harker 1908, p. 130).
E, Average hawaiite of the Hawaiian Islands (Macdonald 1949, p. 1571).

TABLE 6. A COMPARISON BETWEEN THE CHEMICAL ANALYSIS OF MARSCOITE OF GLAMAIG AND CALCULATED MIXTURES OF SPF AND HAWAIITE INCLUSION MIXTURES

	4	8	C	9
SiO_2	76·41	48·84	59·86	58·08
Al_2O_3	11·71	13·17	12·58	12·44
Fe_2O_3	0·77	9·88	6·24	8·12
FeO	1·68	5·24	3·81	2·65
MgO	0·17	4·60	2·83	2·09
CaO	0·42	7·58	4·72	4·80
Na_2O	3·62	2·97	3·23	3·61
K_2O	4·92	1·23	2·71	2·61
$H_2O^{+110°}$	0·50	2·25	1·55	2·33
$H_2O^{-110°}$	0·12	0·46	0·33	0·23
TiO_2	0·14	3·38	2·09	1·86
P_2O_5	0·04	0·77	0·48	0·99
MnO	0·002	0·30	0·18	0·17

4, Southern Porphyritic Felsite, SPF, H868 (from table 2).
8, Hawaiite inclusion, H4540, from Sròn a' Bhealain (from table 4).
C, Composition of mixture of 40 % SPF and 60 % hawaiite inclusion.
9, Marscoite of Glamaig, H569 (from table 4).

mixing. The groundmass of the basic part is fine-grained and dark, but prisms of hornblende, plagioclase laths, and grains of iron ore can be detected. The andesine phenocrysts are well shaped and some of them are fractured. The acid material is essentially a porphyritic felsite consisting of phenocrysts of quartz and potash felspar of the kind found in the NPF, set in a generally fine-grained felsitic groundmass having a spherulitic texture in places. It is also interesting to note the presence of small, angular fragments of basalt or dolerite similar to those in the NPF of Meall Buidhe. Besides the basic and acid material there is some which has evidently resulted from mixing of the two, and this material may contain xenocrysts which are the same as the phenocrysts of both the other rocks.

The rhyolite–basalt complex of the Gardiner River, Yellowstone Park, Wyoming, exhibits certain features in common with the marscoite suite of rocks, such as the partial replacement of quartz by augite and the presence of fingerprint-textured potash felspar. Iddings (1899) attributed the hybrids to the incorporation of older basalt in rhyolite and Fenner (1938, 1944) concurred, but also believed that emanations from the rhyolite had been important in their formation. Wilcox (1944) postulated the simultaneous eruption and intermingling of porphyritic rhyolite and basalt magmas. There is a striking similarity between figures 3 and 4 of plate 3 in Fenner's (1944) paper, showing the Gardiner River rocks, and the illustration of our rock (figure 32, plate 14), so that we are inclined to believe that Wilcox's hypothesis is right and that this American occurrence is another example of the co-mingling of two magmas.

(iii) *Petrology of glamaigite and dioritic glamaigite*

Typical glamaigite, such as the analysed specimen (H 4562) from Glamaig, consists of dark, rounded, rather indefinite patches surrounded by somewhat coarser, lighter-coloured material. In the weathered specimen (figure 17, plate 12) the dark patches are conspicuous but in the photomicrograph (figure 31, plate 14) they are much less so, except for the especially conspicuous dark patch, with plagioclase phenocrysts, which is one of the sporadic hawaiite inclusions. The normal dark patches have a groundmass similar to that of marscoite, although somewhat coarser (cf. figures 29 and 31, plate 14). The leucocratic material is more variable in texture, grain size, and proportions of the minerals; the parts more distant from the dark patches are often relatively coarse and consist largely of quartz and potash felspar with small amounts of low-temperature minerals such as epidote, chlorite and zeolite.

In both dark and light areas alike there are xenocrysts of idiomorphic andesine, of quartz with wide augite reaction rims (or clusters of augite representing completely pseudomorphed quartz) and, occasionally, of rounded potash felspar crystals. The rarity of potash felspar xenocrysts is considered to be due to their having been largely dissolved in the liquid which now forms the groundmass. All the xenocrysts of marscoite are thus present in both the light and dark parts of the glamaigite, although the proportion might be shown to be slightly different if a modal analysis of a sufficiently extensive area of the rock were available. Because of the xenocrysts, both the leucocratic and melanocratic parts of the rock are considered to be hybrid in origin, but the variable texture suggests that mixing was incomplete, and that, during crystallization, a late residuum tended to collect in an indefinite three dimensional network between the darker patches. A few cases were observed of a late acid residuum, mainly quartz and potash felspar, forming relatively distinct veinlets cutting through the dark and light material equally (figure 20, plate 12).

The chemical analysis of glamaigite (table 4) shows that its overall composition is close to that of the analysed marscoite from nearby. This chemical similarity, and the presence in both parts of the glamaigite of the same xenocrysts as are found in the marscoite, indicate a similar, but obviously not identical, origin to marscoite.

In the direction away from the nearest margin, the glamaigite passes gradually into the coarser and more homogeneous dioritic glamaigite (figure 28, plate 13 and figure 32, plate 14). The scarce, dark patches in this rock (see figure 28) are not the abundant dark patches of glamaigite but are modified hawaiite inclusions which still persist. The larger plagioclase crystals are considered the equivalent of the andesine xenocrysts of the marscoite, the rounded patches of granular augite apparently represent the complete replacement of quartz xenocrysts, while the occasional crystals of felspar with fingerprint texture (figure 33, plate 14) are believed to be the modified potash felspar xenocrysts. The bulk of the rock consists of euhedral plagioclase, outlined by cloudy potash felspar which is darkened still further by innumerable chlorite flakes, and the rest is micropegmatite, augite (partly replaced by hornblende), independent crystals of hornblende, iron ore, chlorite, and apatite. The mineralogical composition is similar to that of a rather leucocratic glamaigite.

The analysis of a specimen of the dioritic glamaigite (analysis 11, table 4) shows it to be a little more acid than the average glamaigite, and to be lower in iron and magnesium and higher in alkalis. These characteristics suggest that in the formation of the dioritic glamaigite there was either more of the acid parent or slight fractionation of the crystallizing hybrid, producing a lower temperature fraction. Despite the slightly more acid character, the dioritic glamaigite is essentially glamaigite which has become more homogenized. It is suggested that owing to its central position in the intrusion there was a longer time interval before final solidification, and this permitted greater homogenization, by diffusion, to take place.

(iv) *The petrology of the Meall Buidhe Epigranite*

In the middle part of the intrusion, exposed in the Allt a Bhealaich Bhric, this epigranite forms a distinct and fairly uniform intrusion. At the eastern end it is more melanocratic and merges with the glamaigite, whilst the western end is not exposed. In thin section, the microgranite of the middle section is seen to contain up to 20% of oligoclase phenocrysts mantled with turbid potash felspar (figure 19, plate 12). The groundmass contains independent crystals of potash felspar and quartz, and has a predominantly microgranitic texture. The mafic minerals are green pyroxene, in minor amounts, and more abundant green hornblende and greenish biotite. Some of the hornblende is replacing pyroxene but some probably crystallized directly from the magma. Rare patches of brownish serpentine are probably pseudomorphs after fayalitic olivine. Accessory minerals include ore, apatite, epidote, zircon and chlorite. In the rock at the eastern end of the intrusion the plagioclase phenocrysts are more conspicuous.

Certain petrographic features of the rock suggest an affinity with the Marsco Epigranite; these are the mantled plagioclase phenocrysts, the green pyroxene, the interstitial plates of hornblende, and the predominantly microgranitic, as opposed to granophyric, texture of the groundmass. The Meall Buidhe Epigranite also has affinities with the more acid part of the dioritic glamaigite—a matter discussed briefly, later (pp. 302–3).

An analysis of the Meall Buidhe Epigranite (analysis 12, table 4) shows that it is more basic than the Marsco Epigranite or any of the other epigranites analysed; it has greater amounts of total iron, MgO, and CaO, and lower alkalis. The Meall Buidhe and the Marsco Epigranites are the only Western Red Hills epigranites which have an excess of Na_2O over K_2O and this is a further link between them.

(c) *Suggested origin of the marscoite–glamaigite series*

The general characteristics, the xenocrysts, and the chemical composition of the marscoite of the northern intrusions, indicate an origin similar to that of the marscoite of the southern intrusions, that is, by mixing of an acid magma, containing quartz and potash felspar phenocrysts, with a more basic magma containing andesine phenocrysts. Typical glamaigite also contains the three characteristic xenocrysts of marscoite in both the darker patches and the lighter surrounding material, and the chemical analysis of the whole rock is closely similar to that of marscoite. Thus the glamaigite is also considered to be a hybrid, showing, however, peculiar structural and textural features.

In an attempt to understand the reason for the patchy character of glamaigite, the dark patches were cut from thin sheets of the analysed glamaigite and analysed separately (analysis 10B, table 4). The analysis differs from that of the whole rock in being lower in SiO_2, MgO and alkalis, and slightly higher in total iron, CaO, and TiO_2, while Al_2O_3 is not significantly different. The differences between the analyses of whole rock and dark patches confirms the slightly greater abundance of the higher temperature minerals in the dark patches and a greater abundance of somewhat lower temperature minerals in the surrounding leucocratic material. The only exception is shown by MgO, which may be anomalous because the material analysed was limited in amount and not representative.

The separate analysis of the dark patches is sufficient to show that there are no strong chemical differences between the dark and the light parts of the glamaigite. In seeking an explanation of the unusual structure of glamaigite, the significant points are: (1) that the dark patches (excluding the hawaiite inclusions) are hybrid material, since they contain andesine, quartz, and potash felspar xenocrysts; (2) that the surrounding, lighter-coloured material is also a hybrid because it, too, contains these xenocrysts; and (3) the dark patches are, apparently, a slightly more basic hybrid than the surrounding lighter material. On the basis of these facts, it is suggested that the glamaigite represents the result of mechanical mixing of the two porphyritic parents to give a fairly even distribution of the original phenocrysts but that some heterogeneity of the liquid part remained. On cooling, the somewhat more basic parts of the heterogeneous liquid crystallized first, giving clots of the slightly higher temperature crystals around which was the slightly more acid material, which was still liquid. Because of movement in the magma, perhaps due to convection, the early formed clots became rounded. The patchiness of the glamaigite is thus interpreted as a result of slow cooling of a considerable body of incompletely mixed acid and basic magma, while the marscoite is the result of quicker solidification of a rather more thoroughly mixed magma.

The solidification of both the glamaigite and marscoite took place under conditions of relatively low hydrostatic pressure. The existence of occasional drusy cavities indicates that at times the internal vapour pressure exceeded the external pressure, allowing a gas phase to form. At other times, too, small cracks developed in the almost solidified material, which were filled by a residual liquid giving the quartz and potash felspar veinlets mentioned above. In the Moll Shore section, pink acid veins an inch or so wide cut through the glamaigite (see cross-section, figure 22) and these are also believed to be derived from the surrounding glamaigite. The Meall Buidhe Epigranite has affinities with these acid veins, and may perhaps have been derived by filter-press action on a deeper part of the marscoite–glamaigite intrusion. It is noticeable that the Allt Daraich rocks are less miarolitic and more compact than the marscoite and glamaigite rocks a thousand or so feet higher on Glamaig.

The postulated mechanical mixing of the two magmas to give the marscoite and glamaigite rocks is considered to have taken place below the level at which they are now found. In attempting to arrive at a possible mechanism by which mixing took place, we suggest that a relatively low-density, porphyritic felsite magma overlay a ferrodiorite or hawaiite magma in a small magma reservoir and that convection currents stirred both

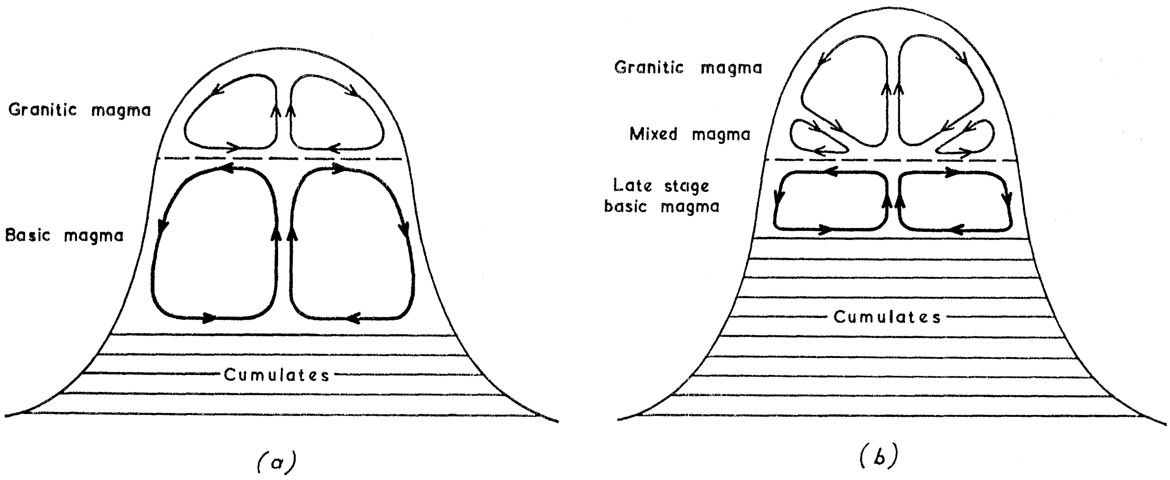


FIGURE 35. Possible convection currents in a cupola-shaped magma reservoir reaching up into the upper part of the granitic layer of the crust. The convecting basic magma provides heat to melt crustal rocks and produce an overlying granite magma in which a separate convecting system is considered to have developed. If a regular system of currents be developed, they may have been as shown in the figures. In (*a*) the gentle currents in the granitic liquid (thin lines) run counter to the presumably more vigorous currents in the basic liquid, and mechanical mixing would tend to occur along the junction zone. In (*b*) a possible later stage is represented; the basic magma, considered a late fraction, overlying a thicker pile of cumulates, has vigorous convection currents, which produce an annular body of mixed magma with a forced circulation due to the currents in the basic and acid liquids. This is the postulated source of the marscoite suite of rocks.

magmas. Because of the considerable differences in density between the more basic and more acid magma, two separate systems of convection currents would be expected in the two bodies of liquid. At the interface between the basic and acid magmas the currents would be travelling in opposite directions (see figure 35 (*a*)), and favourable conditions would exist for mechanical mixing. The systems of currents might, however, have been more complex, and of the kind figured by Holmes (1931, figure 4). In the latter case, the mixed magma would form a body of liquid, near the margins of the magma chamber, with a forced circulation of its own (figure 35 (*b*)).

The sequence of injection of material from the postulated stratified magma reservoir into the upper crust, in both northern and southern areas, seems to have been first porphyritic felsite and then marscoite. After this stage, differences developed between the northern and southern sectors. In the south, the injection of marscoite was succeeded by that of the underlying ferrodiorite liquid, while in the north the underlying, more basic liquid was, apparently, not tapped. Instead, a less well-homogenized hybrid liquid was injected which crystallized to give the glamaigites. The dioritic glamaigite towards the centre of the northern marscoite–glamaigite intrusions has a greater homogeneity and, as suggested above, may have been better mixed before intrusion or have become more homogeneous by diffusion, because its central position resulted in slower cooling.

5. Postulated events in the production of marscoite and related rocks

All the rocks dealt with in this paper have apparently been formed at depth and have reached their present position by intrusive action. The rocks of the marscoite suite tend to have a ring dyke form and were probably injected as a result of slight downward movement of a central block.

Evidence has been given for the production of marscoite by the mixing of an acid magma, containing phenocrysts of quartz and potash felspar, with a basic magma, containing phenocrysts of andesine felspar. It is not easy to picture where and how the mechanical mixing took place and there is, unfortunately, no direct evidence to be obtained at the present level of erosion. In developing any hypothesis on the origin of the marscoite and related rocks it must be remembered that their total amount is relatively small, and that they were developed towards the end of the Western Red Hills igneous episode; they are thus only a minor, late-stage part of the grand series of events which produced the whole complex.

The origin of the epigranites of the Tertiary igneous centres of the British Isles is still an open question, but we picture them broadly as the result of melting of sialic crustal rocks (see also Brown 1963) rather than fractionation of basic magma, as Bowen tended to believe. The cause of such melting must be a local rise of temperature and this, we believe, may have been due to a deep-seated intrusion of basic magma. There is evidence from a gravity survey (Tuson 1959; McQuillin & Tuson 1963, p. 1277) that a dense rock lies at no great distance beneath the granites of the Western Red Hills.

From the postulated basic intrusion, small amounts of hawaiite or ferrodiorite liquids could have been produced by strong fractionation* and thus have provided the more basic parent of the marscoite and related rocks. During the cooling of the postulated basic intrusion, heat, and no doubt water also, would be transferred to the overlying rocks, and perhaps produce an acid melt from suitable pre-existing rock. With increasing melting of heterogeneous crustal rocks there might be changes in the composition of the melt, and the varying early epigranites of the Western Red Hills could represent successive samples intruded into higher levels. Equally, the various epigranites may be samples of successive

* The results of investigations, by Moorbath and Bell (in press), of the isotopic ratio $^{87}Sr/^{86}Sr$ for various Tertiary igneous rocks of Skye, including the epigranites, the ferrodiorite and the hybrids described here, are compatible with the hypothesis of the hybrid origin of the marscoite–glamaigite rocks. Their work also suggests that the origin of the epigranites is, in fact, by remelting of crustal rock but it does not support the origin of ferrodiorite by fractionation of the ordinary basaltic magma of the region, as suggested originally in the paper by Wager & Vincent (1962) on the ferrodiorites of Skye. While the strontium isotope ratios point to the origin of mugearite magma by fractionation, the significantly different ratio for the ferrodiorite magma suggests that this was formed by partial melting of rather special rocks in the basement complex.

residual liquids produced by crystal fractionation of a large body of molten rock when the period of heating up had given place to a cooling stage.

To obtain the marscoite and related hybrid rocks we have postulated the co-existence, at a late stage in the development of the Western Red Hills centre, of two specific magmas situated one above the other in a small magma reservoir—the lower magma, a residual ferrodiorite or hawaiite with andesine phenocrysts, formed by fractionation of an extensive basic intrusion, and the upper, a felsite containing quartz and potash felspar phenocrysts. At the junction between the two porphyritic magmas, mechanical mixing is believed to have taken place. We suggest that the mixing of the presumably viscous porphyritic felsite magma with the more mobile, porphyritic intermediate magma was essentially the result of mechanical stirring, because the phenocrysts have an even distribution in the hybrid product. In the case of the liquid parts of the magmas, diffusion must also have contributed towards homogenization, as well as mechanical mixing.

It is suggested that the mechanical mixing which seems to have been necessary to produce the marscoite and related hybrids was the result of convection currents. Two distinct systems of convection currents would be expected, one in the overlying acid magma, and the other in the denser, underlying, more basic magma. Where the adjacent currents were travelling in opposite directions (see figure 35 (*a*)) there would be favourable conditions for mechanical mixing. The systems of currents may have been more complex (figure 35 (*b*)), resulting in an annular body of mixed magma of intermediate density, with a forced circulation of its own, near the margins of the magma chamber.

From the postulated reservoir containing the three different types of magma we suggest that, first, the overlying porphyritic acid magma was injected into higher levels of the crust to give the intrusions of porphyritic epigranite and porphyritic felsite. Then, while these intrusions were still hot, the underlying hybrid magma was injected, in ring dyke fashion, to give the marscoite intrusions. In the southern sector, this was followed by injection of the ferrodiorite magma, usually into the same fissure as the marscoite, although sometimes into other fissures, so that independent marscoite and ferrodiorite intrusions, as well as composite intrusions, were formed. In the northern sector, on the other hand, the sequence of events, after the initial marscoite injection, was different. Instead of the underlying more basic parent being intruded at high levels, a less-well-mixed hybrid magma was injected from which the glamaigite and dioritic glamaigite were formed. In this case, it would seem that the magma reservoir was not tapped at a level sufficiently deep to allow the injection of the lower, more basic magma, corresponding to the ferrodiorite of the southern sector.

In both northern and southern areas the marscoite suite of intrusions was followed, while still hot, by more acid magma—in the south by the Marsco Epigranite, and in the north by the Meall Buidhe Epigranite. These epigranites, particularly the latter, have characteristics which link them with the marscoite suite.

Without the tell-tale xenocrysts, the origin of marscoite, by the mixing of two magmas, could not easily have been demonstrated. Small amounts of intermediate rock in Mull, and perhaps elsewhere in the British Tertiary volcanic province, may be the result of a similar mixing of basic and acid magmas but if so, the parent magmas were free from phenocrysts and therefore the demonstration of such an origin has not yet been possible. The extent to which mechanical mixing of magmas to give hybrids is an important petrogenetic mechanism is at present unknown but, in the form displayed in Skye, it is probably a rarity.

In the earliest stage of this work we had the benefit of the collaboration of Dr J. E. Richey, for which we thank him warmly. Much of the early mapping and collecting was done with Professor F. H. Stewart when he and the first-named author were colleagues at the Durham Colleges of the University of Durham. We thank Professor Stewart for this early help and the first-named author, particularly, thanks him for many stimulating and critical discussions of the marscoite problem and other aspects of Skye geology.

References

Bailey, E. B. & McCallien, W. J. 1956 Composite minor intrusions, and the Slieve Gullion complex, Ireland. *Liverpool & Manchester Geol. J.* **1**, 466–501.

Bell, J. D. 1959 The geology and petrology of the northern end of the Blaven Range, Isle of Skye. D.Phil. thesis, University of Oxford.

Brown, G. M. 1963 Melting relations of Tertiary granitic rocks in Skye and Rhum. *Miner. Mag.* **33**, 533–562.

Buddington, A. F. 1959 Granite emplacement with special reference to North America. *Bull. Geol. Soc. Amer.* **70**, 671–748.

Fenner, C. N. 1938 Contact relations between rhyolite and basalt on Gardiner River, Yellowstone Park, Wyoming. *Bull. Geol. Soc. Amer.* **49**, 1441–1483.

Fenner, C. N. 1944 Rhyolite-basalt complex on Gardiner River, Yellowstone Park, Wyoming: a discussion. *Bull. Geol. Soc. Amer.* **55**, 1081–1096.

Harker, A. 1904 The Tertiary igneous rocks of Skye. *Mem. Geol. Surv. Scotland*, pp. 1–481.

Harker, A. 1908 The geology of the Small Isles of Inverness-shire. *Mem. Geol. Surv. Scotland*, pp. 1–210.

Harker, A. 1909 *The natural history of igneous rocks*, pp. 1–384. London: Methuen and Co.

Holmes, A. 1931 The problem of the association of acid and basic rocks in central complexes. *Geol. Mag.* **68**, 241–255.

Hughes, C. J. 1960 The southern mountains igneous complex, Isle of Rhum. *Quart. J. Geol. Soc. Lond.* **116**, 111–138.

Iddings, J. P. 1899 Geology of Yellowstone Park. *U.S. Geol. Surv. Mon.* **32**, part II.

Kennedy, W. Q. 1931 On composite lava flows. *Geol. Mag.* **68**, 166–181.

MacDonald, G. A. 1949 Hawaiian petrographic province. *Bull. Geol. Soc. Amer.* **60**, 1541–1595.

MacDonald, G. A. 1960 Dissimilarity of continental and oceanic rock types. *J. Petrology*, **1**, 172–177.

McIntyre, D. B. & Reynolds, D. L. 1947 Chilled and 'baked' edges as criteria of relative age. *Geol. Mag.* **84**, 61–64.

McQuillin, R. & Tuson, J. 1963 Gravity measurements over the Rhum Tertiary plutonic complex. *Nature, Lond.* **199**, 1276–1277.

Moorbath, S. & Bell, J. D. 1964 Strontium isotope abundance studies and Rb/Sr age measurements on Tertiary igneous rocks of Skye. *J. Petrol.* **6** (in press).

Richey, J. E. 1930 Tertiary ring structures in Britain. *Trans. Geol. Soc. Glasgow*, **19**, 42–140.

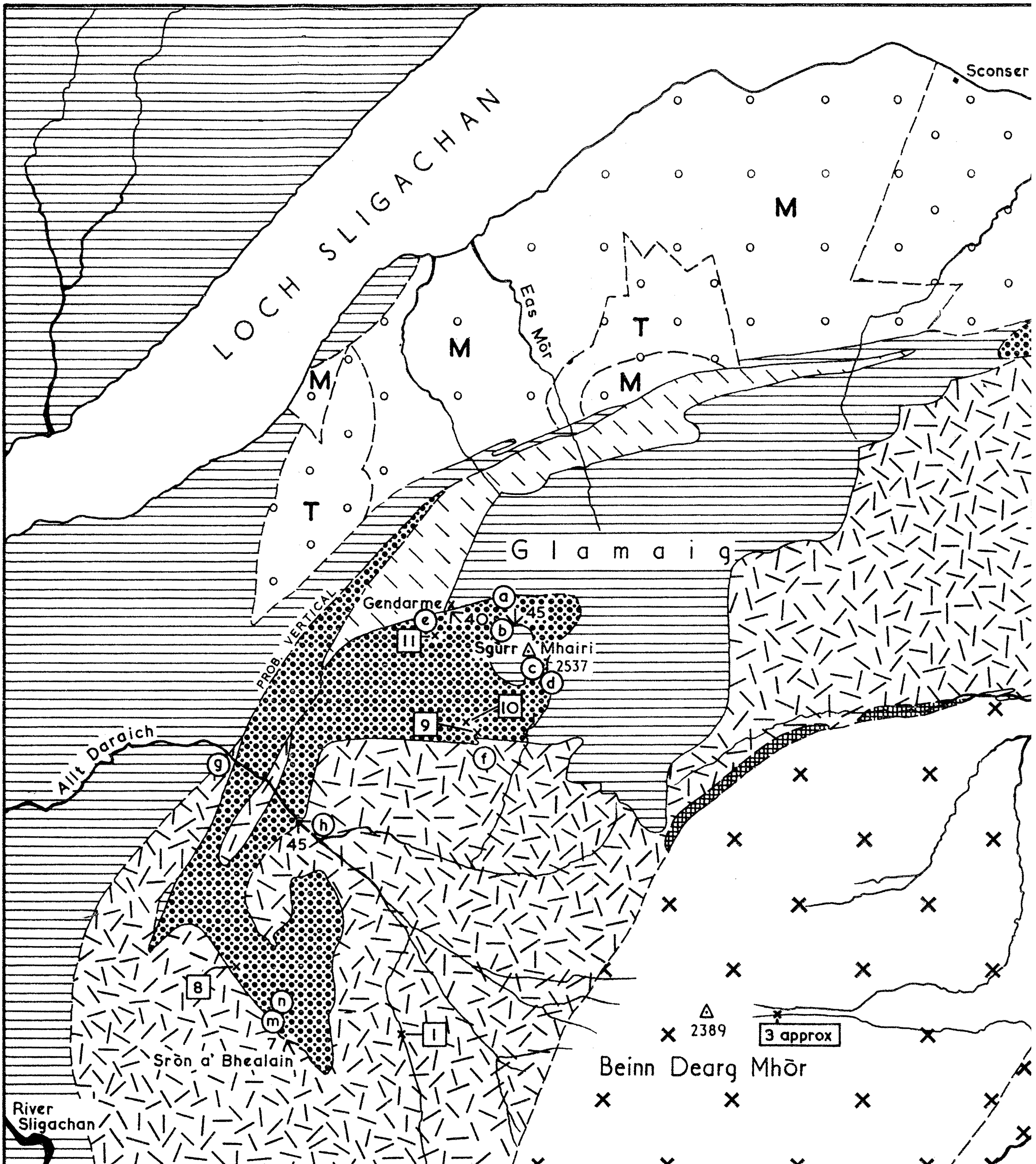
Richey, J. E., Stewart, F. H. & Wager, L. R. 1946 Age relations of certain granites and marscoite in Skye. *Geol. Mag.* **83**, 293.

Richey, J. E., Stewart, F. H. & Wager, L. R. 1947 Age relations of certain granites in Skye. *Geol. Mag.* **84**, 128.

Skelhorn, R. R. 1959 A study of some composite sills in Skye and Mull. Ph.D. thesis, University of London.

Tuson, J. 1959 A geophysical investigation of the Tertiary volcanic districts of Western Scotland. Ph.D. thesis, University of Durham.

Tuttle, O. F. 1952 Optical studies on alkali felspars. *Amer. J. Sci.* Bowen Volume, pp. 553–567.
Tuttle, O. F. & Bowen, N. L. 1958 Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$–$KAlSi_3O_8$–SiO_2–H_2O. *Geol. Soc. Amer. Mem.* **74**, 1–153.
Tuttle, O. F. & Keith, M. L. 1954 The granite problem: evidence from the quartz and feldspar of a Tertiary granite. *Geol. Mag.* **91**, 61–72.
Wager, L. R., Stewart, F. H. & Kennedy, W. Q. 1948 Guide to Excursion C14, Skye and Morar. *Int. Geol. Congr.* 18th Session.
Wager, L. R. & Vincent, E. A. 1962 Ferrodiorite from the Isle of Skye. *Miner. Mag.* **33**, 26–36.
Wilcox, R. E. 1944 Rhyolite-basalt complex on Gardiner River, Yellowstone Park, Wyoming. *Bull. Geol. Soc. Amer.* **55**, 1047–1079.



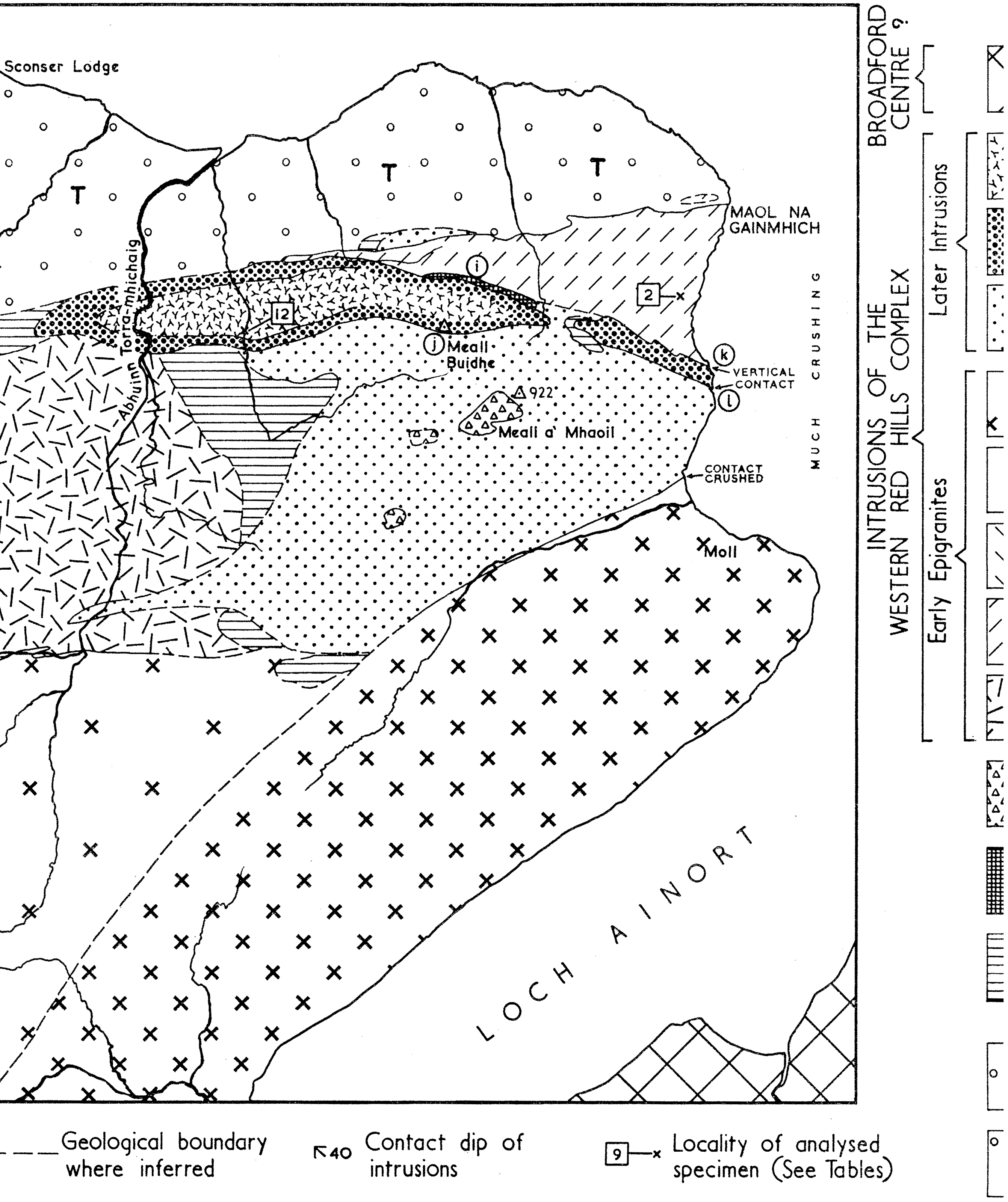
O ¼ ½ ¾ | MILE

0 500 1000 1500 2000 YARDS

Geological boundary where observed

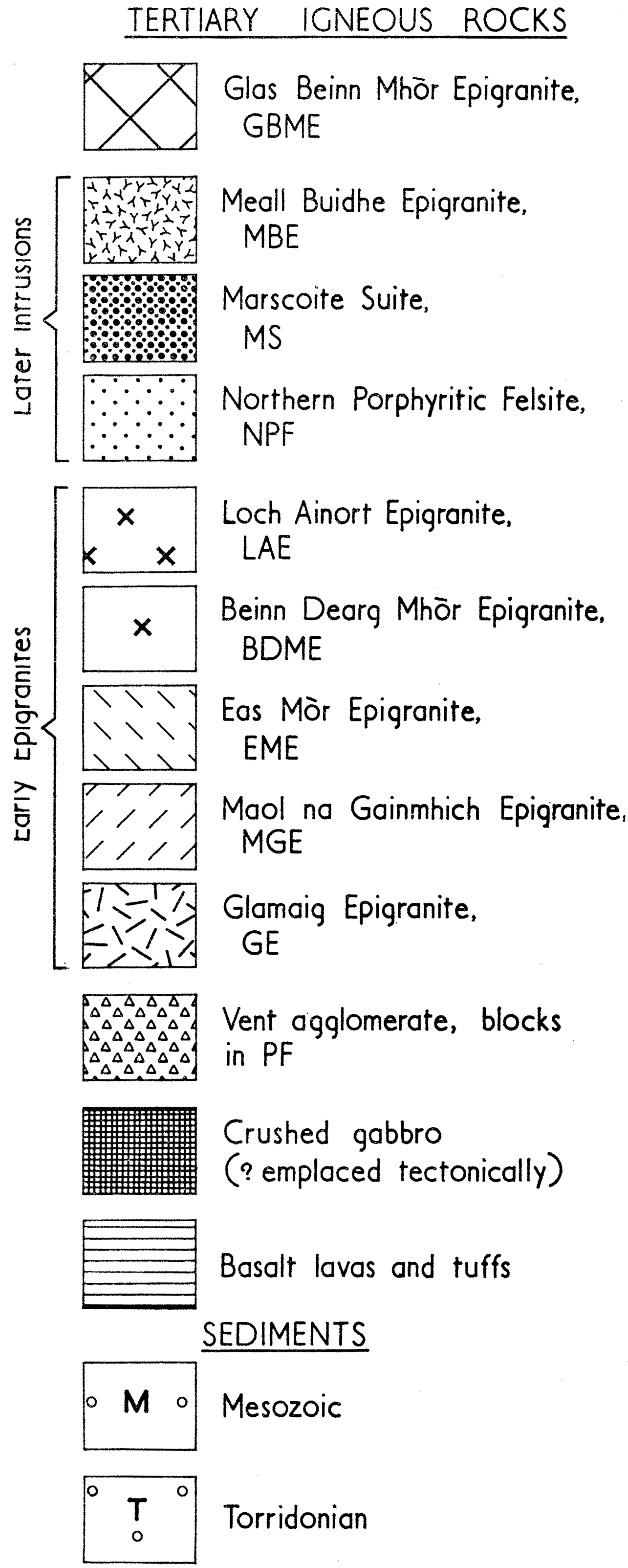
(Position of ends of traverses, shown in figure 22 are

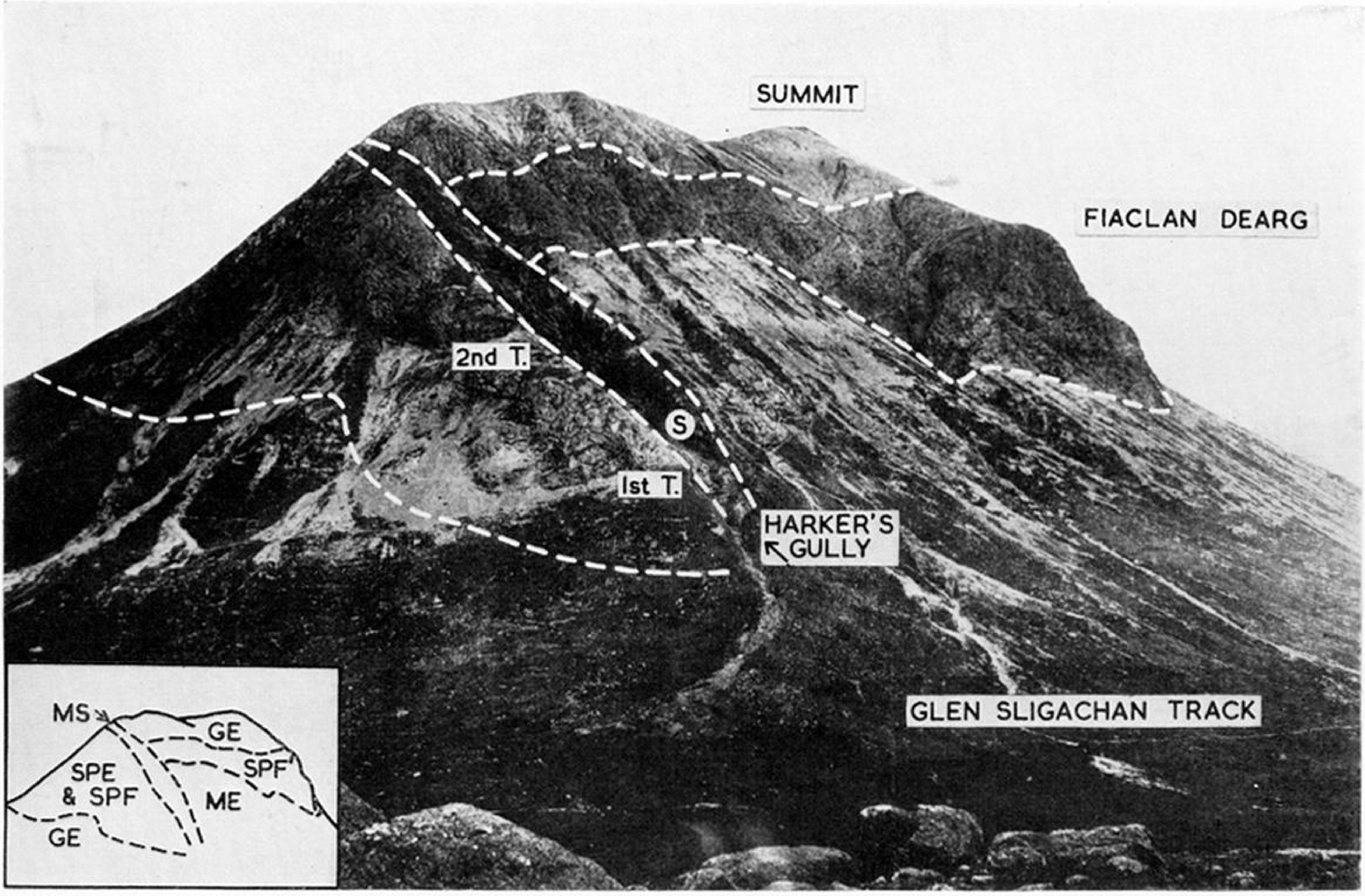
FIGURE 36. Geological ma



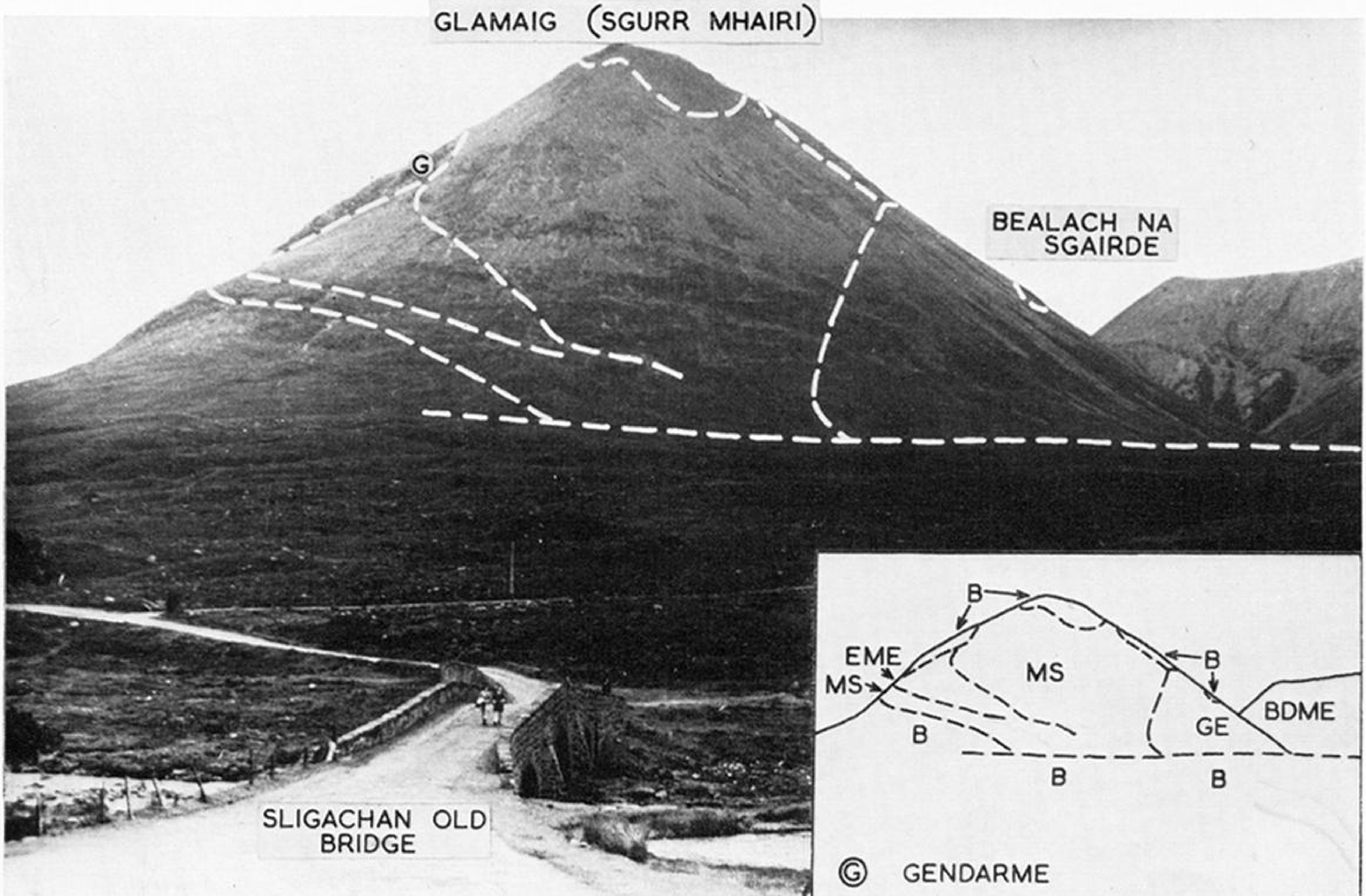
22 are indicated by letters e.g. (a) (b) etc.)

cal map of northern part of the Western Red Hills Complex, Isle of Skye.


TERTIARY IGNEOUS ROCKS
Glas Beinn Mhōr Epigranite, GBME
Later Intrusions
Meall Buidhe Epigranite, MBE
Marscoite Suite, MS
Northern Porphyritic Felsite, NPF
Early Epigranites
Loch Ainort Epigranite, LAE
Beinn Dearg Mhōr Epigranite, BDME
Eas Mōr Epigranite, EME
Maol na Gainmhich Epigranite, MGE
Glamaig Epigranite, GE
Vent agglomerate, blocks in PF
Crushed gabbro (? emplaced tectonically)
Basalt lavas and tuffs
SEDIMENTS
M
Mesozoic
T
Torridonian

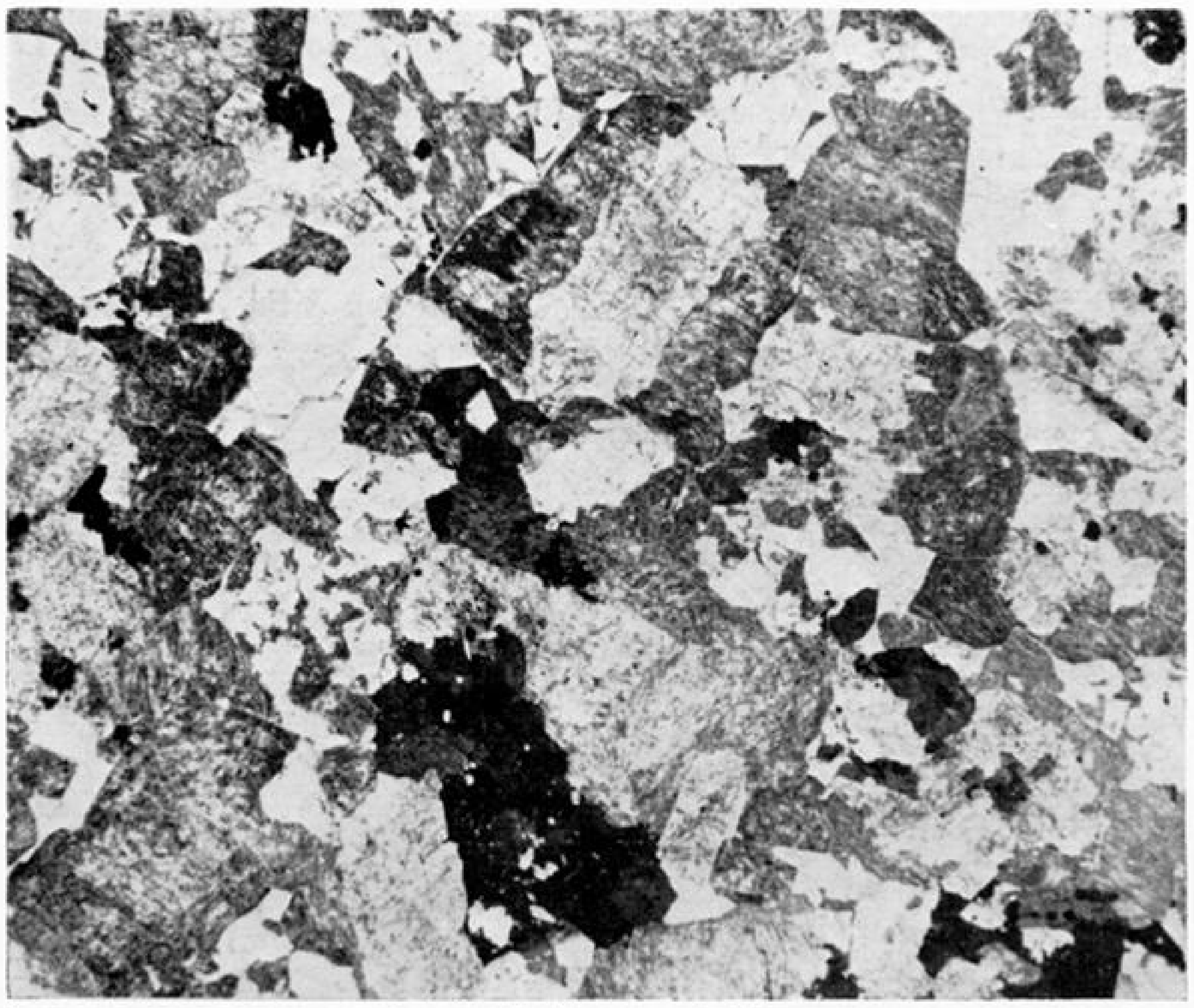

SUMMIT
FIACLAN DEARG
2nd T.
S
Ist T.
HARKER'S
GULLY
GLEN SLIGACHAN TRACK
MS
GE
SPE
& SPF
SPF
ME
GE

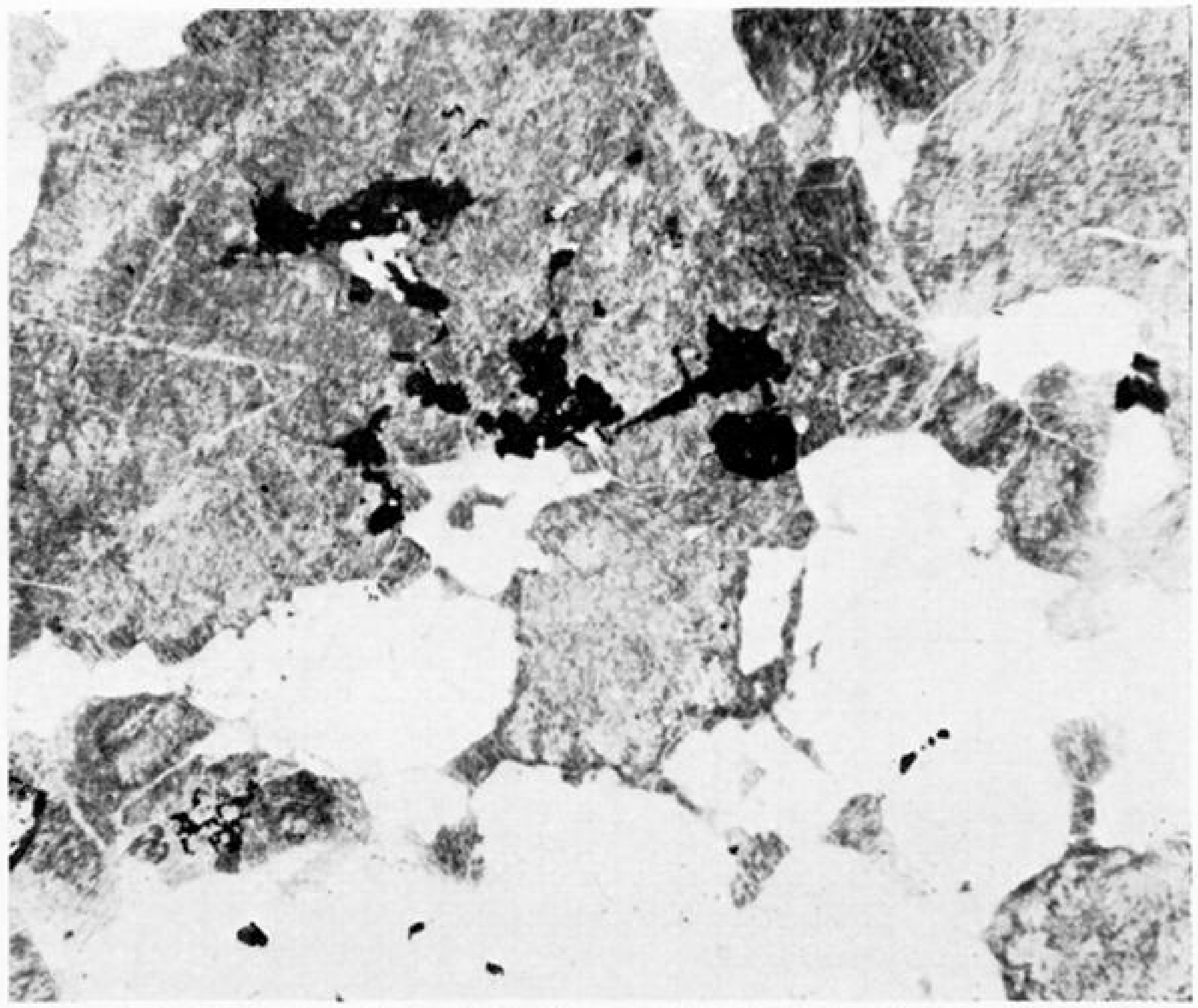
2


GLAMAIG (SGURR MHAIRI)
G
BEALACH NA
SGAIRDE
B
EME
MS
MS
B
B
GE
BDME
B
B
SLIGACHAN OLD
BRIDGE
G GENDARME

3

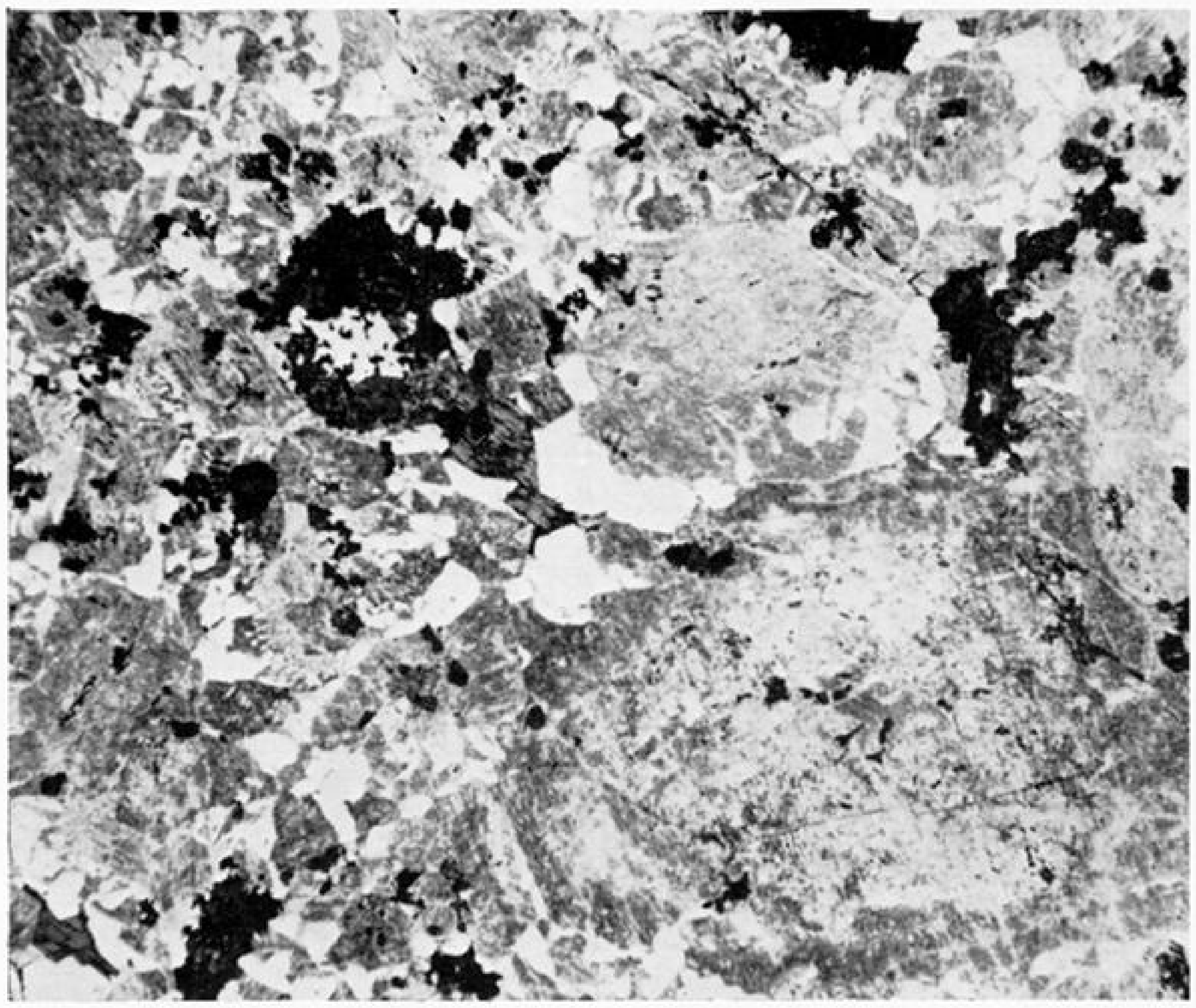
4

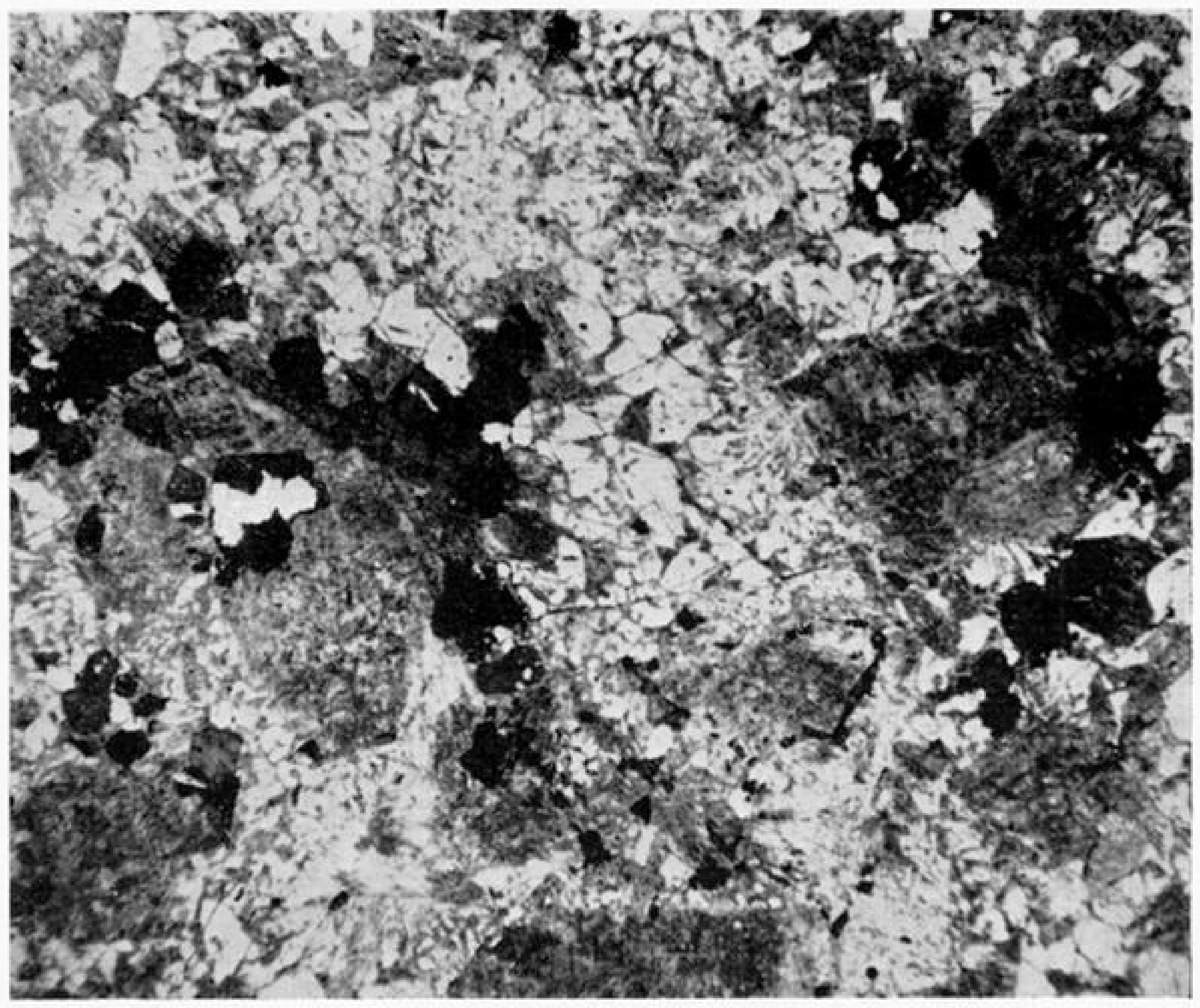




5

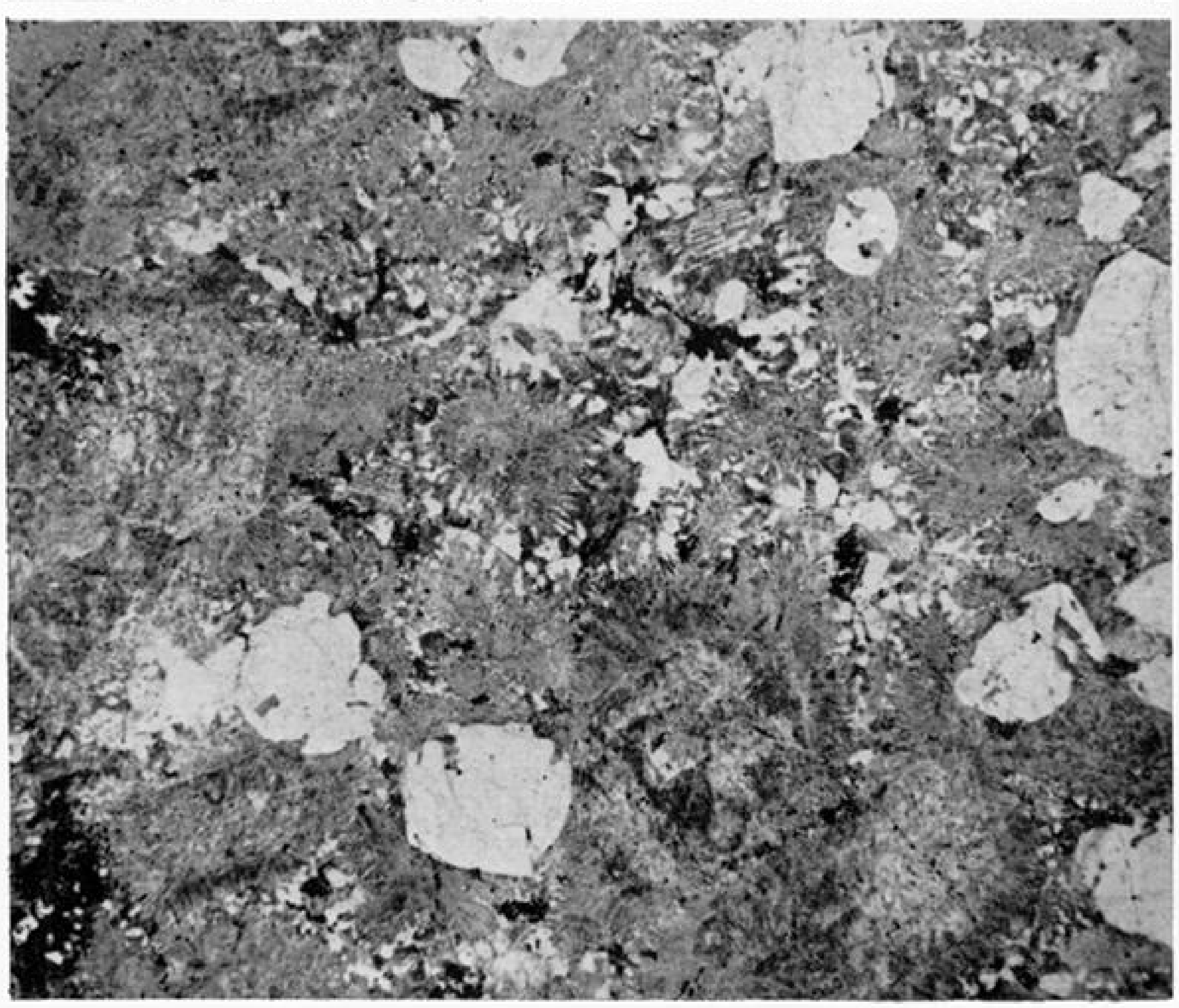
6

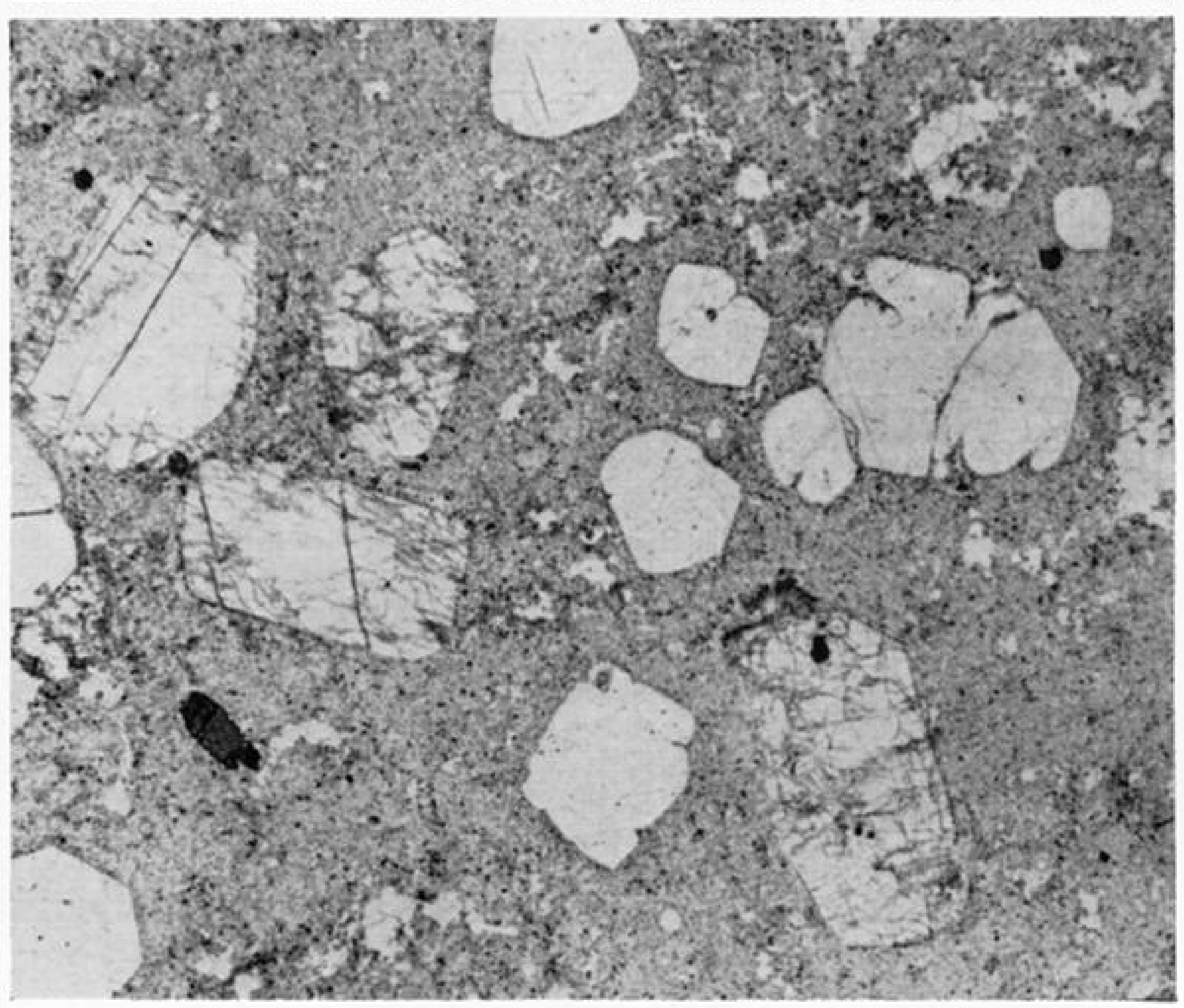




7

8



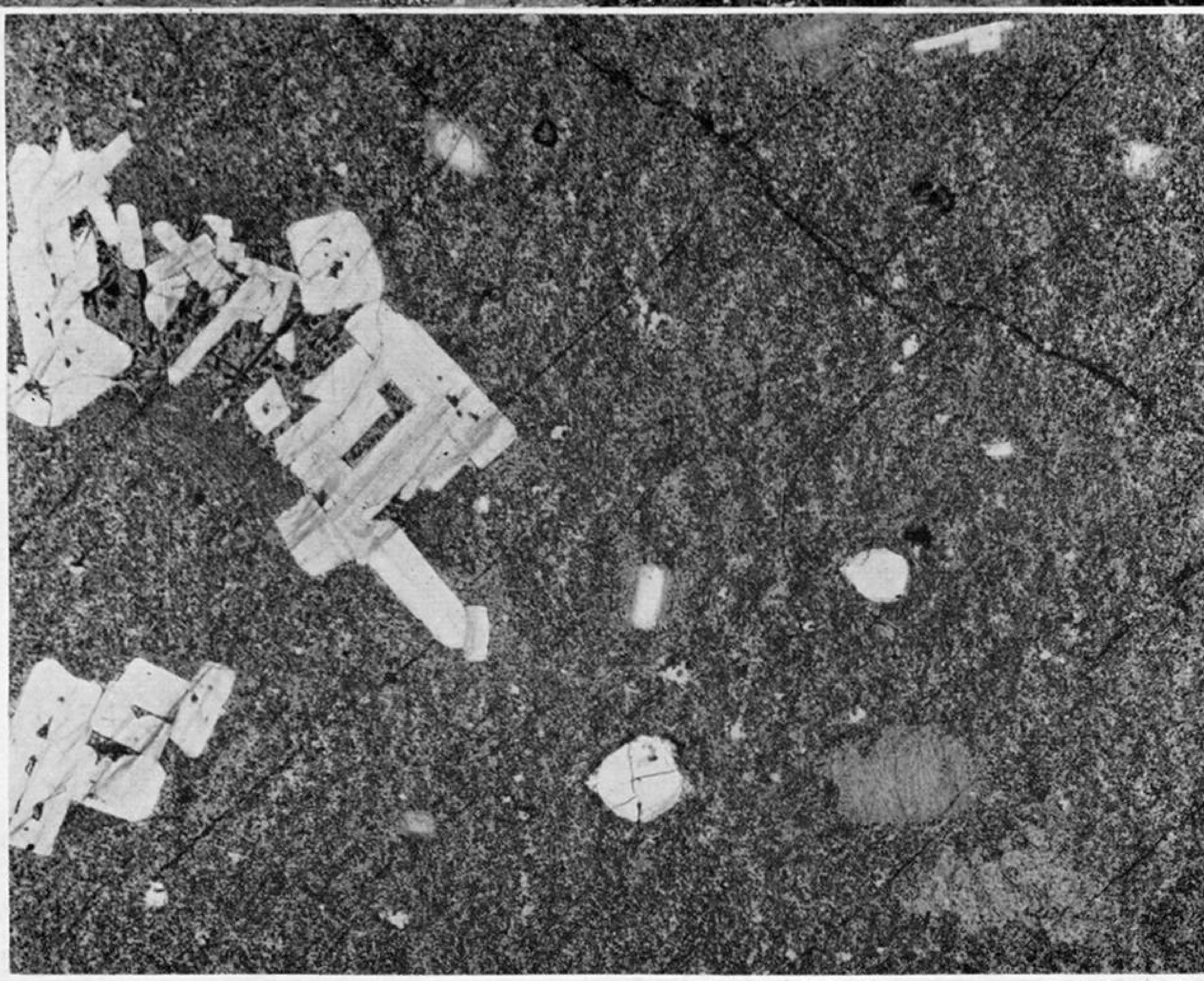


9

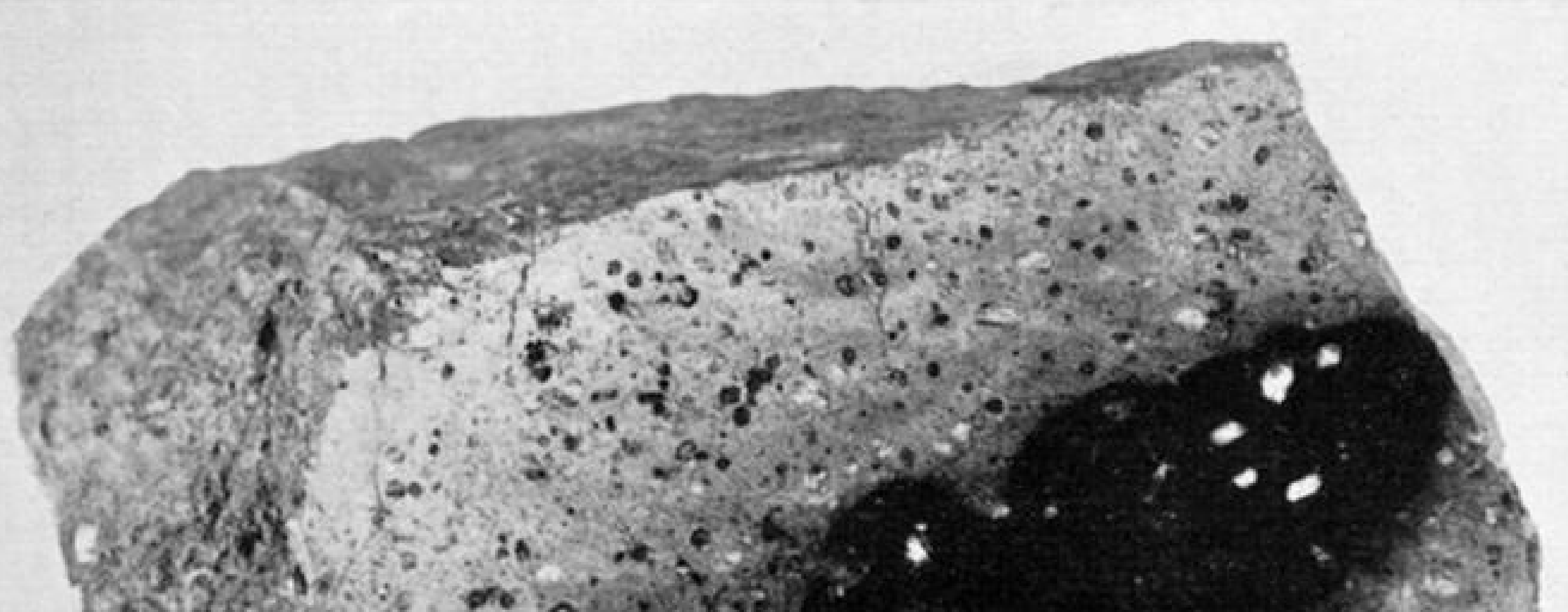
A B

11

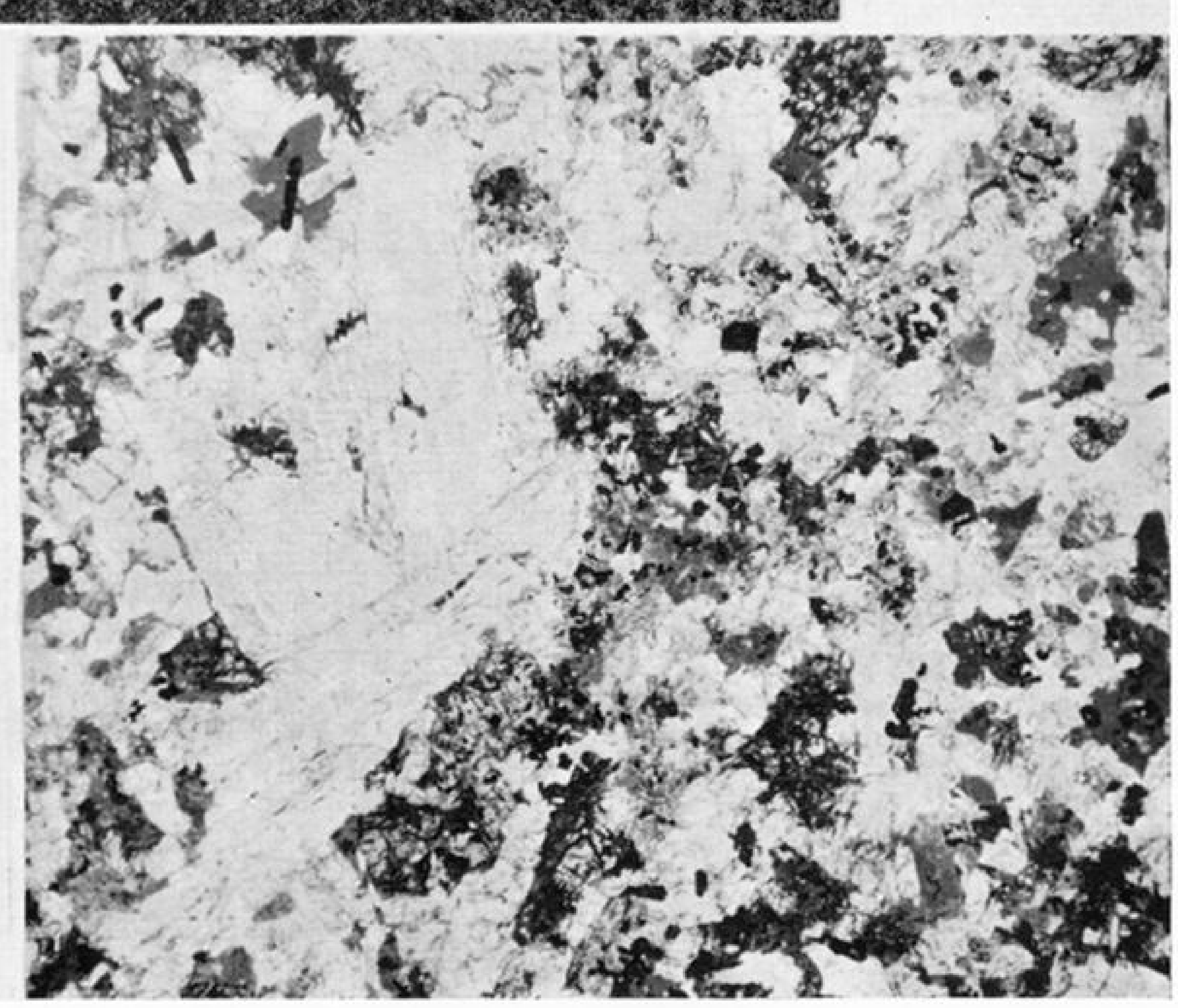
12

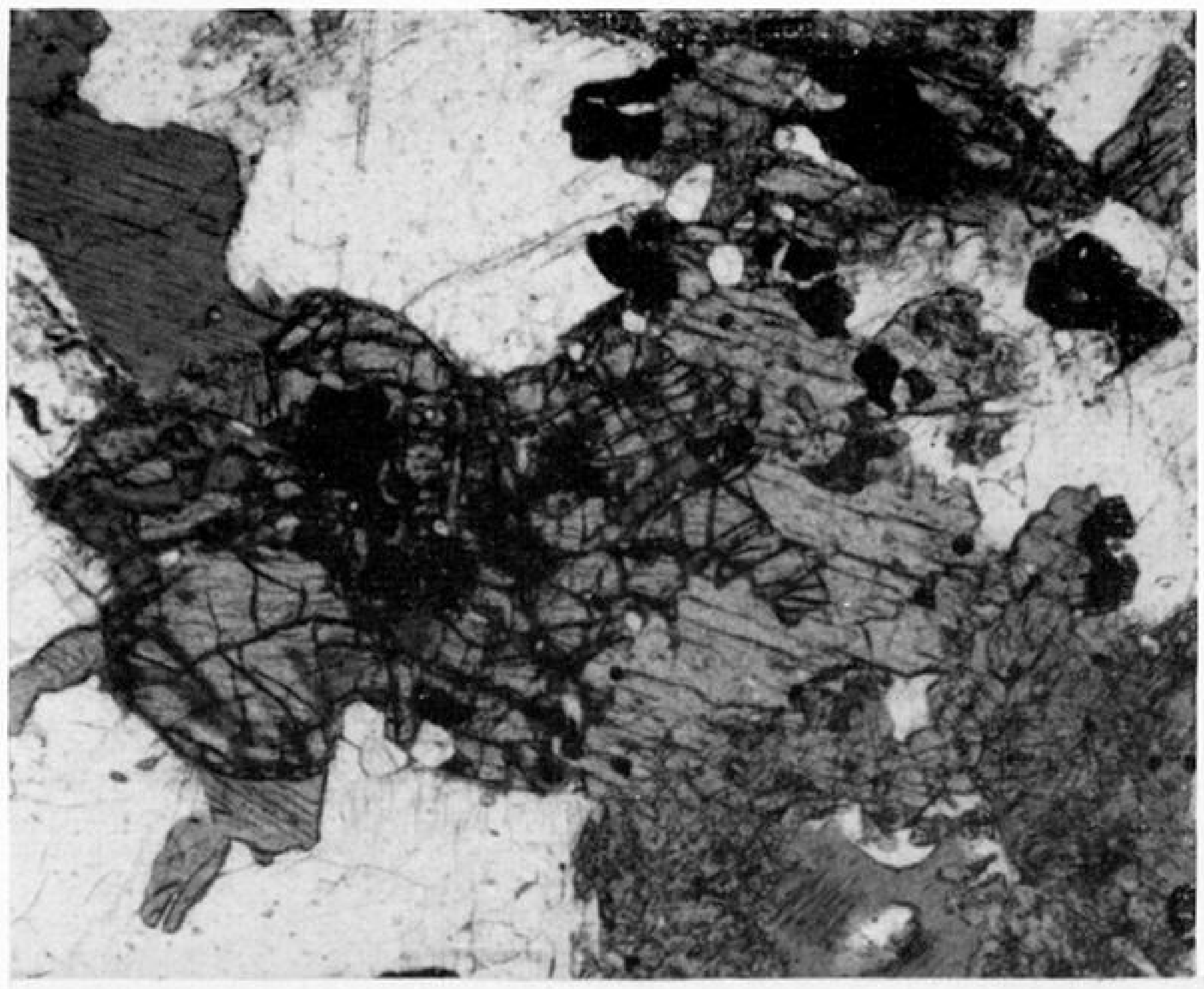


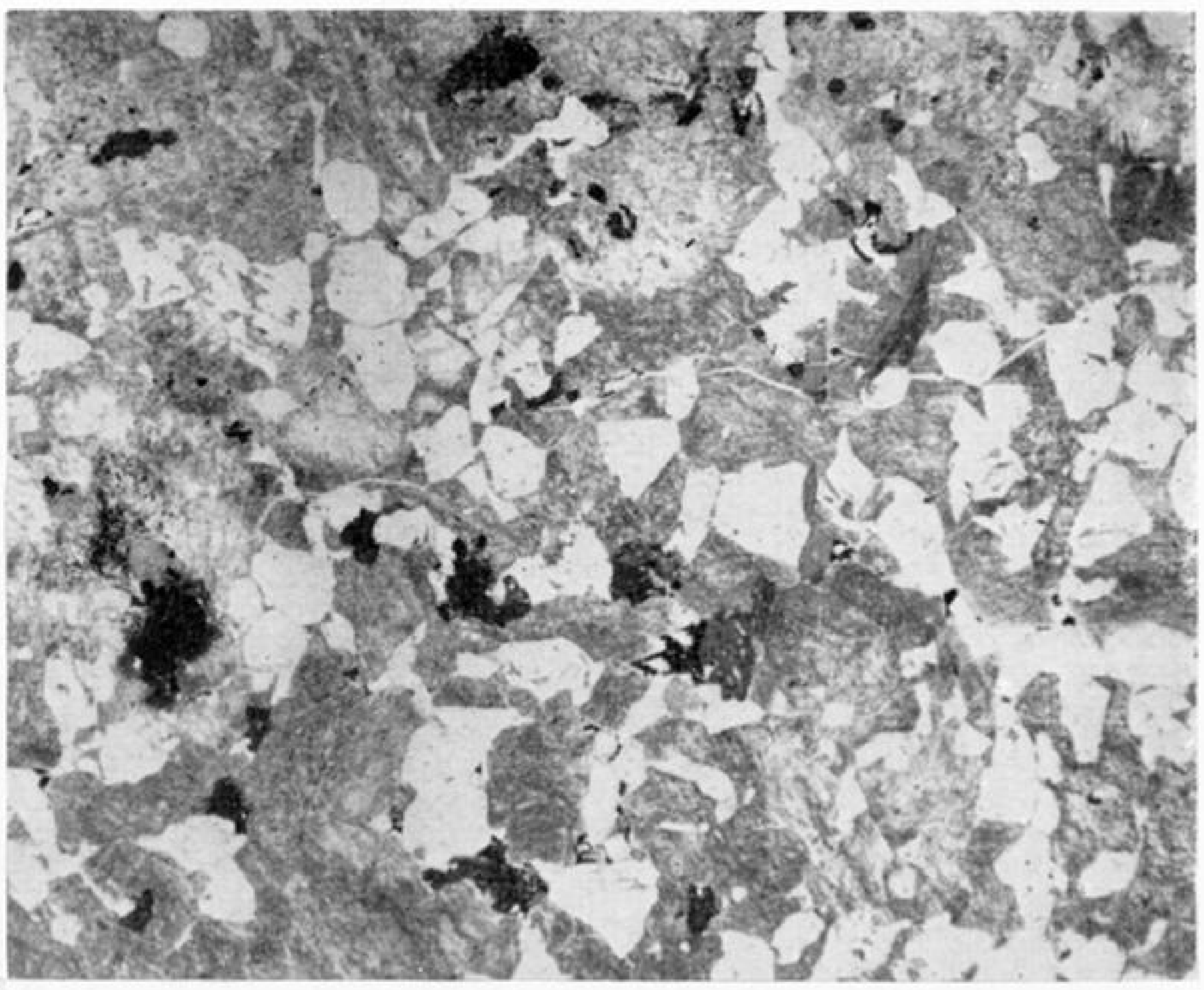
13

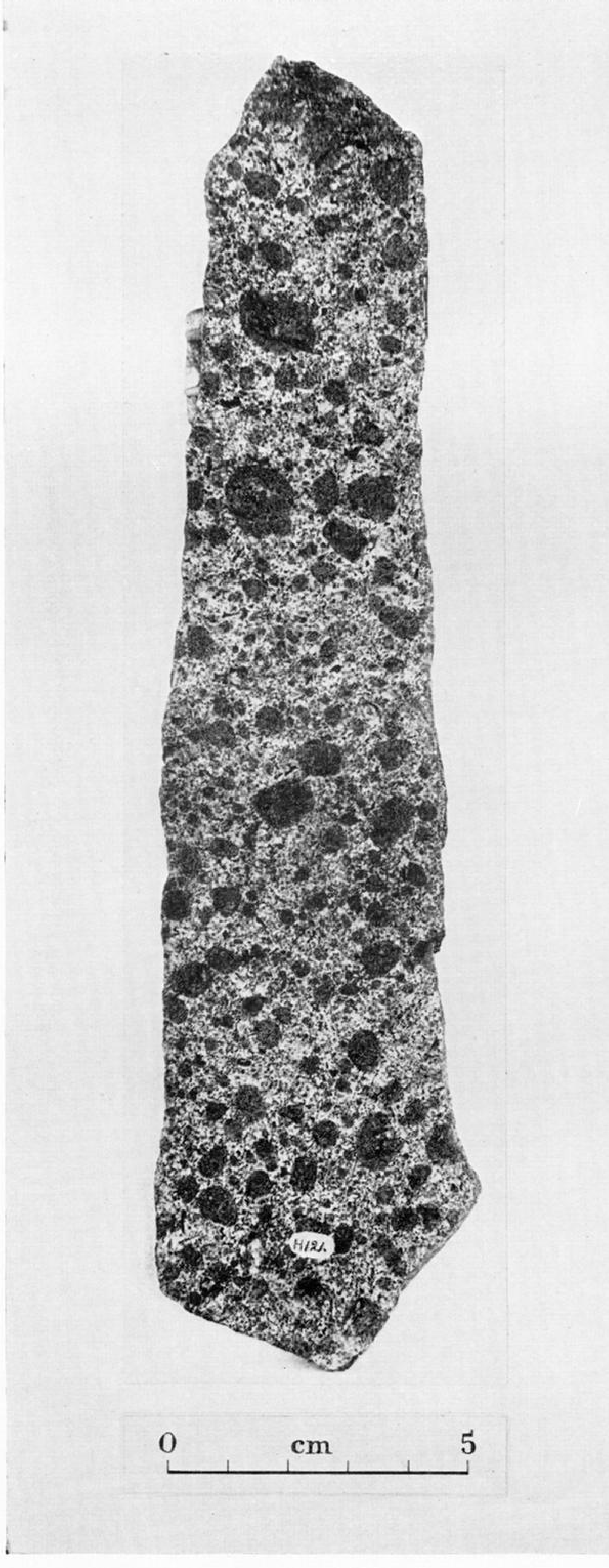


14

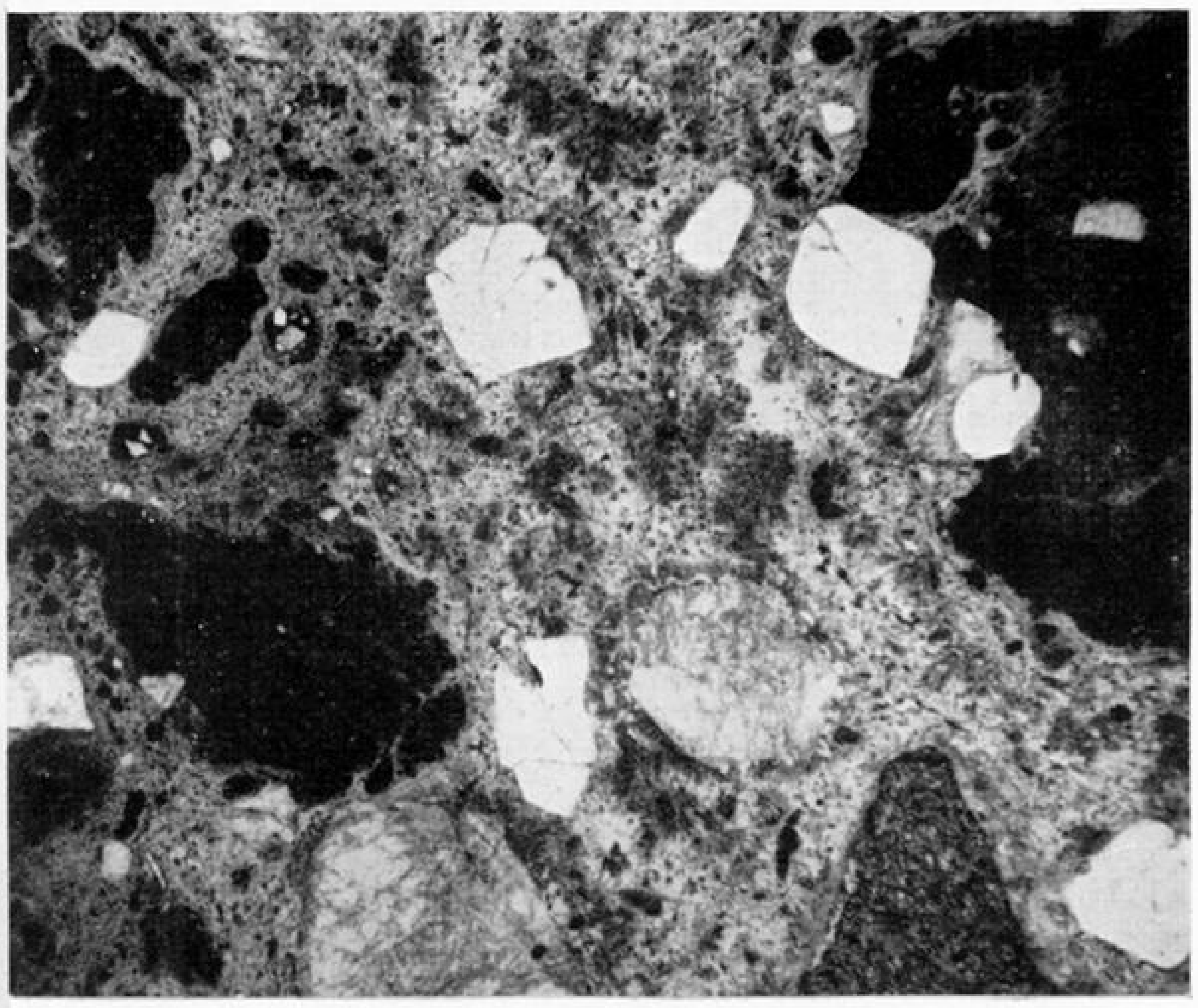


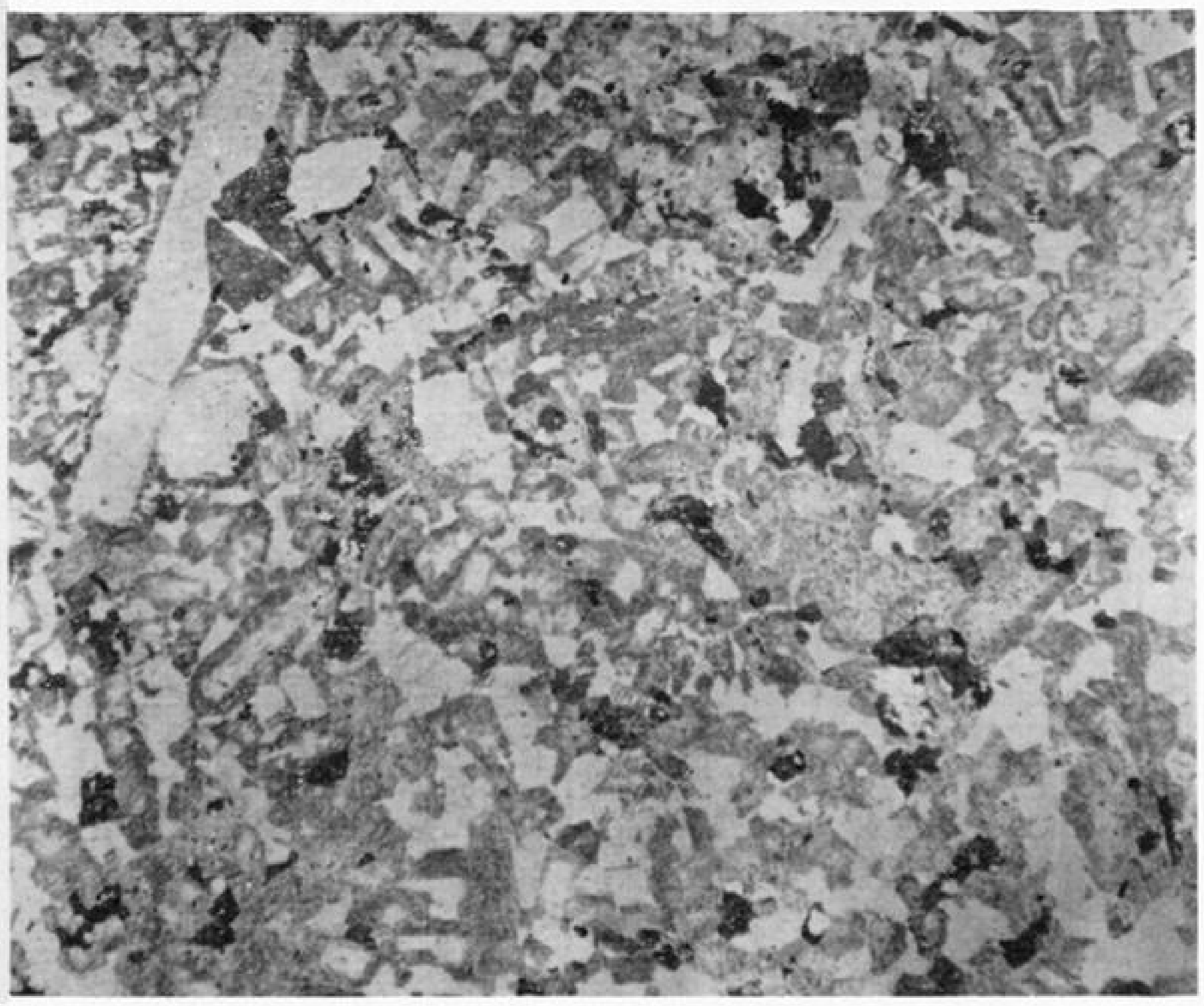

15

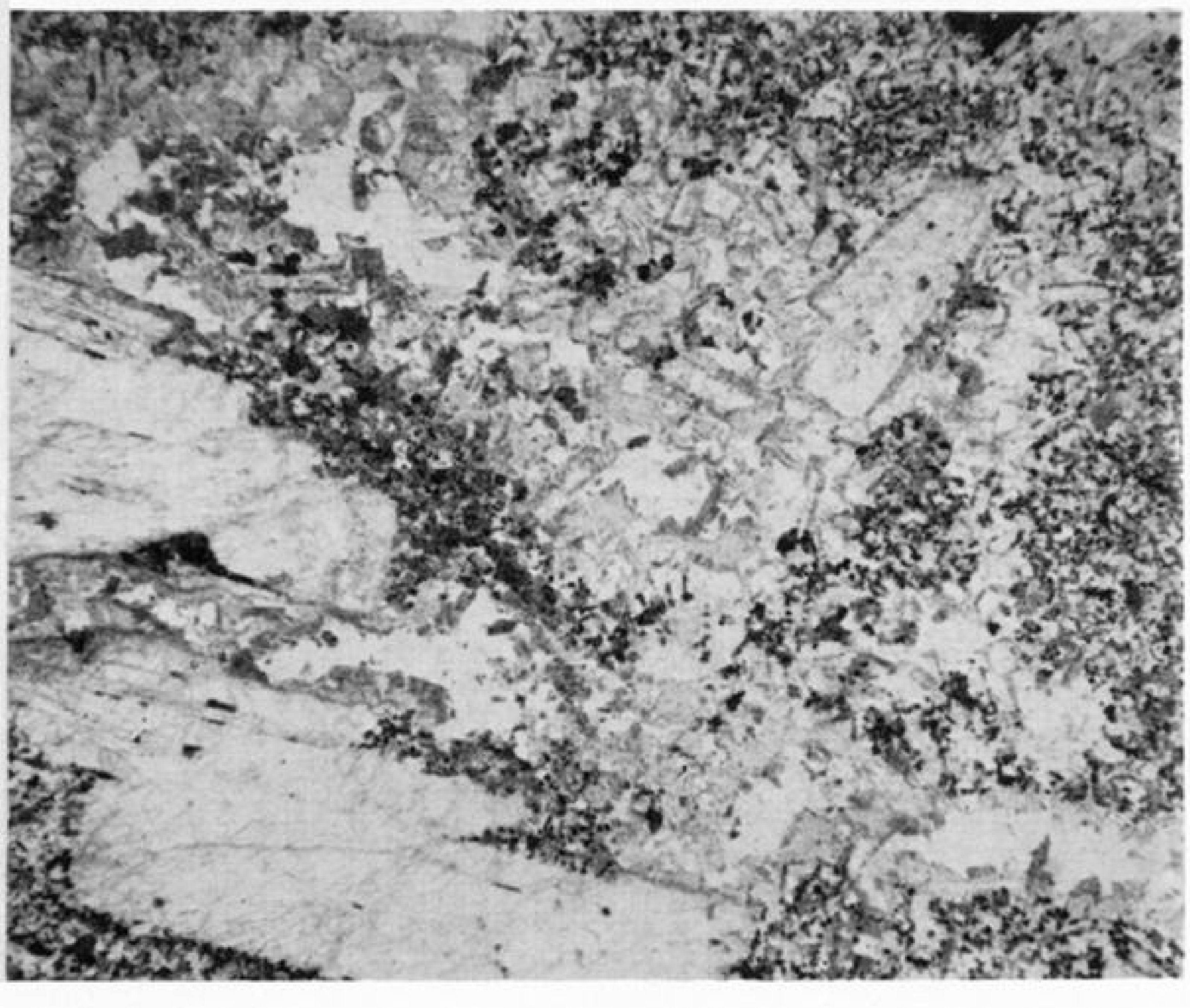

16

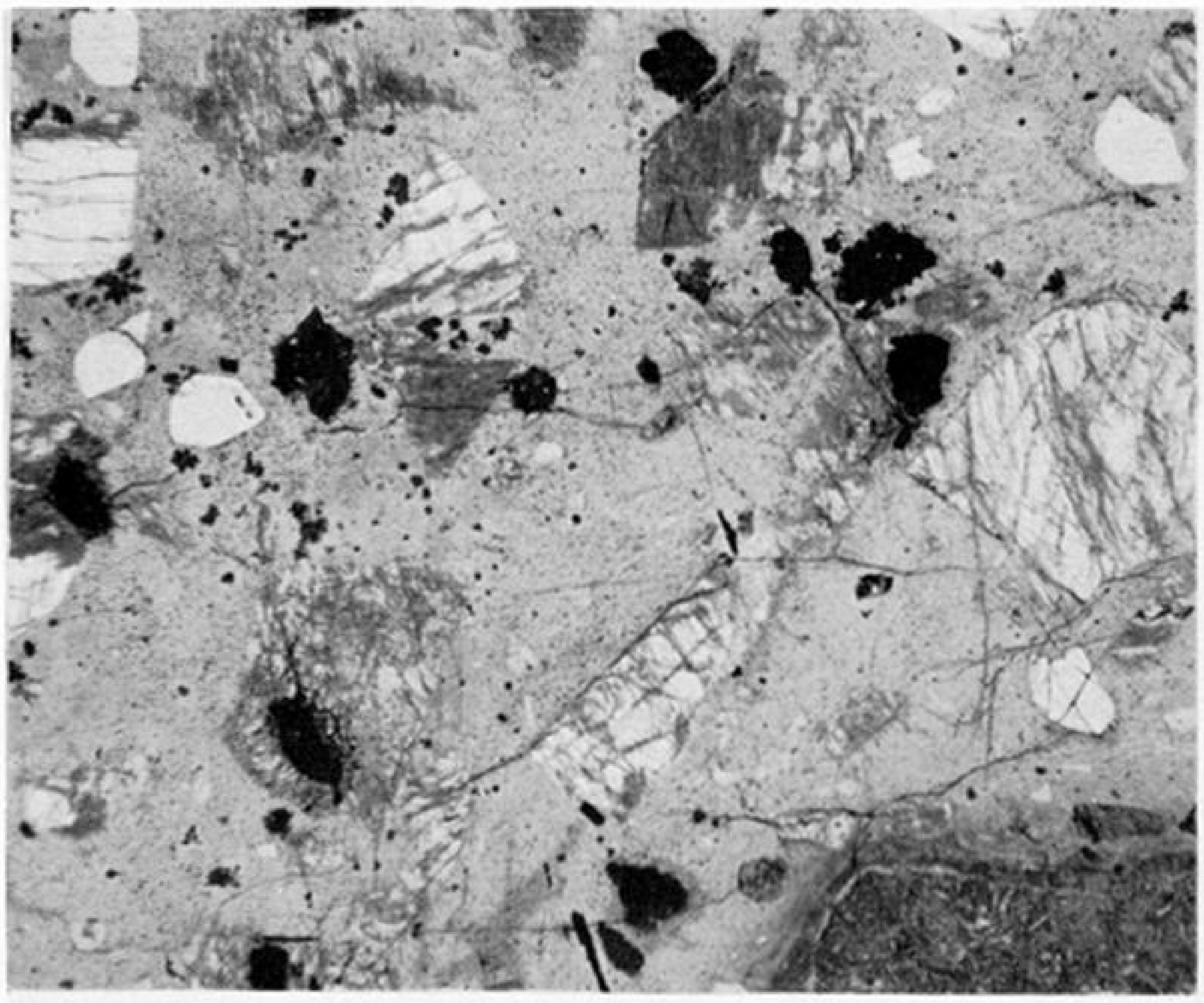


17

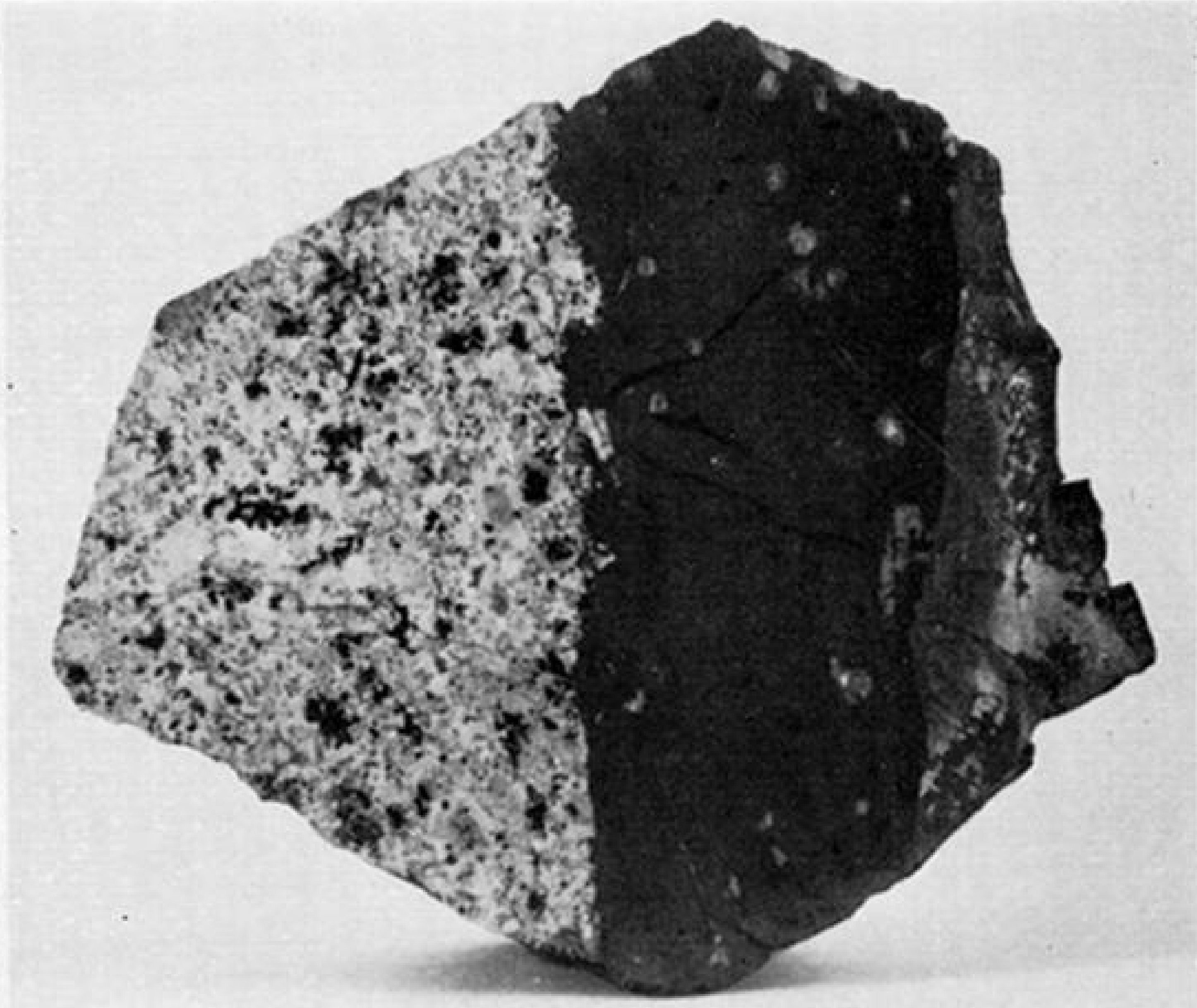

18


19


20



23

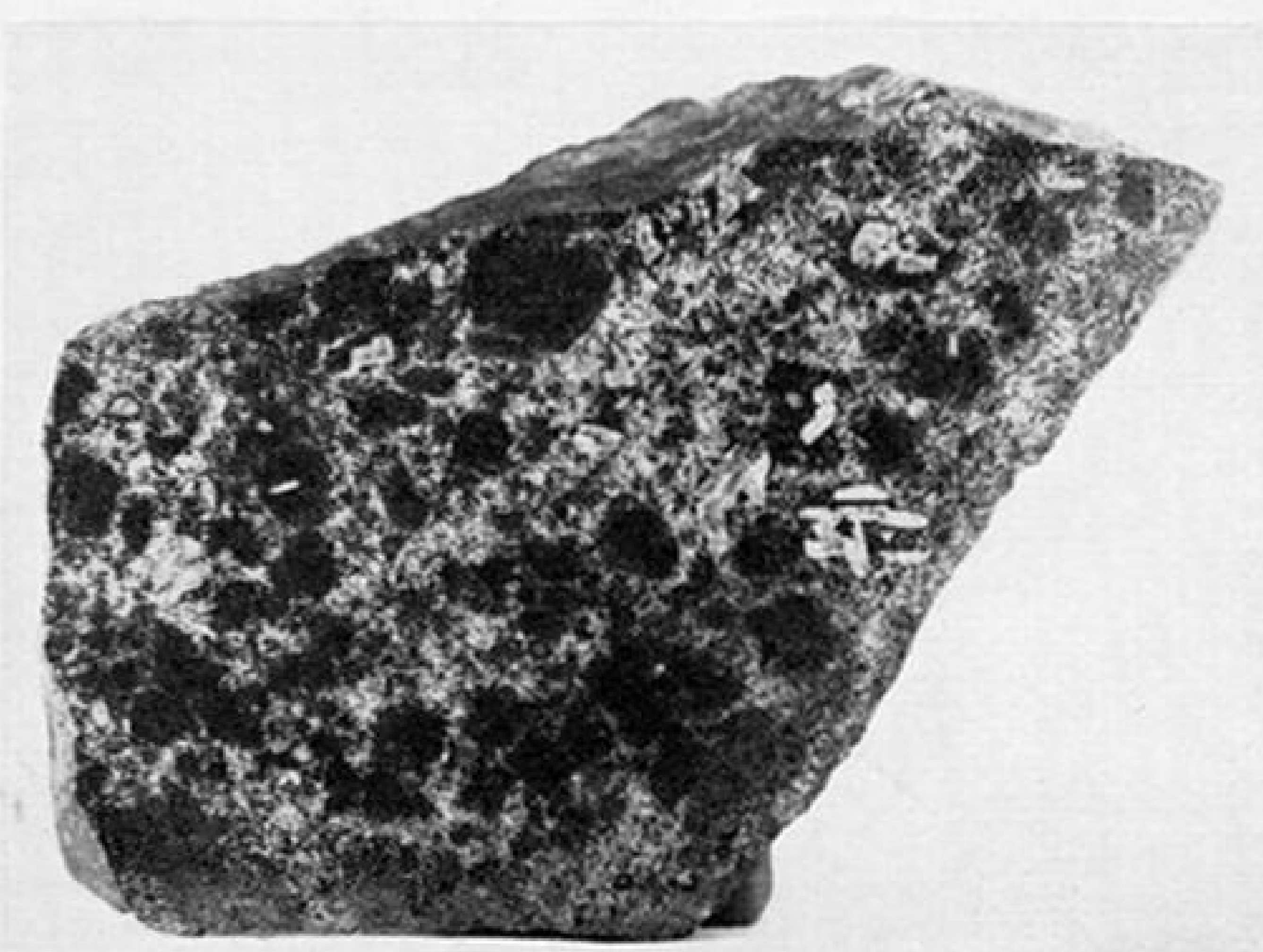


24

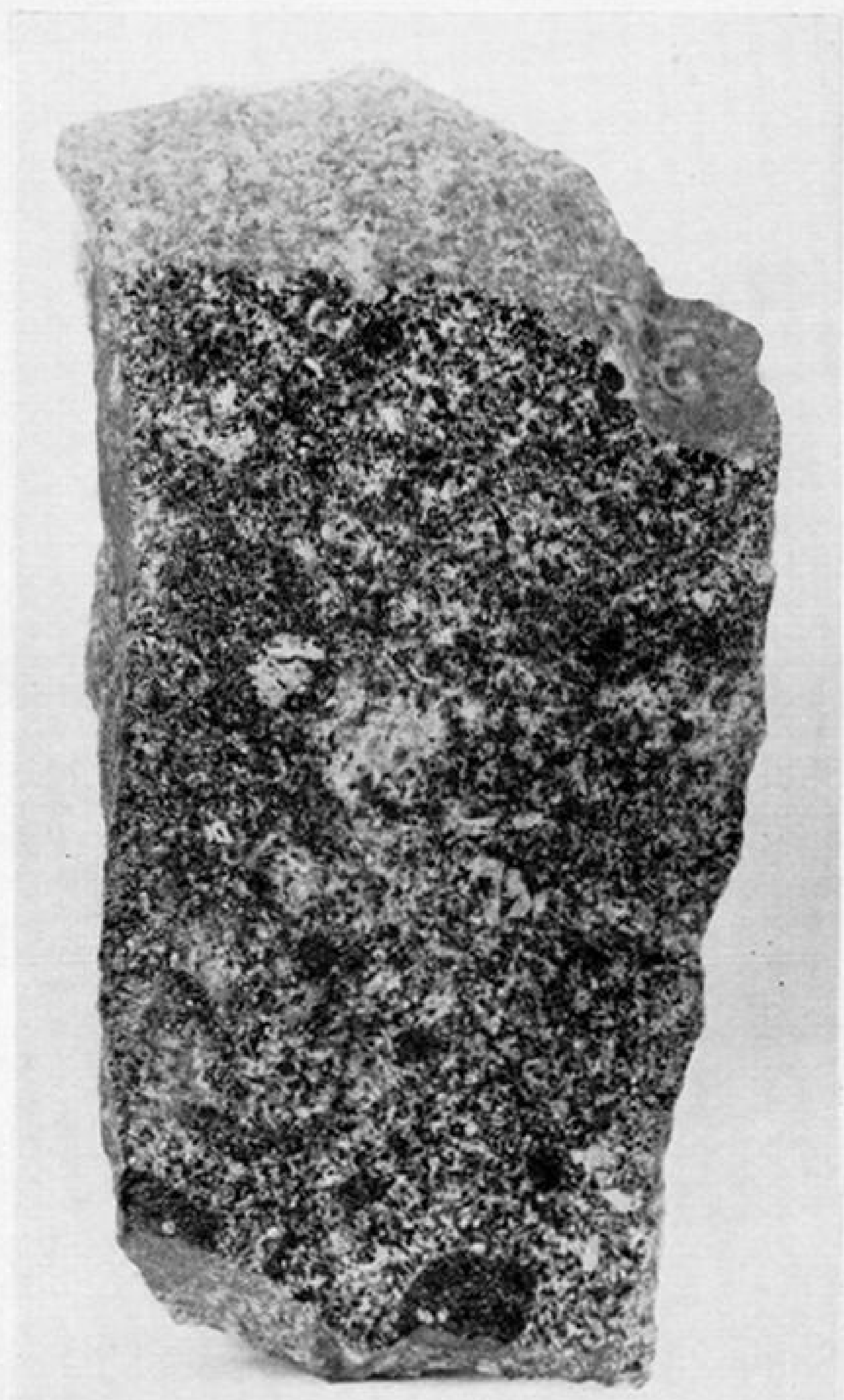
25

26

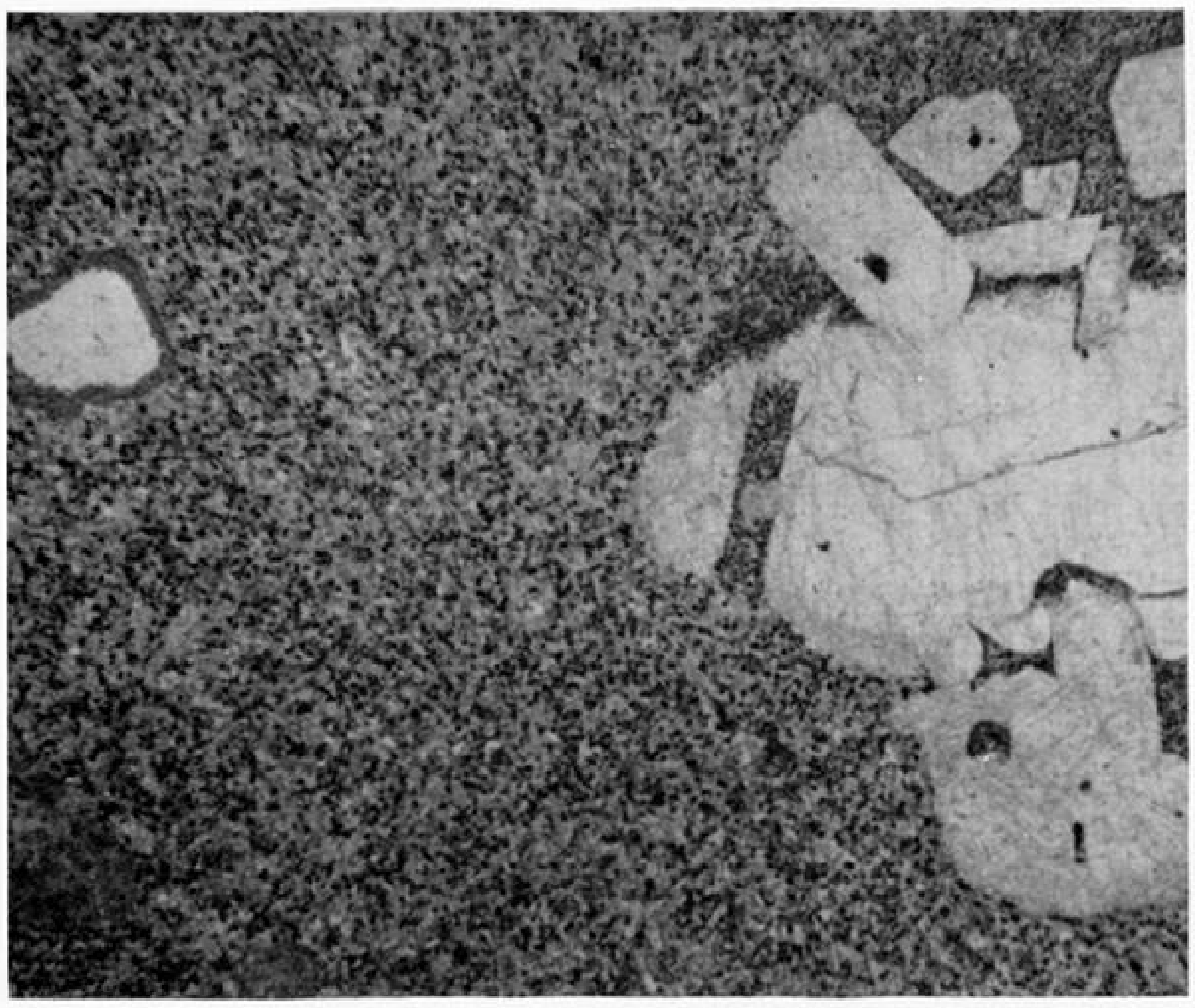
0 cm 5

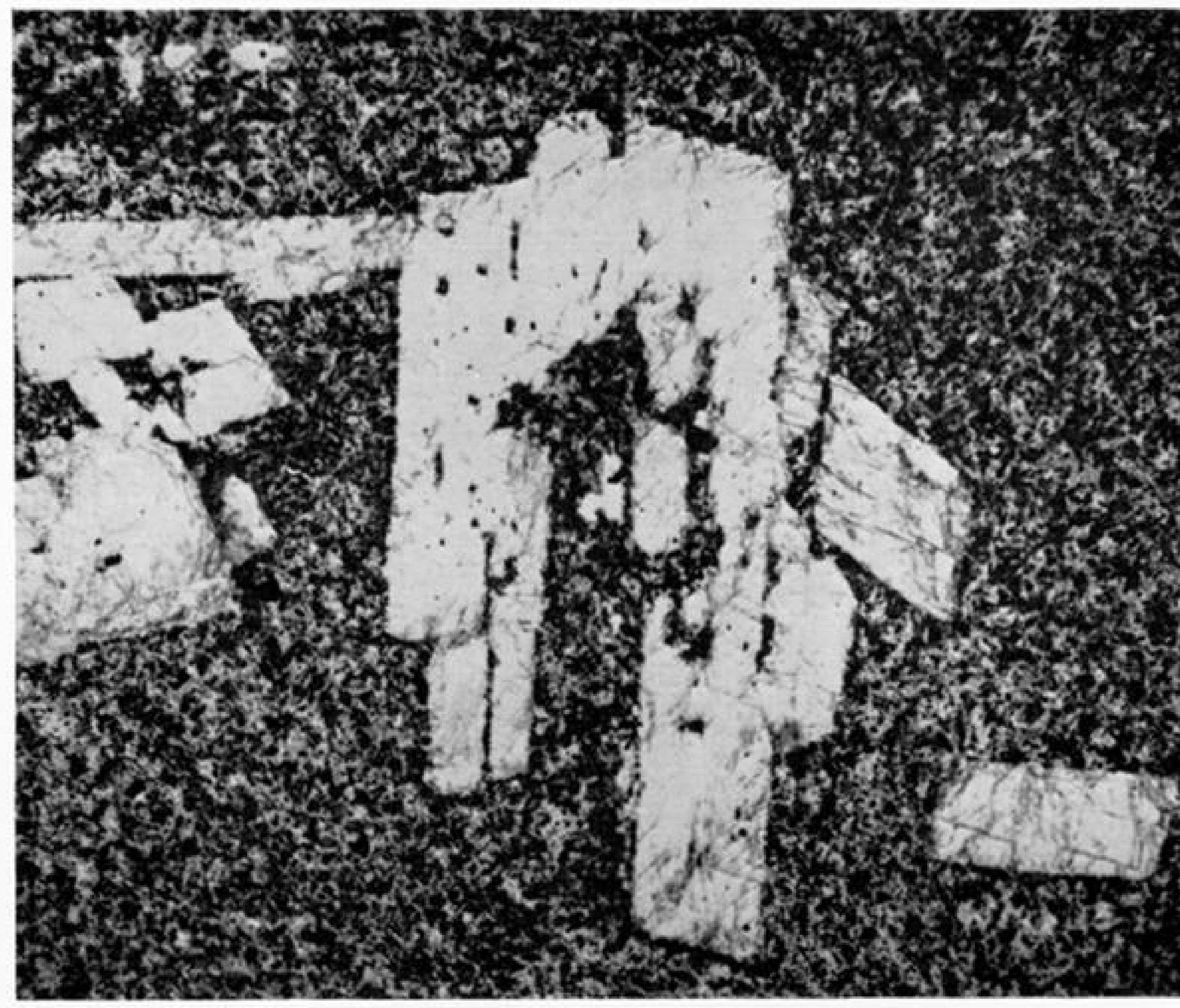


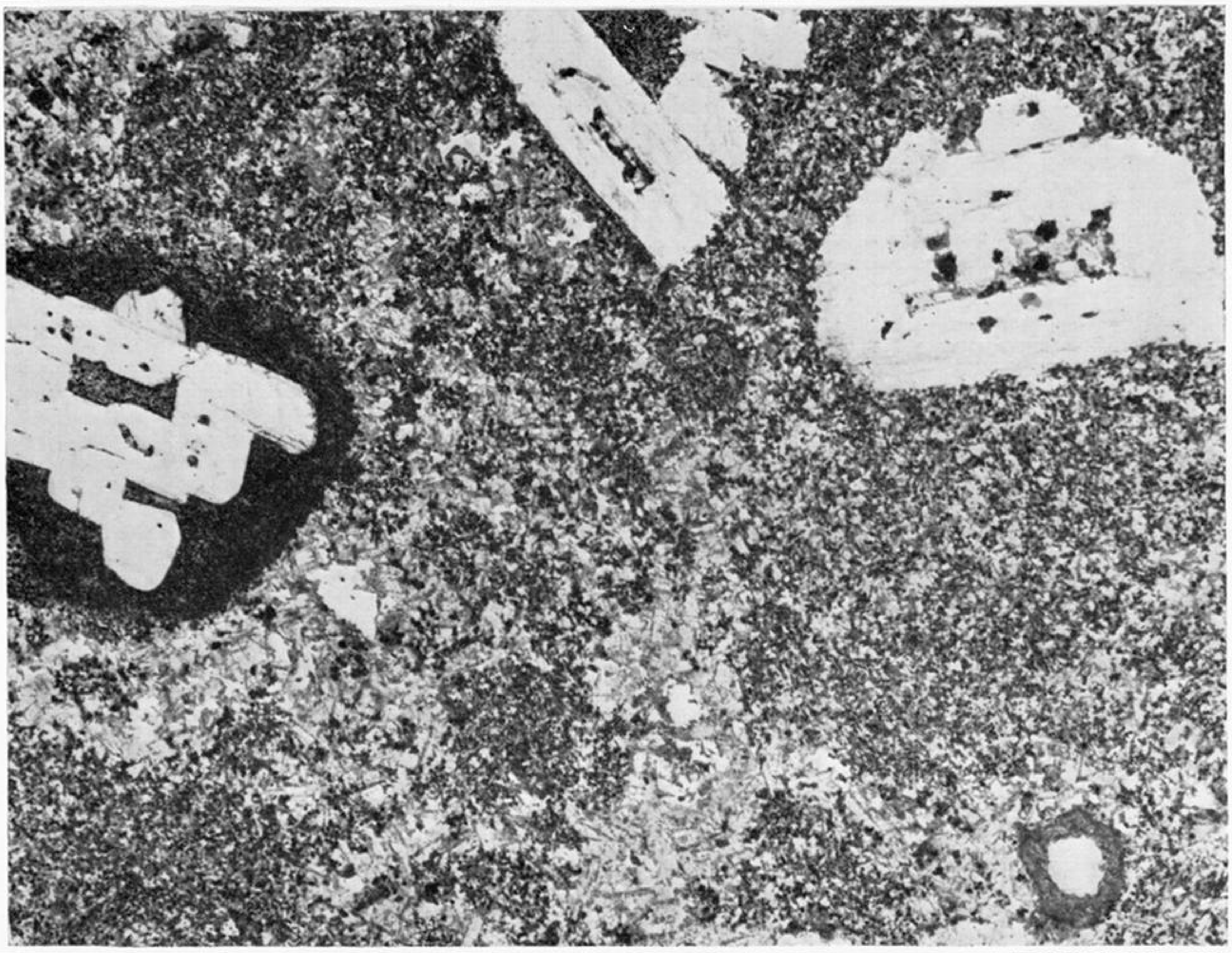
27

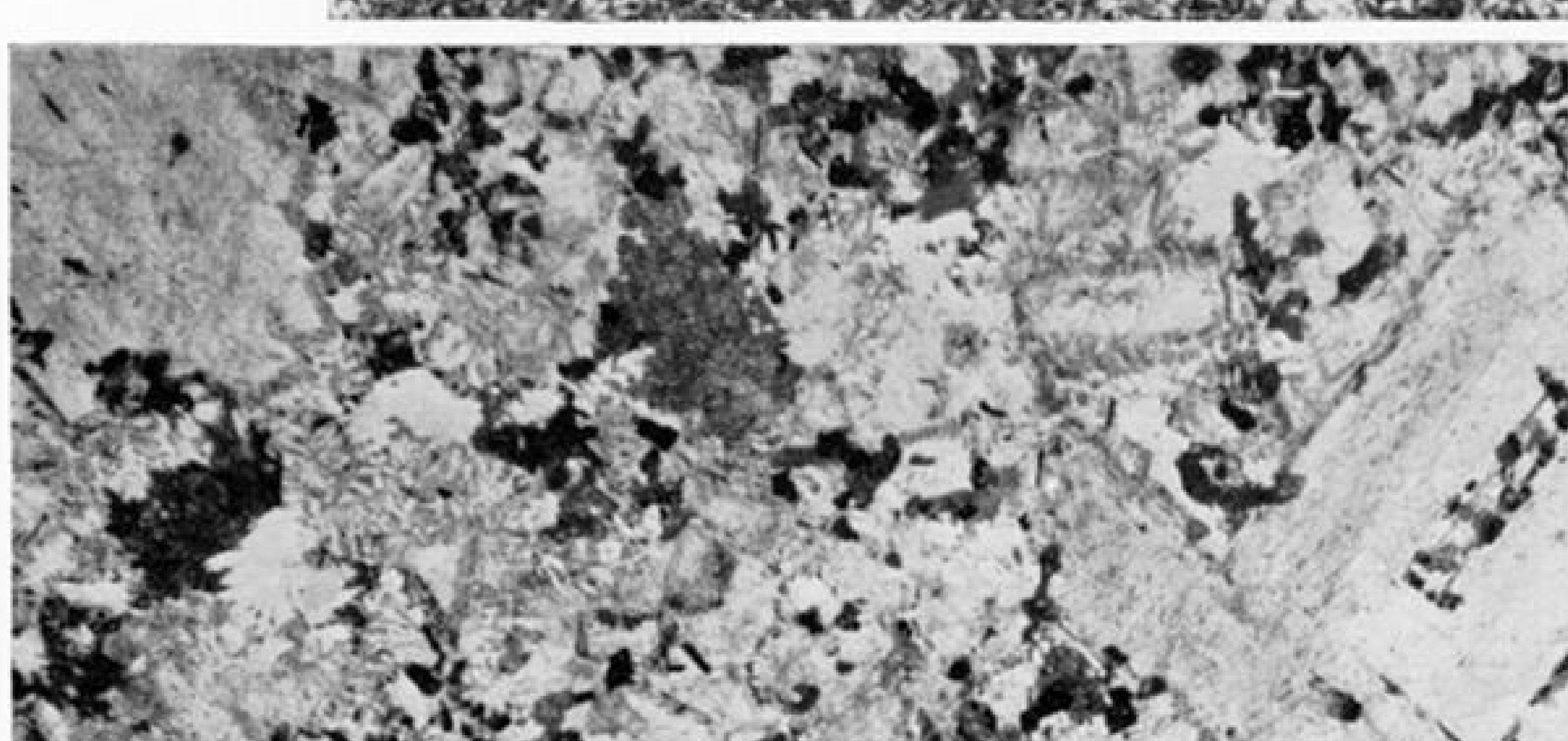


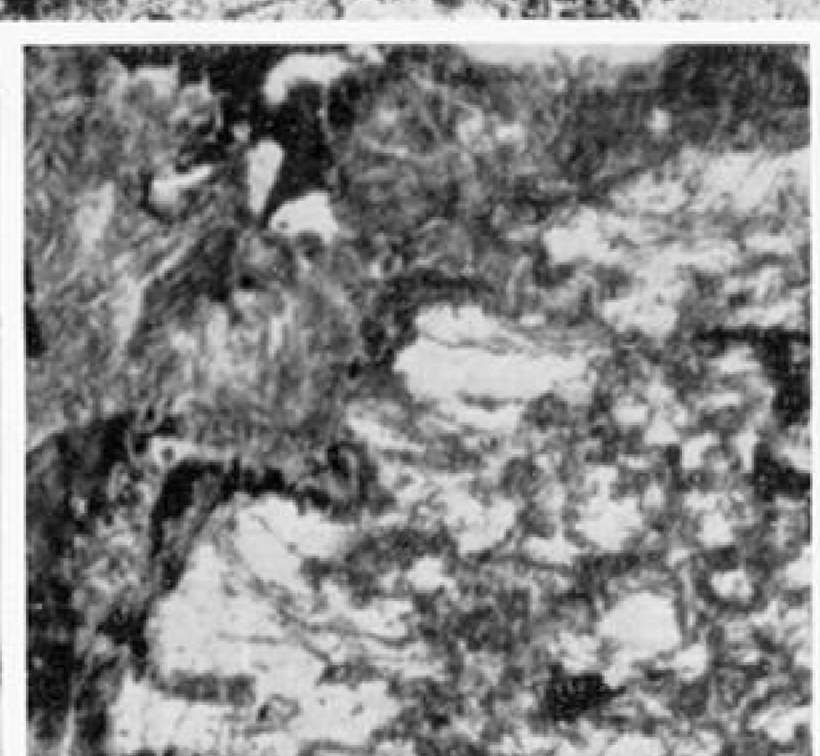
28

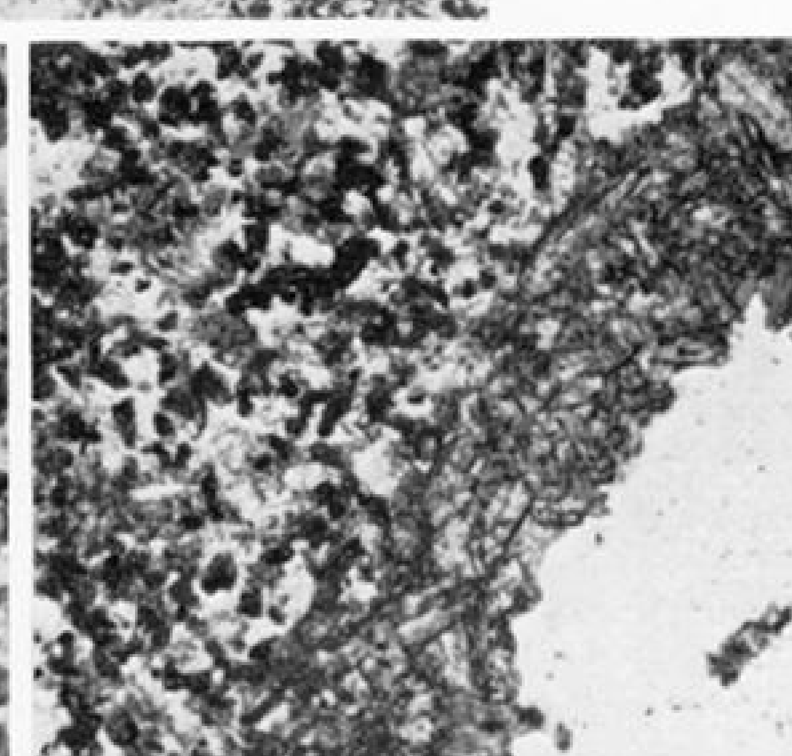

29


30


31


32


33


34

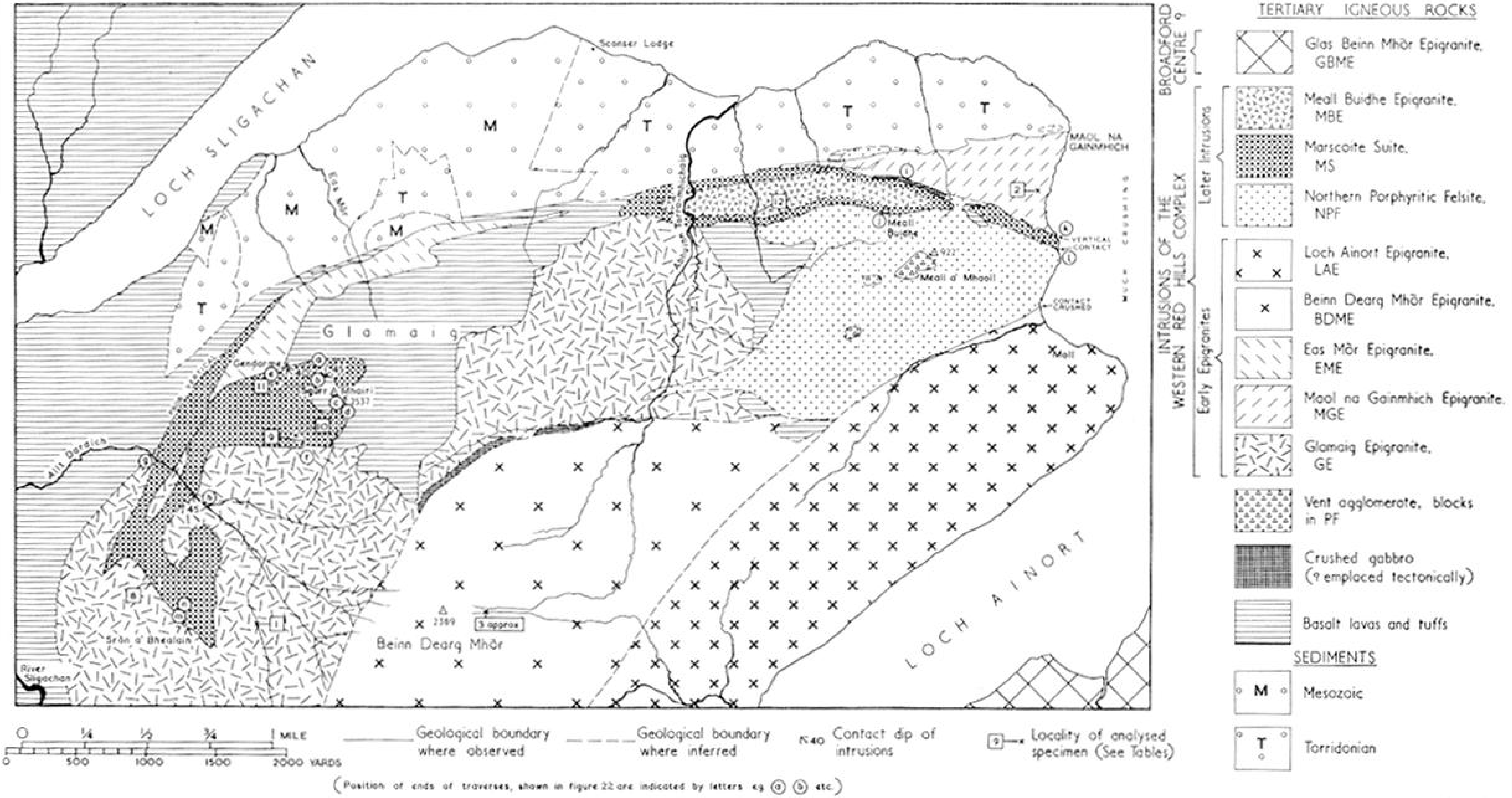


FIGURE 36. Geological map of northern part of the Western Red Hills Complex, Isle of Skye.