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ACID EFFUSIVE AND HYPABYSSAL ROCKS (FROM THE MORAINES)

BY
J. O. G. GLASTONBURY B.A., M.Sc.

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PART 4.

ACID EFFUSIVE AND HYPABYSSAL ROCKS

FROM

THE MORAINES.

BY

J. O. G. GLASTONBURY, B.A., M.Sc.

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ACID EFFUSIVE AND HYPABYSSAL ROCKS FROM THE MORAINES.

BY

J. O. G. GLASTONBURY, B.A., M.Sc.

I. INTRODUCTION.

THERE are several classes of felsites and porphyries in this collection. None of them, however, has glassy matter which has not devitrified but, on the other hand, practically every rock shows signs of more advanced metamorphism than mere devitrification. They fall into more or less well-defined groups,* viz., felsites, granophyres, quartz porphyries and entirely recrystallised rocks. There is, however, a tendency for the felsites to grade into the granophyres, and a tendency for each of these groups to grade into porphyries proper.

The reason, of course, is that the division into felsites and granophyres, in the one case, and porphyries and non-porphyries in the other is quite arbitrary. The felsites are here (as usual) taken to be those porphyritic rocks in which there is no residual hyaline base whatever and the granophyres are those felsites which exhibit the granophyritic texture, that is a definite kind of intergrowth of quartz and felspar. Now, in this group of rocks, at any rate, there are many clear evidences of grades of crystallization of the ground-mass. The most primitive is mere devitrification, where no recognizable mineral matter nor mineral forms are identifiable. The next is the development of a spherulitic texture where differences in mineral matter and in molecular and crystallographic nature are rendered evident by the very presence of the spherulites themselves. The third stage seems to be a production of granophyric texture in parts of the rock and frequently in association with (or at any rate accompanied by) the spherulitic texture. It frequently happens, then, that all three stages are present in the one specimen, and, in consequence, the name given to the rock depends on the relative proportions of these structures. The irregular outlines and the relatively large part of the rock occupied by such structures makes any micrometric measurement practically valueless as far as statistical work is concerned, and so the division into felsites and granophyres is, as has been said above, quite arbitrary.

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*The rocks here classified in broad and general terms, based primarily on their physical characters, undoubtedly include representatives of both alkali and calc-alkali types of magma. But as no chemical analyses have been undertaken, and as the chemical nature of such partially crystalline rocks is not completely ascertainable from the microscopic study, no allocation of the rocks to alkalic or calcic subdivisions has been attempted. Nevertheless, it will be evident from the descriptions which follow that a considerable range in this regard is represented, leaving no doubt that, with fuller chemical data, representatives of all these divisions, namely, rhyolites, toscanites and dacites, would be demonstrated. [ED.]

There is not the necessity so fully to elaborate the reasons why the terms granophyre, felsite and porphyry are arbitrary. The last term is used to denote those rocks whose ground-mass is composed of identifiable mineral matter. It follows that the more usual mode of occurrence of porphyries (defined in this way) is as hypabyssal rocks, but this is not an exclusive criterion. It is clear that those agencies which brought about devitrification on the one hand or complete recrystallization of the whole rock on the other would by intensification and prolongation of action, or weakening of action, as the case may be, produce rocks indistinguishable from stages from the early felsitic rock to the porphyry proper are not lacking in this group of rocks.

Similar difficulties are encountered in connection with what is here called metamorphism proper. Those internal reconstructions which seem capable of occurring by the mere effluxion of time under normal physical and environmental conditions are not here included under the heading of metamorphism. Nor are they so included if they seem to have been hastened and intensified by the effect of merely local hot solutions entering them, even though evidence of this action is not lacking. But, the metamorphic process is limited to the sense as found in Harker's work on this process. This gives rise to some difficulty in discriminating between the lowest grades of true metamorphism and the most profound effects produced by the devitrification process (plus, where necessary, the accentuation of this effect produced by solutions). In consequence of all this, it has been deemed advisable to class as metamorphic rocks only those which have recrystallized throughout. This is but a matter of convenience in description, and consequently, it will be found that rocks which have undoubtedly been metamorphosed to some extent (even in the sense used in this work) are included under the heading, felsites (or granophyres or quartz porphyries), because the felsitic nature seems the more determinative.

II. THE FELSITES.

A. Descriptions of Hand Specimens of the Felsites.

The felsites are readily divisible into three well-defined groups according to the colours they assume macroscopically. These groups are the light coloured felsites, and the dark felsites and those intermediate between the former two. There is usually some correspondence in basicity of the rocks to the darkness assumed in the hand specimen, but there are some specimens which do not show such correspondence.

(1) The Light Coloured Felsites.

There are two subdivisions of this group. These are determined by the relative largeness and abundance of the phenocrysts:

Group a. Small Phenocrysts, Relatively Few.

The three rocks of this group have a very fine base which is reddish in all, but somewhat darker in No. 1252. Phenocrysts of quartz or felspar (or both) are seen as rectangular or equidimensional crystals not exceeding 3 mm. in any dimension. In No. 848 there is a larger number of iron ore phenocrysts than in the other specimens.

Group b. Larger Phenocrysts, more Abundant.

There are seven members of this group. Felspar, quartz (in two specimens) and chlorite are identifiable phenocrysts. Some of the felspar laths reach 1 cm. in length, and the average dimension of all the phenocrysts ranges from 3.0 mm.-5.0 mm.

(2) The Intermediate Felsites.

The two specimens of this division differ markedly from one another.

Specimen No. 1245 consists of a vast number of phenocrysts of pale pink felspar lathes and irregular dull white opaque quartz crystals. Considerable chlorite is also seen. The ground-mass in contrast to the phenocrysts is a deep dull red brown. The nearly equal amounts of the two contrasting colours throw the rock in this intermediate group.

No. 1247 consists of few but larger (0·8 mm.-0·3 mm.) laths of white opaque felspar. There is a faint yellow tinge in some cases. A little ferro-magnesian is present. The ground-mass is very fine and compact. It is dark brownish red in colour.

(3) The Dark Coloured Felsites.

There are four rocks representing this division. Again, the members are quite dissimilar in appearance.

No. 461 consists of a fine dark ground-mass in which is set a few white vitreous phenocrysts of rounded quartz. No other minerals are recognisable.

No. 839 is nearly black. It is a water-worn boulder made of heavy fine-grained dark ground-mass in which occur some few small rounded quartz-like crystals. Evidence of flow structure is seen along the saw mark which was made when a section was being cut.

No. 1246 is much lighter than the previously described members of this division. The most interesting feature of this rock is the flow structure developed. Alternate dark and lighter bands varying from 1 mm. to 1 cm. are seen in parallel alignment. In the finer masses small white phenocrysts are seen set in line. The phenocrysts are too small to identify with certainty with the naked eye, but are most probably quartz.

No. 1256 resembles No. 1245 in that its phenocrysts are rectangular to equi-dimensional in shape and are roughly of the same size and matter. The ground-mass, however, is very much darker and flow structures are faintly visible. A lighter reddish band crosses the middle of the rock, and a crack in this part suggests that it was a weaker zone along which hot solutions have been able to attack the rock.

B. Description of the Microscopic Characters of the Felsites.

(1) The Light Coloured Felsites.

No. 1203. The felspathic phenocrysts and ground-mass are coloured dark red by a large quantity of patchily developed haematite and granulitic magnetite; some felspar phenocrysts have large areas kaolinized and coloured by iron ore which results in their assuming a much darker hue than is usual. Concentration of these areas at the borders of the phenocrysts serves to separate them from the rest of the rock in a decided manner.

The quartz phenocrysts on the other hand are particularly clear except for "islands" of matter contaminated by the iron ores. These "islands" are resorption areas which are the sections by the plane of the slide with the embayments which belong to other planes.

Apart from the colouration effects seen in the felspar and mentioned above the following points are worthy of comment.

Most of the felspar was originally acidic plagioclase.

Some appears to have been orthoclase. The latter is the more considerably kaolinized, the former shows remnants of twin lamellae, a patchy (perthitic) nature and a relative freedom from turbidity. It is occasionally saussuritized to a slight extent. Apart from the patchiness mentioned above zonal arrangements are absent. Granulation of the felspars has not taken place.

Large embayed phenocrysts of pale green diopside, although not nearly as common as the quartz and the plagioclase are characteristic of the rock. Rare simple twins occur. The grains of this mineral have been serpentinized to some degree, occasionally entirely. The serpentine is a dull brown green semi-opaque mass. In places it has, in its turn, been superseded by a reddish brown iddingsite-like mineral.

Biotite which in some grains is pleochroic in very dark and light browns and in others is more chloritic showing greens of light and dark shades is not uncommon. Very frequently inclusions of euhedral apatite hexagons give the mica a characteristic appearance.

The devitrified ground-mass except for its homogeneity which is only broken by a very rare development of granophyric matter or an isolated mosaic of very small quartz grains, is practically characterless.

No. 848. In general characters this rock resembles No. 1203. The following differences are to be noted.

Zonal arrangements in the plagioclase are seen. In one instance an interesting result of this difference in composition is seen. The centre and periphery, though both unchanged, differ in extinction position. The intermediate, region, on the other hand, has been entirely replaced by an alteration mass coloured pale yellow green, possibly by limonite. Twin lamellae are more commonly visible. One large quartz phenocryst is optically intergrown (in a simple fashion) with the edge of an equally large felspar crystal.

Very little original diopside is present ; the mineral has been almost completely serpentinized. Biotite and chlorite derived from it are not quite so common. Some zircon is present.

The ground-mass is not so fine grained nor so uniform as in No. 1252. Quartz is easily recognized. Small areas of fine textured myrmekite are seen.

Flow textures are only suggested by the shape of some of the more particularly elongated chlorite laths. The ground-mass shows no sign of this texture.

No. 1252. This rock has a very fine-grained almost homogeneous base in which occurs an occasional vein of granophyric matter.

The phenocrysts are mostly felspar which is suggestive of anorthoclase. There are some quartz phenocrysts which show crystal outlines which are frequently degenerate because of resorption.

Accessory minerals present include allanite, apatite, zircon, biotite and chlorite.

No. 204. Phenocrysts of quartz and felspar are set in a devitrified ground-mass. The former mineral occurs as clear crystals frequently showing hexagonal basal sections which are rarely biaxial. The felspar is turbid, untwinned, patchy orthoclase which possesses a good cleavage.

The ground-mass shows a greater development of the granophyric texture along veins than does No. 1252.

The accessory minerals are pale green, shredded chlorite, apatite, pale brown biotite, magnetite and diopside. The last mineral is invariably cracked, and has a chlorite infilling along the cracks.

No. 204B. Quartz and orthoclase phenocrysts occur much like those of No. 204. The quartz is, however, much more cracked and contains occasional inclusions of zircon. Some more basic felspar than the orthoclase was originally present, for some of the altered crystals contain considerable epidote. A little fibrous and considerably altered biotite occurs as phenocrysts which carry lawsonite lenses interlaminated between the fibres.

The ground-mass is much like that of No.204 except that there is no granophyric matter at all.

No. 204C. This rock, too, is much like No. 204. The main differences are that diopside is absent, the biotite is not so chloritized, and more strongly developed granophyric matter which seems to develop from the ground-mass is present. The granophyric areas include true spherulites.

A little highly sodic plagioclase in which the extinction angle varies from one end of the lath to the other is present. Very rare allanite grains occur.

In another slide of this rock some anorthoclase is seen. It has a patchy nature, is twinned, and has $2V$ about 50°.

No. 204D. Orthoclase is not present in this rock. The original felspathic phenocrysts were highly calcic. Very small (almost incipient) crystals of epidote and clinozoisite have developed from this felspar. Old multiple albite twins are still present. The extinction measured from these shows the present composition of the plagioclase to be andesine.

Chloritic biotite in which the small individual crystals are arranged in the decussate manner is the only noticeable ferromagnesian.

The ground-mass is more coarsely crystalline than in the preceding rock. Occasionally quartz is recognizable. A coarse granophyric texture is rarely developed.

No. 75A. This rock is considerably more basic, though quartz phenocrysts, which are much corroded, are common.

There is a little orthoclase. Much plagioclase, Ab_{70} An_{30}, is present.

Small, but essential, quantities of diopside which is becoming serpentinized to brown matter, hornblende which is possibly original, and brown biotite which in places is converted to a pale green chlorite, are present. Noticeable zircon inclusions occur in the biotite.

Tensional effects which have not been controlled by the cleavage directions are apparent in the felspar.

The ground-mass is very haematitiferous. The only identifiable mineral of the ground-mass is shredded secondary chlorite. There are faint suggestions of fluxion textures in the neighbourhood of the phenocrysts. Accessory minerals include magnetite, sphene, apatite and allanite.

No. 1251. Clear crystals of quartz with resorbed borders are prominent.

Felspathic crystals—whose limits under ordinary light are poorly defined from the turbid material which constitutes the ground-mass — are resolved under crossed nicols into definite phenocrysts. Occasional zonal textures are seen. Extraordinary fluxional characteristics are seen within the crystals themselves. These suggest that while the magma was viscous a dragging-out of the crystals occurred as they grew. Perthitic intergrowths of an ill-defined nature are almost invariably present. Twins are practically absent.

Chloritic biotite is an essential phenocrystic member. Haematite, usually somewhat concentrated in definite zones, is present. More apatite than is usual in this group of rocks is present. Some magnetite and zircon are found.

The ground-mass occupies considerably less of the rock than is usual in these felsites, nor is it so nearly homogeneous as ordinarily. Its mineralogical nature is irresolvable in places ; elsewhere quartz and felspar are identifiable. Some of these regions exhibit true granophyric intergrowths. This texture, however, is of very limited occurrence in this rock. Fluxional textures are almost entirely absent from the ground-mass of the rock.

No. 837A. This rock is characterized by the relative absence of haematite and the consequently clear aspect. Large phenocrysts of clear resorbed quartz are present.

Felspar crystals whose outlines are very irregular and jagged and which again are difficult to distinguish from the turbid ground-mass are present. These crystals are of a patchy nature due in part to differential decomposition, and in part to preferential recrystallization or development of perthitic matter. This last material consists of little rectangular felspars whose refractive index is higher than that of their host. Sometimes very fine twin lamellae are seen. Indications of the zonal character of the original calcic plagioclase are given. The peripheral zonal regions are frequently granulated. In one place a mosaic of crushed matter has developed within a large phenocryst. The finely divided matter has had an opportunity to adjust itself to the new conditions and now appears as clearer and more acidic felspar.

Phenocrysts of pale green to colourless fibrous chlorite (after biotite) are essential. Some are considerably darker (in browns and greens). Most are associated with magnetite. Bending of the laths is common.

Larger, more isolated grains of magnetite are present which appear to be original. Diopside appears as pale green grains exhibiting a good cleavage. Zircon, apatite and a very little allanite constitute the remaining minerals.

Flow texture in the ground-mass (which ordinarily is very fine grained) is evident in some places. Very rare granophyric textures are developed, and even less common is a very fine-grained myrmekitic intergrowth, presumably of quartz and felspar.

(2) The Felsites Which Have Intermediate Colour.

No. 1245. Much the same as the previous rocks is this member of the intermediate group. It contains patchy and zoned plagioclase whose characteristics have been largely determined by alteration. Some clear felspar, possibly sanidine, is also present.

The quartz shows resorption. Some little biotite and zircon occur. The occurrence of some chlorite with calcitic nuclei within the plagioclase is interesting.

The ground-mass is felsitic. No evidence of granophyric or other intergrowths is found. Flow textures are absent.

No. 1245A. The felspar is a little more basic than in No. 1245. The plagioclase is of interest, for pericline twins are developed as well as albite. The orthoclase, which in this slide is particularly turbid, shows occasional carlsbad twins which are invariably absent from the other rocks described. The quartz presents the same characteristics as before noted (1245).

The pyroxene present is much altered. Originally it was diopside, but most has changed to a deep, semi-opaque green serpentiniferous mass. Magnetite is more abundant than is usual in these rocks. Large grains form phenocrysts and small specks give a characteristic dark appearance to the groundmass.

The ground-mass is felsitic with occasional small patches of granophyric matter.

No. 1247. This rock is quite distinctive. Quartz as a primary mineral is absent. Orthoclase is entirely absent.

The phenocrysts consist of basic plagioclase. The zoned nature of some of these phenocrysts shows the plagioclase to range from Ab_{70} An_{30} to Ab_{50} An_{50}. There are abundantly developed albite twins, occasional pericline twins and very rare carlsbad twins. The most noticeable feature of the plagioclase, however, is the degree of epidotization which occurred. The felspar has been rendered remarkably poikiloblastic by this development.

Another of the most important features of the rock is the presence of deep reddish-brown biotite whose cleavage flakes are split by lenses of lawsonite. In places this calcic mineral is surrounded by a mere sheath of fibrous mica, in other places several lenses have developed separated from one another by the biotite flakes.

There has been a considerable development of chlorite, an earlier stage than that of the epidotization. Concomitantly with the chlorite formation was the segregation of the excess silica into definite patches of quartz. This secondary development of this mineral is in marked contrast to the large primary phenocrysts found in the more acidic felsites.

Magnetite is present, as is some haematite.

The ground-mass is holocrystalline, but apart from a suggestion of the presence of quartz the mineral matter is unidentifiable. The whole mass is remarkably even grained and uniform. This uniformity results in there being practically no point of interest to discuss.

(3) The Darkest Members of the Felsites.

No. 839. The most interesting part of this rock is the ground-mass which accordingly will be dealt with first. Flow effects are rendered recognizable by an unusual development of a kind of incipient biotite-like growth along the flow lines. Long thin fibrous masses of this mineral are seen to wind their way through the whole mass and to give it a characteristic appearance. This matter occurs in more or less parallel bands of greater and less intensity.

Set in this groundmass are phenocrysts of quartz and considerably altered lime felspar. The quartz is rectangular to equidimensional in shape and usually clear. It is sometimes much granulated, especially peripherally. The felspar is found in three forms, clear and well cleaved, very greatly clouded with kaolin-like matter and iron ore stains, and in cleaner masses where recrystallization has proceeded more definitely with the consequent production of minerals like pale green fibrous amphibole and epidote (very small crystals). Granulation of the felspar has occurred. A little fluorite is an unusual accessory of some interest.

No. 461. The most prominent feature of this rock is the dark line which it has assumed because of the very considerable quantity of iron ore (usually closely associated with biotite of an intensely dark nature) disseminated throughout the rock.

The phenocrysts are more obvious than the ground-mass which consists of a recrystallized mass of very fine matter composed of quartz and felspar (presumably from a basic plagioclase) and green chlorite and dark brown biotite. The phenocrysts are in part basic plagioclase, which has in part been metamorphosed sufficiently to become quite clean except for the presence of some little green chlorite and black specks of iron ore dust. The remaining phenocrysts consist of biotite flakes in equidimensional globules in the decussate manner. A feature of the biotite is that not infrequently there has developed a core of green-yellow epidote. The epidote, is composed of a felted mass of very small crystals.

No. 1246. By far the most interesting portion of this rock is the ground-mass. This consists of two distinct kinds of matter. One is fine grained very pale brown in colour under ordinary light, and flecked with black and white felspathic or quartzose patches under crossed nicols. Some peculiar veins intrude this portion of the rock. These peculiar veins seem to be regions where a more definite recrystallization of the ground-mass has occurred. Associated with these veins of definitely recrystallized felspar (or quartz) are veins of light brown matter very similar to some referred to in the description of No. 839. The other portion of the ground-mass is spherulitic. Under ordinary light this portion is a little more deeply stained with iron ores, and nuclei of the spherulites can be distinguished by the concentration of this iron matter at the centres of some of them. The very definite spherulitic nature of this region is rendered most apparent under crossed nicols when a uniform field of this texture is present.

Fluxional textures are seen both in the arrangement of spherulitic masses in the neighbourhood of phenocrysts and also in the stream line development of the veins around phenocrysts.

The phenocrysts are mostly corroded quartz and cloudy perthite. The perthite is almost invariably present in the plagioclase phenocrysts and it represents an early stage in recrystallization of original intermediate lime felspar whose albite twin lamellae are still usually visible.

Irregular masses of iron ore and elongated laths of pale brown mica indiscriminately present throughout the whole rock help to characterize it.

No. 1256. Devitrification has proceeded sufficiently to render the ground-mass of this rock microcrystalline, but, it has not, for the most part proceeded far enough to produce identifiable grains.

The ground-mass exhibits several features. One is the presence of particularly well preserved stream lines which demark the original flow lines of molten magma. Their irregular outline and the swirls past phenocrysts of quartz suggest that even in viscous lavas eddies, are set up within the fluid mass, of sufficient permanence to be recorded by the disposition of the stream lines. The intimate connection with the resorbed borders of the corroded quartz phenocrysts is made manifest by the intensification of the stream lines around these borders. Another feature of the ground-mass is the presence of spherulitic areas where a further stage in recrystallization is seen. Possibly these areas represent those portions of the magma from which less water vapour escaped and where a medium more favourable for later molecular concentration and rearrangement has consequently been formed. Veins of epidote (very fine prismatic crystals) and irregular crescent-shaped patches of poorly developed brown biotite also influence the aspect of the groundmass.

The quartz usually occurs in round corroded pellucid crystals except in the border regions where ejected inclusions form a peripheral zone of highly concentrated dust.

The phenocrysts of this rock are more varied than in most of the other felsites from this region.

The felspar forms large, well-cleaved crystals whose general colouring and appearance closely approximate those of the ground-mass. Under crossed nicols the alteration which has occurred is seen by the patchy nature of the crystals, the poor definition of the broad multiple twin lamellae and the presence of small secondary minerals like chlorite and epidote. The borders of the felspar are marked either by a concentration of dust like those of the quartz phenocrysts or by a clear separation zone between the felspar proper and the ground-mass. The second feature has been brought about by recrystallization in this area and reaction between the felspar and ground-mass in immediate juxtaposition.

Pale green masses of chlorite, with associated sphene, are occasionally seen. More fibrous chloritic masses, associated with residual biotite and secondary epidote, form laths of more common occurrence. Usually there is a well-defined zone of recrystallization, surrounding these laths and separating them from the ground-mass. These zones are reaction regions which have been instrumental in supplying some matter (mainly lime) to the earlier biotite to produce the later chlorite and epidote. A simultaneous discharge of iron ore is evidenced by the occurrence of small black grains of this substance in the vicinity of the chlorite.

Allanite is an important accessory. It is invariably surrounded by a very broad dark border.

III. THE GRANOPHYRES.

The five representatives of this group show wide differences both in the hand specimen and under the microscope. They are included together in this group because each, in its own way, develops the granophyric texture.

No. 204A. This is a dark brick-red coloured rock which has a dense, massive, fine-grained base in which is set a mass of light-coloured phenocrysts of opaque felspar. A banding in the specimen is suggestive of flowage.

Under the microscope the most obvious feature is the dense nature of the brown ground-mass of the rock. Evidence of the initial stages of a low grade of metamorphism is provided by the small green chlorite clusters which form an integral part of the ground-mass. Small circular aggregates of minute iron ore particles are also frequently seen. Crossing the nicols shows this region of the rock to consist of holocrystalline material, very fine in grain, composed mostly of felspar. Some little quartz occurs also.

The phenocrysts of quartz which are frequently quadrilateral or hexagonal in outline, and nearly as frequently circular or irregularly curved and embayed are prominent. Other phenocrysts consist of felspar, highly turbid and discoloured. This results in these phenocrysts closely resembling much of the ground-mass in ordinary light. Crossed nicols show these phenocrysts to have albite twin lamellae (not very frequent) and to contain very small chlorite and epidote inclusions.

The granophyric nature of the rock, strangely enough, is given by a localized area which shows this texture very coarsely developed. Associated with these intergrowths are distinct squares and rectangles of quartz and felspar which seem to function as kinds of nuclei around which the intergrowths form.

No. 1201 is a dense compact lustreless light fawn-coloured rock which has arenaceous affinities. Its general appearance is characterless but this is relieved by an occasional small blob of reddish felspar or irregular streak of green chlorite matter.

The definite nature of the rock appears at once under the microscope.

In ordinary light the general impression gained is of a light coloured mass (slightly stained brown by kaolinized iron ore) of radially grouped crystals of felspar which form meshes of circular aggregates. In this felspar mass is set a host of thin laths of chlorite whose directional arrangement is quite independent of the radii of the felspar spheres. The spherulitic nature of the felspar aggregates is enhanced when viewed under crossed nicols. The spherulites are larger than is usual and not so symmetrically developed as in some other rocks from this area.

Associated with these spherulites is the granophyric matter which gives this rock its name. Here the granophyric texture is definitely confined to the ground-mass in marked distinction to its occurrence in the other rocks of this suite. In consequence, its texture is much finer, and it is much less prominently present. Nevertheless, it occurs sufficiently for the rock to be designated by it.

Regions occur where the spherulitic ground mass lacks this character. They consist of a much finer grained mosaic of quartz and felspar particles. In the ground-mass are also found areas of clear quartz comparable in size with the spherulites, but distinct from them. They seem to be a kind of residuum from the original magma.

Phenocrysts in this rock are particularly rare. Those of felspar are the only ones at all common. They are rectangular in shape, particularly darkly stained by a brown iron ore matter and kaolin. A remarkable relationship between them and the crystals of the spherulites is occasionally seen. Instead of the crystallites preserving their radial arrangement here, they are found aligned parallel to the longer direction of the felspar lath, producing at the ends of the laths a kind of fibrous continuation.

A little orange yellow allanite is also present.

No. 445. In the hand specimen this rock resembles strongly a very fine grained pink granite. Small quartz and innumerable pink felspar crystals are visible to the naked eye. A few greenish patches of chlorite and some flakes of mica are present.

The difference in the character of this rock from the previously described members of this group is even more pronounced under the microscope. The ground-mass is not so greatly removed in grain size from the phenocrysts, although each possesses its own peculiar characteristics. The phenocrysts are of quartz, felspar and mica. This last mineral did not figure prominently in either No. 204A or No. 1201. It is of interest here, even though less common than the other two phenocryst-forming minerals, because of its approximation to phlogopite. It is faintly pleochroic in pale brown and colourless. The cleavage lamellae are frequently bent, and small patches of a few grains of the mineral are usually tucked away in the midst of quartz crystals. The quartz grains themselves are quite irregular in outline with a possible predominance of equidimensional forms. Magnetite figures prominently as an inclusion in these phenocrysts. Fluorite, as an inclusion in the quartz, occurs in isotropic purple grains.

The felspar cannot be designated any more accurately than this on account of its particularly turbid and altered nature. Inferences as to its original nature can be drawn from the character and distribution of its alteration products. As these products are chiefly epidote and confined more particularly to the central portions of the phenocrysts the calcic nature of the original felspar is established, as is also the zonal character of this plagioclase.

Rarely a small lozenge of sphene or a grain of zircon is seen.

The ground-mass consists entirely of definitely crystalline quartz and felspar in very intimate intergrowth. This part of the rock suggests that for some reason or other the rate of cooling of the parent magma was accelerated and at the same time the composition had reached that of the eutectic of quartz and felspar and the two crystallized together in this manner quite distinctive from that of the phenocrystic area.

No. 566 is again of an entirely different nature. The hand specimen is unusually pale for a rock of this kind. Glassy quartz grains and very pale pink felspar crystals are closely interlocked. A ferromagnesian, unidentifiable with the naked eye, occurs sporadically through the rock.

The phenocrysts occupy a relatively larger portion of the rock than in any other member of this group. They are larger, too, although some smaller members are present. These last seem to represent the effects of crushing on the weaker phenocrysts and their peripheries.

The mineralogical nature of the phenocrysts is, quartz commonest, two varieties of felspar and biotite. The quartz is clear except for inclusions of magnetite dust. The two varieties of felspar are identifiable by differences in turbidity, twinning and metamorphic products. One is more than likely orthoclase.

The other certainly is a plagioclase for the almost complete replacement of some crystals by granular epidote attests to this. The biotite is stringy and split by lenses of lawsonite. It contains inclusions of apatite, allanite and ilmenite. Some of the biotite areas are stained quite dark by hydrated iron compounds and produce a characteristic feature of the rock.

The granophyric areas are not common. In places they might be better called micrographic. True granophyric textures are present, however.

No. 840. This specimen resembles No. 566 in the hand specimen. Under the microscope, however, wide differences between the two are apparent, for, unlike No. 566, this rock has few and unimportant phenocrysts, but much ground-mass which presents some interesting features.

The minerals of the ground-mass are quartz and orthoclase, with a very little plagioclase. The first two minerals occur in almost equal proportions, and are intergrown throughout almost all the rock. In the neighbourhood of the phenocrysts (which are of quartz) true granophyric textures are produced, although they are not altogether absent from other parts of the rock.

Chlorite laths and epidote grains are the expression of metamorphic changes which have involved the calcic portion of the rock.

IV. THE PORPHYRIES.

The three members of this group are Nos. 224A, 919, 820. They are much alike and will be described *en bloc*.

Each is a brick-red dense rock in which are set very prominent circular and square phenocrysts of yellowish and pink felspar. Vitreous quartz and chloritic dark matter are also recognisable.

The ground-mass is deep reddish brown in colour and consists of orthoclase stained by iron ores. Magnetite is still recognisable. The quartz of the ground-mass is characteristically square in section and of even grain-size.

The phenocrysts are of much embayed clear quartz, and very highly saussuritized felspar. Chlorite, in flakes and scales, allanite as occasional yellow grains with strong borders, and apatite also occur.

V. THE RECRYSTALLIZED ROCKS.

There are three members of this group, viz., Nos. 283, 569, 924. There are certain affinities which these rocks have for one another, and also certain differences which peculiarize each. They are all dark grey with a tone of green, which in No. 569 is more sombre than in the others. The ground-mass of each is fine and dense. No. 283 carries prominent phenocrysts of slightly bluish quartz, more or less square in section, and about 2 mm. long. Smaller, less conspicuous, but equally numerous phenocrysts of opaque felspar are also seen. The phenocrysts of No. 569 are larger, up to 5 mm. by 4 mm., and are mainly of blue opalescent quartz. Some felspar and biotite are present. This rock possesses a definite schistosity, and in this respect differs from the other two. No. 924 has fewer and smaller phenocrysts of quartz (1 mm. square) and more felspar phenocrysts. The differences between the three rocks are much more evident under the microscope.

No. 283. The phenocrysts of quartz are readily distinguished from the rest of the rock, even under ordinary light. They are clear, except for some little magnetite dust. They are usually bordered by a fringe of small pale green chlorite laths which

serve as a demarcation line from the ground-mass proper. Under crossed nicols these quartz phenocrysts are seen rarely to be crushed, but usually to have an uncertain extinction. Some regions which seem to represent, not true phenocrysts, but interstitial regions where a large original quartz content was present in the earlier rock, have recrystallized as a mosaic of small grains. Among these are found needles and fibres of chlorite which never penetrate the definite phenocrystic areas.

The felspar phenocrysts, unlike those of quartz, are with difficulty distinguished from the ground-mass when viewed under ordinary light. The main difference is in the abundance of the chlorite laths present, which is greater than in the ground-mass. The clouded nature of some of the phenocrysts and the presence of tiny epidote particles also serve as discriminating criteria. This is true, too, of the fluxional arrangement of some of the laths of chlorite in portions of the ground-mass. Under crossed nicols, however, there is no possibility of confusion. The felspar phenocrysts are usually multiply twinned according to the albite law. Pericline twins are also present. Extinction measurements show the composition of the felspar to be basic andesine. The inclusions of chlorite in the plagioclase are more evident with nicols crossed. In some places they give the mineral a schiller appearance. Frequently, although not invariably, the felspar phenocrysts are separated from the ground-mass proper by a fringe of chlorite laths which are larger than the average set in a matrix of quartz grains. This is suggestive of a selective separation of calcic and silicic material during the formation of the two minerals.

In places there has been a little more iron present than elsewhere. This has resulted in the chlorite giving place to biotite, small knots of which are scattered throughout the rock. Small grains of magnetite, of irregular sizes, occur infrequently.

The ground-mass, as has been suggested above, contains a vast number of green laths of chlorite. These laths, of small dimensions, are in a disorderly state and present a meshwork in which is set small crystals of quartz (mainly) and felspar. The whole is remarkably uniform except when found between two large phenocrysts. Here a fluxional arrangement of the laths is evident. Zircon and apatite figure as rare accessories.

No. 569. The marked schistosity, entire absence of recognisable felspar, and great predominance of biotite over chlorite serve to distinguish this rock from the other two members of the group.

The phenocrysts are of quartz. They are usually rounded, and rarely show peripheral granulation. They vary considerably in size and distribution. Each individual is mainly clear, but ordinarily carries some little chlorite and magnetite dust as inclusions.

The biotite is quite common, occurring in bands of dark, brown slender flakes and fibres and in more massive patches of laths arranged in the decussate manner. These latter areas possibly represent earlier hornblende. Associated with the biotite are epidote

and lawsonite, the latter much more intimately than the former. It presents small lenses and lozenges between the fibres of the biotite. Zircon, with attendant pleochroic haloes, and magnetite are also found in euhedral crystals within the biotite.

Green chlorite in small laths is not uncommon in the ground-mass but it is particularly found as fringe-material around the quartz phenocrysts. The uncoloured ground-mass consists of very fine and even crystals of quartz. Apatite is a rare accessory.

No. 924. This rock is more basic than either of the other two. There are no phenocrysts of quartz, nor is this mineral present in the ground-mass. Biotite is absent, and chlorite is relatively rare. On the other hand actinolite is present in important quantities.

The general aspect of the rock is a ground-mass of fine, untwinned, felspathic matter, long pale green slightly pleochroic laths of actinolite and chlorite, and small clusters of minute epidote grains. In this ground-mass is set phenocrysts of clear, well-cleaved felspar. Around the phenocrysts the laths of the groundmass are arranged in true fluxional fashion.

As in No. 283, the phenocrysts of felspar are not immediately distinguishable from the ground-mass under ordinary light. Crossed nicols, however, render them apparent at once. They are usually multiply twinned. They contain characteristic inclusions of epidote, zoisite and chlorite.

Phenocrysts of actinolite, though rare, are present. They are not infrequently simply twinned. The rock is singularly free from magnetite and other iron ores.

VI. APPENDIX: SOME RELATED ROCKS.

There are three rocks, Nos. 381, 679 and 1261 (the latter is an erratic from Cape Hunter) which show junctions between porphyritic rock and other material. A fourth rock, No. 738, differs notably from the already described rocks, and a description of it by Dr. W. R. Browne is included here.

No. 381. This rock is a vein about 5 cms. wide of very fine-grained, even texture, reddish-brown felspathic material intersecting a coarse gneissic granite. In the hand specimen it is a featureless felsite.

Under the microscope there is to be noted amongst the finer material rectangular masses of considerably greater dimensions. These coarser masses are found, under crossed nicols, to consist of fine-textured granophyric intergrowths of quartz and felspar. The granophyric texture occurs also throughout the finer groundmass, and is, in fact, quite a characterizing feature of it. The rest of the ground-mass consists of small rounded grains of quartz and felspar with rarely a slightly larger grain of microcline or a more continuous patch of interstitial quartz.

No. 679. Two porphyritic masses of different grades of coarseness are in contact. The coarser is also lighter, due to the presence of phenocrysts of pink and white felspar (up to 2 cm. by 1 cm.). The finer portion has similar, but much smaller (3 mm. by 1 mm.), phenocrysts. The ground-mass is very fine, dull and irresolvable (by the naked eye) into definite minerals.

The coarser part is like the felsites described on page 120 *et seq.* The finer presents similar features, necessarily on a smaller scale.

No. 1261. The two divisions are not so clear-cut in this rock from Cape Hunter. Each portion is fine-grained, consisting mainly of quartz, pink felspar, ferro-magnesians and very fine ground-mass.

Microscopically, the ferro-magnesians are seen to be pale green diopside and fibrous brown biotite. The biotite laths are often bent (as much as a right angle), the concave side of the bend being opposite a corner of a quartz or felspar phenocryst. Lawsonite is found interlaminated with the biotite.

The quartz phenocrysts are greatly resorbed. The felspar is acidic oligoclase. The ground-mass is devitrified, but mineralogical determinations are impossible.

Rock No. 738 : a quartz keratophyre.* This is a compact dark-grey rock, with smooth fracture, and sparingly porphyritic in small whitish tabular felspars. A little pyrites is visible. Under the microscope the rock is holocrystalline, and slightly porphyritic in acid plagioclase and orthoclase up to 2 mm. in length. The ground-mass is composed of the same minerals, with some quartz and ilmenite in addition.

All the felspar is much altered, being spangled with minute mica flakes. The plagioclase appears to be a fairly pure albite, but determination is difficult. Orthoclase is not very abundant.

Former ferro-magnesian minerals are now represented almost entirely by abundant interstitial chlorite and carbonates, with minutely granular sphene. Occasionally pseudomorphs suggest the shape of hornblende.

Quartz, a very minor constituent, is mainly moulded on the felspars, but may show traces of micrographic intergrowth. Some of it may be secondary. Ilmenite is quite abundant at times in sections about ·5 mm. in diameter but mostly in granules. Some magnetite is also present, and a few apatite needles are seen.

*Description supplied by Dr. W. R. Browne, who examined the rock in 1920.

DESCRIPTION OF PLATE V.

Fig. 1. *Dark Felsite*, Moraines, C. Denison: Specimen No. 1256.
Flow structure, exhibiting remarkably well formed stream lines, is shown. Phenocrysts of turbid felspar are also to be seen. Mag. 22 diams.

Fig. 2. *Dark Felsite*, Moraines, C. Denison: Specimen No. 1246.
A mass of very uniform spherulites is illustrated. Mag. 95 diams.

Fig. 3. *Porphyry* (plagioclastic type) partly recrystallized, Moraines, C. Denison: Specimen No. 924.
Here is shown a large phenocryst of felspar. The crossed nicols enable one to mark-off its borders from the surrounding ground-mass. Twin lamellae and metamorphic products (epidote, zoisite and chlorite) are also thus rendered visible. Mag. 24 diams.

Fig. 4. *Quartz-Felspar-Porphyry*, Moraines, C. Denison: Specimen No. 204A.
Illustrating a granophyric intergrowth of quartz and felspar. Under crossed nicols. Mag. 20 diams.

Micro-photographs prepared by H. E. E. Brock.

Fig. 1.

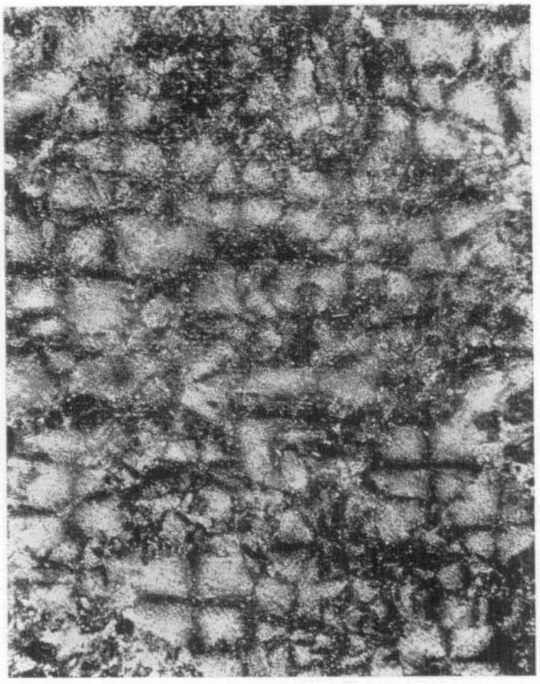

Fig. 2.

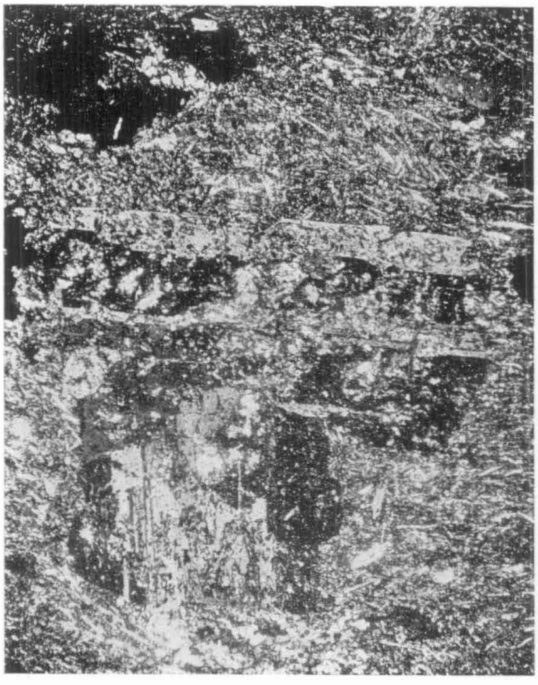

Fig. 3.

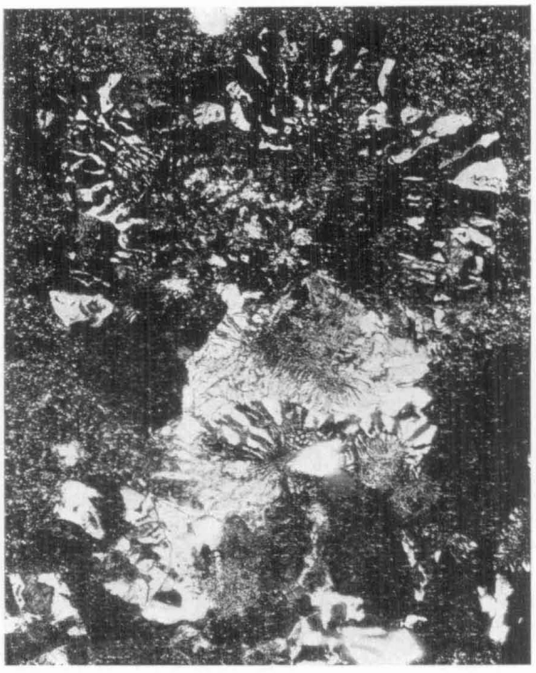

Fig. 4.

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