A PETROGENETIC STUDY OF THE EVANS LAKE GRANODIORITE
OMAK WASHINGTON

by

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ABSTRACT

The Evans Lake granodioritic mass is located eight miles northwest of Omak, Okanogan County, Washington, and covers approximately ten square miles. The mass occurs within geosynclinal Paleozoic sediments, which are strongly folded and exhibit metamorphism varying from low to high grade. The granodioritic body forms the core of an overturned syncline, replacing chiefly argillite-derived schists and para-amphibolites. Both field and petrographic data suggest that the igneous-appearing mass has formed by metasomatic granitization. The structures within the mass are harmonic and continuous with those of the adjacent metasediments, and the areal distribution of the different types of granitized rocks is to a considerable extent controlled by the composition of the original metasediments.

Five main petrographic types are distinguished. Fairly homogeneous massive or gneissose granodiorite and quartz monzonite with large microcline porphyroblasts are most widespread and occupy the central parts of the mass. Non-porphyroblastic medium-grained granodiorite, trondhjemite and diorite chiefly form the marginal parts of the mass. Migmatitic belts and zones rich in relict inclusions (variously migmatitized) are common, especially in the marginal zones of the mass. All contacts are gradational and irregular.

All rock types are typically crystalloblastic, and porphyroblastic textures commonly occur.

The beginning of granitization was synkinematic. This phase was restricted chiefly to the southwestern portion of the Evans Lake mass. Postkinematic granitization was superposed and considerably extended beyond the limits of synkinematic granitization. A retrogressive phase is represented by myrmekite and albitization.

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INTRODUCTION

The area here described comprises about ten square miles in the central part of the Okanogan County, northwest of the town of Omak and west of the Okanogan River. The first geological data published in this general area was by A. C. Waters and K. Krauskopf (1941), who mapped the region farther north and northeast. In their report they also make reference to the small granodiorite body at Evans Lake, which is the subject of the present paper, describing it as a possible offshoot of the Colville batholith. During the summer of 1948 the University of Washington geology department sponsored a field course for two months from mid-June to mid-August in which I participated under the direction of Professor P. Misch. General mapping of this area included stratigraphy, structure and metamorphism. It was proposed to me to make a detailed petrogenetic study of the Evans Lake granodiorite for my Master's thesis. In addition to the time spent on the field course, I spent nearly one month during August and September in the field. The making of a detailed map of the granodiorite body at the scale of 1:10,000 from aerial photographs was part of this field work, with reference to the Okanogan and Chopaka quadrangle base maps. Representative rock specimens were collected systematically from the whole granodiorite body. They total 365. Of these, 155 were studied in thin section.

LOCATION AND TOPOGRAPHY

The Okanogan River of north central Washington flows south from the Canadian border along a major north-south fault zone. Immediately to the east lies a large granodioritic mass known as the Colville batholith, the western portion of which has been described by A. C. Waters and K. Krauskopf (1941). Approximately 15 miles to the west of the Okanogan River lies another large granodioritic mass which is the southern prolongation of the Similkameen batholith, described by Daly (1912, Part I, p. 455-459). Between these two granitic masses, a group of variously metamorphosed

Paleozoic sediments is preserved. Within these sediments, the Evans Lake granodiorite lies 8 miles northwest of Omak and just north of Johnson Creek.

The topography throughout the area is characterized by glacial features. Remnants of glacial debris are found all over the area and also at elevations exceeding that of the Evans Lake granodiorite. There are a number of high terraces formed by glacial outwash and several low terrace levels, some of them very recent and excellently preserved.

The topography of the Evans Lake granodiorite mass is subdued. It forms a surface which rises gently from south to north. The total relief in the mass does not exceed 1,000 feet. Faulting is mainly responsible for producing small steep cliffs that average 40 feet in height and continue for long distances, some nearly across the granitic mass. Most of these small fault line scarps trend north-south, though some deviate to the northeast. Small intermittent creeks tend to follow the bases of cliffs and slopes and merge into small swamps and alluvial flats. Lower elevations are mantled with glacial cover. Approximately 25 per cent of the granodioritic area is composed of rock outcrops. Widely scattered clumps of yellow pine dot the region, and much of the ground is covered with grass and sagebrush.

OUTLINE OF AREAL GEOLOGY

Stratigraphy

Stratigraphic relations of the complex Paleozoic metamorphosed sediments in the Okanogan Valley region between the Colville and Similkameen masses are imperfectly known. The most widespread unit, which at the Canadian border has been termed the Anarchist series by Daly (1912), consists of greenstones, phyllites, quartzites, metaconglomerates, chlorite schists, and crystalline limestones. They are considered to be Carboniferous and Permian in age. The "Anarchist series" has been extended to the south and has been described in more detail by A. C. Waters and K. Krauskopf (1941), and an area of calcareous rocks in the south has been assigned a Triassic age by these authors.

During the University of Washington field course in the summer of 1948 the area between Johnson and Pine Creeks, which includes the Evans Lake granodiorite, was mapped in detail, and the stratigraphic relations of the calcareous rocks and the so-called "Anarchist series" were determined (cf. Misch, 1949b, chap. III). New stratigraphic names, of local derivation, were proposed for these rocks by Misch.

Oldest is the Alkali Lake formation. Its lower member is an ash gray partly dolomitic and locally argillaceous limestone, which contains brachiopods. The upper member is a massive white, gray and buff dolomitic limestone and marble, locally containing pelecypods.

The Alkali Lake formation is conformably succeeded by the Evans Lake formation. Its base often consists of gray dolomitic quartzite and schistose dolomite which are usually strongly banded and sheared. Above this lies a black, blue and gray dolomite and dolomitic limestone. The upper member of the Evans Lake formation consists of an interbedded series of (1) black phyllite and schist and (2) actinolite-tremolite-granulite and -schist, locally grading into impure dolomitic rocks.

Fossil remains were obtained in the lower and upper members of the Alkali Lake formation, and in the black dolomite in the basal part of the Evans Lake formation. Professor H. E. Wheeler in this department has made a preliminary examination of molluscs from the two upper horizons and assigned them to a definite Paleozoic and probable Devonian age.

The Evans Lake formation is conformably overlaid by the Scotch Creek schist. It comprises black phyllites, biotite schists, andalusite schists, local kyanite schists, and thin bands of quartzites, dolomitic schists, and local limestones. The upper Evans Lake member and the Scotch Creek schist are equivalent to the lower parts of the "Anarchist series" (not, however, to those rocks classified as "lower Anarchist" by A. C. Waters and K. Krauskopf (1941)). A continuous stratigraphic sequence from the upper Alkali Lake formation to the lowest part of the Scotch Creek schist is present just north of the Evans Lake granodiorite. It continues northeast for two miles to the vicinity of Alkali Lake.

Structure

The structure in the region of Paleozoic sediments between the Colville and Similkameen batholiths is imperfectly known, with the exception of the area mapped during the field course. Here deformation was found to be very intense and to represent the type characteristic of eugeosynclines (cf. Misch, 1949b, chap. III). The predominant strike is northwest-southeast, and the direction of overfolding and thrusting is to the northeast.

The area mapped during the field course, in the south central part of which the Evans Lake granodiorite is located, is characterized by overturned and isoclinal folds, part of which are recumbent and part of which have steeply inclined axial planes. The major anticlines consist of the lower limestones (Alkali Lake formation), and in the synclines the younger actinolite-tremolite rocks and biotite schists, including the Scotch Creek schists, have been preserved. Tertiary block faulting has been widespread and it cuts the older folding structures into many small blocks.

The Evans Lake granodiorite mass occurs in the core of an overturned open syncline that trends northwest-southeast. A general cross section of this syncline is presented on the geologic map. In the northeast limb of the syncline the dips are variable from 45 to 75 degrees to the southwest, i.e., the sediments dip beneath the granodiorite. In the southwest limb the sediments dip from 70 degrees to the northeast to vertical. On the northeastern side of the granodioritic core of the syncline, the sedimentary section is more complete than in the southwestern limb. It is shown in Figure 1.

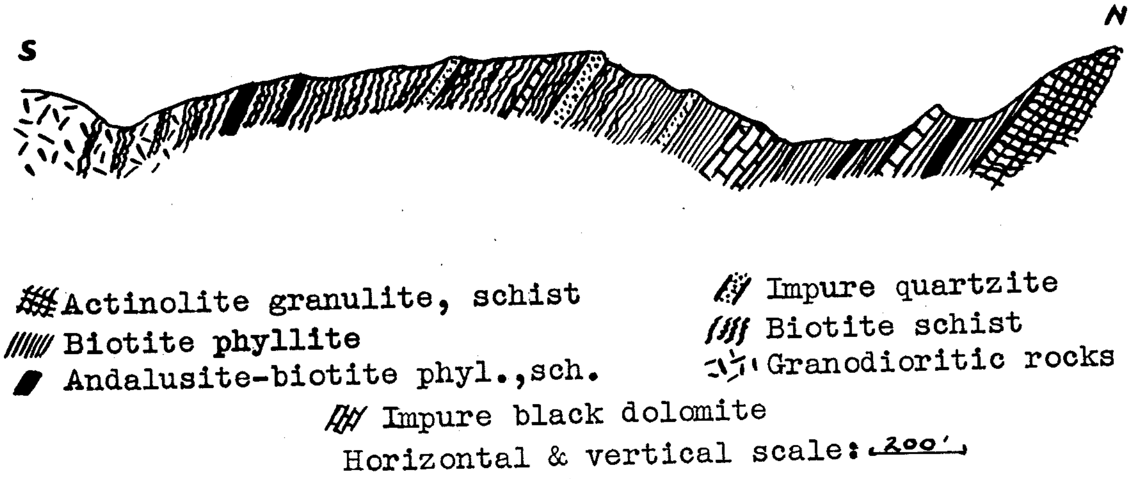

Fig.1. Metasedimentary Section. Northeast of Evans Lake mass.

The youngest sediments preserved here outside the granodioritic synclinal core correspond to the lower portion of the Scotch Creek schist. The steeply tilted normal succession in the southwestern limb of the syncline during the field course was found to be succeeded on the south by the lower limb of a recumbent anticline. This latter consists of lower limestone (Alkali Lake formation) and black dolomite (Evans Lake formation) in reversed succession. This overfold has been partly eroded, and its nose is not preserved, but must originally have covered the southern portion of the Evans Lake syncline.

In the dolomite forming the southern limb of the syncline, there occurs an elongate dome-shaped body of serpentinized peridotite which trends northwest-southeast. It is separated from the granodiorite by 100 feet of the black dolomite (lower Evans Lake). The peridotite was intruded prior to the strong overfolding described above. It acted as a resistant mass between which and the overfolded rock mass the weak-thin bedded black dolomite was sheared and greatly reduced in thickness.

The large syncline in which the Evans Lake Granodiorite occurs pitches toward its central portion both on the northeast and southeast.

Superposed Tertiary faulting has complicated the outcrop pattern in parts of this area and strongly influenced the pattern of erosion in considerable portions of the Evans Lake granodiorite.

Metamorphism

The degree of regional metamorphism in Paleozoic sediments varies considerably. Generally, the grade of metamorphism increases towards the granitic area bordering the sediments on the west.

In the Evans Lake area the lower limestones have mostly been metamorphosed to marbles which usually exhibit minor folding. The black dolomites (lower Evans Lake) have become phyllitic and schistose. Interbedded phyllitic biotite schists and actinolite rocks which form the upper part of the Evans Lake formation are "lower-most" epizonal to upper mesozonal.[1] Actinolite schists and actinolite granulites occur as lenticles and bands (cf. Fig. 1). They consist of members of the actinolite-tremolite series, occasionally with actinolitic hornblende, and with variable mostly minor amounts of quartz, calcite, epidote and carbonaceous matter. The phyllitic schists contain biotite, quartz, sericite and carbonaceous matter.

The Scotch Creek schist is predominantly of argillaceous derivation. It comprises phyllitic schists, biotite-

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[1] In the definition and interpretation of the zones of orogenic regional metamorphism, I follow P. Misch (1949a, chap. I).

quartz schists, andalusite-biotite-quartz schists, biotitic quartzites and hornblende-biotite-epidote-quartz schists. Kyanite is rather rare, and garnet is practically absent. The highest grade of synkinematic metamorphism reached by the Scotch Creek schist in the Evans Lake area corresponds to the kyanite-schist facies ("lower," i.e., hottest mesozone).[2]

A later static phase of thermal metamorphism is superposed. It resulted in the formation of andalusite porphyroblasts in some of the biotite phyllites and biotite schists. These porphyroblasts attain a maximum length of 2 in. Small transverse biotite porphyroblasts are common and formed during the same phase of static crystallization. The schists often exhibit superposed hornfelsic textures which may almost obliterate the former schistose structures. This static thermal metamorphism is more pronounced near the borders of the Evans Lake granodiorite.

FIELD DESCRIPTION OF THE EVANS LAKE GRANODIORITE

The Evans Lake granodiorite covers an area approximately 2¼ miles wide and 4 miles long. It has an elliptical shape with its long axis trending northwest-southeast.

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[2] *Ibid*.

The character of the granodiorite body varies. Partly, there are migmatitic border zones between the granodiorite rocks and the altered sediments, and partly there are fault contacts.

On the northeast the granodiorite borders Scotch Creek schist. The contact is in part gradational and in part rather sharp.[3] In detail, however, the border is very irregular and crenulated. Migmatitic zones rich in granitic material protrude into the schist as much as 100 to 200 feet obliquely to the strike. Between such migmatite lobes, the strikes and dips of the schists are the same as in the schists farther north not associated with migmatites. The migmatite border zones contain many tongues and lobes of various granitic types which penetrate the schists in irregular and gradational patterns. Also schist inclusions are common within the granitic mass. They have the same attitude as the schists outside the contact zone. In the northwestern part of the area the strike of the schists locally becomes east-west, and the trend of the granitic contact participates in this change. Some minor faults have offset the contact for short distances.

In the south and southwest the granodioritic rocks are in contact with the dark dolomites and the dolomitic

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3 Contacts classified as "sharp" in the field reveal a gradational character when studied in thin sections (cf. below).

schists of the lower Evans Lake. The contact is in most part rather sharp. A portion of the contact, however, consists of a migmatite zone and has a gradational character (cf. Pl. V). This zone is 50 to 100 feet wide. Farther east the contact is formed by a fault. Along the contact there is evidence of strike faulting which is probably related to the overfold from the south which has been described above.

The western margin of the granodioritic area is a postgranodiorite major fault which brings the massive limestone (upper Alkali Lake) into contact with the granodioritic mass. Farther east another large cross fault forms the west margin of the topographically elevated central portion of the granodioritic mass ("west central cross fault"). Between these two major faults the western granodioritic area is cut by intersecting minor block faults. Much of this area is covered with glacial debris, and thus the scattered outcrops are difficult to correlate. Generally, each western block has been elevated relative to its eastern neighbor. Thus, the eastward pitch of the synclinal axis is further accentuated.

In the eastern part of the area the Evans Lake granodiorite is covered by Tertiary rhyolite flows. In the northeastern part of the area three north-south faults have offset the granite contact for approximately 1,000 feet each.

The southeastern part of the area is complexly block faulted. A huge block of granodiorite with recrystallized relic sediments within which the strike is east-west has been uplifted on the east. Thus, here again the pitch of the synclinal axis has been accentuated by later faulting. Much of this area is covered with glacial drift and alluvium.

The only primary contacts, then, between the granodiorite rocks and the sediments, which have been preserved, are on the northeast and southwest. They deserve a discussion (cf. below).

On the whole, the Evans Lake granodiorite is very homogeneous structurally and very heterogeneous petrographically. Structures within the granodiorite mass conform to the regional northwest-southeast strike. Many of the granitic rocks are gneissose. Their schistosity invariably follows the regional structural trend. Similarly, the trends of zones of migmatites and of migmatitic inclusion zones, as well as their internal parallel structures are conformable with the gneissic structure and the regional trend. The boundaries between the belts of various granitic types described below also conform to the regional tectonic pattern. I have not observed one single case where the position of an elongate inclusion or any intragranitic contact is not in harmony with this pattern. Although the fault blocks may be slightly rotated, the later faulting has not much distorted the original structure, and, in fact, it has accentuated the axial pitch of the syncline. There is absolutely no structural discontinuity or any sign of displacement of the schists where the granodiorite mass borders the schists on the north. Apart from some later faulting, the same holds true on the south. Both on the north and on the south the sediments dip into and under the granodioritic mass.

There are numerous petrographic types exposed in the Evans Lake granodioritic mass. The main types are: coarsely porphyroblastic granodiorite to quartz monzonite; more even granular, mostly medium grained granodiorite, trondhjemite, and diorite; and biotite-quartz schist, amphibolite, diopside-quartz hornfels, and diopside-wollastonite marble in various stages of migmatitization.[4] The distribution of these rock types varies from rather sharply defined belts to complexly mixed zones with very irregular and gradational boundaries. Microscopic features will be discussed in the chapter on petrography.

Coarsely Porphyroblastic Granodiorite to Quartz Monzonite

These rocks are characterized by large microcline porphyroblasts occurring in a usually medium-grained matrix. Rocks of this group are most abundant. They form the core

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4 The names used for igneous-appearing rocks are here applied in a purely descriptive sense, without any genetic connotations.

of the mass, but also occur in parts of the border zones. Rocks of granodioritic composition predominate in this group. In the central and northeastern portion of the mass, the amount of microcline porphyroblasts often exceeds that of plagioclase; these rocks have a composition of a quartz monzonite. The average size of the porphyroblasts in the rocks of this group varies but little; it is from 25 to 12 mm. Part of these rocks have a massive-directionless structure. Others are gneissose (cf. Pl. I). These latter are augen gneisses in which the porphyroblasts show an elongated shape and more or less parallel orientation. Megascopically, the majority of the porphyroblasts have an idioblastic appearance, especially those found in the non-gneissose rocks. More rounded augen and idioblastic porphyroblasts may occur together in the same hand specimen, and there is complete gradation between the massive and gneissose types. Generally the augen gneisses are more common in the southwestern part of the area where granodiorite predominates, and the massive variety prevails in the central and northeastern parts of the area where quartz monzonite is more abundant. In hand specimens of the augen gneiss, idioblastic porphyroblasts are commonly transverse to the gneissic structure. Some of the porphyroblasts which are oriented parallel to the gneissic structure, however, may also be idioblastic. It is possible megascopically to see mafic inclusions in nearly every one of the porphyroblasts (cf. Pl. I).

In the quartz monzonite five or six average-sized porphyroblasts may occur close together in a patch which has a roughly rectangular outline, suggesting a larger crystal that may be 50 mm long (cf. Fig. 2). In this case, groundmass inclusions are more abundant. At several localities within the quartz monzonite microcline porphyroblasts are concentrated in 3-in. to 1-ft wide bands which trend northwest-southeast and continue for several dozen feet. Their boundaries are gradational in every case, and the individual porphyroblasts are generally aligned parallel to the bands.

Fig.2. Very large microcline porphyroblast in quartz monzonite. Natural size.

These bands have a composition of a microcline-granite.

Approximately along the granodiorite and quartz monzonite contact in the southeast, medium-grained non-prophyroblastic granodiorite forms several bands, each varying from 1 ft to 20 ft in width. They are at least 700 ft long, have gradational borders, and all trend northwest-southeast.

Along the northern contact massive porphyroblastic granodiorite is in gradational contact with the schists. Its contact with the schists is highly varied and irregular and mostly transitional. Many schist inclusions and aplites are intermingled with the granodiorite, and both have gradational or migmatitic border. On the south this marginal granodiorite belt grades into trondhjemite, by a gradual decrease in the amount of microcline porphyroblasts, a decrease in grain size, and an increase in the amount of mafics. This transition zone between porphyroblastic granodiorite and trondhjemite ranges from 1 ft to 100 ft in width, and generally trends northwest-southeast, though in detail the pattern is very irregular and crenulated.

A slight decrease in the amount of microcline porphyroblasts and an increase in mafics are observed westward from the central part of the area toward the "west central cross fault." This change is accompanied by an increase in the amount of dioritic inclusions and a progressively more gneissic character of the structure. However, granodiorite remains the predominant rock type throughout this broad transitional area.

In the migmatite areas the occurrence of porphyroblastic granodiorite is spotty and irregular. Although microcline porphyroblasts may occur in diorites and amphibolites their volume amounts to very little in these rocks.

Non-Porphyroblastic Medium-Grained Granodiorite

This rock is free of large microcline porphyroblasts. It is a fairly even-grained rock, and the mafics exhibit a faint alignment (cf. Pl. II) parallel to the regional northwest-southeast strike. The main occurrence of this rock type is in the southeastern portion of the Evans Lake granodiorite mass where it forms a fairly uniform mass. Only in a small area measuring approximately 100 by 50 ft, does the microcline become coarsely porphyroblastic. These porphyroblasts are mostly irregularly rounded augen rather than idioblastic crystals.

Along its southern margin, the medium-grained granodiorite grades into trondhjemite and then into diorite. The passage zone exhibits a very irregular and patchy distribution of rock types, and has a migmatitic character.

In the northern and northwestern parts of the Evans Lake granodiorite area, there are small outcrops of similar non-porphyroblastic medium-grained granodiorite, most of which is massive-directionless. Here, the occurrence of this type is exceedingly irregular and patchy, and the granodiorite is usually mixed with and grades into trondhjemite and diorite. The granodioritic rock occurs in very irregular and ill-defined zones that are parallel to the regional trend.

As has been mentioned above, there are also intercalated bands of similar medium-grained non-porphyroblastic granodiorite in the southeastern area of porphyroblastic granodiorite (cf. p. 17).

Non-Porphyroblastic Medium-Grained Trondhjemite

Trondhjemite is found everywhere between diorite and granodiorite as a transitional phase. A large trondhjemite zone occurs in the northern part of the area and trends northwest-southeast. It is in gradational contact with porphyroblastic and non-porphyroblastic granodiorite on the north, and with diorite on the south. This zone is poorly defined in the field because of the gradational relationships and the similar appearance of the various rock types. Thin section study was necessary for identification and correlation.

In general, the trondhjemite is medium- to fine- and comparatively even-grained, directionless to slightly gneissose, and dark to intermediate in shade (cf. Pl. III). Many of the dioritic inclusions have a trondhjemitic border, and nearly all of the migmatitic zones and pods are marginally composed of trondhjemite. Occasionally small trondhjemitic patches and zones occur within the dioritic and non-porphyroblastic granodioritic areas. The largest and most continuous zone of trondhjemite occurs in the north.

Diorite

This rock occurs partly in irregularly scattered patches and partly in rather well defined belts within the Evans Lake granodiorite mass. In the northeastern part of the area a large diorite belt, which trends northwest-southeast is in gradational and irregular contact with trondhjemite. Here, the diorite is mostly massive with only small areas that exhibit gneissose structures. It is medium-grained and dark in shade (cf. Pl. IV). The diorite-trondhjemite contact is ill-defined in the field because of the rather similar appearance of the two rock types. In general, leucocratic minerals decrease in abundance and mafics increase from trondhjemite to diorite. Locally quartz diorite occurs as a transitional phase. Trondhjemite and rarely granodiorite locally occurs in the dioritic zone as small irregular patches. Diorite, which is in transitional and irregular contact with numerous granitic types, is a common constituent of migmatitic zones. Most of the migmatites on the southwestern part of the area are dioritic and rather schistose. On the northeastern margin of this belt, diorite irregularly grades into a belt of trondhjemite. The diorite inclusions in the porphyroblastic granodiorite (cf. p. 17) vary in length from 1 ft to more than 30 ft. They are always elongated in a northwest-southeast direction. Their borders are irregular and they vary from gradational to rather sharp. A narrow transitional zone of trondhjemite always lies between the diorite inclusion and the porphyroblastic granodiorite. Many of these inclusions grade along the strike into ghost-like patches (cf. Fig. 3).

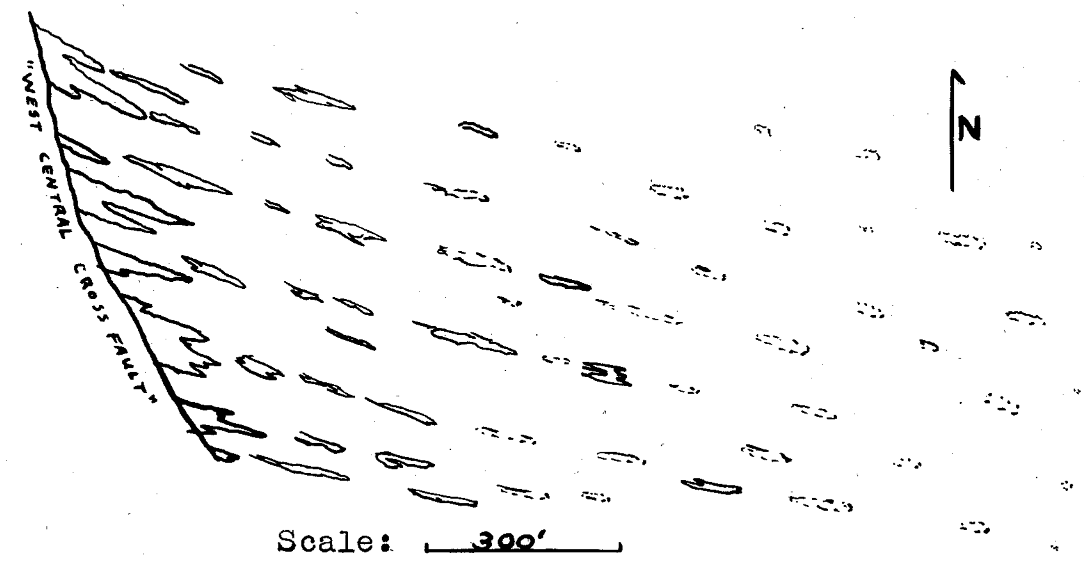

Fig. 3. Generalized sketch. Migmatitic inclusions grade along strike into ghost-like relict patches from "west central cross fault" to southeast.

Migmatites and Relict Inclusions

The term migmatite is here applied to rock types which clearly display a mixed origin within individual outcrops. The term relict inclusion is applied to inclusions of metasediments similar to those found outside the Evans Lake granodiorite mass. These inclusions show varying degrees of migmatitic-metasomatic transformation and always have migmatitic and gradational borders.[5]

The northern and northeastern parts of the granodioritic mass contain relict inclusions of biotite-quartz schist, andalusite-biotite schist, diopside-wollastonite marble, and diopside-quartz hornfels. They all occur in thin straight bands which are in every case structurally conformable with the regional northwest-southeast strike. The andalusite- and biotite-schist inclusions become increasingly abundant near the border of the granodiorite body. The schist bands are seldom more than 1 ft wide and continue, as far as could be determined, for at least 20 ft. Outcrops are spotty and confined to small, more or less circular areas on tops of hills, making it difficult to trace the inclusions for any great distance. The degree of schistosity is variable, and, in general, the more fine-grained schists are hornfelsic. The contacts of the inclusions with the granitic rocks are

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[5] These relict inclusions are equivalent to G. E. Goodspeed's "skialiths" (Goodspeed, 1948).

gradational and irregular. The schistose structure remains straight and continuous where small granitic replacement lobes irregularly penetrate the schist bands. Within the schist bands aplitic dikes and irregular patches commonly occur. These aplitic dikes and patches commonly cut across the foliation of the schist, but have preserved the foliated structure of the schist as a relic.

A white diopside-wollastonite marble band, which is 3 to 4 ft wide and trends northwest-southeast, occurs in a complex narrow belt of calcic migmatites in the northeastern part of the granodioritic body, within the diorite zone described above. In the same belt a sandy-appearing gray diopside-quartz hornfels occurs in irregular pods and narrow bands. Good outcrops are lacking, and therefore the exact relationships to the adjacent rocks could not be determined. In general, the marble and hornfels occur in the central portion of the dioritic migmatite belt. There is an increase in grain size (irregular in detail, but distinct as a whole) from the marble inclusion through amphibolites,[6] diorites and trondhjemites to the porphyroblastic granodiorite. The zone within which this transition takes place varies from 2 to 100 ft in width.

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[6] The term amphibolite is here applied to rocks which are similar to diorite but consist of more than 50 per cent amphibole.

In the northwestern part of the granodioritic mass there are many belts and elongate pods of more or less migmatitized relict inclusions of biotite-quartz schist and diopside-quartz hornfels. Their relationships are difficult to determine because of the lack of good outcrops. However, in every observed case the borders of the inclusions as well as their internal structures are parallel to the regional trend.

In the area of porphyroblastic granodiorite, inclusions of gneissose diorite and varied migmatites increase in abundance toward the "west central cross fault." The volume of these relatively more basic inclusions of dioritic and trondhjemitic composition here exceeds that of the porphyroblastic granodiorite. These inclusions are elongate and trend northwest-southeast. However, most of these more basic relics "die out" toward the southeast within the porphyroblastic granodiorite within a distance of about 2,000 ft. Farther southeast in the granodiorite there are many lenticular schistose dioritic inclusions varying from 1 to 30 ft in length. They grade into ghost-like shadows (cf. Fig. 3). Along the "west central cross fault" occur all passages between porphyroblastic granodiorite, medium-grained granodiorite, trondhjemite, diorite, and amphibolite. Usually these rocks are irregularly mixed within individual outcrops. A breccia in a granodioritic matrix containing dioritic blocks, some of which are connected by thin septa and links, is locally exposed. Irregular aplitic dikes and patches are intermingled with all varieties of migmatite. Where bands of different rock types cross the prevailing northwest-southeast strike, which they commonly do at low angle, there is no offset.

On the southwestern margin of the igneous-appearing mass a narrow migmatite belt occurs along the whole length of the contact between dolomitic schist and diorite (cf. Pl. V). It exhibits the characteristic transition from diorite to trondhjemite and granodiorite. Crosscutting aplites are common in the dioritic rock and show no evidence of dilation.

A wide migmatite zone occurs in the fault block which forms the southeasternmost part of the granodiorite mass. It trends east-west, because it is in the south limb of the northwest-pitching syncline and is in addition in an eastern upfaulted block (cf. p. 13). Generally, the core of this zone consists of an amphibolite and schistose diorite which are transected by aplites and pegmatites, all of which have irregular borders and some of which have preserved a relict schistosity. Leucocratic and relatively more melanocratic fine and coarse grained rock types are repeated many times and occur in haphazard smudgy patterns. Along the southern contact of this more basic relict zone trondhjemitic types grade into medium grained granodiorite, whereas on the northern contact they grade into porphyroblastic granodiorite.

All the migmatites and relict inclusions described share the following characteristics: (1) Size, texture, and contacts (both between the different rock types within migmatitic zones and between these latter and the metasediments) lack any uniformity. (2) The composition of the relicts is generally more basic, and, except in the case of the marble, their color is darker than that of the adjacent granitic types; only the inclusions of the andalusite- and biotite-schists are less calcic than the enclosing rocks. (3) The structures within the inclusions, as well as their boundaries, everywhere conform to the regional strike. (4) The abundance of relict material increases toward the margins of the Evans Lake granodiorite mass.

Summary statement of the field description. On the northeast and southwest the granodioritic rocks are in contact with the metasediments. The other borders of the granodiorite mass are formed by faults, or covered by glacial material, rhyolite, or alluvium. The metasediments on both sides dip into the granodioritic mass, and the contact is generally parallel to the strike of the sediments. The structures within the granodioritic mass and the boundaries between its component zones are conformable with the structure of the sediments which form a syncline that from both sides pitches toward its center. All these structures are in complete harmony with those of the wider region mapped during the field course (cf. Misch, 1949b, chap. III).

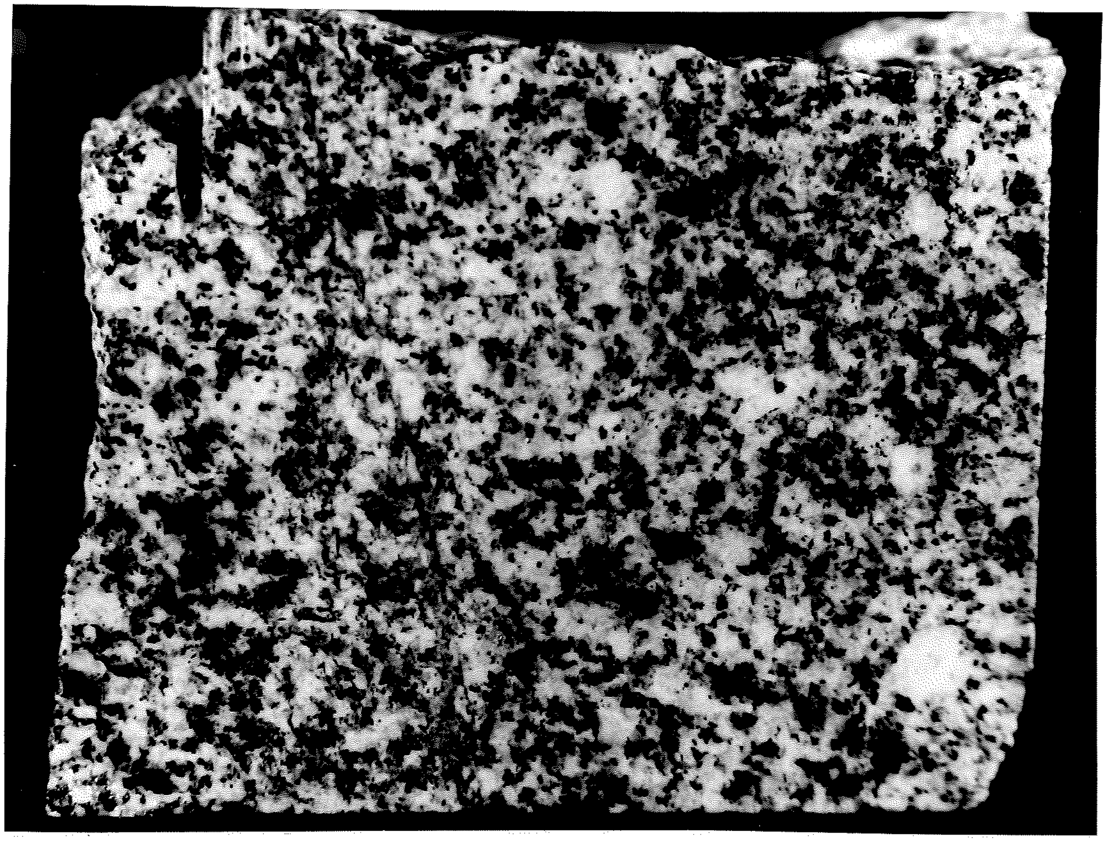
Porphyroblastic granodiorite is the most widespread rock type. It forms the central part of the mass, as well as a narrow marginal zone at the northeastern contact with the schist. Medium grained granodiorite occurs mainly in the southeastern part of the mass, and on a smaller scale and in a very irregular fashion in the northwestern portion. Trondhjemite occurs in a narrow belt next to the granodiorite in the northeast, also forms irregular inclusions and is found in migmatitic zones. Diorite forms a zone in the northeastern part of the area, and is commonly the main constituent of basic relict inclusions. Migmatites and inclusions are absent in the central portion and are increasingly abundant toward all margins. The boundaries between all petrographic types are gradational and irregular. In conclusion, the Evans Lake granodiorite is structurally uniform and continuous with the sediments, and petrographically heterogeneous.

PLATE I.

Coarsely porphyroblastic granodiorite, slightly gneissic. Southwestern part of Evans Lake mass. Rounded microcline porphyroblasts, in part transverse. Mafic inclusions in porphyroblasts. (spec. no. 8/28/48-65-13a)

PLATE II.

Non-porphyroblastic medium-grained granodiorite, slightly schistose. Southeastern portion of Evans Lake mass. (spec. no. 8/25/48-11-8a)



1/4 inch

PLATE III.

Non-porphyroblastic medium-grained trondhjemite, directionless. Northern part of Evans Lake mass. Uneven "mottled" texture. (spec. no. 8/30/48-132-29).

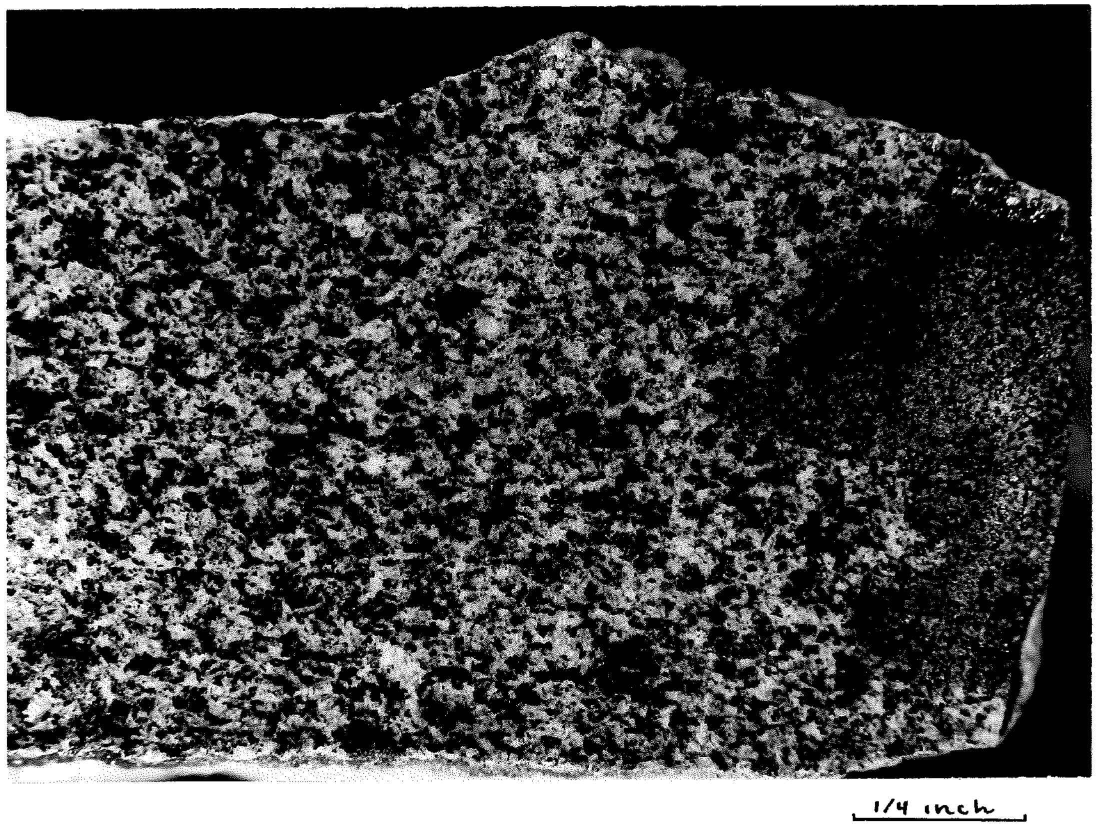


PLATE IV.

Directionless diorite. Northern part of Evans Lake mass. (spec. no. 8/30/48-132-29a)

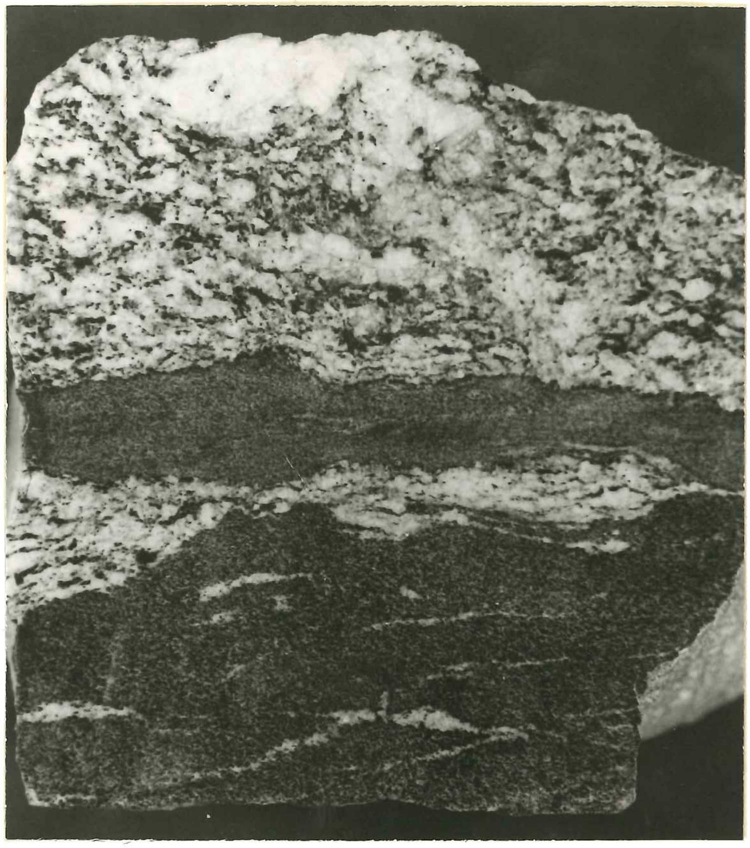


PLATE V.

Migmatite composed of granodiorite gneiss and fine-grained sediment derived basic schist. Southwest margin of Evans Lake mass. Replacement contacts. Incipient porphyroblastic stringers in basic schist. (spec. no. 8/28/48-66-14b)

PETROGRAPHY

Porphyroblastic Granodiorite and Quartz Monzonite

These two rock types grade one into another and differ only in the amount of microcline. Since the granodiorite is more widespread than the quartz monzonite, these two types will be referred to as "porphyroblastic granodiorite."

The essential minerals are, in order of abundance: microcline, oligoclase, quartz, and biotite. Accessories are: hornblende, epidote, orthite, sphene, magnetite, albite and myrmekite, chlorite (secondary), apatite, clinozoisite and tourmaline.

The mineral microcline is of particular interest from a genetic standpoint. The predominant average size of microcline porphyroblasts is 25 mm in length and 12 mm in width, while the maximum size observed is 50 mm in length, and the minimum less than 0.1 mm. The more idioblastic crystals invariably are simple Karlsbad twins. The more rounded augen-like crystals are less commonly twinned. Even those porphyroblasts which have a euhedral megascopic appearance, microscopically all exhibit crenulated borders and complex intergrowth with the groundmass minerals (cf. Pls. VI, VII, X). Small delicate microcline septa of various shapes often intricately penetrate the groundmass (cf. Pls. VI, VII). This feature is more pronounced in the massive granodiorite, whereas in the gneissose variety the crystal borders often are sharper. The latter variety of microcline porphyroblasts is frequently bordered by a very fine-grained intergrowth of quartz and albite.

All of the microcline porphyroblasts contain inclusions of groundmass minerals (cf. Pl. VI, VII, VIII, IX, X). The inclusions may occur anywhere and in any arrangement within the porphyroblast, although they are usually more abundant near the margins. Every mineral that is found in the groundmass (those listed on p. 33) may be completely enclosed within the microcline porphyroblasts. The inclusions usually maintain the characteristic mineral associations which are seen in the groundmass (cf. Pl. IX). An example is included patches of intergrown hornblende and epidote with adjacent biotite that contains sphene oriented parallel to its cleavage. Quartz, oligoclase and biotite are the most frequently included minerals, and these are also the most abundant minerals in the groundmass. Quartz inclusions average 0.5 mm in size and, as a rule, are not strained, whereas the groundmass quartz is usually much larger and always possesses undulous extinction. The included plagioclase is mostly oligoclase and rarely andesine. It averages 0.5 mm is size. The larger crystals show albite twinning (cf. Pl. VI, Fig. a). Nearly every plagioclase inclusion has a clear albite rim (cf. Pl. VI, Fig. a; Pl. VIII, Fig. a). Biotite inclusions average 0.2 mm, though some are 1 mm long. Many are partly or completely chloritized (cf. Pl. VIII, Fig. a). In many of the microcline porphyroblasts part of the inclusions, mostly quartz and plagioclase, are concentrated in a well-defined zone about three-fourths of the distance toward the periphery from the porphyroblast center (cf. Pl. VI, Fig. b; Pl. VII). The inner margin of this inclusion zone is well defined and marks an earlier stage of growth. The marginal portions of such crystals are richer in inclusions than their cores. This peculiar feature is almost invariably exhibited by the more idioblastic porphyroblasts.

The microcline porphyroblasts are marginally penetrated by blebs of myrmekite, usually whenever a plagioclase is in contact with the microcline (cf. Pl. V; Pl. VII, Fig. a; Pl. X). Irregular and patchy albite also occurs unevenly scattered through the microcline porphyroblasts (cf. Pl. VII, Fig. a; Pl. VIII, Fig. a). It does not, however, occupy sufficient volume to warrant the name microperthite.

The matrix of the granodiorite also contains some microcline crystals. They are never twinned, average 2 mm and seldom exceed 5 mm in size. Like in the large porphyroblasts, any groundmass mineral may be included (cf. Pl. VIII, Fig. b; Pl. XI; Pl. XII; Pl. XIII; Pl. XIV), though inclusions other than quartz, plagioclase and biotite are rare. The margins are intensely crenulated (cf. Pl. VIII, Fig. b), and different parts of one crystal may be linked by only narrow septa (cf. Pl. XI). The smaller microclines are always xenoblastic. Myrmekitic blebs usually penetrate microcline where the latter is in contact with plagioclase. Some of the smaller microcline crystals are entirely replaced by albite and quartz.

The amount of microcline in the "porphyroblastic granodiorite" is between 25 and 45 per cent, and it averages approximately 30 per cent. The sizes of the microcline porphyroblast share two maxima of frequency as illustrated in Fig. 4. By far the largest percentage of microcline in the "porphyroblastic granodiorite" occurs in the form of large porphyroblasts.

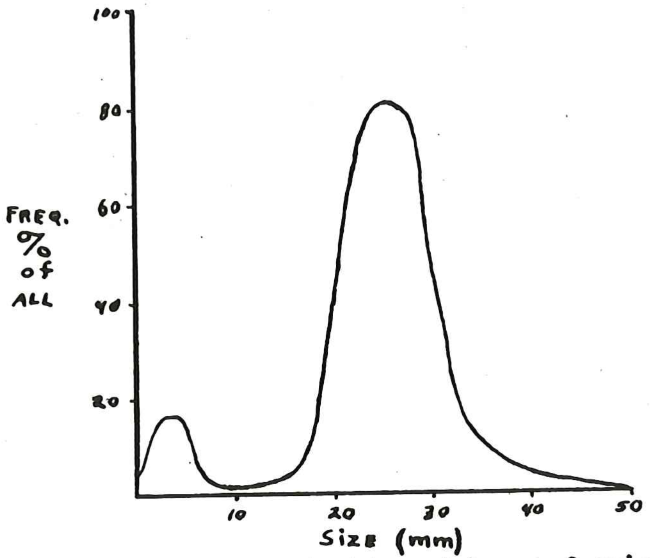


Fig.4. Size relationships of microcline crystals in "porphyroblastic granodiorite".

Plagioclase is the second most abundant mineral in the "porphyroblastic granodiorite," averaging 35 per cent and varying from 25 to 50 per cent. It varies in composition from oligoclase An26 to andesine An34 and averages An28. Albite is discussed in connection with myrmekite (cf. pp. 39, 40). The size of the plagioclase crystals varies from 0.3 mm to 5 mm.

Various stages of glomeroblastic growth of plagioclase occur in the "porphyroblastic granodiorite." Occasionally the incipient, intermediate and later phases of growth are present in one thin section. In the incipient stage, individual plagioclase crystals tend to segregate and complexly interpenetrate while still maintaining their individual twinning and zoning. In the intermediate stages of glomeroblastic development, small inclusions of quartz, epidote, sphene, hornblende and biotite are common, and they persist in the later stages. In the later phase of development (cf. Pl. XIII), the glomeroblast is large and it displays very complex twinning, discontinuous zoning and mottled and irregular extinction. The final glomeroblast may be hypidioblastic, but is more commonly xenoblastic. In general, two or three twinning directions predominate in glomeroblasts in their late stages, and usually only small relics of earlier twinning remain. Zoning, when present in plagioclase glomeroblasts, is usually discontinuous and complex. Occasionally the large glomeroblasts exhibit rather uniform zoning, although relicts of earlier zoning are always present. The distribution of oligoclase and andesine within the glomeroblasts is very irregular and completely gradational, although the glomeroblast cores are usually more calcic. The zoned portions, for the most part, have andesine cores and more sodic oscillatory marginal zones. Usually the glomeroblasts are larger in the massive-directionless "porphyroblastic granodiorite" than in the augen gneiss variety.

A considerable amount of oligoclase-andesine occurs in the groundmass (cf. Pls. X, XI, XII, XIV), in addition to the glomeroblasts. There is a wide gradation from plagioclase glomeroblasts to the individual plagioclase crystals of variable size and irregular distribution in the groundmass. Probably more than one-half of the plagioclase is not glomeroblastic. Many of the plagioclase crystals are slightly bent.

<u>Quartz</u> follows plagioclase in order of abundance, composing an average of 20 per cent of the "porphyroblastic granodiorite" and ranging from 15 to 35 per cent. The size of quartz crystals is extremely variable. It may range from less than 0.3 mm to 6 mm within a very small area. Quartz is invariably xenoblastic, and it usually has sutured and crenulated borders. The larger crystals tend to form aggregates while the smaller are scattered irregularly through the groundmass. All quartz grains in the "porphyroblastic grano-

diorite" exhibit varying degrees of undulous extinction. The same applies to all other rocks in the Evans Lake granodiorite mass. Inclusions are absent in quartz.

Biotite is the least abundant of the essential minerals. It averages about 10 per cent and ranges from 3 to 15 per cent, with the highest percentage in the augen gneiss. Its maximum size is 3 mm, and its average size is 0.8 mm, and both are consistent throughout the "porphyroblastic granodiorite." Usually the biotite flakes exhibit no preferred orientation in the massive-directionless granodiorite. In the augen gneiss they exhibit faint to good alignment (cf. Pl. I). Across their cleavage the biotite flakes are always jagged. Commonly several small biotite crystals occur in a patch (cf. Pl. XIV). Some biotite flakes are slightly folded. Biotite may be concentrated and "draped" around the edges of large microcline porphyroblasts (cf. Pl. X). Biotite is commonly associated with hornblende. Both minerals may be intergrown, and biotite may include hornblende. Minute sphene crystals are commonly included in biotite parallel to its cleavage. Other inclusions in biotite are epidote, orthite, quartz, magnetite, apatite, and clinozoisite (cf. Pl. XIV). Many biotite crystals are partially or completely chloritized.

Myrmekite, an intimate intergrowth of quartz and albite which replaces potash feldspar, is the most common accessory constituent. It averages about 3 per cent, but may compose as much as 6 per cent of the "porphyroblastic granodiorite." It is commonly present where microcline and oligoclase-andesine are in contact (cf. Pl. VI; Pl. VII, Fig. a; Pl. X; Pl. XII, Fig. a; Pl. XIV; Pl. XVII, Fig. b). In the massive granodiorite, the myrmekite usually forms sutured lobes or blebs which marginally penetrate microcline porphyroblasts. In the augen gneiss myrmekite occurs in the same fashion in microcline, as well as in the form of very fine-grained intergrowths of quartz and albite and microcline in recrystallized cataclastic bands (cf. Pl. XII, Fig. b; Pl. XV).

Biotite, epidote, orthite, hornblende, sphene, clinozoisite and magnatite usually occur intimately associated in small patches. Epidote is commonly included in biotite (cf. Pl. XIV) and hornblende and occasionally in plagioclase. It always at least partially surrounds small orthite idioblasts. Hornblende usually exhibits poikiloblastic texture with inclusions of quartz, and less commonly biotite and epidote. Occasionally former large hornblende crystals (3 mm in length) are nearly completely replaced and exhibit only skeletal relicts. Secondary chlorite is frequently associated with, and commonly pseudomorphic after, biotite. Apatite is widely scattered through the "porphyroblastic granodiorite," and small tourmaline crystals are often present. Albite occurs in association with myrmekite, as discussed above. In addition, some small frequently twinned albite crystals are present in recrystallized granulation bands. Patchy albite and albitic rims around oligoclase occur within microcline porphyroblasts.

The microscopic <u>texture</u> of the "porphyroblastic granodiorite" is everywhere crystalloblastic. Most of the microcline is porphyroblastic. The groundmass is characterized by complex intergrowths and irregular distribution and grain size of its component minerals. The mafics tend to occur in patches, and the plagioclases tend to form complex glomeroblastic aggregates. As a whole, the texture is exceedingly irregular and typically crystalloblastic.

The microscopic <u>structures</u> of the "porphyroblastic granodiorite" are of two varieties: (1) massive-directionless and (2) gneissic. The former is characterized by complete lack of preferred orientation in any of the rock constituents. The gneissic type usually exhibits a moderate degree of preferred orientation of the large microcline-augen-porphyroblasts, the plagioclase and the biotite crystals. Recrystallized mylonitic bands are usually wavy in pattern, but invariably they roughly parallel the gneissic structure. Thin bands of extreme mylonitization with no recrystallization occur locally.

Medium-Grained Granodiorite

This rock differs from porphyroblastic granodiorite by its lacking of large microcline porphyroblasts.

The essential minerals of the medium-grained granodiorite are, in order of abundance: plagioclase, microcline, and quartz. Accessories are biotite and secondary chlorite, epidote, sphene, orthite, hornblende, myrmekite and albite, tourmaline, apatite, magnetite, and secondary sericite, kaolin and calcite.

The plagioclase is an oligoclase-andesine. Its composition varies between An28 and An35, and averages about An32. The amount of plagioclase ranges from 30 to 50 per cent, and averages about 40 per cent. In its texture, the plagioclase of the medium-grained granodiorite resembles that of the porphyroblastic granodiorite (cf. p. 37). However, in the medium-grained granodiorite plagioclase glomeroblasts are not quite as well developed and are usually not as large. Many of the glomeroblastic growths have reached an intermediate and a few the later stage of development. Both are characterized by complex twinning, zoning, irregular intergrowths, mottled extinction, and a wide range in size. The glomeroblastic growths may include all other minerals, except microcline. Most plagioclase grains occur singly in the medium-grained granodiorite.

Microcline is rather irregularly distributed throughout the medium-grained granodiorite. It ranges from 15 to 30 per cent and averages about 25 per cent of the rock. The size of microcline crystals is extremely variable, ranging from minute intergranular growths to a maximum of 6 mm. Karlsbad twinning is absent. The grain boundaries are everywhere extremely crenulated and sutured. The microcline may include all other minerals of the rock. Microcline is usually marginally penetrated by myrmekite.

In a small area (cf. p. 18) the microcline crystals gradually increase in size and become almost as large as in the porphyroblastic granodiorite. Such larger microcline crystals all have irregular augen shapes in the medium-grained granodiorite.

Quartz is irregularly scattered in the medium-grained granodiorite. It represents about 20 per cent of the rock. Its average size is approximately 1 mm, and its maximum size is 3 mm. Quartz is characterized by sutured borders, complex intergrowth, and undulous extinction.

Chlorite is secondary and is usually pseudomorphic after biotite. Some of it is patchy, very fine grained, and irregularly scattered around biotite, hornblende, and epidote. Magnetite usually occurs along the cleavage planes of chlorite pseudomorphs. The amount of chlorite is extremely variable; it averages 5 per cent and may be as high as 15 per cent, or it may be absent. Generally, the greater the amount of secondary sericite and kaolin in the plagioclase, the greater the abundance of chlorite.

Biotite and hornblende are not always clearly recognizable, because they have been extensively altered to chlorite, and, to a less extent, to calcite. Epidote and sphene usually occur as hypidioblastic crystals. Sphene commonly occurs in crystals 2 to 3 mm in length. Orthite is usually idioblastic, and invariably is associated with epidote. Apatite, magnetite, tourmaline, and calcite are very minor constituents.

The mineral composition of the medium-grained granodiorite is quite similar to that of the porphyroblastic granodiorite. The medium-grained granodiorite, however, lacks large microcline porphyroblasts, and has more chlorite and less biotite.

Along the southern margin of the Evans Lake mass, some of the medium-grained granodiorite has been mylonitized. It here grades into trondhjemite. Two types of mylonites occur. In one type, bands of cataclastic mortar are recrystallized as a fine-grained intergrowth of quartz, albite and microcline, and small undeformed myrmekite blebs commonly penetrate adjacent microcline crystals from these bands. In the other type, cataclastic granulation is extreme, and recrystallization of myrmekites are absent.

The microscopic texture of the medium-grained granodiorite is typically crystalloblastic. It is characterized by uneven grain size and mineral distribution and by complex intergrowth of the minerals. The mafics usually occur intimately associated in small patches, and the plagioclase occurs partly as glomeroblastic aggregates and partly as single crystals. As a whole the texture is very irregularly granoblastic.

The microscopic structure is predominantly massive-directionless. In megascopically gneissic varieties, a faint alignment of mafics and plagioclase is usually visible under the microscope.

Trondhjemite

In mineral composition, texture, and structure, this rock imperceptibly grades into medium-grained granodiorite on the one hand and into quartz-bearing diorite on the other hand. True quartz diorite is comparatively rare. It differs from trondhjemite only by containing slightly less quartz and microcline, and slightly more hornblende, and, by the more calcic nature of its plagioclase. The occurrence of quartz diorite in the Evans Lake mass is similar to that of trondhjemite.

Essential minerals in the trondhjemite are plagioclase, quartz, biotite, and microcline. Accessories are hornblende, diopside, epidote, sphene, myrmekite and albite, clinozoisite, orthite, chlorite (secondary), apatite, magnetite, muscovite and tourmaline.

Plagioclase is the most abundant mineral. Its composition ranges from An28 to An36, and it averages An33. The amount of plagioclase (in volume) may vary from 45 to 55 per cent and averages 50 per cent. Generally, the plagioclase crystals are smaller than in the medium-grained granodiorite. Most of the grains are rather irregularly distributed, and some occur in incipient and intermediate stages of glomeroblastic development. The grain boundaries of plagioclase are everywhere irregular and crenulated (cf. Pl. XVII, Fig. a), and twinning and zoning are rather complex. Inclusions of quartz, hornblende, biotite, epidote, and clinozoisite are occasionally present (cf. Pl. XVII, Fig. a).

Irregularly distributed quartz is always present. It varies from 10 to 25 per cent and averages 15 per cent of the rock. The size of quartz grains seldom exceeds 1.5 mm, and it averages 0.8 mm. The grain borders are crenulated and sutured.

The amount of biotite varies and averages 15 per cent. The size of biotite flakes averages 1 mm and is fairly consistent. Biotite is often irregularly distributed. It commonly includes quartz, hornblende, epidote, and sphene. The biotite may exhibit a marked preferred orientation.

Microcline varies in abundance, distribution, and size. Its borders are crenulated and commonly penetrated by myrmekite (cf. Pl. XVI; Pl. XVII, Fig. a). Inclusions of all other minerals in the rock are occasionally present. The microcline in the trondhjemite is similar to that in the medium-grained granodiorite, except for its smaller size and fewer inclusions.

Hornblende is usually present. In some cases it composes as much as 15 per cent of the rock. Its average size is 1 mm, and rarely its grains attain a length of 5 mm. Hornblende commonly exhibits poikiloblastic texture (cf. Pl. XVIII, Fig. a). It frequently includes quartz, as well as biotite, epidote, and in rare cases diopside. Hornblende is usually partially surrounded by biotite and intergrown with epidote.

Epidote and sphene are widespread accessories in the trondhjemite. The former is more intimately associated with hornblende, and the latter with biotite.

Generally, when more hornblende is present, biotite and microcline are less abundant, and the plagioclase is more calcic.

Myrmekite characteristically penetrates microcline margins. Clinozoisite, orthite, secondary chlorite, apatite, magnetite, muscovite, and tourmaline are very minor constituents in trondhjemite.

The microscopic texture is typically crystalloblastic. Minerals are rather irregular in distribution and size. The mafics are inclined to occur partly in patches and partly scattered through the rock as individual crystals. Plagioclase may occasionally be glomeroblastic, although most of it occurs as single crystals.

The microscopic structure is usually slightly gneissic, with biotite and plagioclase exhibiting a moderate degree of preferred orientation.

Diorite

In its mineral composition, texture, and structure, this rock grades into trondhjemite on the one hand and into amphibolite on the other hand. The diorite differs mineralogically from trondhjemite in containing very little or no microcline and quartz, more hornblende and less biotite, and plagioclase of a more calcic composition. The diorite differs from massive amphibolite in containing less than 50 per cent of hornblende.

The essential minerals are plagioclase, hornblende, and biotite. Accessories are quartz, microcline, myrmekite and albite, diopside, sphene, magnetite, epidote, orthite, and secondary chlorite.

The composition of the plagioclase varies from An33 to An55 and averages An36. Its percentage varies from 45 to

65 and averages 55. The average size is 1 mm. The andesine seldom forms large glomeroblastic aggregates but more commonly is uniformly distributed. It exhibits a slight to moderate degree of preferred orientation. Complex twinning, zoning, and mottled extinction are locally present. The plagioclase contains inclusions of hornblende, and more rarely of biotite, epidote, and quartz.

Hornblende exhibits features similar to those in trondhjemite, although its crystals are usually larger. It varies from 10 to 50 per cent and averages 25 per cent of the diorite. The hornblende is poikiloblastic, including quartz, and less commonly biotite and epidote (cf. Pl. XVIII, Fig. b). Preferred orientation of hornblende is slight.

Biotite is less abundant than hornblende. It ranges from 5 to 25 per cent and averages 20 per cent. Usually biotite crystals are small and intimately associated with hornblende, completely or partially surrounding the latter mineral.

Quartz, when present, occurs in very small irregularly scattered crystals. It averages 2 per cent. Microcline may be lacking or be present in amounts less than 1 per cent. Its crystals are very small and irregular and usually occur as intergranular growths. Myrmekite may marginally penetrate microcline. Diopside is very rare and occurs only in the cores of a few hornblende crystals. Sphene is commonly included in biotite. Secondary *chlorite* associated with *magnetite* surrounds hornblende and biotite. *Epidote* and *orthite* are closely associated with hornblende and are sometimes included in it.

The relationships of the minerals in diorite are similar to those in trondhjemite. When microcline is present, there is more biotite and less hornblende, and the plagioclase is more sodic. Generally, with an increase of biotite, sphene also increases slightly.

The microscopic *texture* is crystalloblastic. The mafic minerals are complexly intergrown and usually occur in patches. The plagioclase is irregular in size and distribution. Quartz and microcline are exceedingly irregular in distribution. As a whole, the texture is unevenly granoblastic.

The microscopic *structure* is in part massive-directionless, and in part slightly gneissic, with plagioclase and hornblende exhibiting a moderate degree of preferred orientation.

Migmatites and Relict Inclusions

Biotite schist and *andalusite-biotite schist inclusions* are common near the northern and northeastern border of the Evans Lake granodiorite mass.

These schist inclusions are composed of biotite and quartz, with varying amounts of andalusite, magnetite, muscovite, chlorite, and albite-oligoclase. Most of the biotite shows marked preferred orientation (cf. Pl. XIX, Fig. a), although quite a few biotite flakes are oriented transversely to the schistosity. Quartz is usually evenly distributed in very small crystals. Occasionally lenticles of larger quartz crystals are present. Andalusite porphyroblasts average 1 mm in cross section and may be 3 to 4 mm long. They are oriented in various directions transversely to the schistosity. Albite-oligoclase is present in very small turbid and crenulated incipient porphyroblasts. It is a relatively rare constituent.

The microscopic texture of the relict schist inclusions is evenly fine-grained and crystalloblastic. The microscopic structure is mostly schistose and more locally grades into hornfelsic texture.

These relict schist inclusions may be in transitional contact with trondhjemite, medium-grained granodiorite, or porphyroblastic granodiorite. In the passage from schist to these granitic types, the grains of biotite and quartz become enlarged, and their distribution becomes irregular. The plagioclase increases in abundance and size, and microcline appears, beginning in the form of small intergranular growths, and finally (in the case of transition to porphyroblastic granodiorite) attaining the stage of large porphyroblasts. Microcline may form intensely crenulated incipient porphyroblasts, which contain many quartz and biotite inclusions (cf. Pl. XXI). Also, in the passage from schist to fine granitic types, the schistose structure shows no evidence of displacement (cf. Pl. XX).

Aplitic dikes and patches rich in quartz and microcline occasionally transect relict schist inclusions. Their contacts with the schist are crenulated and gradational (cf. Pl. XIX, Fig. b). The biotite flakes in the aplitic dikes display alignment which transects the dikes and is parallel to the schistosity of the surrounding schist. The alignment of biotite in aplite obviously represents inherited relict schistosity.

A band, 3 to 4 ft thick, of diopside-wollastonite marble occurs in the northeastern part of the Evans Lake mass in a complex migmatite belt, in which nearly all of the various rock types described occur. The marble is usually in sharp contact with amphibolite and diorite. The minerals present in the marble are, in order of abundance: carbonate (80 per cent), diopside, wollastonite, quartz, microcline, sphene, and garnet. Microcline forms small crenulated incipient porphyroblasts. The microscopic texture is crystalloblastic. The microscopic structure is massive-directionless, although locally it may be faintly banded.

In the band of marble and migmatite, as well as in other relict inclusion zones in the northern part of the area, thin bands of diopside-quartz hornfels occur. This kind of hornfels consists of quartz, diopside, calcite, sphene, epidote, microcline, zoisite, apatite, and albite. The amounts of quartz and diopside are about equal, whereas the distribution of the other minerals varies widely. The amount of albite is usually very small. Myrmekite is absent. The microscopic texture is typically crystalloblastic and the structure is massive-directionless.

The migmatitic zones and patches consist of amphibolite (locally), diorite, trondhjemite, medium-grained granodiorite, and porphyroblastic granodiorite. These rocks texturally, structurally, and mineralogically grade one into another. The transition zones vary in width from a half inch to several feet. A trondhjemite zone always occurs between diorite and granodiorite. Commonly microcline-quartz veinlets irregularly penetrate all rock types (cf. Pl. XXII). Irregular pegmatitic dikes rich in quartz, microcline and tourmaline locally occur.

PLATE VI.

Porphyroblastic granodiorite and quartz monzonite. Evans Lake mass.

Fig. a. Porphyroblastic quartz monzonite. Crossed nicols. Northeast central part of Evans Lake mass. Microcline, quartz, oligoclase, myrmekite, biotite, hornblende. Margin of large microcline porphyroblast with projections protruding into the groundmass. Myrmekite penetrates microcline from plagioclase. (spec. no. 8/26/48-28-8)

Fig. b. Porphyroblastic granodiorite. Crossed nicols. Northeast marginal portion of Evans Lake mass. Microcline, quartz, oligoclase, biotite, hornblende (h), myrmekite. Large microcline porphyroblast showing concentric zone rich in inclusions, and irregular replacement border. (spec. no. 8/31/48-152-13a)

PLATE VI.

Fig. a
20X

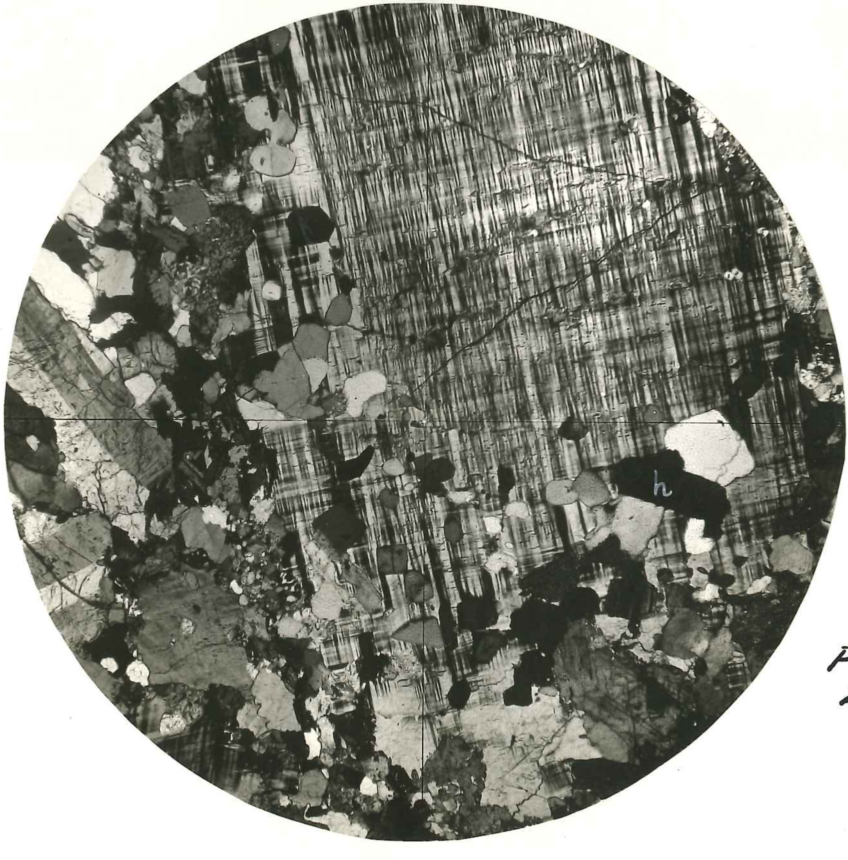


Fig. b
20X

PLATE VII.

Porphyroblastic granodiorite and quartz monzonite.
Evans Lake mass.

Fig. a. Porphyroblastic quartz monzonite. Crossed nicols. East central part of Evans Lake mass. Microcline, quartz, oligoclase, myrmekite. Large microcline porphyroblast showing concentric zone rich in quartz inclusions, and irregular replacement border. (spec. no. 8/26/48-34-7)

Fig. b. Porphyroblastic granodiorite. Crossed nicols. Marginal area in northeastern part of Evans Lake mass. Microcline, quartz, oligoclase, biotite. Large microcline porphyroblast showing concentric zone of quartz and plagioclase inclusions. (spec. no. 8/31/48-156-21)

PLATE VII.

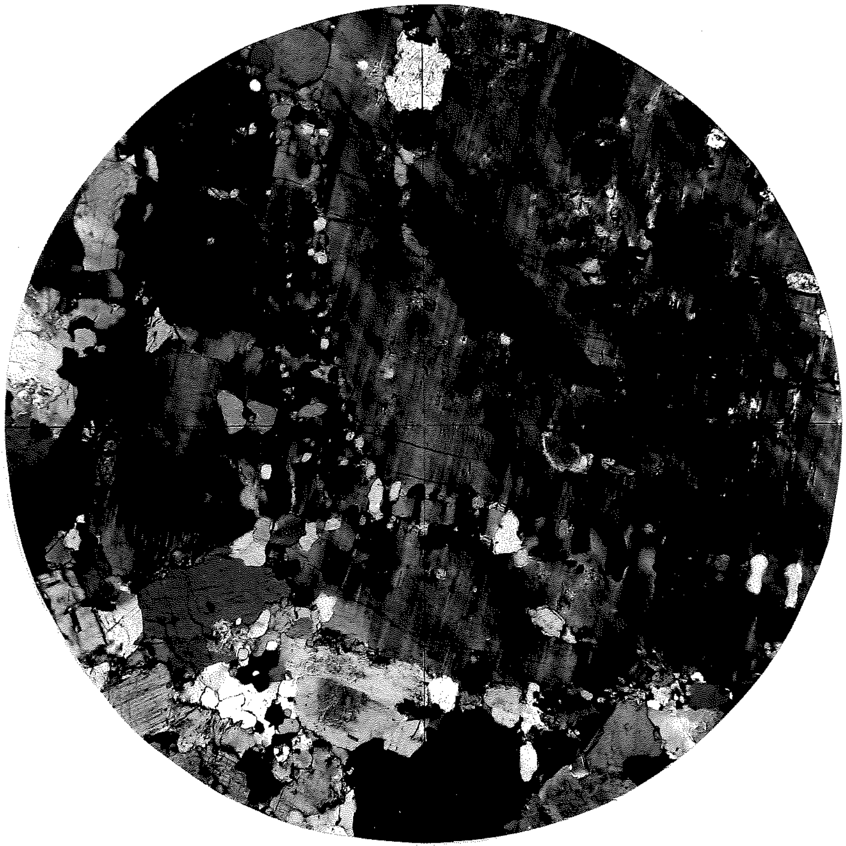


Fig. a
20X

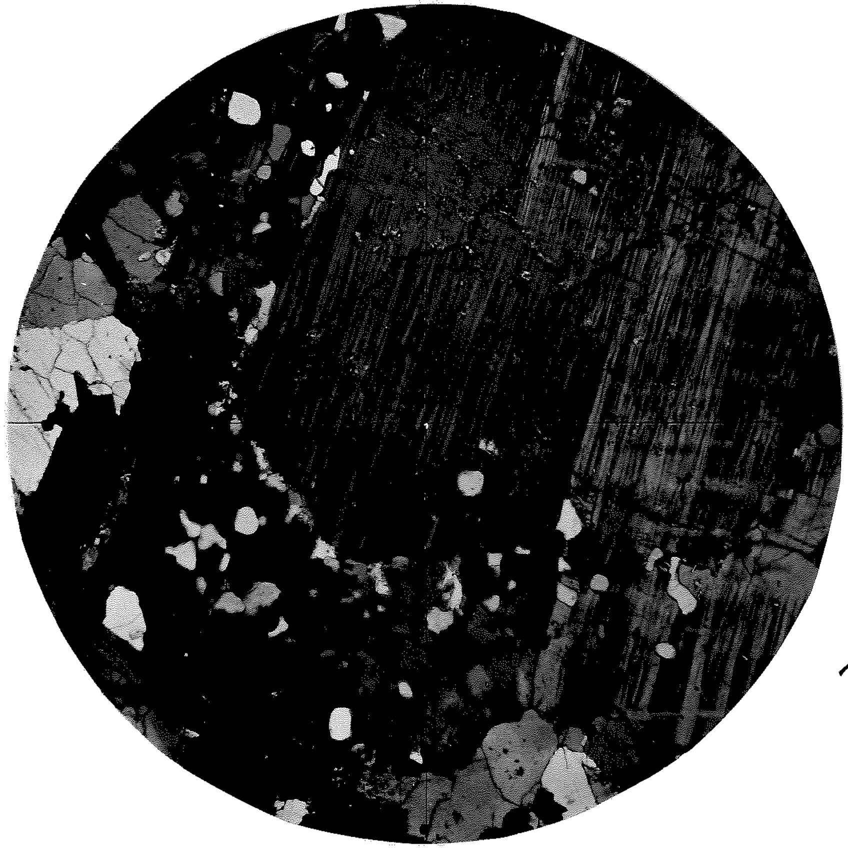


Fig. b
20X

PLATE VIII.

Porphyroblastic granodiorites. Evans Lake mass.

Fig. a. Specimen from east central part of mass. Crossed nicols. Core of large microcline porphyroblast with inclusions of chloritized biotite (b), quartz (q), and oligoclase (o) with albite rims. Retrogressive albite patches show white. (spec. no. 8/26/48-34-17)

Fig. b. Specimen from northeast central portion of mass. Crossed nicols. Crenulated microcline in the groundmass with inclusions of partly chloritized biotite, magnetite, epidote, sphene, oligoclase, and quartz. (spec. no. 8/31/48-167-43)

PLATE VIII.

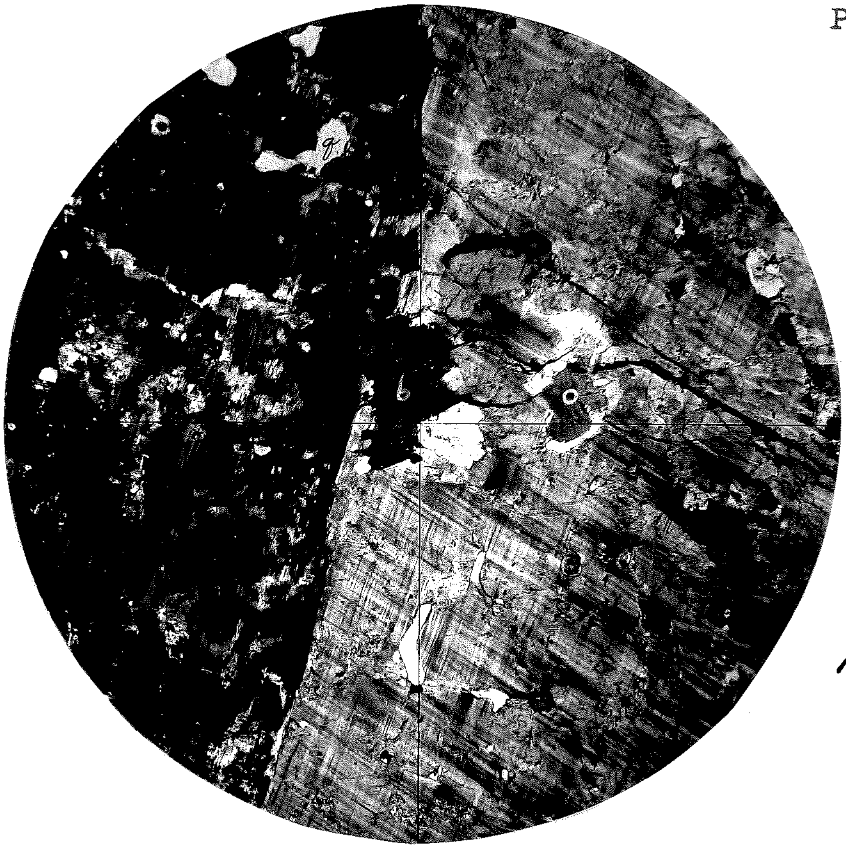


Fig. a
20X

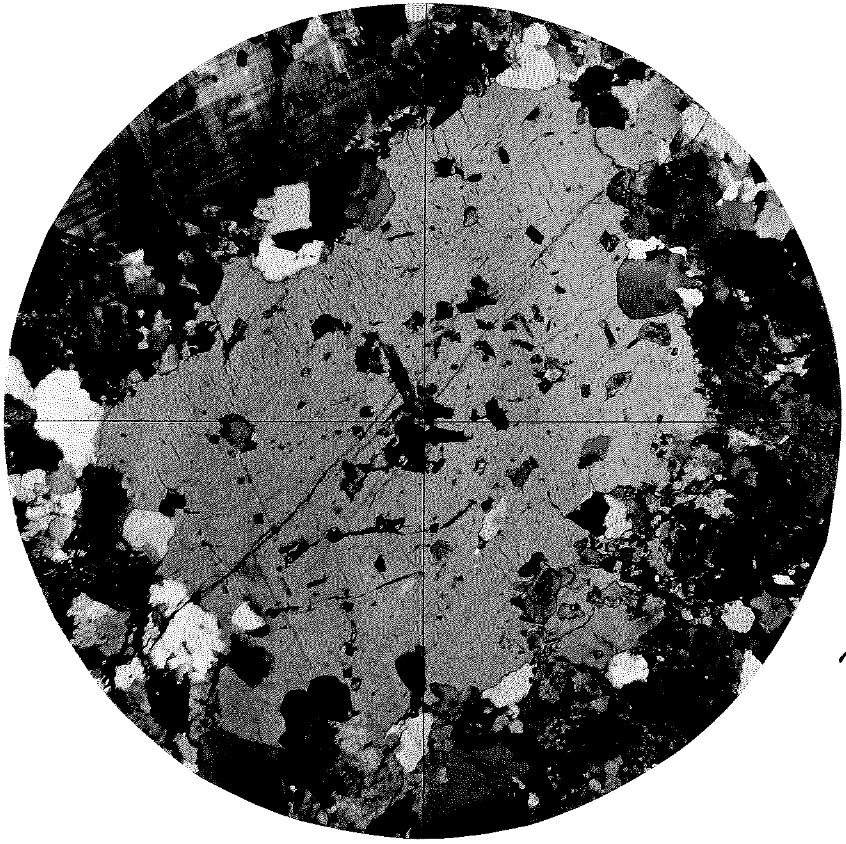


Fig. b
20X

PLATE IX.

Porphyroblastic granodiorite. Northeastern part of Evans Lake mass. Inclusions of sphene (s), epidote (e), secondary chlorite (c), and oligoclase (kaolinitized)(o) in a large microcline porphyroblast. (spec. no. 9/2/48-182-18)

Fig. a. Plain polarized light. Fig. b. Crossed nicols.

PLATE IX.

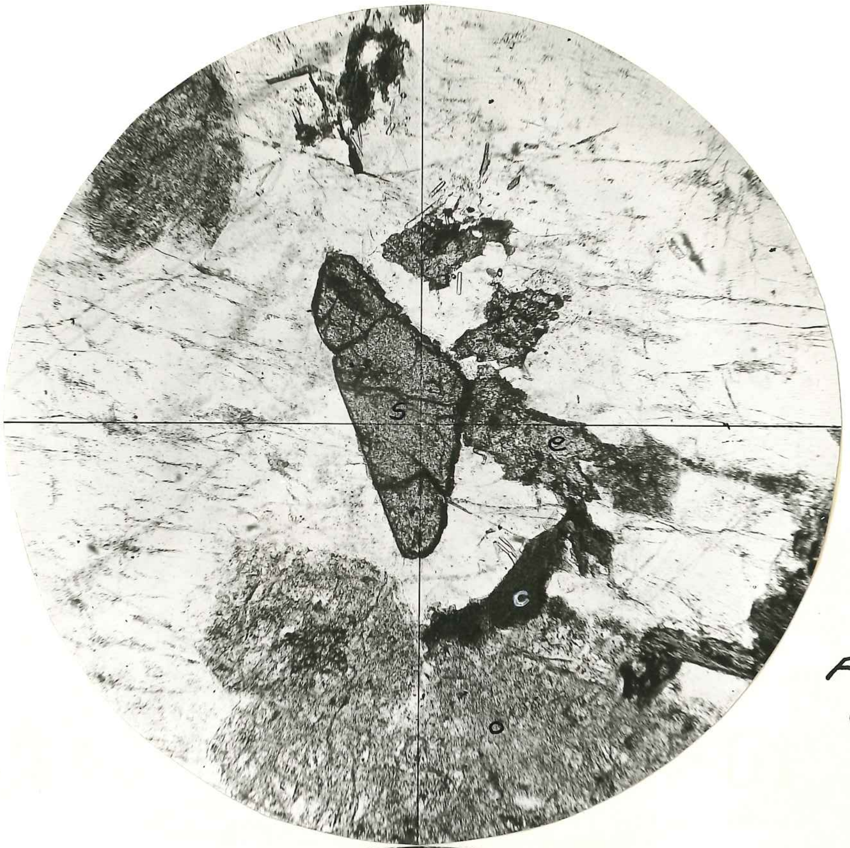


Fig. a
60X

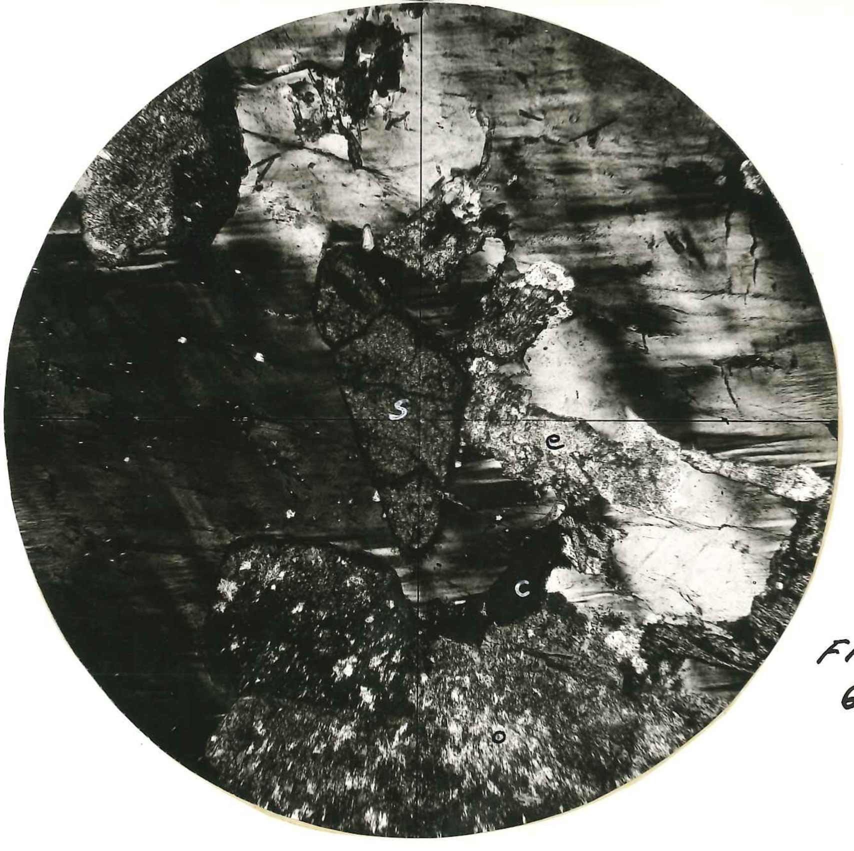


Fig. b
60X

PLATE X.

Porphyroblastic granodiorite. Northeastern marginal part of Evans Lake mass. Microcline, quartz, oligoclase, biotite (b), myrmekite, sphene, epidote. Biotite "draped" around margin of large microcline porphyroblast. (spec. no. 8/31/48-163-34)

Fig. a. Plain polarized light. Fig. b. Crossed nicols.

PLATE X.

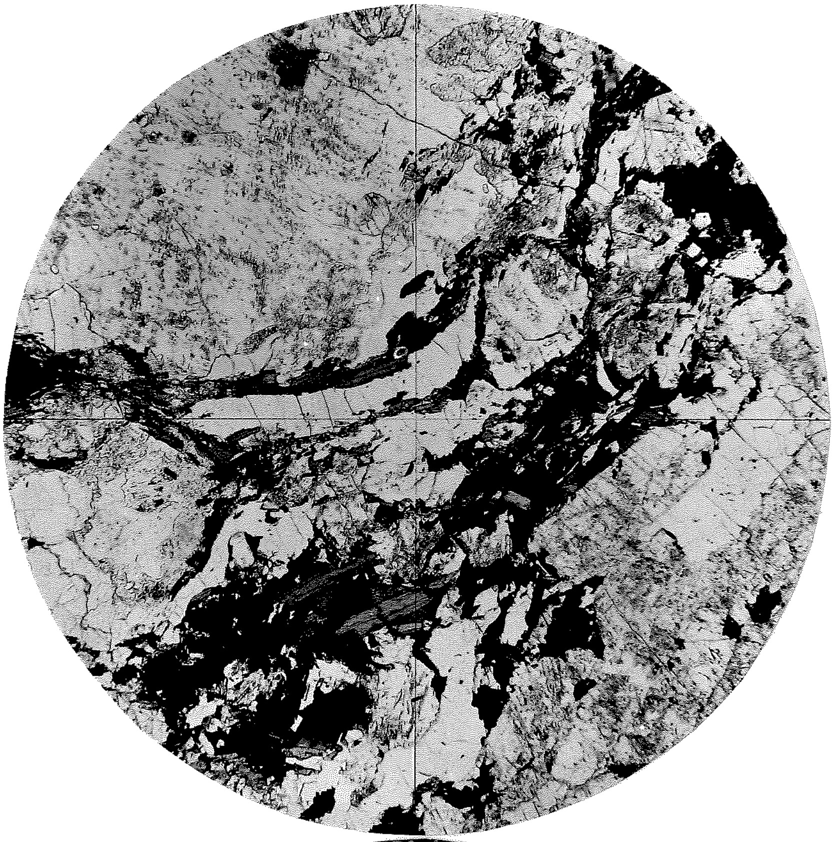


Fig. a
20X

Fig. b
20X

PLATE XI.

Porphyroblastic granodiorite. Central part of Evans Lake mass. Microcline, oligoclase (o), quartz (q), biotite (b), epidote (e), hornblende (h), sphene (s). Several patches of microcline are in optic continuity, representing early stage of growth of microcline porphyroblast. (spec. no. 8/29/48-101-10)

Fig. a. Plain polarized light. Fig. b. Crossed nicols.

PLATE XI.

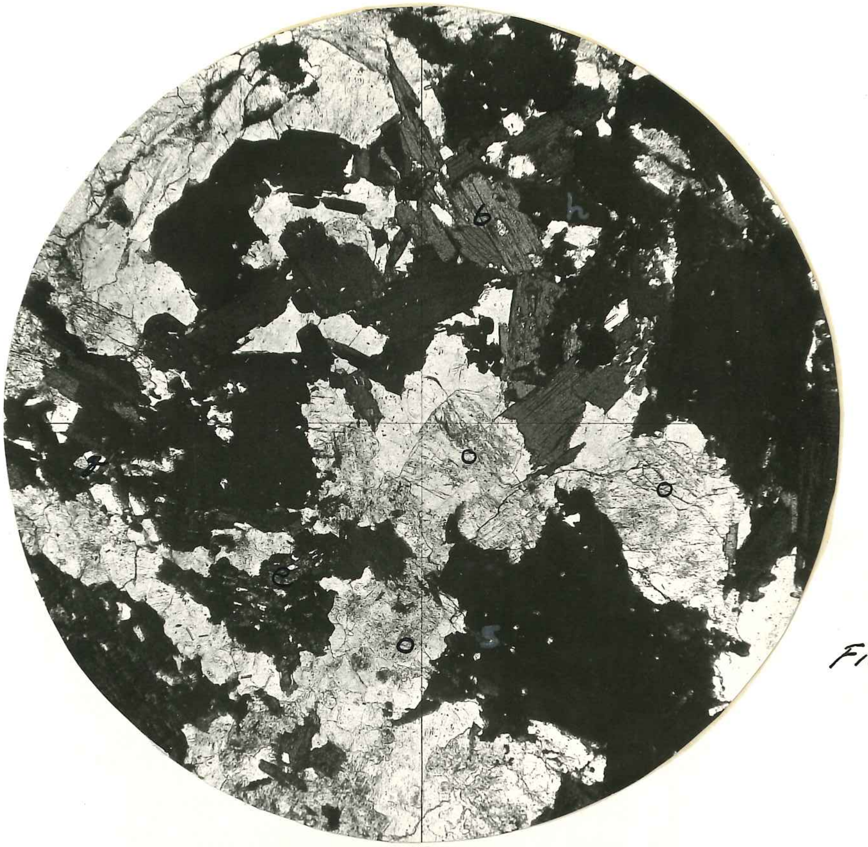


Fig. a
20X

Fig. b
20X

PLATE XII.

Porphyroblastic granodiorites. Evans Lake mass.

Fig. a. Specimen from northeastern marginal part of mass. Crossed nicols. Microcline (m), quartz (q), oligoclase (o), myrmekite (my), hornblende (h), biotite (b). Groundmass microcline includes oligoclase and secondary chlorite. Myrmekite lobes penetrate microcline. (spec. no. 8/31/48-152-13a)

Fig. b. Specimen from near southwestern margin of mass. Crossed nicols. Microcline (m), quartz (q), myrmekite (my), albite (a), oligoclase (o). Recrystallized cataclastic structure. (spec. no. 8/27/48-49-25).

PLATE XII.

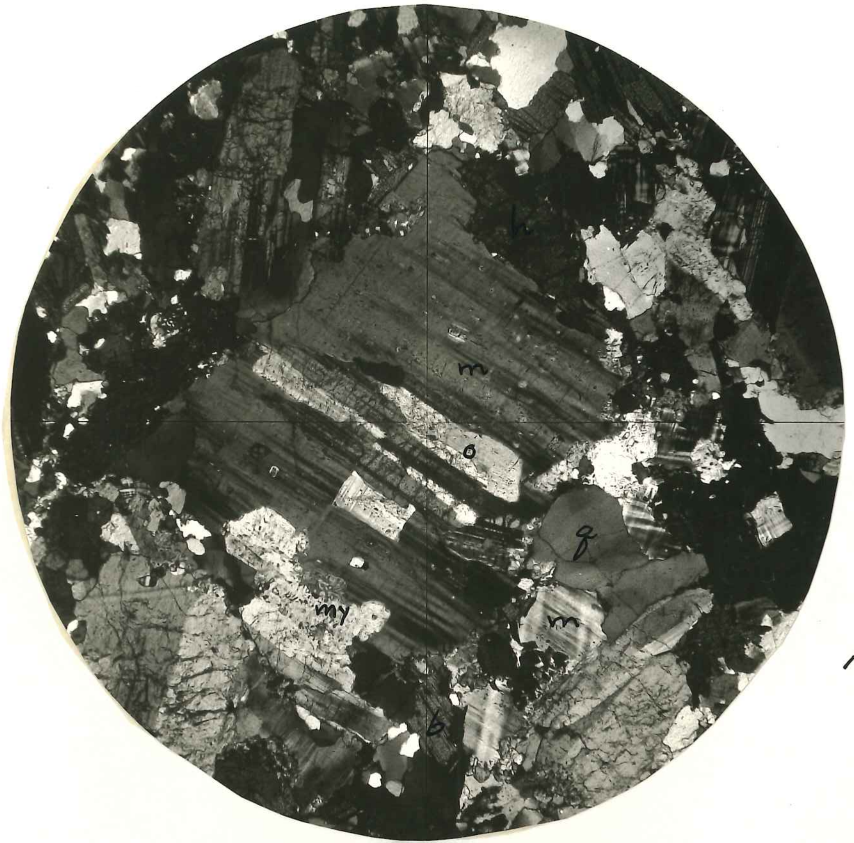


Fig. a
20X

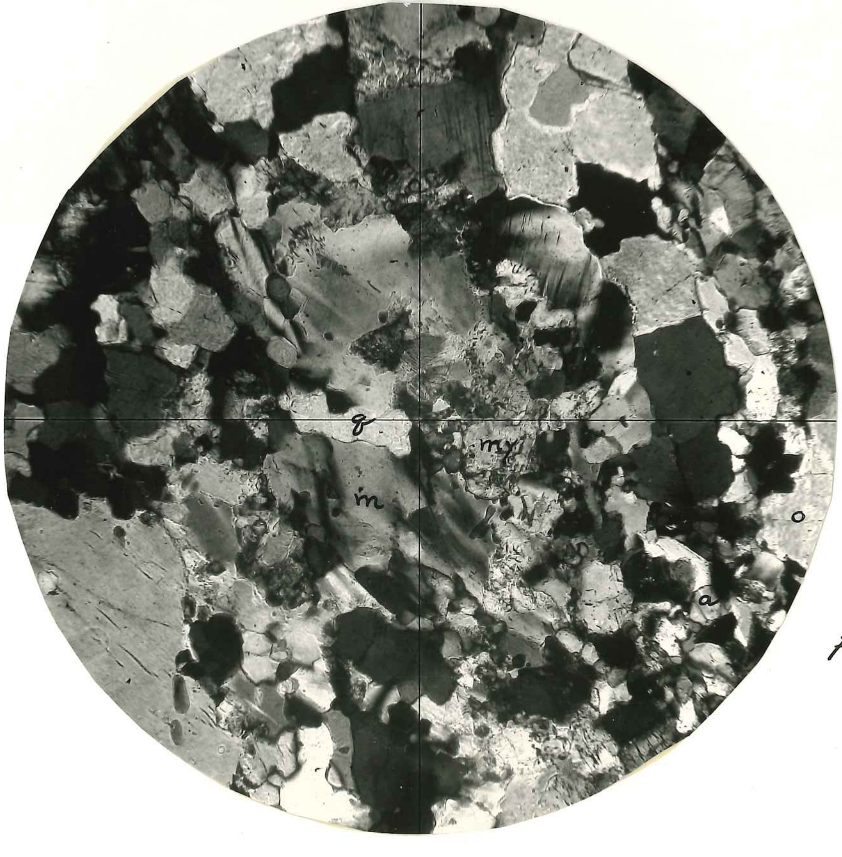


Fig. b
60X

PLATE XIII.

Porphyroblastic granodiorite and quartz monzonite.
Evans Lake mass.

Fig. a. Porphyroblastic quartz monzonite. Crossed nicols. East central part of Evans Lake mass. Oligoclase-andesine (o-a), quartz (q), microcline (m), myrmekite (my). Late stage of glomeroblastic growth. Plagioclase includes biotite. (spec. no. 8/26/48-34-17)

Fig. b. Porphyroblastic granodiorite. Crossed nicols. Central part of Evans Lake mass. Oligoclase-andesine (o-a), quartz (q), microcline (m), myrmekite (my), biotite (b), epidote, sphene. Late stage of glomeroblastic growth. Plagioclase includes biotite and is complexly twinned. (spec. no. 8/31/48-149-9)

PLATE XIII.

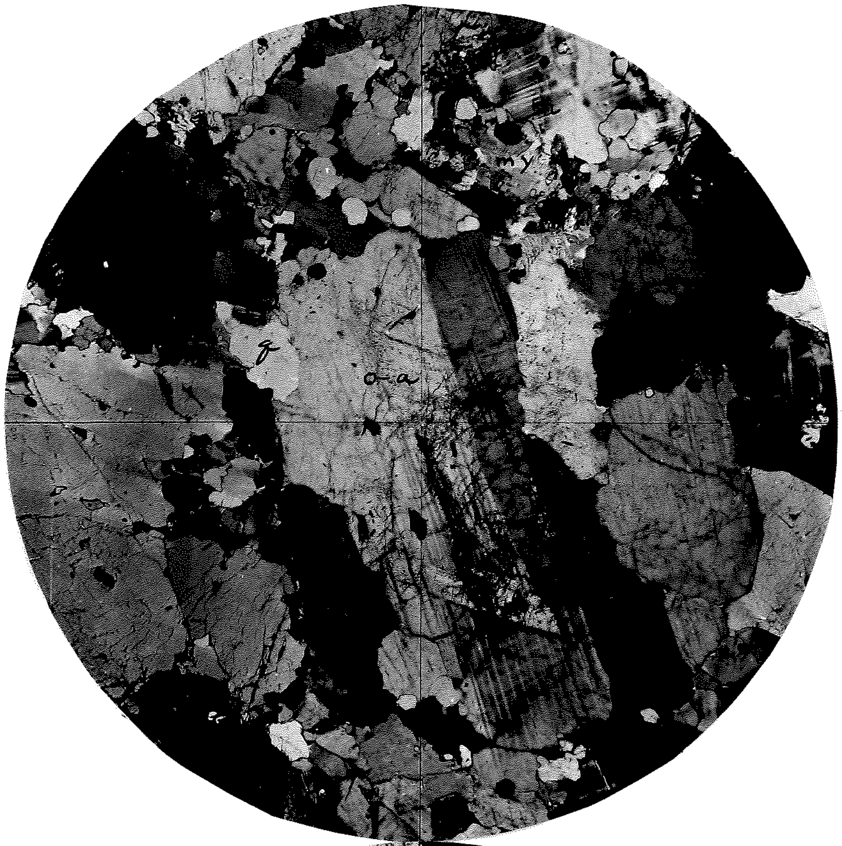


Fig. a
20X

Fig. b
20X

PLATE XIV.

Porphyroblastic granodiorite. West central part of Evans Lake mass. Microcline, quartz, oligoclase, biotite (b), epidote (e), myrmekite (my). Relict cluster of mafics in groundmass. Biotite includes quartz and epidote. (spec. no. 8/27/48-58-33)

Fig. a. Plain Polarized light. Fig. b. Crossed nicols.

PLATE XIV.

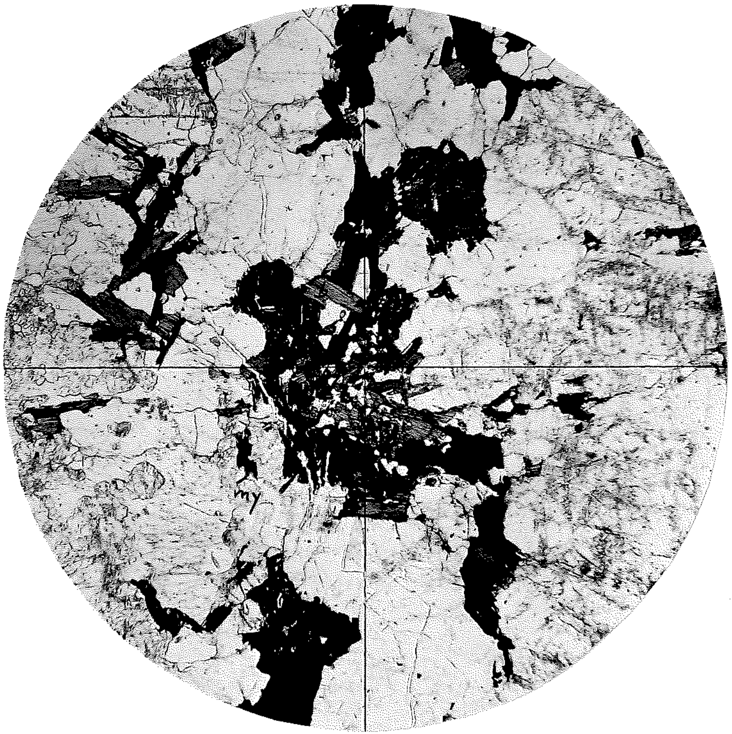


Fig. a
25X

Fig. b
25X

PLATE XV.

Recrystallized mylonitic band in porphyroblastic granodiorite. Near southwestern margin of Evans Lake mass. Post-mylonitic replacement albite and myrmekite. (spec. no. 8/28/48-74-23)

Fig. a. Plain polarized light. Fig. b. Crossed nicols.

PLATE XV.

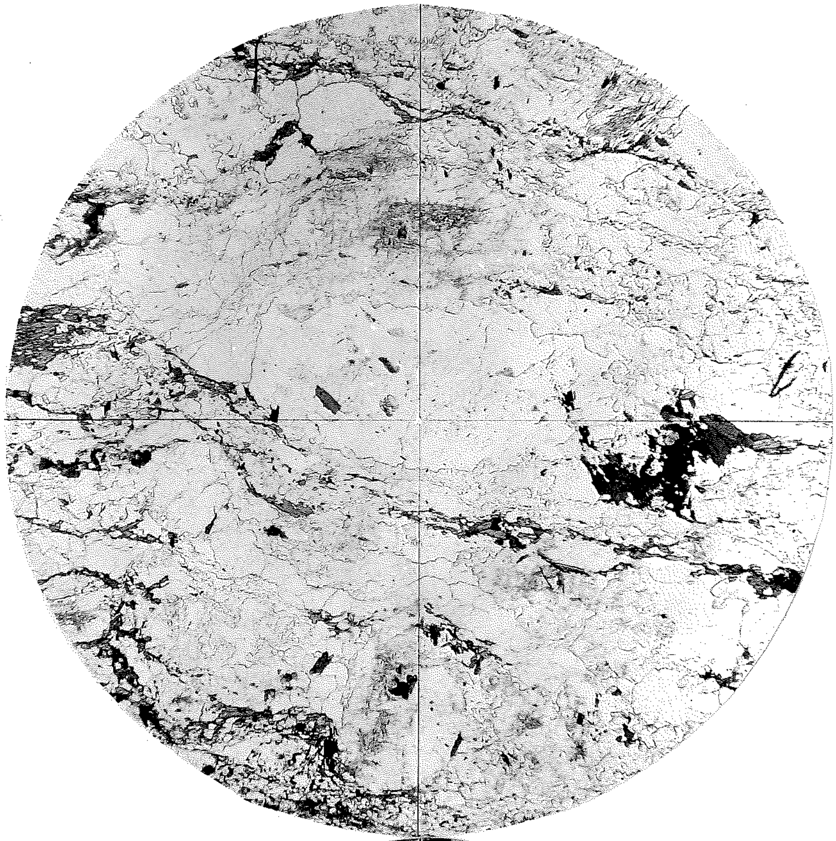


Fig. a
20X

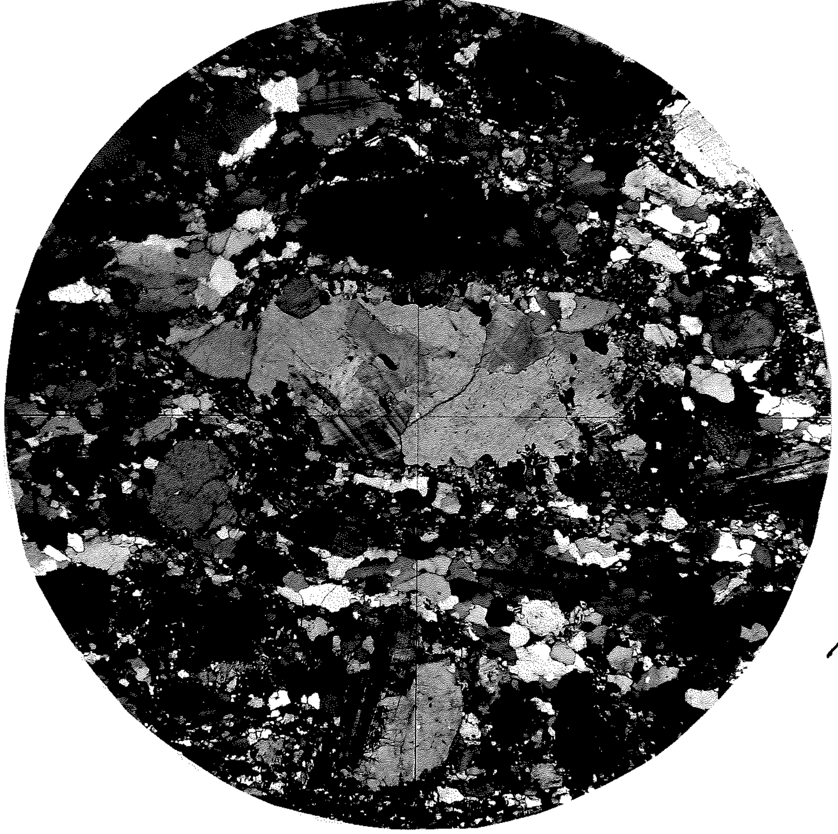


Fig. b
20X

PLATE XVI.

Trondhjemite. Western part of Evans Lake mass. Microcline (m), oligoclase-andesine (o-a), quartz (q), hornblende (h), biotite (b), myrmekite (my). Size and distribution of microcline are irregular. Myrmekite replaces microcline. (spec. no. 8/27/48-51-27)

Fig. a. Plain polarized light. Fig. b. Crossed nicols.

PLATE XVI.

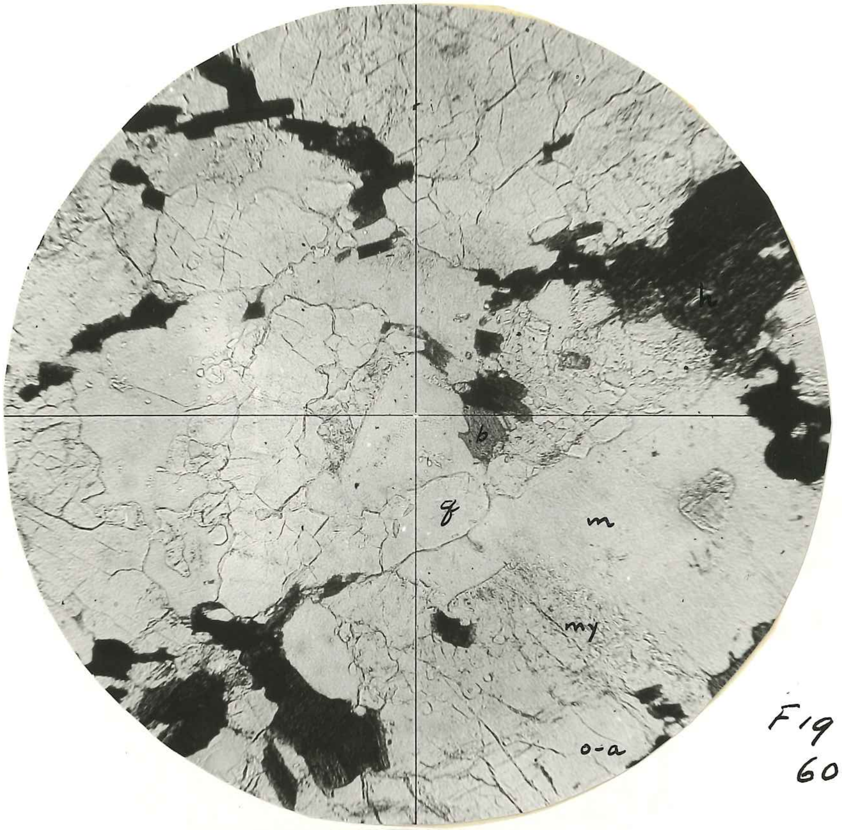


Fig. a
60X

Fig. b
60X

PLATE XVII.

Trondhjemite and porphyroblastic quartz monzonite.
Evans Lake mass.

Fig. a. Trondhjemite. Crossed nicols. Western part of Evans Lake mass. Oligoclase-andesine (o-a), microcline (m), quartz (q), biotite (b), hornblende (h), sphene, myrmekite, epidote. Plagioclase includes biotite and epidote. Microcline replaces biotite. (spec. no. 8/27/48-51-27)

Fig. b. Porphyroblastic quartz monzonite. Crossed nicols. Central part of Evans Lake mass. Microcline, myrmekite, quartz, oligoclase. Several microcline porphyroblasts coalesce. Microcline includes quartz, is marginally penetrated by myrmekite. (spec. no. 8/30/48-137-22)

PLATE XVII.

Fig. a
60X

Fig. b
20X

PLATE XVIII.

Trondhjemite and diorite. Evans Lake mass.

Fig. a. Trondhjemite. Plain polarized light. Northwestern part of Evans Lake mass. Poikiloblastic hornblende (h) with inclusions of quartz (q), and biotite (b). (spec. no. 8/28/48-81-31b)

Fig. b. Diorite. Plain polarized light. Northern part of Evans Lake mass. Andesine, hornblende, biotite, quartz. Poikiloblastic hornblende with diopside cores and with inclusions of quartz and biotite. (spec. no. 8/28/48-73-22a)

PLATE XVIII.

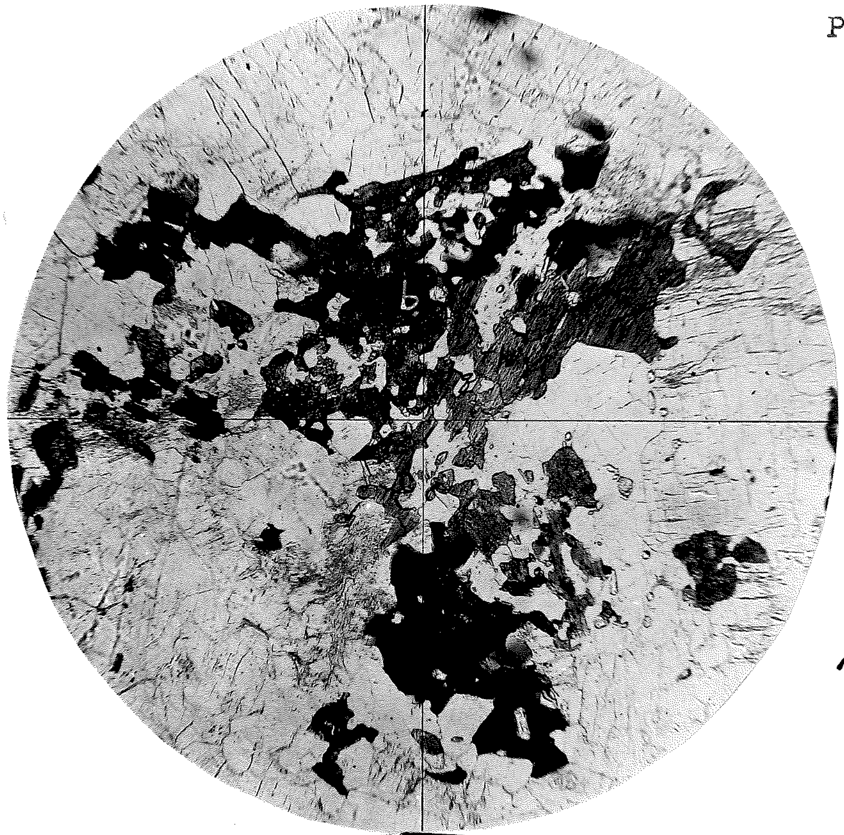


Fig. a
60X

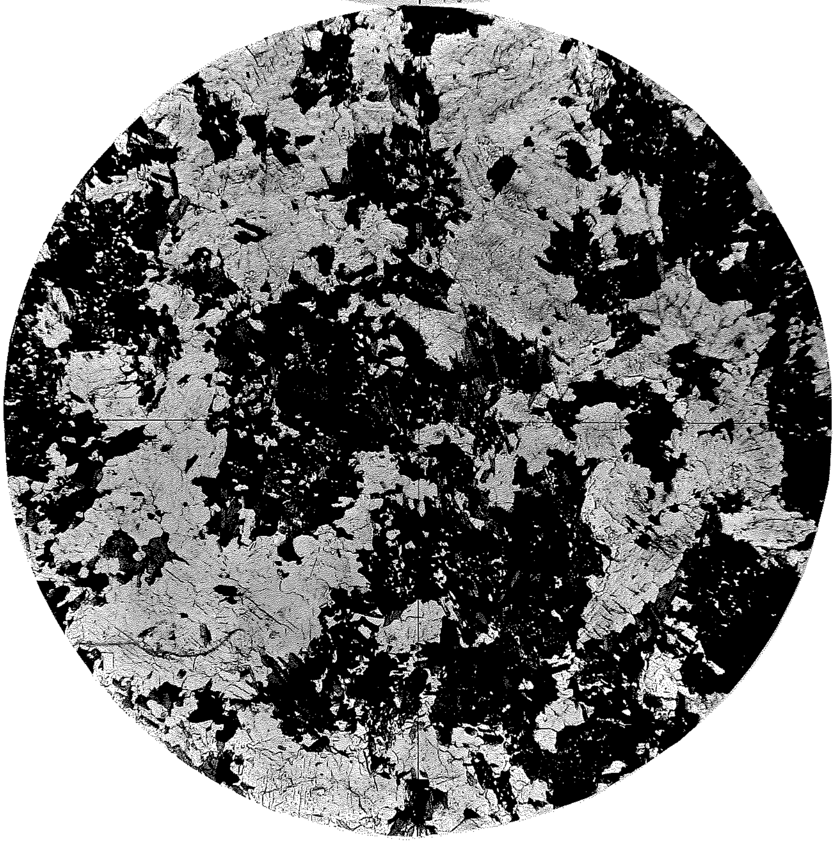


Fig. b
20X

PLATE XIX.

Biotite schist and partially granitized biotite schist.
Evans Lake mass.

Fig. a. Biotite schist. Plain polarized light. Northeastern portion of Evans Lake mass. Biotite, quartz, muscovite, chlorite, epidote, sphene, albite. (spec. no. 9/2/48-186-29)

Fig. b. Gradational and irregular replacement contact between biotite schist and aplitic granodiorite. Plain polarized light. Northwestern portion of Evans Lake mass. (spec. no. 8/27/48-56-32)

PLATE XIX.

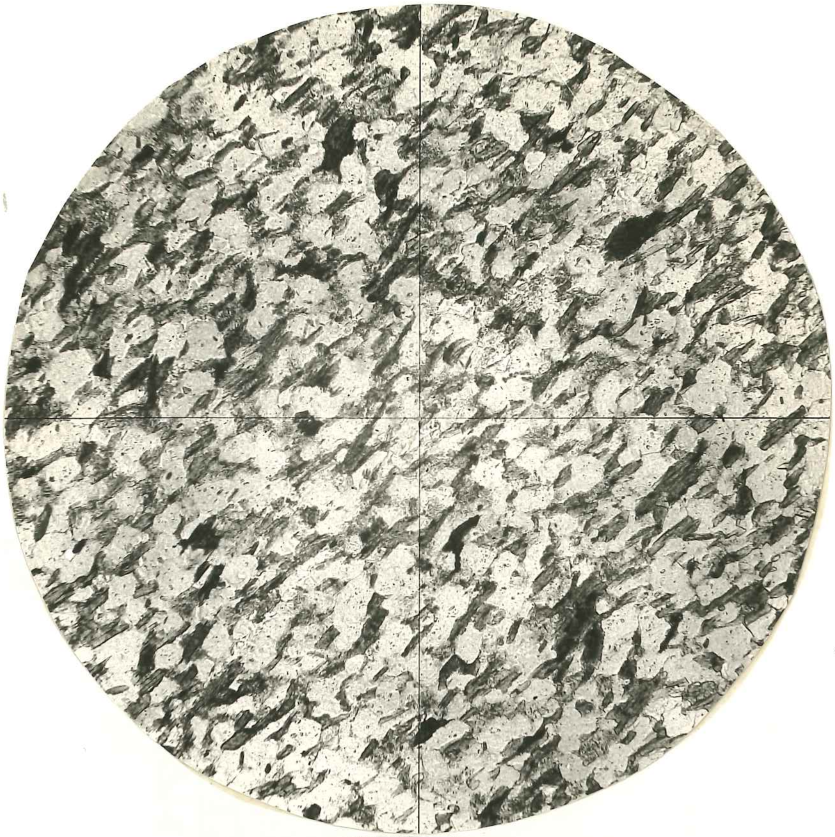


Fig. a
60X

Fig. b
20X

PLATE XX.

Metasomatic-migmatitic contact of granodiorite and hornfelsic biotite schist. Northeastern margin of Evans Lake mass. Foliation of biotite schist is transected by granodioritic bands without being disturbed. Contacts are crystalloblastic. (spec. no. 8/31/48-158-27a)

Fig. a. Plain polarized light. Fig. b. Crossed nicols.

PLATE XX.

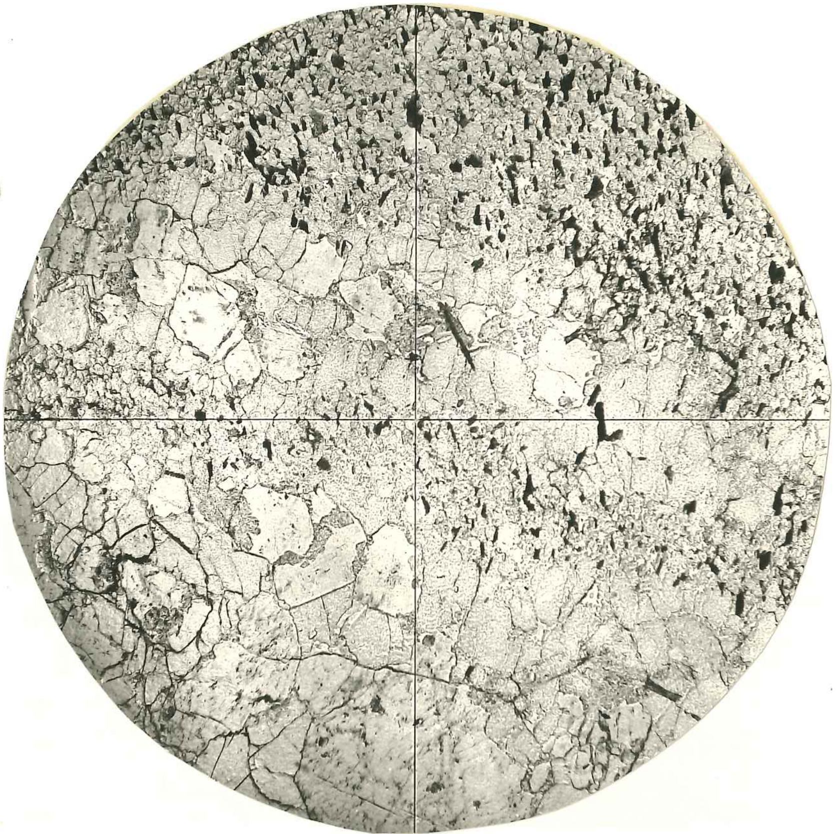


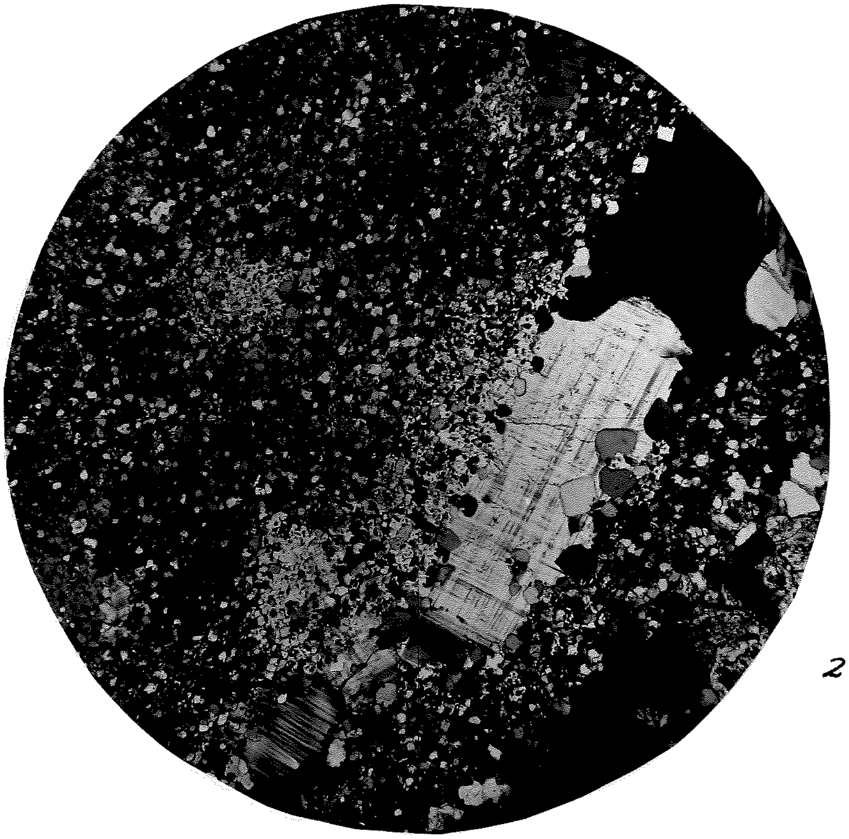
Fig. a
20X

Fig. b
20X

PLATE XXI.

Quartz-biotite hornfels in contact with porphyroblastic granodiorite. Northeastern part of Evans Lake mass. Hornfels on left contains small indistinct crystalloblastic patches of microcline (incipient porphyroblasts). On right: advanced stage of microcline porphyroblast replacing hornfels. (spec. no. 8/31/48-163-37)

PLATE XXI.



20X

PLATE XXII.

Migmatite. Southwestern margin of Evans Lake mass. Replacement veinlet of microcline and quartz in diorite. Contacts are irregular, gradational and crystalloblastic. (spec. no. 8/26/48-35-18)

Fig. a. Plain polarized light. Fig. b. Crossed nicols.

PLATE XXII.

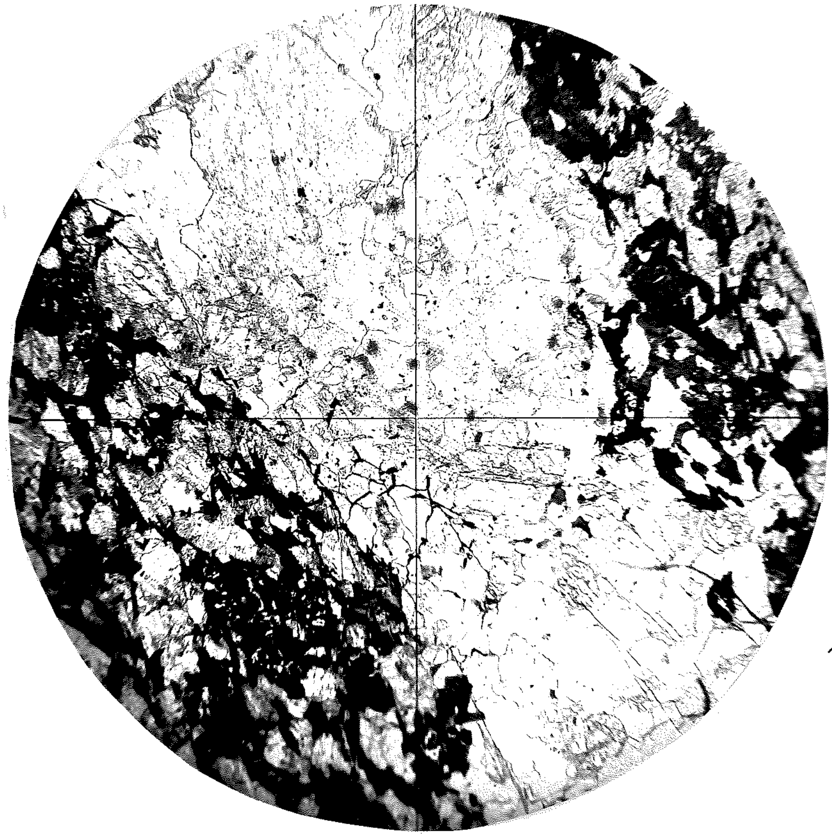


Fig. 9
20X

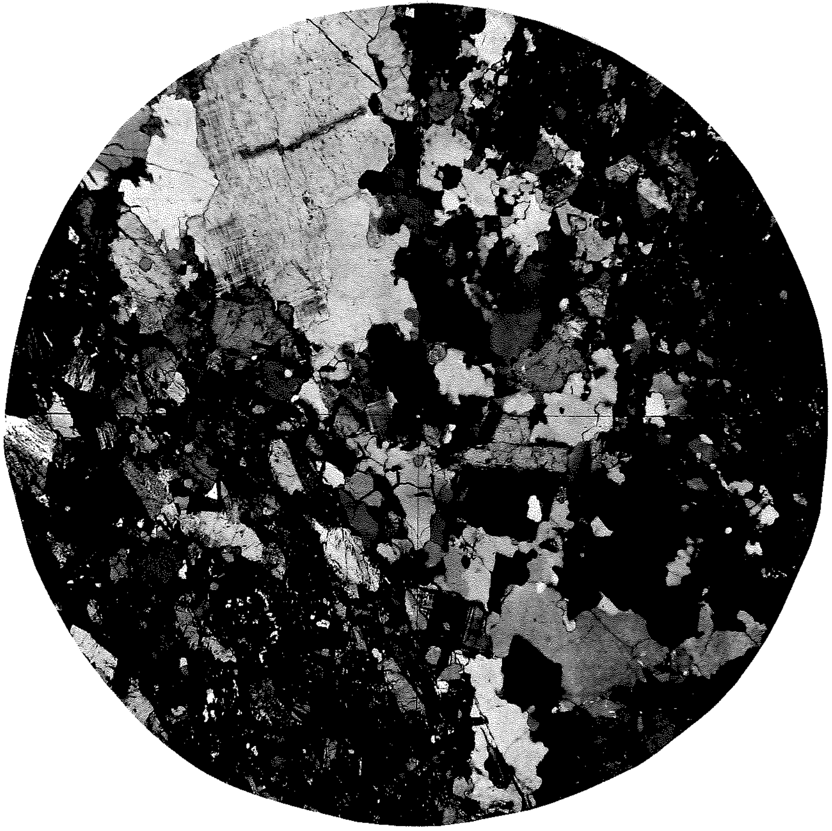


Fig. 6
20X

GENETIC DISCUSSION OF THE EVANS LAKE GRANODIORITE

The field and petrographic data recorded suggest that the Evans Lake granodiorite was formed *in situ* by metasomatic granitization of Scotch Creek schist and amphibolite.

In view of a possible igneous interpretation of the Evans Lake mass, I have outlined a few criteria for igneous rock bodies (cf. Goodspeed, 1948) which might on casual observation be believed to apply in the case of the Evans Lake mass.

1. The following features might be taken as indicative of flow structure: (a) the alignment of microcline crystals, (b) the occurrence of various rock types in zones parallel to the margins of the mass, and (c) apparent protoclastic structure.
2. The local presence of rather sharp contacts (on a field scale) between different rocks within the mass, and between the mass and the adjacent metasediments, might be taken as evidence of intrusion.
3. The occurrence of more uniformly coarse-grained acidic rocks in the core of the granodioritic mass, and of finer-grained more basic rocks in parts of the marginal zones, might be considered as indicative of an igneous origin (differentiation and chilling).

4. Some textures might be described as hypallotriomorphic-granular and porphyritic, i.e., as igneous.
5. The occurrence of occasional diopside and commonly of hornblende and biotite in successive more or less concentric zones agrees with Bowen's (cf. Bowen, 1928) reaction series and might be considered as indicating an igneous origin.

These apparent indications of an igneous origin of the Evans Lake granodioritic mass will now be discussed and will be compared with the criteria in favor of a granitization origin of this mass.

The structures within the Evans Lake mass are continuous, parallel and harmonic with those of the sedimentary area in which this mass occurs.[7] There is no trace of mechanical displacement where the granodiorite is in contact with the metasediments; in fact, the metasediments dip into and under the granodioritic mass. If the mass had been formed by the intrusion of magma, the intruded rocks would have been disrupted, at least to some extent, and the thin included sedimentary relict bands would have been broken and shifted.

However, the structural continuity of the granodiorite mass with the surrounding sediments might conceivably be explained if magmatic intrusion preceded the synclinal folding (cf. Harker, p. 298). In this case, folding, which

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[7] The significance of such structural continuity has been emphasized by Misch (1949a,b).

would have occurred before the magma had completely solidified, might have forced the intrusive mass and all of its inclusions into tectonic harmony with the country rock. Yet, could it have been possible that in a magma, which was subjected to intense orogenic stress, very thin schist and limestone bands were preserved that extend for at least several tens of feet? Furthermore, would thin limestone bands not have been fused in liquid silicate melt?[8] The strongest argument against such pre-orogenic or early-orogenic intrusion, however, is the lack of schistose or gneissose structure in most of the granodioritic and related rocks composing the Evans Lake mass.

Protoclastic and flow structures would occur if the magma, before it had completely solidified, was deformed under stress, or if it was intruded as a mixture of crystals and highly viscous melt. The cataclastic structure localized at the southwestern margin of the mass might be interpreted as protoclastic, and the gneissic structure, which is widely developed in the southwestern part of the mass, might be considered as igneous flow structure. However, the protoclastic-appearing structure is due to (1) local syn-granitization faulting (cf. below) related to the overthrusting of the southern limestone anticline, and (2) to subsequent Tertiary faulting in this same general zone. The apparent igneous

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[8] As has been pointed out by Misch (1949a) in case of the northwestern Himalayas.

flow structure is gneissic structure due to synkinematic and therefore oriented growth of microcline porphyroblasts in a solid rock. Also, if the mass were magmatic and had been later on tectonically deformed together and harmoniously with the metasediments, it would exhibit protoclastic structures along all margins. However, the northeastern margin completely lacks such structures.

A magma would preferably intrude an anticline rather than a syncline. As has been pointed out by Misch (1949a,b), the Evans Lake granodiorite, as well as other granitic bodies in this region, occurs in a synclinal area, which apart from the granitic rocks contains Scotch Creek schist.

In conclusion, the structural pattern of the Evans Lake mass in relation to that of the general region may be explained more plausibly by metasomatic granitization of solid rocks comprising Scotch Creek schist and amphibolite.

If the Evans Lake mass were intrusive, the more rapid cooling of the marginal zones could conceivably have resulted in a finer grain and a more basic composition than in the interior of the mass. Such an interpretation might be applied to the southwestern basic margin, but not to the northeastern margin, where coarse-grained porphyroblastic granodiorite forms the border zone.

There is no evidence of chilling, flow structure, or protoclasis at the contacts between different rock types within the mass that would suggest separate intrusions of igneous rocks of different composition. The different rock types grade into each other irregularly, in texture, structure and mineral composition. The passage zones vary in width from fractions of an inch to tens of feet.

The areal distribution of different igneous-appearing rock types in the mass is better explained by granitization than by magmatic intrusion. The rather heterogeneous composition of the Scotch Creek formation is reflected in the Evans Lake granodioritic mass and has led to "differential granitization," to use the term of Misch (1949a,b). The argillite-derived schists, having a chemical composition close to that of granite, have been most readily granitized, as they require only a minor amount of metasomatically introduced alkalis. The calcareous and dolomitic bands, on the other hand, have a composition more unlike granite. They require considerably more addition of alkali, silica and aluminum, as well as removal of most of the calcium and magnesium, to be transformed into a granitic rock. Granitizing solutions have acted differentially on rocks of different chemical composition and have selectively granitized the chemically most susceptible rocks. This is the reason, in the first place, for the location of the Evans Lake granodioritic mass; it was formed in a mostly argillaceous synclinal core. The limestone and dolomite in the neighboring anticlines have escaped granitization, as has already been pointed out by Misch (1949b, chap. III). The thin and impure dolomitic and calcareous bands within the Scotch Creek formation have been altered and partially metasomatized to amphibolite and diorite, and these basic bands are structurally relics inherited from the sedimentary syncline. The diorite zone in the northern and northeastern part of the area is continuous with the trend of a more calcic metasedimentary band, the prolongation of which is present in a portion of the marginal zone in the northeast. The dioritic inclusions and migmatites increase in abundance toward the western margin, due to the fact that a dolomitic and calcareous member approaches the surface from below, due to the axial pitch of the syncline. The rocks higher in the Scotch Creek formation which form the core of the syncline were mostly argillite-derived schists. Their granitized equivalent forms the main body of porphyroblastic granodiorite and quartz monzonite. Diorite, trondhjemite, and granodiorite are successive stages in the metasomatic series which begins with amphibolite and ends with potash-rich monzonite. The occurrence of these variously granitized rocks is simultaneously a reflection of the differences in composition of the metasediments which varies from dolomitic and calcareous to argillaceous schists.

To summarize, the distribution of the various igneous-appearing rock types is chiefly controlled by the composition of the original sediments that were granitized, although the different stages reached by granitization at different places have a modifying influence.

Petrographic criteria in favor of an origin of the mass by metasomatic granitization are present in all rock types.

The microcline crystals in the porphyroblastic granodiorite and quartz monzonite might upon superficial examination be called phenocrysts. However, phenocrysts are among the first crystals to form from a magma and could not, therefore, contain inclusions other than pyrogenic minerals - minerals segregated at higher temperature than the mineral of the phenocryst - and occasionally glass. Also, phenocrysts characteristically have sharp borders.

The large microcline crystals in the Evans Lake area exhibit features which indicate that they were formed by porphyroblastic growth in a solid rock. These features are: (1) inclusions of groundmass minerals, and (2) crenulated borders with delicate growth projections that protrude into the groundmass. Every porphyroblast of microcline examined contains inclusions. The most common inclusions are quartz, oligoclase and biotite, and these minerals are also the most abundant in the groundmass. Often one large microcline porphyroblast includes all of the groundmass minerals. This indicates that the microcline porphyroblasts were the last crystals to form (except for later albite and myrmekite which replaces microcline), and that they must have formed, not from a magma, but by reaction and growth in the solid, due to metasomatic introduction of alkali, mainly potassium, through the intergranular spaces in the rock. Crenulated borders with delicate projections which intricately penetrate and partially include the minerals in the groundmass are evidence for the replacement origin of these large microcline porphyroblasts. Phenocrysts "floating around" under high pressure in an igneous melt could not conceivably preserve thin delicate projections.

From diorite to quartz monzonite the amount of microcline gradually increases. Directly proportionate to this increase in abundance is an increase in size, an increase in the amount of inclusions, and an increase in the development of crystal form from initial very irregular intergranular growths in diorite to the final idioblastic porphyroblasts in quartz monzonite. These features shown by the microcline in the Evans Lake mass are evidence for successive stages of potash metasomatism in altered sediments of different composition.

The properties of the plagioclase in the Evans Lake mass are also indicative of crystalloblastic growth. Characteristic are glomeroblastic aggregates, complex twinning and zoning, mottled extinction, crenulated borders, and inclusions of quartz, biotite, hornblende, epidote, and sphene. The composition of the plagioclase varies from An36 in amphibolite and diorite to An28 in porphyroblastic granodiorite and quartz monzonite. This gradation is accompanied by a decrease in abundance, an increase in grain size, more advanced glomeroblastic development, and slight increase in the amount of inclusions.

The sodium content of all the rocks in the Evans Lake mass is too high to have been derived from the original sediments. The characteristics of the plagioclase crystals exclude a magmatic origin. Therefore, the relatively high content of sodium in the rocks must be due to a metasomatic introduction of this element.

In all rock types in the mass, biotite commonly replaces hornblende marginally and occasionally along its cleavage planes, while at the same time biotite may be included within the hornblende. Thus, the relationship between biotite and hornblende may be readily explained by a process of biotitization of hornblende, rather than by the order of magmatic crystallization according to Bowen's reaction series. As hornblende decreases in abundance from diorite to quartz monzonite the amount of microcline and the degree of biotitization of hornblende increase. This is in accordance with the relative amount of potash introduction. In all rock types, the hornblende usually exhibits poikiloblastic texture with inclusions of quartz, such as could never exist in primary igneous hornblende. The calcium released from the biotitized hornblende has formed sphene and epidote. Minute sphene crystals may be included in biotite, particularly in those biotite flakes that are closely associated with hornblende. Epidote is nearly always intimately associated with biotite in biotitized hornblende patches. Some epidote forms hypidioblasts and idioblasts. It is commonly included in biotite as idioblastic crystals. Also, similar epidote-biotite-hornblende aggregates may be included in microcline porphyroblasts. I conclude that epidote is a primary constituent in all rock types in the Evans Lake mass. Epidote is a relatively low temperature mineral and could never be a primary mineral in an igneous melt. All of the chlorite in the Evans Lake mass is secondary, mainly after biotite, and, to a less extent, after hornblende. It is in part a retrogressive low temperature alteration product of mafics, and, in part, a weathering product.

Replacement features and crystalloblastic textures are present in all petrographic types of the Evans Lake granodioritic mass. These textures are characterized by consistently irregular and interlocking mineral grains. The borders of most minerals are sutured and crenulated. Inclusions of certain minerals are characteristic throughout the mass. As a whole, all rock types have irregular and gradational textures which are typical of crystalloblastic growth and replacement in a solid rock, rather than magmatic fractional crystallization.

The gneissic structures of part of the igneous-appearing rocks are partly relics of shearing of the metasediments before granitization and partly due to tectonic deformation during granitization. The massive-directionless structure is the result of postkinematic, i.e., static recrystallization and granitization which obliterated earlier schistose structure of the sediments. Nearly all of the gneissic rocks have superposed directionless structures, such as transverse porphyroblasts, which are due to post-tectonic crystallization. The gneissic rocks show incomplete obliteration of earlier schistosity.

The complex mineralogical, textural and structural changes in the transition zones between rock types within the mass, and between the mass and the adjacent schists, are best explained by metasomatic migmatitization. Crystalloblastic replacement contact zones of varying widths, which are everywhere gradational and irregular, are evidence of granitization. Megascopic and microscopic structural continuity through all rock types in all transition zones are evidence of granitization.

History of Metamorphism of the Evans Lake mass. The rocks in the Evans Lake syncline have been progressively metamorphosed in the low-grade zone (epizone), in the medium-grade zone (mesozone), and in the beginning of the high-grade zone (katazone). Initial synkinematic and superposed post-kinematic granitization were the climax of progressive metamorphism in the Evans Lake area. Retrogressive metamorphism is slight.

A study of the parageneses of the most common minerals in the Evans Lake area is a key to the history of the advance of metasomatic granitization.

The actinolite schists and phyllitic biotite schists (upper Evans Lake) to the north of the Evans Lake mass are transitional between epizone and mesozone. Toward the Evans Lake mass the grade of metamorphism increases to the hotter part of the mesozone in the lower Scotch Creek schists, as is indicated by the presence of kyanite in the schists in the migmatitic marginal zone of the granitic mass. Before the kyanite schist facies is reached, incipient porphyroblasts of albite-oligoclase occur in the schists bordering the granodiorite. This suggests an introduction of sodium under mesozonal conditions when temperature had not yet risen to that of the hottest mesozonal kyanite schist facies. Microcline first appears in the kyanite zone. This suggests the initial introduction of potash in the hottest part of the mesozone.

These conditions are identical with those described by Misch (1949a).

The relation of the minerals in the rocks of the Evans Lake mass also indicates that sodium metasomatism was active prior to, and at lower temperature than, potash metasomatism. The succession of crystalloblastic growth of the more abundant minerals present in the granitized argillaceous schists (trondhjemite, granodiorite, quartz monzonite) is roughly as follows: (1) quartz, biotite, with minor amounts of hornblende, (2) oligoclase-andesine, epidote, sphene, and biotite, (3) microcline, and (4) albite and quartz. Phase (1) represents the mesozonal mineral composition of the metasediments before affected by sodium or potash metasomatism. Phase (2) is the result of sodium metasomatism and incipient potash metasomatism in the metasediments. Introduction of sodium is indicated by the presence of large amounts of oligoclase-andesine. The sodium in the plagioclase far exceeds that present in the original sediments. Phase (3) is that of potash metasomatism which resulted in the widespread formation of microcline. This is the main granitization phase and presumably was at somewhat higher temperature than the phase of sodium metasomatism. Microcline is the latest mineral in the progressive metamorphism and granitization of the schists. Microcline includes every other mineral, except for retrogressive albite and myrmekite. Potash metasomatism was the climax of progressive metamorphism and granitization in the Evans Lake area. Phase (4) which consists of the formation of albite and myrmekite, is retrogressive and will be discussed on p. 87.

The succession of crystalloblastic growth of the minerals in the altered and granitized impure calcareous and dolomitic schists (amphibolite and diorite) is roughly as follows: (1) hornblende and quartz, (2) andesine, biotite, sphene, and epidote, (3) biotite with minor amounts of microcline, and (4) minor amounts of albite and myrmekite. Phase (1) represents the mesozonal crystallization of the metasediments, probably combined with some silica introduction, but before they were attacked by sodium or potash metasomatism. Phase (2) reflects the time when these metasediments were affected by sodium and by very incipient potash metasomatism. The presence of large quantities of sodic andesine indicates that considerable amounts of sodium were added which reacted with part of the calcium in the hornblende to form mesozonal plagioclase. Very incipient introduction of potash biotitized minor amounts of hornblende. Phase (3) represents the climax of granitization in these magnesium and calcium rich rocks. Potash metasomatism biotitized variable amounts of hornblende, with resulting segregation of sphene and epidote, and led to the formation of very minor amounts of microcline. Phase (4) is retrogressive (cf. below).

The succession of crystalloblastic growth and metasomatic processes in the Evans Lake mass suggest a period of slowly rising temperature. This would be contrasted to magmatic crystallization under decreasing temperature.

Sodium metasomatism, presumably combined with silica introduction, was transforming the impure calcareous and dolomitic sediments into amphibolite and diorite; it only biotitized a part of the hornblende and initiated small intergranular growths of microcline. Both sodium and potassium metasomatism were active in transforming the argillaceous schists to granodiorite.

Granitization began synkinematically in the Evans Lake syncline. This is evidenced by the crystallization foliation of the augen gneiss - the general alignment of most of the microcline and of the mafics. The gneissic rocks are most abundant in the southwestern part of the area and are quite rare in the northeastern part. Therefore, the early stage of granitization was active mainly in the southwestern part of the area. During this synkinematic phase, the temperature never became higher than mesozonal, as is indicated by the paragenesis of epidote, oligoclase-andesine and microcline, and by the absence of katazonal minerals.

Metasomatic granitization lasted longer than deformation. During this postkinematic phase, the front of metasomatism spread generally from the southwest to the northeast beyond the limits reached by synkinematic metasomatism. The evidence for postkinematic granitization in the central, northern and northeastern parts of the Evans Lake mass mainly consists of the massive-directionless structures exhibited by the rocks in these areas. In the synkinematically granitized area in the southwest, there is evidence for superposed postkinematic granitization. Many of the microcline porphyroblasts in the augen gneiss exhibit a latest stage of growth, which was static. This stage is characterized by delicate projections and crenulated borders, which could not have persisted if the rock had been differentially deformed while the porphyroblasts were growing. The augen gneiss also contains transversely oriented microcline porphyroblasts which obviously formed under static conditions, i.e., later than the synkinematic augen. There is a complete gradation from the synkinematic augen gneiss in the southwest to the massive-directionless granodiorite in the core and northeastern part of the mass. This suggests that the border of synkinematic granitization was not sharp but consisted of a broad gradation zone. The front of postkinematic granitization, on the other hand, is rather sharp at the northeastern margin of the mass. The best explanation seems to be that the metasomatic front has remained stationary for a period after it had reached its maximum extent under static conditions.

The zones in which inclusions are concentrated in some of the microcline porphyroblasts may owe their origin to two stages of crystalloblastic growth, the first being synkinematic and the second postkinematic. The lesser amount of inclusions in the cores of the porphyroblasts suggests that differential shearing during the growth of the cores facilitated the removal of inclusions. The outer zone of static growth contains more inclusions.

The postkinematic granitization in the Evans Lake mass is matched by the superposed hornfelsic texture in the schists at the northern contact and the static growth of high temperature minerals such as andalusite, diopside and wollastonite (cf. Misch, 1949b, chap. III). These high-grade minerals indicate that in postkinematic time temperatures must have somewhat exceeded those of synkinematic metasomatism. The greater abundance of microcline in the postkinematic quartz monzonite in the northeast is in accordance with stronger metasomatism and higher temperature.

Thus, the climax of metamorphism and granitization in the Evans Lake area was postkinematic potash metasomatism, during which locally temperatures corresponding to the high-grade zone were attained.

When the temperature declined, sodium metasomatism was again active during a retrogressive phase, though on a minor scale. This is indicated by the myrmekite growths (phase 4) which penetrated and marginally replaced the microcline porphyroblasts, and by the patchy replacement albite within the porphyroblasts, as well as by clear albite rims around oligoclase inclusions. The formation of myrmekite at contacts between plagioclase and microcline is probably due to the ease with which sodium is able to replace oligoclase and form albite, and to subsequent encroachment of the growing albite rim upon microcline with the liberation of silica which formed the quartz in the myrmekite.

The recrystallized mylonitic bands (protoclastic-appearing) in the southwest indicate that faulting occurred after potash feldspar had formed, but before the formation of retrogressive albite and myrmekite. The fractured microcline porphyroblasts are cemented and penetrated by undeformed myrmekite and albite. It would seem unlikely that delicate myrmekites and sutured albites would have persisted during cataclasis while other minerals were being intensely sheared and granulated. This is evidence that faulting has occurred contemporaneously with granitization and that the rocks remained in a solid state during granitization.

SUMMARY

After a detailed field and petrographic study and consideration of a possible igneous origin, it is concluded that the Evans Lake granodiorite body was formed by a process of metasomatic granitization, which was both synkinematic and postkinematic. The evidence is summarized as follows:

1. All structures within the mass are continuous with the regional structures.
2. The areal distribution of the various igneous-appearing rock types is controlled by the original composition of the sediments.
3. There is complete gradation between the different rock types, and the contacts are irregular.
4. All of the igneous-appearing rocks have crystalloblastic and porphyroblastic textures.
5. The rocks contain primary minerals indicative of fairly low temperature (epidote).
6. The succession of crystalloblastic growth of the minerals indicates formation during rising temperature.
7. The granitization represents the climax of metamorphism in the Evans Lake area.

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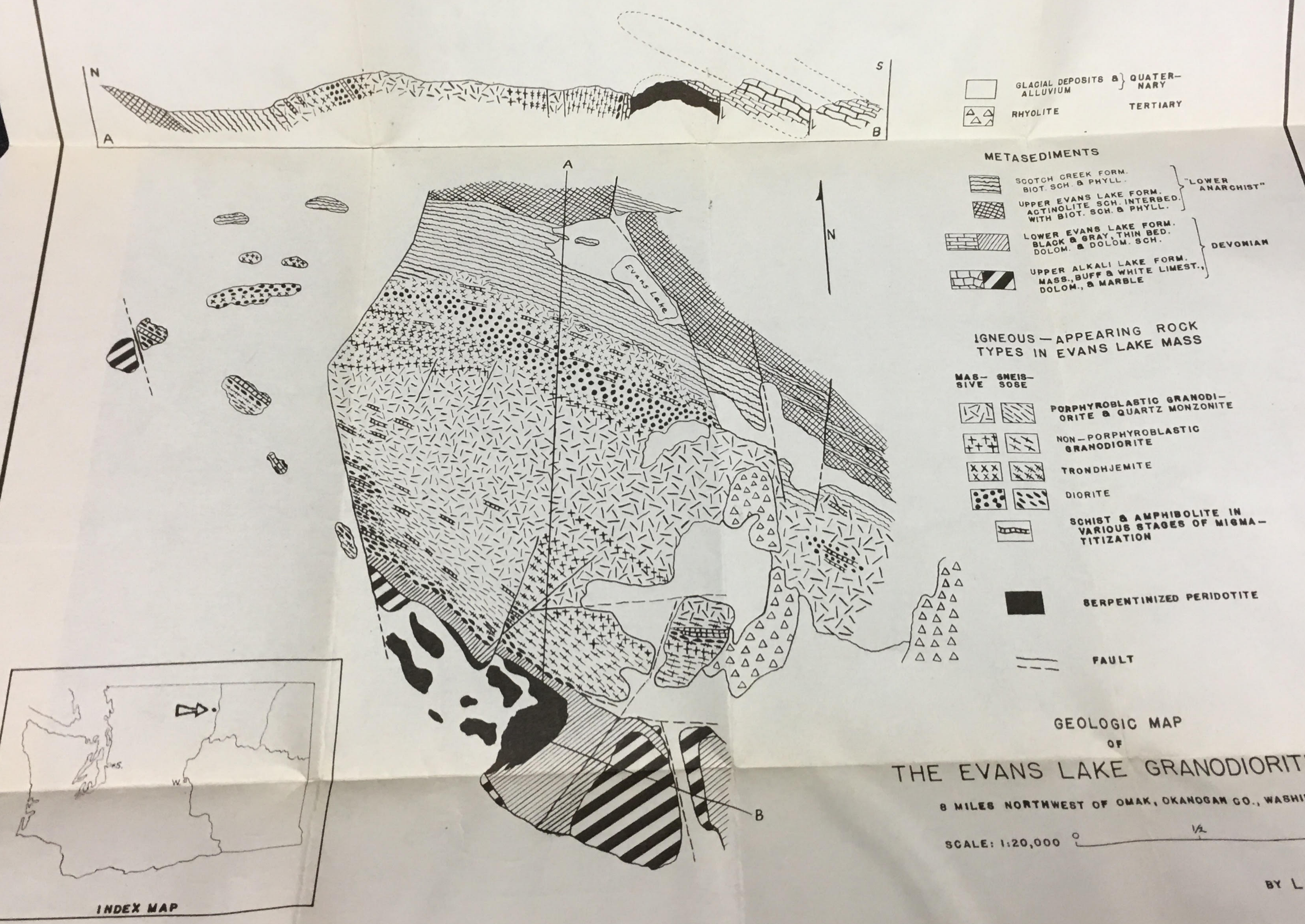

GEOLOGIC MAP
OF
THE EVANS LAKE GRANODIORITIC MASS

8 MILES NORTHWEST OF OMAK, OKANOGAN CO., WASHINGTON

SCALE: 1:20,000 0 ½ 1 MILE

BY L. T. GROSE