THE TEXTURE, ORIGIN, AND EMPLACEMENT OF THE GRANITIC ROCKS OF GLENLYON RANGE, YUKON, CANADA

Thesis by

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In Partial Fulfillment of the Requirements

For the Degree of

Doctor of Philosophy

California Institute of Technology

Pasadena, California

1959

ACKNOWLEDGMENTS

For help, encouragement, and valuable criticism during the progress of this study the writer is indebted to Dr. Ian Campbell and Dr. L. T. Silver who acted, in succeeding periods, as advisors. Dr. Campbell always seemed ready and willing to help in overcoming various obstacles which were encountered along the way. Dr. Silver devoted much time in an already overcrowded schedule to the detailed criticism of the original draft of the manuscript. Thanks are due also to Dr. J. A. Noble who reviewed the manuscript in detail. Many helpful suggestions were made by Dr. R. H. Jahns. Assistance and advice from those mentioned above and from others on the staff of the Division of Geological Sciences of the California Institute of Technology are gratefully acknowledged.

None of this work might have been accomplished had it not been for the cooperation of the officials of the Geological Survey of Canada who supported both the field work and much of the time spent on laboratory investigations. Particular thanks are expressed to Dr. H. S. Bostock. Many hours of discussions and arguments with Dr. J. A. Roddick of the Geological Survey of Canada contributed to this work.

The material assistance provided by Kennco Explorations (Canada), Limited through Mr. C. J. Sullivan is acknowledged with thanks.

ABSTRACT

In Glenlyon range the older pre-intrusive rocks include quartzo-feldspathic schists (amphibolite facies) with minor carbonate and lime-silicate rocks of the Yukon group overlain by a succession of limestones and slates and phyllites (green schist facies) of the Harvey Group. These rocks form the north limb of an east-west trending anticlinorium. The Drury quartz monzonite is intruded into the axial region of the anticlinorium. This mass grades continuously from a biotite granodiorite core to an outer zone of quartz monzonite in which the proportions of hydridized inclusions and septa of metamorphic rock increase with complete gradation to the granite-free metamorphic host terrane. Tothe north and east a second large mass, the Peak granodiorite, identical with the core of the Drury quartz monzonite, has been emplaced with clearly crosscutting intrusive relations. A pattern of large scale faulting associated with the contact of the Peak granodiorite suggests that fault block movement may have provided some of the intrusive space requirements. Smaller alaskite dikes cut both the metamorphic complex and the Drury quartz monzonite.

Detailed petrographic studies of the textures and mineral modes of the granitic rocks argue for a similar crystallization history of the Peak granodiorite and the core of the Drury quartz monzonite. The textural evidence for paragenesis and the mineral composition trends of the entire intrusive complex are combined with discussions of the crystallization of a hypothetical granodiorite magma based on available experimental data of the system $KAlSi_3O_8$ - $NaAlSi_3O_8$ - $CaAl_2Si_2O_8$ - SiO_2 - H_2O. All of the significant natural paragenetic relations, particularly the important role of potash feldspar (including replacement reactions) in the later crystallization stages, can be explained as resulting from magmatic crystallization. These effects are distinguished from metasomatic phenomena in the host rocks.

The validity of such arguments rests in part on a detailed analysis of the sampling of these granitic masses and problems of representation of modal data. The results of approximately 150 modal analyses are presented in four mineral-component tetrahedrons to support these discussions.

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INTRODUCTION

Scope of this Thesis

In this thesis the writer has attempted to deduce the origin and mode of emplacement of a group of closely related granitic rocks in Glenlyon Range, Yukon, on the basis of field observations, detailed textural study, and extensive petrographic modal analyses.

The thesis is lengthy partly because of the detailed description of the textures of the granitic rocks, which are illustrated with many photomicrographs. This description is perhaps the most significant part of the work. For the reader who is interested only in the general problems and in the conclusions reached, it may suffice to read the general descriptions of the rocks and to glance over the illustrations. A reader who is himself working with the details of granitic rocks may compare his own observations with the textural features of the granitic rocks of Glenlyon Range by more extensive examination of this section.

Detailed descriptions of the texture of granitic rocks are not common in the geologic literature. Information of this type from many localities may show, eventually, that certain characteristics of the texture of granitic rocks are general features, and as such, are significant in regard to the origin of the rocks. Thus part of the purpose of this work is to provide a comprehensive description of the textures and to show that they are truly granitic and not the result of a complete recrystallization of a primary granitic texture.

It is also the writer's intention to show that petrographic modal analyses of medium-grained inequigranular rocks can be used to give significant average modal compositions for large homogeneous granitic masses. It is necessary to establish this in order that variations in the compositions of the rocks as indicated by the analyses may be accepted as real. If they are accepted then they provide another factor bearing on the origin of the rocks.

When all the data have been discussed and interpreted an attempt is made to develop the crystallization history of granitic magma on the basis of available experimental data. Finally the various features of the granitic rocks of Glenlyon Range are discussed with respect to the theoretical crystallization of magma of equivalent composition. It is concluded that essentially every detail of the occurrence, texture, and mode of these rocks might have been predicted on the basis of the crystallization of a granitic magma of appropriate composition.

Location of Area and General Statement

Glenlyon Range is in central Yukon Territory, Canada, and occupies most of the area bounded by 62 degrees 10 minutes to 62 degrees 45 minutes north latitude and 134 degrees to 135 degrees west longitude. The range rises on the southwest side of the valley of Pelly River, one of the main tributaries of Yukon River.

The writer, while an officer of the Geological Survey of Canada, was engaged for several years beginning in 1949 in mapping the geology of Glenlyon area (62 to 63 degrees north latitude and 134 to 136 degrees west longitude). The results of this work are for publication at the scale of 1 inch to 4 miles. A preliminary map of the north part of the area has been published (Campbell, 1954). In the course of this project parts of three summers were spent in mapping most of the northern end of Glenlyon Range on the scale of 1 inch to $\frac{1}{2}$ mile, and it is mainly the results of this latter work that are presented in this thesis (plate 1).

Climate and Vegetation

In terms of mean annual temperature the climate of central Yukon is sub-arctic; in terms of annual precipitation it is semi-arid. In this environment perennially frozen ground is common but is mainly restricted to slopes of northern and eastern exposure, and to flat poorly-drained areas. Spring thaw and runoff do not usually begin until about mid-April, and runoff continues through the summer at a reduced rate from thawing of the frozen ground after the snow has gone. Freeze-up normally begins in the latter part of October.

In spite of the small total precipitation ample moisture is available for vegetative growth in the short summer season. Forest growth is light but extensive and consists of scrubby spruce and birch on northern and eastern slopes and larger spruce, aspen, and pine on the drier southern and western slopes and on the well drained flat areas. Stands of large spruce grow on the flood plains of the rivers. In unforested areas the cover is mainly arctic black birch, willow, sage, and various grasses. Near timber-line (4500 feet) alpine balsam is common, and above timber are heather, arctic black birch, and other alpine plants. Mosses and lichens are common throughout and form thick mats on northern slopes and on poorly drained areas.

Accessibility and Methods of Work

Glenlyon Range is about 60 miles from the nearest road (Whitehorse-Mayo-Dawson road) and from the nearest settlement, the town of Carmacks. Transportation within the area was provided by pack horses and by canoes on Pelly and Macmillan Rivers. Supplies were delivered to certain rendezvous every three or four weeks and were carried by motorboat or by float plane.

Most of the field work in the 4900 square mile area was devoted to mapping on worksheets at the scale of 1 inch to 2 miles to be published at the scale of 1 inch to 4 miles. This work might be called detailed reconnaissance. Parts of three seasons were spent in mapping 230 square miles of the geology of the northern end of Glenlyon Range at the scale of 1 inch to ½ mile.

The base map used for the more detailed work is an enlargement of the 2 mile work sheet. It was found that positions could be located on the map by the intersection of radial lines from the centers of adjacent vertical aerial photographs. With key positions established in this manner it was possible to develop a fairly complete triangulation net using the Brunton Compass. The whole system of points was checked and adjusted from the triangulation stations established by the Topographical Survey. These stations and the centers of aerial photographs were placed as accurately as possible with reference to latitude and longitude when the tracing from the original enlargement was made.

While errors in topography undoubtedly exist in the map it is believed that the positions of contacts and of structure symbols are accurate, considering the limitations of the map, with respect to latitude and longitude. It did not seem feasible to correct all the minor errors in topography though the attempt was made where the errors were obvious; no gross errors in topography were discovered.

Previous Work

Pelly River was first explored by white men in 1843. In that year Robert Campbell, an official of the Hudson Bay Company, crossed the divide from the headwaters of Liard River to Pelly River which he followed down to its junction with Yukon River. Some time later Campbell established Fort Selkirk at the confluence of the two rivers. In the course of his travels Campbell named Pelly River and many of its tributaries, including Glenlyon River.

The next reported exploration of Pelly River was in 1887 by G. M. Dawson (1887) who made a rapid examination of the bedrock and unconsolidated deposits along the banks. In 1902 R. G. McConnell (1902) explored Macmillan River and in 1907 Joseph Keele (1908) explored the headwaters of Pelly and Ross Rivers.

W. E. Cockfield (1928) in 1928 made a geological reconnaissance of the Little Salmon area which includes the southern tip of Glenlyon Range and the area adjacent to Drury Lake. A reconnaissance study of the geology along Pelly River valley between Macmillan River and Hoole Canyon was made by J. R. Johnston (1936) in 1936. During this work he investigated some of the geology of Glenlyon Range adjacent to the river.

From 1933 to 1949 H. S. Bostock was engaged more or less continuously in mapping areas adjoining Glenlyon area. These include Laberge area to the south, Carmacks area to the west, McQuesten area to the northwest, and Mayo area to the north (Bostock and Lees, 1939, and Bostock, 1936, 1948, and 1947 respectively).

Apart from the reconnaissance work of Cockfield and Johnston and the exploration of Dawson no geological work has been done in or near Glenlyon Range until the work of the present author was begun in 1949.

Physiography and Glaciation

General Physiography: Glenlyon Range lies within the Interior System of the Western Cordillera; more specifically it is part of Pelly Mountains (Bostock, 1948, p. 66), a large group of mountain ranges that stretch along the southwestern side of Pelly River and which are included within the Southern Yukon Plateaux of the Northern Plateaux and Mountain Area (Bostock, 1948, Map 922A).

The Yukon Plateaux, which have been divided by Bostock into many smaller plateaux, are characterized by a general uniformity of summit levels of long, flat ridges. This level is, here and there, interrupted by individual mountains and by mountain ranges. The general plateau level is cut up by large valleys so that only the regular skyline presented by the flat ridge-tops marks the original surface. Streams on the upland surface flow through broad open valleys then plunge steeply, often in canyons, to the larger streams below.

Drainage anomalies, old high terraces, and other evidences of crustal fluctuations of parts of Yukon Plateaux are described by Bostock (1948, p. 69). He suggests that the evidence indicates crustal unrest dating back to late Tertiary time and perhaps earlier. Little is known of such movements in Yukon Plateaux in general, but Bostock's observations indicates that no generalizations regarding an old continuous surface can be made at this time. It is probable that the surfaces represented by the flat ridge-tops have a highly complex history and that similar surfaces in adjacent areas may be of different age.

Part of the northeast side of Glenlyon Range lies along Tintina Valley, a great trenchlike feature comparable to the Rocky Mountain Trench (Bostock, 1948, p. 60). Pelly River flows in the valley in this vicinity. The valley stretches for over 400 miles from the south part of Pelly Mountains northwestward into Alaska. It is the locus of a zone of faulting for at least some of its length. Bostock considers that parts and perhaps all of the valley have been depressed since early Tertiary time and perhaps longer.

Physiography of Glenlyon Range: Glenlyon Range forms a long narrow triangle at the apex of a northward pointing "V"; the remainder of the "V" is comprised of the rest of Pelly mountains stretching to the south and southeast. Magundy River Valley is a deep east-west trough which isolates Glenlyon Range from the ranges to the south (plate 2). The southwest side of the triangle is sharply marked by the valley of Drury Lake and less distinctly by the valley of Tummel River. The northeast side over almost its whole length is a huge scarplike face rising 3500 to 5000 feet from the valleys of Pelly River (here occupying Tintina Valley) and Glenlyon River and Lake.

The highest summit in Glenlyon Range is Glenlyon Peak, which is 7184 feet above sea level. Many other peaks are between 6500 and 7000 feet. The large valleys surrounding the range lie close to 2000 feet and the maximum relief is 5000 feet. Most of the streams rise in basins between 5000 and 5500 feet above sea level and debouch from the range at about 2500 feet hence the local relief varies from 1000 to 4500 feet.

Viewed from the northeast the mountains of Glenlyon Range appear rough and jagged, though flat-topped ridges are evident (fig. 1). From the southwest the aspect is different; the slopes leading to the peaks are smooth and rounded though serrate ridges and rugged cirques are visible in some places (fig. 2). All the larger streams within the range head in the rugged cirques that face in northerly directions, and they flow out between serrate ridges into deep, steep-sided, U-shaped valleys. The break from the subdued topography of the ridge-tops to the steep sides of the valleys is usually abrupt; there is no gradation. The rugged, precipitous, young topography is cut into the subdued older topography of the uplands producing a conspicuous physiographic discontinuity (see figs. 1 and 2). Where the streams flow out from the mountains into the valleys that bound the range they commonly occupy canyons cut into bedrock which break the profile of the U-shaped troughs with a sharp V cut into the bottom.

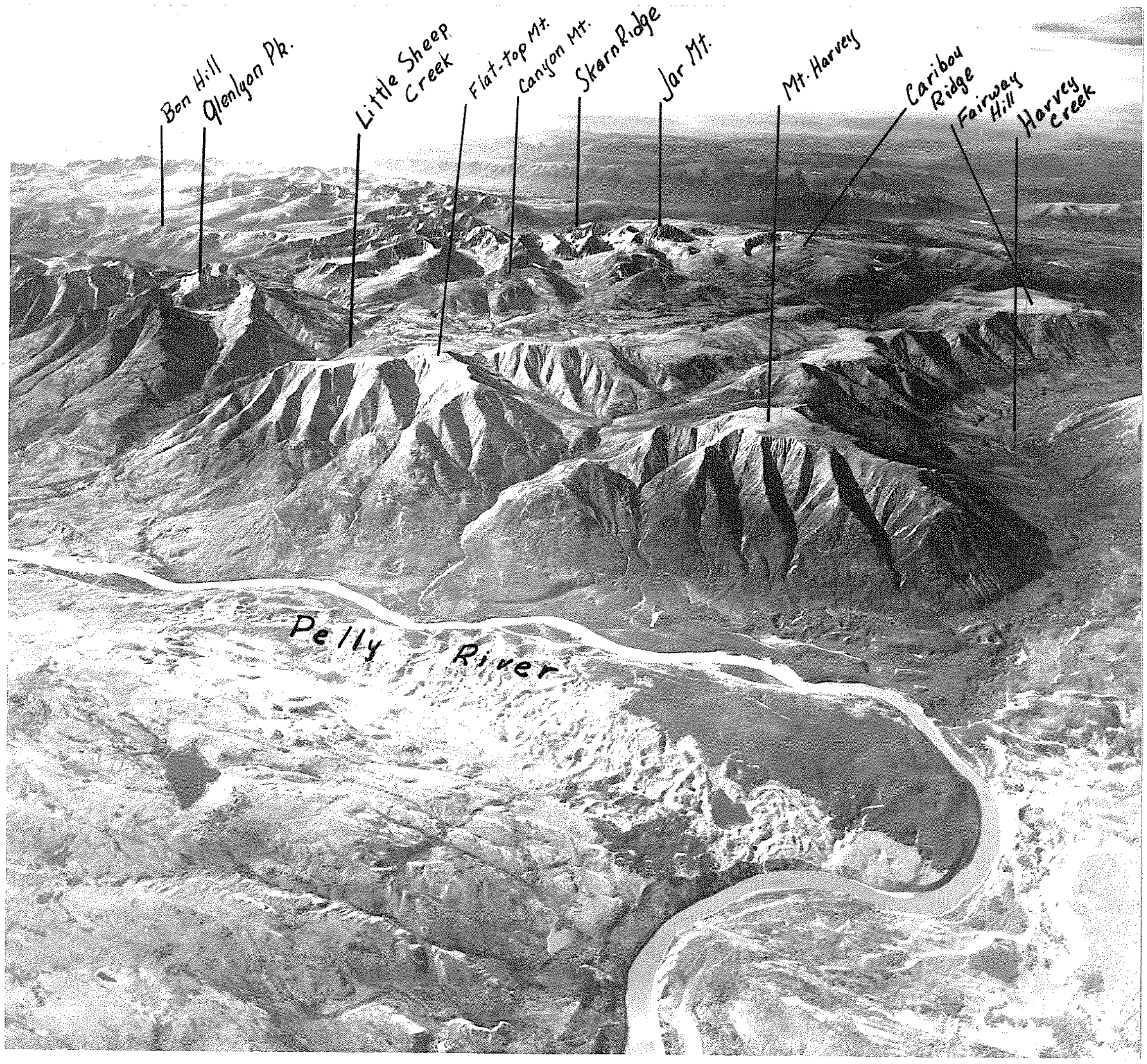

Figure 1

The view is looking south over Glenlyon Range with Pelly River in Tintina Valley in the foreground. Note the deep trough valleys and the flat-topped ridges. At the extreme right is the valley of Harvey Creek.

Figure 2

The view is looking north over Glenlyon Range with Drury Lake in the foreground.

On the rolling ridge-tops there is little outcrop and the surface is covered with rock debris that is mostly fine but is locally very coarse. Felsenmeer, stone stripes, and solifluction terraces are common. Such outcrops as are found on the ridge-tops are small ledges forming vertical banks over which debris can move or are abruptly rising projections through the overburden producing forms aptly known as "castles."

Most of the outcrops in Glenlyon Range are confined to the peaks and serrated ridges overlooking cirques and to the upper slopes of the headwaters of the trough valleys. In the downstream parts of some of the valleys there are large outcrops in the valley walls and, locally, in the bottoms.

It is apparent that Glenlyon Range was once part of a rolling surface on which streams flowed in broad, open valleys between rounded hills and ridges. Regional and probably local differential uplift caused the streams that flow around the margins to cut rapidly into the surface leaving many of the smaller streams hanging high above on the old surface. These hanging streams eroded canyons at the margins of the range, but their headwaters still flowed through wide, shallow valleys. Subsequent alpine glaciation deepened some of these valleys and converted them into U-shaped troughs. Even this, however, did not suffice to bring them into accordant relations with the surrounding streams, and they have subsequently cut canyons into the bottoms of the troughs at the margins of the range.

Glaciation of Glenlyon Range: In at least one period Glenlyon Range was subjected to two types of glaciation which may have been partly simultaneous. The physiographic features produced by alpine glaciation are obvious as are those of continental or ice-sheet glaciation. The ice of the latter surrounded and entered but did not inundate the range.

The evidence is clear that local or alpine glaciation preceded or occurred during the early stages of continental glaciation. At the maximum stage of the development of the ice sheet local valley glaciers did not exist or were very small, and they did not grow again after the withdrawal of the ice sheet.

No morainal features that could be attributed to local glaciers were found except a few small end moraines close to the headwalls of the cirques. On the other hand many moraines in the trough valleys of the alpine glaciers can be attributed to the maximum or sub-stages of the ice sheet. They are arcuate with the convex side facing up the valleys. Many can be related to or directly connected with lateral moraines that slope downward in the upstream direction and curve around the spurs into adjacent valleys.

Below and at the limit of the ice sheet evidence of glaciation is fresh and well preserved. Most distinctive are the lateral moraines of which those on Moraine Mountain are a spectacular example (fig. 3). Lateral stream channels are also very prominent especially on the southwest side of the range (fig. 2). Many are cut into bedrock, and some form rugged canyons up to 500 feet deep and several miles long. Glacial and aqueoglacial deposits, which are widespread throughout the area, are essentially all the product of continental glaciation. There is no comparably fresh evidence of alpine glaciation. Tremendous talus slides have developed on the walls of the cirques and the trough valleys. There are no lateral moraines or stream channels and very few glacial deposits that can be attributed to valley glaciers.

The ice sheet evidently advanced from the east and moved down Pelly River valley and curved around both the south and north ends of Glenlyon Range (Campbell, 1951 and 1954). Long fingers of it reached up some of the larger valleys, and the sides of the range and of the valleys into which the ice actively moved were severely scoured and grooved. Little talus has developed on these slopes.

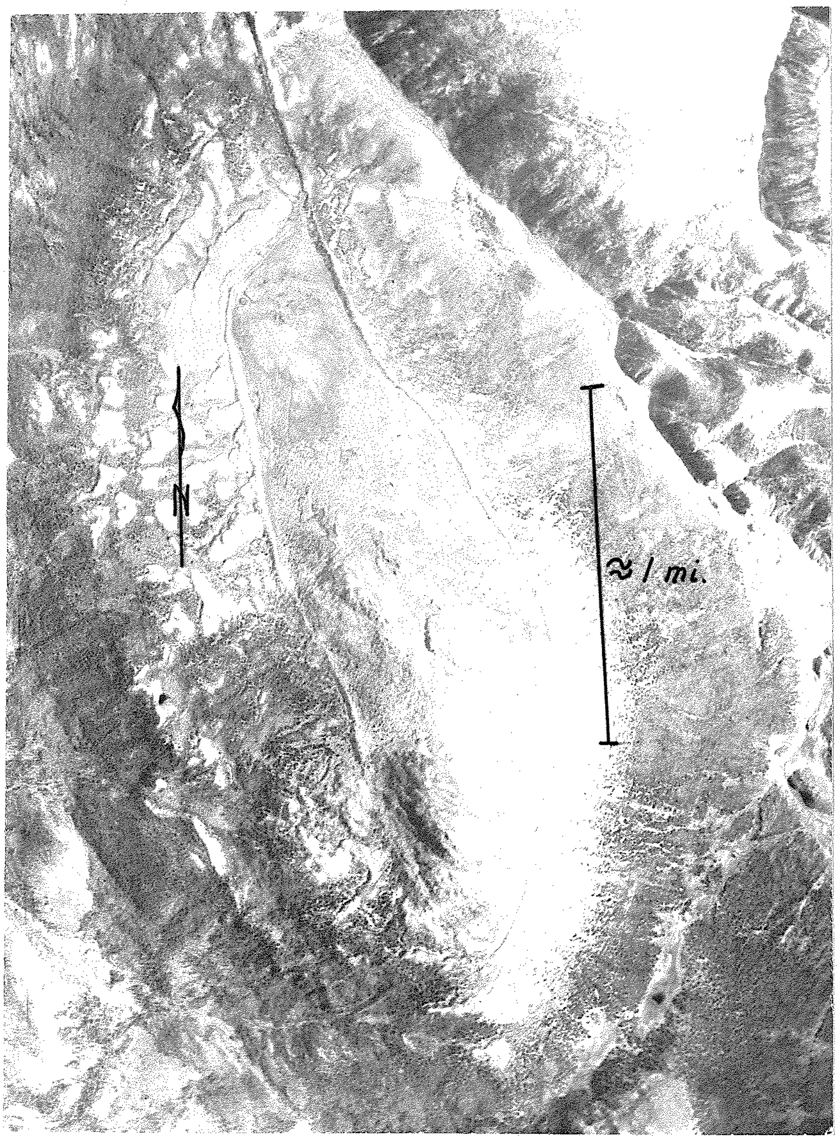

Figure 3

The picture is a vertical photograph of the top of a mountain (center) which is ringed by a lateral moraine. The mountain, understandably, is called Moraine Mountain.

GENERAL GEOLOGY

Geologic Setting

Southern Yukon in General: Tintina Valley, which is a physiographic feature similar to the Rocky Mountain Trench, passes through Glenlyon area and lies along part of the northeastern margin of Glenlyon Range. The valley begins north of the northern end of the Trench and extends northwesterly for over 400 miles diagonally across Yukon Territory. There are many other parallel lineaments in the territory, of which Shakwak Valley is a notable example (Bostock, 1948 and 1952). This valley, in the southwest corner of Yukon, has been shown to mark the trace of a fault (Bostock, 1952 and Muller, 1958) and is the site of part of the Denali Fault which St. Amand has inferred from seismic and physiographic evidence (St. Amand, 1957).

The area between Tintina and Shakwak valleys is underlain and characterized by metamorphic rocks of which part, at least, are Precambrian. Within this metamorphic terrane there are small areas underlain by Palaeozoic, Mesozoic, and Tertiary volcanic and sedimentary rocks. The plutonic complex of the Coast Range of British Columbia and southeastern Alaska terminates as a continuous mass of granitic rocks in southwestern Yukon. Beyond it are many satellite bodies which intrude Jurassic and all older strata and locally those of lower Cretaceous age. Upper Cretaceous and lower Tertiary rocks are not intruded by these masses though later small granitic and syenitic intrusives do cut them.

Northeast of Tintina Valley the geology is characterized by a thick section of Palaeozoic sedimentary rocks. Precambrian and Mesozoic sedimentary and volcanic rocks are of limited extent. In this area, too, there are plutonic granitic rocks in many scattered localities. Wheeler (1953) found evidence that some of these granitic rocks intrude Upper Cretaceous volcanic rocks. For a general picture of the geology of Yukon the reader is referred to the recently published geologic map of the territory (Bostock, 1958).

Glenlyon Area: Tintina Valley is the locus of a profound geologic discontinuity in Glenlyon area. The Palaeozoic sections on either side of the valley may be of similar age yet no correlation can be made from one section to the other in terms of the stratigraphic succession (plate 2 and Campbell, 1954). A thick succession of volcanic and sedimentary rocks, which may be of Permo-Triassic age, lies along the northeast side of the valley but is not found anywhere along the southwest side. Metamorphic rocks of the Yukon group which may be of Precambrian age are restricted to the area southwest of the valley. All of these factors indicate that the valley marks the site of a fault which for various reasons is assumed to be a major strike-slip break (see section on structural geology).

Except for a small connection to Pelly Mountains, across Magundy River Valley to the south, the rocks of Glenlyon Range do not extend into any of the adjacent territory (plate 2). Metamorphic rocks of the Yukon group (map-unit 2) are found in many other areas but those of the Harvey group (map-units 3 and 4) are not known to occur in any other locality and are restricted to the areas shown in plates 1 and 2. Glenlyon Range is geologically isolated from its surroundings and this, plus physiographic factors, leads to the belief that it is surrounded by faults. With but few exceptions these inferred faults lie in broad drift-filled valleys and cannot be observed in actual exposure or even defined precisely between closely spaced outcrops. For this reason these faults are shown in plate 2 by a wiggly line symbol to distinguish them from more accurately located faults. In a few places the bounding faults have been located with relative precision and are accordingly shown by a heavy line or dashed line symbol.

Because of the geological isolation of Glenlyon Range the surrounding geology does not bear directly on the problems with which this thesis is concerned, and it is not described further. For more detail on this geology the reader is referred to the work of Cockfield (1928), Johnston (1936), and Campbell (1954). The main features are shown in plate 2.

GEOLOGY OF GLENLYON RANGE

Yukon Group

In Glenlyon Range, as elsewhere, the dominant rock type of the Yukon group (map-unit 2, plates 1 and 2) might be classed either as a quartzose mica schist or as a micaceous quartzite. The rocks grade from highly quartzose schist on the one hand to highly micaceous schist on the other. These rocks are all more or less feldspathic and typically are quartz-biotite-plagioclase schist. The relative bulks of the various types of these rocks are difficult to determine even though sections were measured in several localities. The section is interrupted by many granitic bodies, and the strata are intersected by many faults. No definite marker horizons were located, and correlation of the section from fault block to fault block could not be satisfactorily accomplished. The attempt is made in a later section (Modal Analyses) to arrive at an "average" modal composition for the total section including limy rocks with the following result: potash feldspar 1-3 per cent; plagioclase (An 25 to An 30 usually) 15-20 per cent; quartz 35-45 per cent; biotite 20-25 per cent; muscovite 7-12 per cent; and calcite 2-4 per cent. Apatite is a common accessory; garnet, sillimanite, andalusite, and rarely staurolite occur less commonly.

The average grain size in the schist is less than 1 mm but some porphyroblasts, particularly of plagioclase, are 4 mm long or more.

The Yukon group contains minor bedded limestone with lime-silicate rocks and some associated amphibolite (map-unit 1). The limestone is crystalline with carbonate grains averaging about 1 mm; it is commonly cream-coloured and weathers buff.

The lime-silicate rocks are varied but most commonly they are layered so that layers of diopside and calcic plagioclase, with or without hornblende, biotite, and quartz, alternate with layers of quartz, more sodic plagioclase, and biotite. The layers are usually from 0.5 to 1 mm thick and are, in general, fine-grained. A less common type of lime-silicate rock is composed of fine to coarse grains of diopside and garnet, and in one locality a bed consists entirely of rosettes of fibrous anthophyllite. Potash feldspar is rare in the lime-silicate rocks but does occur in some where they are in close association with granitic rocks.

Amphibolite consists mainly of pale green hornblende and somewhat less plagioclase (about An 60). In a few localities diopside is an important constituent, and where it is the amount of hornblende is less than normal. Well developed euhedra of sphene are always present. Quartz and potash feldspar occur infrequently in amphibolite in very small quantities, but biotite was not found in it.

In four modal analyses of amphibolite, plagioclase varies from 25-49 per cent and hornblende plus diopside from 46-71 per cent.

An unusual rock type, perhaps intermediate between the quartzose and calcareous metasedimentary rocks is quartz-biotite schist containing labradorite or bytownite.

Harvey Group

The Harvey group (map-units 3 and 4, plates 1 and 2) consists of metasedimentary rocks which are known only within Glenlyon Range. It is composed of about 1200 feet of thin-bedded, platy, brown limestone overlain by at least 4500 feet of dark-brown or black slate and phyllite. The top of the section is not known because the upper beds are everywhere intruded by granodiorite. The section is well exposed in the valley of Harvey Creek from which the name Harvey group is derived.

The age of the Harvey group is not known with certainty. It overlies the Yukon group, which may be Precambrian, with apparent conformity. The beds are non-fossiliferous. Nothing similar to this group is known in association with the Yukon group in other localities, and the succession has no known counterpart in the nearby Palaeozoic sections, which, in part at least, are of Mississippian age. If the Yukon group is indeed Precambrian then the Harvey group may be Precambrian or lower Palaeozoic. It is probably an intuitive feeling that the writer, in consultation with Dr. H. S. Bostock who has had wide experience with the geology of Yukon, considers the Harvey group to be Lower Palaeozoic.

In the lower Harvey group limestone member (unit 3) there are some thin horizons of argillaceous material which, near the base of the section, are fine-grained quartz-biotite schist. Higher in the section similar material forms phyllite and slate beds.

At the bottom of the section the limestone has been converted to thinly layered (1 mm to 1 cm) lime-silicate gneiss. Layers rich in diopside, or pale green actinolitic amphibole, or biotite, or all of these minerals together, alternate with layers relatively rich in quartz. Plagioclase (about An 30) occurs in both femic and quartz-rich layers. The layering seems to represent original sedimentary units in which calcareous alternated with argillaceous or quartzose beds. In a few cases epidote was observed in the lime-silicate rocks and in one specimen idocrase was seen. Non-perthitic potash feldspar is quite common though not abundant in these rocks.

Lime-silicate rocks also occur in the lower Harvey group along the contacts of the Fairway dyke. Here garnet has formed, plagioclase is calcic (An 50), and the associated argillaceous rocks are converted to andalusite-cordierite-biotite hornfels. Perthitic potash feldspar is common in this zone.

The slate and phyllite of the upper member of the Harvey group is commonly a dull black colour but some is brown. Locally there is shiny silvery-black chlorite-sericite schist. All these rocks contain thin (1 to 5 mm) light-coloured layers spaced from a few mm to several cm apart. The layers represent compositions relatively richer in quartz. The argillaceous rocks are converted to blue-black biotite-andalusite-cordierite hornfels along the contacts of Peak and Nub Hill granodiorite. The hornfels retains the compositional layering of the slaty rocks and some of the cleavage but otherwise is harder and less fissile. Quartz and biotite in the hornfels are very fine grained, and the mica may or may not be well oriented. Andalusite and cordierite grains range up to 5 mm. Plagioclase (about An 30) is very fine grained. Rare tiny veinlets of potash feldspar cut the other minerals and there are also sparse fine grains of potash feldspar.

Along the contact of Peak granodiorite the zone of hornfels may be absent or it may be as much as 2000 feet wide. In the field it is marked by the deep red colour of the weathered exposures; the colour comes from the oxidation of iron derived from finely disseminated pyrrhotite. Between the hornfels and the unaffected slate and phyllite is a zone of spotted slate locally reaching several thousand feet in width. The spots are dark brown or black and represent the incipient or actual crystallization of andalusite or cordierite or both. In other cases very fine biotite has developed and the rock is less fissile than normal. The zone of hornfels and spotted slate is particularly wide in the vicinity of Nub Hill and is narrow south of Glenlyon Peak.

Granitic Rocks

General Remarks: The granitic rocks of Glenlyon Range (map-units 5 to 10, plate 1) have been mapped on the basis of units which can be separated in the field on the basis of occurrence or compositional differences or both. Thus Peak granodiorite (unit 10) which can be mapped as a single intrusive mass is shown as a unit in spite of the fact that it is probably genetically related to and is compositionally similar to part of Drury quartz monzonite. Similarly Nub Hill granodiorite (unit 9) and the Fairway dyke (unit 8) are mappable units though they too may be closely related in origin to rocks mapped as different units. Nub Hill granodiorite is similar in appearance to Peak granodiorite and is close to it in space. The Fairway dyke is very similar to rocks mapped as alaskite (unit 7).

The alaskite is a distinctly leucrocratic granitic rock and characteristically occurs in relatively small bodies, mainly dykes; on the strength of these factors it is a separable rock type.

The hornblende-biotite-quartz diorite (unit 5) may be regarded either as a hybrid phase of Drury quartz monzonite or as a variation of the lime-silicate rocks of the Yukon group, and it could be mapped with one or the other. It has a distinctive composition and occurrence and can usually be readily recognized in the field. The quartz diorite is important in respect to the origin of the granitic rocks and hence is mapped and discussed as a separate unit.

Problems were encountered in mapping and naming Drury quartz monzonite (unit 6). The largest part of this unit lies south of the area mapped in detail (plate 1), and this forms the bulk of the core zone (unit 6x). The core zone is actually granodiorite on the basis of the modal analyses made from samples of it, and is compositionally and texturally identical to Peak granodiorite. Thus Peak granodiorite and the core of Drury quartz monzonite could be mapped as a unit. Within the area of primary interest, however, map-unit 6 is, in bulk, truly quartz monzonite. The core zone grades directly into the intermediate zone (unit 6y) with which it is quite obviously closely related. The outer zone (unit 6z) is also interpreted as having a close relationship in origin to the remainder of the quartz monzonite. There is no obvious way in which these rocks can be separated other than into the related and gradational zones which have been mentioned. Thus Drury quartz monzonite has been mapped and named as a unit even though it may be granodiorite in overall bulk and may in part be closely related to Peak granodiorite.

A further problem in mapping Drury quartz monzonite is one of scale. The granitic rocks form a complex with the metamorphic strata of the Yukon group. Many granitic bodies are too small to show at the scale of the map, and the granitic rocks may contain much metamorphic material distributed in masses too small to show on the map. For these reasons the granitic rocks of Drury quartz monzonite and the metamorphic rocks of the Yukon group are mapped in terms of the relative proportions of one type in the other (see legend of plate 1). The proportions were estimated during the field work.

Drury quartz monzonite is, in a sense, the parent of all the other granitic rocks and thus is described first in the succeeding section.

Drury Quartz Monzonite: Drury quartz monzonite underlies most of the central and southern parts of Glenlyon Range and is in direct contact only with rocks of the Yukon group and with other granitic types. From Jar Creek south it underlies almost the entire surface of the range, covering an area which is about 24 miles long and 10 miles wide (plate 2). North of Pass Creek (in the area mapped in detail, plate 1) the quartz monzonite is a complex of large and small bodies in the metamorphic rocks of the Yukon group.

Drury quartz monzonite has been divided into three zones: the core (unit 6x), the intermediate zone (unit 6y), and the outer zone (unit 6z). These zones are best developed and have been most intensively studied in the area west of Pass Lake and Little Sheep Creek and east of Moraine Mountain. There are no sharp boundaries between the zones.

Many faults cut and displace the boundaries of the zones. The boundary of the core lies in lower Felix Creek in the eastern part of the range (plate 2) from whence it is offset northward to the headwaters of Pass and Lyon Creeks. From the valley of Lyon Creek it is again offset northward beyond Moraine Mountain.

The intermediate zone underlies Divide Ridges, Skarn Ridge, Jar Mountain, and the south part of Caribou Ridge beyond the north boundary of the core. The outer zone, still farther north, is well developed on the northerly slopes of Canyon Mountain and may also be represented in the ridges between Canyon Mountain and Caribou Ridge.

Beyond the outer zone of the quartz monzonite the strata of the Yukon group are "granite-free" except for a granitic mass in the valley of East Tummel River directly east of Fairway Hill. This mass seems to grade upward into alaskite which may be related to the Fairway dyke. The quartz monzonite in this body has not been studied in detail, but what is known of it suggests that it is more closely related in composition and texture to the core than to the intermediate or outer zones. Perhaps some parts of the intermediate zone are similar to the core and are small discrete intrusives. Drury quartz monzonite may consist of a central plutonic mass (the core), above which are rocks modified from the core type by fractionation, granitization, and other effects, and from which there were small satellite intrusions of core-type material.

In a traverse north from the core (see cross sections of plate 1) the first foreign rocks encountered near the margin of the homogeneous granitic mass are inclusions of limy metamorphic rocks which are usually surrounded by aureoles of hornblende-biotite-quartz diorite. In a few places quartz diorite occurs without any apparent limy rocks. In the intermediate zone the inclusions are composed of schist as well as limy rocks and they are relatively much larger. Within the schist inclusions there are many small quartz monzonite sills. In the outer zone, still farther from the core, the proportion of granitic to metamorphic rocks is still less, and the quartz monzonite occurs as small concordant bodies.

Except for the mass of core-type quartz monzonite in East Tummel River valley, and for the Fairway dyke, there are no granitic rocks in the Yukon group above the outer zone of Drury quartz monzonite. The Fairway dyke, Nub Hill granodiorite, and Peak granodiorite, all of which are obviously intrusive bodies, are the only granitic rocks in contact with the Harvey group.

As might be expected for a granitic rock which occurs in various sizes and shapes of bodies there are variations in composition and texture in Drury quartz monzonite from place to place. In general the rock is medium-grained and usually contains phenocrysts or oikocrysts of potash feldspar. The main differences from place to place are in the granularity of quartz, the composition and zoning of plagioclase, the colour and grain size of biotite, and the amount of potash feldspar. In terms of these factors the quartz monzonite may be divided into three zones which correspond to those already described. Textural differences will be discussed in a later section. In summary, from the core to the outer zone, quartz becomes more granular, plagioclase becomes more sodic and less strongly zoned, and biotite changes from olive-green in the core to red-brown in the other two zones and is finer grained in the outer zone. Compositionally the rocks of the intermediate and outer zones are richer in potash feldspar and poorer in plagioclase and biotite than the core; the quartz content remains about the same.

Eighteen petrographic modal analyses of 15 samples of the core have an average content of 18.8, 40.2, 30.3, 9.7, and 1.0 per cent of potash feldspar, plagioclase, quartz, biotite, and accessories, respectively. In the intermediate zone the proportions of the minerals in the same order as above are 26.5, 34.8, 30.4, 7.4, and 0.9 per cent as the average of 31 analyses from 25 samples. From the outer zone 12 analyses were made from 9 samples and the average mineral proportions in these, as above, are 22.0, 34.5, 31.9, 10.0, and 1.5 per cent respectively. The derivation and significance of these averages are discussed in another section (modal compositions).

Plagioclase in the core averages about An 38, is slightly more sodic in the intermediate zone, and averages about An 28 in the outer zone. Plagioclase compositions were determined in thin sections by the comparison of the indices of refraction to those of quartz and Canada balsam and by use of the Michel-Levy method. For plagioclase of the compositional range found in the granitic rocks and in the schist of the Yukon group in Glenlyon Range these methods give reasonably accurate results.

Where Drury quartz monzonite occurs as small bodies in a complex with metamorphic rocks of the Yukon group the contacts, foliation, bedding, and schistosity are commonly parallel. The large inclusions of schist in the more continuous areas of granitic rocks (intermediate zone) commonly show no strong discordance between the bedding, schistosity, contacts, and foliation; the orientation of the inclusions does not demand that they have been rotated within an intrusive granitic mass. There are a few cases, however, in which quartz monzonite dykes are definitely discordant and cross-cut the bedding and schistosity. These are most common in lime-silicate rocks.

Many of the sills in schist have narrow selvages 0.5

to 6 inches wide that consist predominantly of very coarse grains of potash feldspar (up to 2 cm or more) associated with medium-grained plagioclase and fine-grained granular quartz and a little biotite and muscovite (fig. 5). For purposes of description these are here termed pegmatitic selvages. These selvages have sharp contacts against the schist but have irregular replacement relations to the granitic rock. Similar pegmatite occurs around some small inclusions in the sills, and in a few places pegmatite cuts through the inclusions with no apparent dilation. There are also narrow veins of pegmatite within the quartz monzonite of the sills, and these differ from the surrounding rock in that they contain more and larger grains of potash feldspar which may extend from the veins into the finer-grained rock. Rarely, independent pegmatite dykes and sills up to 10 feet thick are found in the metamorphic rocks, but these seem to be more closely related to alaskite than to Drury quartz monzonite.

Some contacts between quartz monzonite and schist are gradational across 4 or 5 feet; the schist becomes progressively richer in feldspar until the rock is granitic in composition and appearance. The foliation and schistosity are parallel, and schlieren of schisty material in the granitic rock are in parallel orientation to the nearby metamorphic rocks (fig. 4).

In some of the areas of granitic-metamorphic complex

Figure 4

The sketch shows a vertical section across a gradational contact between feldspathic quartz-mica schist of the Yukon group and quartz monzonite. The exposure is close to the junction of the main branches of Little Sheep Creek.

Figure 5

The sketch shows a vertical section of "pegmatitic" selvage on the contact of a quartz monzonite sill and schist. The contact of the pegmatite with the quartz monzonite is ill-defined and gradational but that with the schist is sharp. The exposure is in a gully in the headwaters of East Tummel River.

Figure 6

The sketch shows a sill of quartz monzonite that terminates abruptly in schist. There is no deformation or evidence of faulting in the schist. The exposure is on the south slopes of Jar Mountain.

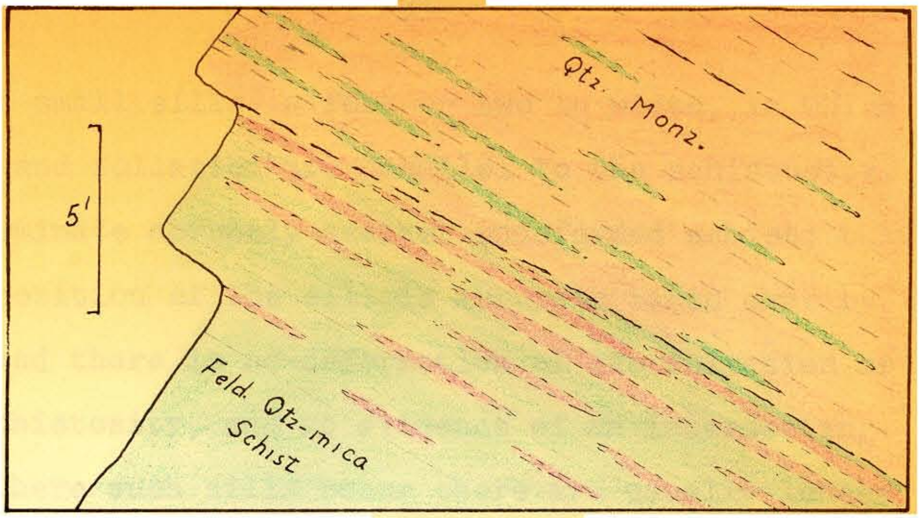

Figure 4

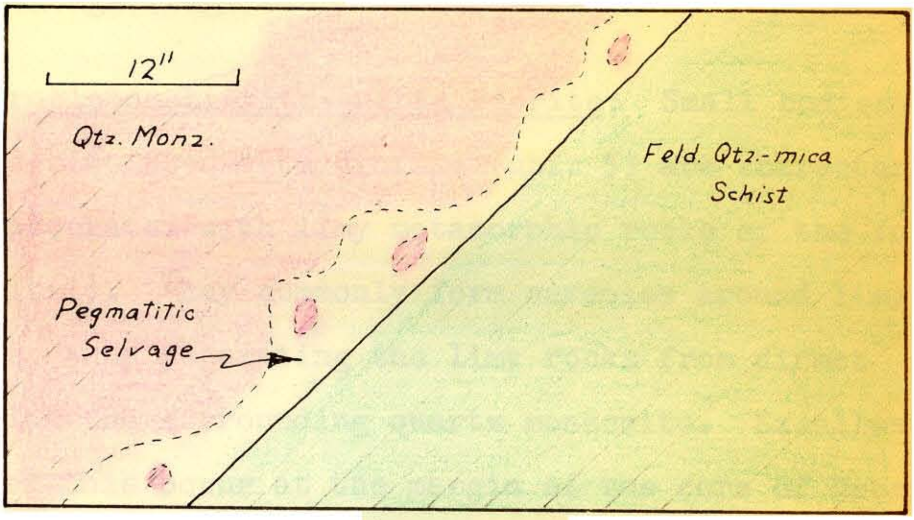

Figure 5

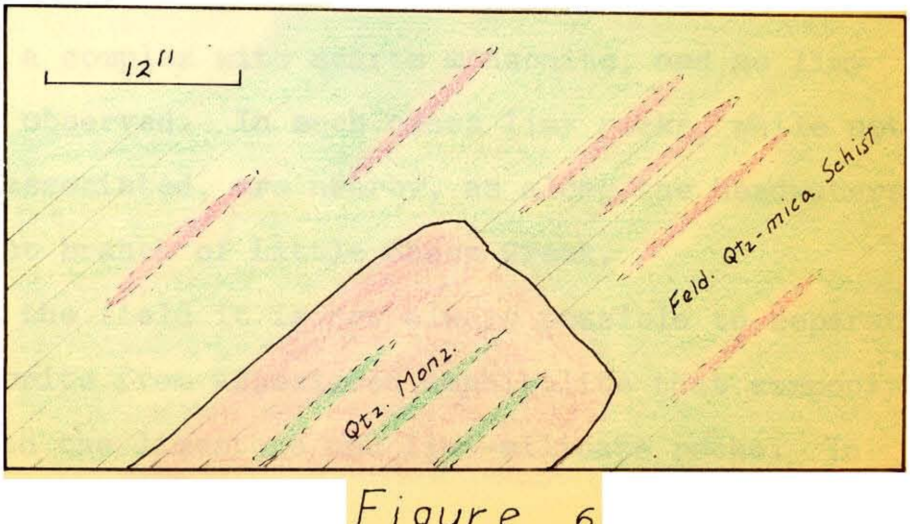

Figure 6

there are small sills, a foot or two in width, in which the contacts and foliation are parallel to the schistosity. The sills terminate abruptly against undeformed schist; that is, the position of the sill is abruptly taken over by schist, and there is no deformation of the foliation or of the schistosity, and no evidence of an intersecting fault. Where such sills occur there are usually lenses and streaks of granitic material in the schist parallel to the cleavage (fig. 6).

Hornblende-biotite-quartz Diorite: Small bodies of hornblende-biotite-quartz diorite (unit 5) are characteristically associated with limy metamorphic rocks of the Yukon group (unit 1). They commonly form aureoles around limy inclusions, thus separating the limy rocks from direct contact with the surrounding quartz monzonite. Excellent examples of this occur at the margin of the core of Drury quartz monzonite in the ridge south of the headwaters of Pass Creek (see plate 1). In other places quartz diorite occurs in a complex with quartz monzonite, and no limy rocks are observed. In such cases limy rocks, while not directly associated, are nearby, as along the headwaters of the west branch of Little Sheep Creek.

In the field it is not always possible to separate quartz diorite from associated amphibolite that commonly occurs with the limestone and lime-silicate rocks. In general, amphibolite is clearly layered and quartz diorite is not; amphibolite contains little if any quartz and no biotite whereas both minerals are constituents of quartz diorite. Amphibolite, however, seems to grade into quartz diorite and may, in some cases, have been mistaken for it. For this reason complexes of quartz diorite with quartz monzonite or alaskite are mapped as containing both quartz diorite and lime-silicate rocks in that the two may be indistinguishable and are usually in close association.

The hornblende-biotite-quartz diorite is typically a fine-grained dark rock in which the average mode of 14 analyses on 12 samples is 50.6 per cent plagioclase, 19.5 per cent hornblende, 16.6 per cent biotite, 11.3 per cent quartz, 0.2 per cent potash feldspar, and 1.8 per cent accessories, dominantly sphene, though apatite is common. The plagioclase probably averages about An 45 but differs, from core to rim, from extremes of An 74 to An 30. Sphene is usually euhedral, hornblende may be euhedral or subhedral, biotite is in shreddy, irregular grains, plagioclase is subhedral to anhedral, and quartz is anhedral. All the minerals are fine-grained except some quartz, of which a few grains are 2 to 3 millimeters in diameter. The quartz is commonly so full of inclusions that a single grain may appear in several separated patches in a thin section (fig. 28). The plagioclase often has highly calcic, unzoned or weakly zoned cores that are more or less replaced by much more sodic material in progressively zoned overgrowths or reaction rims (figs. 22 and 23).

On the one hand quartz diorite seems to be gradational to amphibolite and on the other to quartz monzonite. In general the contacts of quartz diorite with quartz monzonite are gradational except in the case of a few small quartz monzonite dykes in the more basic rock which have sharp contacts. There are also sharply bordered veinlets of light-coloured rock, 0.5 to 3 inches wide that wander about in an apparently aimless pattern. The veinlets pinch and swell and lens out smoothly at the terminations. These veinlets are most common in the amphibolite but do occur in the quartz diorite.

Alaskite dykes cut the lime-silicate rocks and, not infrequently, the quartz diorite. They commonly cut across the structure of the rocks and have sharp contacts; there are no apparent gradations between quartz diorite and alaskite.

Alaskite: Rocks in Glenlyon Range that are leucocratic quartz monzonite or soda granite are here called alaskite (map-unit 7). They do not fit exactly the mineralogical requirements of alaskite as given by Johannsen (1932, Vol. 2, p. 107) being richer in both the amount of plagioclase and in the lime content of the plagioclase. The term is used because of the leucocratic character of these rocks. The alaskite forms dykes and sills, usually of small size (5 to 10 feet) but locally much larger, that cut all rocks of the Yukon group as well as quartz diorite and Drury quartz monzonite.

The alaskite is pale creamy-coloured on the fresh surface and weathers dull, chalky white. Biotite occurs in sparse, scattered flakes and is the only dark mineral. Generally the rock is medium grained and inequigranular; potash feldspar tends to form larger grains than the other minerals. In a few localities, as in the granitic-metamorphic complex southwest of Mount Jar, the grains are sufficiently coarse, particularly those of potash feldspar, for the rock to be termed pegmatite.

Plagioclase in the alaskite is unzoned or very poorly zoned; its composition ranges from An 10 to An 25 and is more sodic than the plagioclase of any associated rocks. Quartz may be in highly granular aggregates but there are usually a few non-granular grains. Biotite and muscovite occur in very fine flakes and fine fibrous sillimanite is a common accessory. The texture of the alaskite is very complex and confused, in detail it is highly seriate. A common though not universal feature is the micrographic intergrowth of quartz and potash feldspar (figs. 52 and 53).

Analyses of five samples of alaskite gave an average mode of 30.8, 30.0, 35.0, 1.6, 1.8 and 0.8 per cent of potash feldspar, plagioclase, quartz, biotite, muscovite, and accessories (mainly apatite and sillimanite) respectively. This composition is much richer in potash feldspar and quartz than any other granitic rocks in the area. The low biotite content, the presence of muscovite, and the sodic composition of plagioclase are definite and characteristic features of this alaskite. The high quartz content may or may not be a definite feature, and the amounts of plagioclase and potash feldspar differ between fairly wide limits.

Many dykes of alaskite cut the metamorphic rocks athwart the structure and seem definitely to be intrusive. Such dykes are perhaps most common in the limy rocks but they cut quartzose schists as well. In the schist the alaskite often occurs as sills. It has sharp contacts against all the metamorphic rocks and some of the dykes and sills contain angular fragments of the wall-rocks, certain of which could be fitted precisely into irregularities in the contact nearby. The inclusions show various stages of conversion to granitic material.

Many alaskite sills in the schist have a vague suggestion of foliation parallel to the contacts and to the schistosity. Inclusions in the sills are structurally parallel to the wall-rocks. There are all stages, from sills of essentially pure alaskite, through alaskite with many inclusions of schist, to zones mainly of schist with only small bodies of alaskite.

Some dykes of alaskite in quartz monzonite are marked by an abrupt change in colour index, but nothing can be observed, microscopically, to indicate that they have an intrusive relationship. The change, on a small scale at least, is gradational, and individual mineral grains cross the line marked by the change in colour index.

Fairway Dyke: The name Fairway dyke is applied to the tabular body of leuco-granitic rock which cuts north-westerly across Fairway Hill and extends down into the valley of Harvey Creek. It is at least 6 miles long and, while apparently it is variable in thickness, it averages about 500 feet assuming it dips in rough concordance with the enclosing strata. In strike the dyke cuts the bedding of the surrounding rocks at a very small angle.

The dyke has been inadequately sampled, hence no reliable modal composition can be given. However, the composition seems to have the features which are considered to be characteristic of alaskite; that is a low content of biotite, considerable muscovite, and rather sodic plagioclase. It may be richer in plagioclase and poorer in potash feldspar than the average of the alaskite samples.

Toward the west end the dyke may lie along the contact of the Yukon and Harvey groups but the relations are very imperfectly known because of poor exposures. At the east end it is entirely within the lower member of the Harvey group and is the only granitic rock known to be in direct contact with those strata.

On the upper or north side of the dyke the limy beds of the Harvey group are converted to both layered and massive diopside-garnet rocks for about 1000 feet from the contact (400 to 500 feet stratigraphically). In this zone the plagioclase is more calcic than in other silicated rocks of the Harvey group limestone and near the contact there is considerable perthitic potash feldspar. Perthitic potash feldspar is not known elsewhere in the Harvey group except in the inclusion of Peak granodiorite on the north slopes of Glenlyon Peak. Below, or on the south side of the dyke, exposure is poor, and little is known of the contact effects. From what can be seen the effects do not seem to be as intense or as widespread as those to the north.

The eastern end of the dyke is intersected by a fault beyond which alaskite associated with Drury quartz monzonite and strata of the Yukon group continues on the same trend. This alaskite seems to grade downward into the quartz monzonite. Because of its proximity in space to the Fairway dyke it may be part of the dyke but is mapped as alaskite (unit 7).

Peak Granodiorite: Peak granodiorite (map-unit 10) forms a pluton along the northwest flank of Glenlyon Range. It is at least 25 miles long and averages about 3.5 miles in width of exposure. Twenty miles of it, from the southeast end northwestward, are included in the large scale map area (plate 1). Peak granodiorite is known to be in contact only with rocks of the upper Harvey group except for a large inclusion of lower Harvey group limy rocks on the north slopes of Glenlyon Peak. The northeastern contact has not been observed because it is obscured by glacial deposits in Tintina Valley. Presumably the pluton is bounded on the northeast by a fault or faults, in fact the front of the range may be a scarp.

The southwestern contact is straight and vertical over most of its length and is discordant to the upper Harvey group strata. There is little doubt that the granodiorite intrudes the slates. The hornfelsed slates are contorted for distances ranging from 100 to 1200 feet from the contact; the contortion, in general, is not widespread.

The batholith is uniform in appearance throughout its length and breadth and from the highest to the lowest outcrops. Specimens collected from the contact are indistinguishable from those collected anywhere else in the body. The rock is medium-grained and porphyritic with potash feldspar phenocrysts or oikocrysts. It is faintly foliated. The texture and modal composition are essentially identical to that of the core zone of Drury quartz monzonite. The average composition of 45 modal analyses from 33 samples is 18.5, 41.0, 29.6, 10.0,and 0.9 per cent of potash feldspar, plagioclase (mostly between An 35 and An 40), quartz, biotite, and accessories (mainly apatite) respectively. Hornblende was observed in small amount in two thin sections only.

Two large inclusions of Harvey group metasedimentary rocks occur in Peak granodiorite. One, composed of the limy lower member, is on the northern ridges of Glenlyon Peak and is over 12,000 feet long and up to 1,200 feet wide. Both the elongation of the inclusion and the bedding within it are roughly parallel to the strike of the bedding in the Harvey group beyond the contact. Some thin-bedded limestone still exists in the inclusion, but the rocks are mainly lime-silicate gneiss or schist that contain plagioclase (An 50), diopside, biotite, quartz, carbonate, and up to 20 per cent of potash feldspar. The other inclusion is a similarly shaped lens about 4,000 feet long and 1,200 feet wide. It is composed of argillaceous rocks and is a hornfels similar to that found along the southwest contact of the batholith. It is close to the contact on the slopes of the ridge immediately south of Glenlyon Peak. In this inclusion also the elongation and the bedding are roughly parallel to the strike of the bedding in the Harvey group. The tabular form of both inclusions in strike and dip is roughly parallel to the foliation in the granitic rock.

Peak granodiorite contains sparse, small (1 to 2 inches), rounded, rather inconspicuous, dark, fine-grained inclusions, which, when lenticular, lie parallel to the foliation marked by biotite. These are composed of biotite and plagioclase (about An 40), with more or less quartz and potash feldspar.

Dykes were found in Peak granodiorite and in the contact rocks at one place only. At this place, on the southwest contact (lat. 62 degrees 29.75 minutes north and long. 134 degrees 23.5 minutes west), there are a few small aplite and pegmatite dykes both in the hornfels and in the granodiorite. About 4000 feet northeast of this locality, well within the batholith, is a small body of fine-grained hornblende-augite lamprophyre.

Nub Hill Granodiorite: Nub Hill granodiorite (unit 9) forms an elongate, bulb-shaped body that is narrow on Nub Hill and expands to the west. Its continuation to the east is unknown because of lack of exposure, and it may join Peak granodiorite. On Nub Hill the body seems to be concordant to the intruded upper Harvey group rocks, but the relations are obscure at the west end. It seems possible that the granodiorite is generally concordant to the structure of the intruded rocks and its shape may result from the relation of topography and altitude. The body is at least 4 miles long and, if it is concordant, it is 1,200 feet thick on Nub Hill.

The contact of Nub Hill granodiorite is sharp and well defined, and there are no fine-grained selvages or other evidence of chilled margins. The slates are converted to hornfels identical to those in contact with Peak granodiorite. The hornfels zone is over 1000 feet wide on the south slope of Nub Hill, and between the top of Nub Hill and the contact of Peak granodiorite to the north all the rock is hornfels. Around the western part of the body contact effects are much more limited.

Nub Hill granodiorite is very similar to Peak granodiorite in texture and mode; it is a little finer-grained and the biotite is red-brown rather than olive-green or green-brown.

Structural Geology

Folds, Schistosity, and Foliation: With one exception the contact of the Yukon and Harvey groups dips to the north wherever known (see plates 1 and 2). Within the Yukon group in the area mapped in detail (plate 1) the general dip of the strata is to the north though there are reversals due to small folds. South of the core of Drury quartz monzonite the general dip of the Yukon group strata is southerly, but unfortunately the Harvey group does not occur in this locality. The axes of some minor folds, both north and south of the core of the quartz monzonite, trend east-west or a little north of west and plunge 20 degrees or more to the west. The axial planes of the folds in the northern part of the range are nearly vertical or dip steeply to the north. The general nature of the structure is shown in the cross sections of plates 1 and 2.

The north part of Glenlyon Range thus seems to lie on the north limb of a large anticlinal structure of which the axis trends a few degrees north of west and plunges to the west. The dip of the axial plane would seem to be close to vertical. The core of the anticline or anticlinorium is occupied by continuous masses of Drury quartz monzonite (the core zone, unit 6x, plate 1).

The actual configuration of a single horizon involved in this large structure (e.g. the margin of the quartz monzonite core or the contact between the Harvey group and Yukon group) is complicated by the many faults within Glenlyon Range. Furthermore, no single horizon can be traced around the nose of the plunging structure because all recognizable boundaries are intersected by the faults which surround and geologically isolate the range.

The north boundary of the core of the quartz monzonite cannot be precisely mapped, but it seems to conform generally to the trend of the bedding in the Yukon group. The intermediate and outer zones, although not uniformly developed in all localities, also generally conform to this trend. Thus, from the core of the anticlorium to the contact of the Yukon and Harvey groups, the relative proportion of granitic to metamorphic rocks becomes progressively less and less and the upper beds of the Yukon group are granite-free with but minor exceptions.

The contacts between the lower and upper members of the Harvey group and between the Harvey and Yukon groups strike about east-west and dip generally about 30 degrees north. The upper of these contacts, wherever it is known, dips to the north, but the lower, in one place, has a southerly dip. This is on the mountain directly north of Moraine Mountain where beds of the lower Harvey group form a small pod abutting against a fault. Between this pod and north dipping strata of the lower Harvey group to the north is a series of Yukon group beds which are folded in a gentle and poorly defined anticline. The axis of the fold lies in the valley of East Tummel River.

Several small folds trending slightly north of west occur in association with the outer and the intermediate zones of Drury quartz monzonite on and around Canyon Mountain. No one of these folds can be traced for more than two miles because they are intersected, at either end, by faults. They plunge 20 degrees or more to the west. The contacts and foliation of the granitic rocks involved in these folds conform to the folding, being parallel to the bedding and schistosity of the metamorphic rocks.

Bedding in the lower part of the upper Harvey group retains the attitude of the lower, limy strata, but higher in the section the argillaceous rocks are irregularly contorted along the contact of Peak granodiorite. From the normal attitude in which the strikes range a few degrees from east-west and dips range from 15 to 50 degrees north the strike becomes northwest, locally north, and in places enters the northeast quadrant, and corresponding dips become steep to the east or are vertical and locally are southerly.

The attitudes in the contorted zone are not rigidly parallel to the batholith contact but they are more nearly so than the general attitude of the Harvey group strata.

In general bedding and cleavage or schistosity in all the metamorphic rocks are parallel, except in detail in the slaty rocks of the upper Harvey group. The bedding shows small isoclinal folds measuring 2 or 3 inches from limb to limb, but the slaty cleavage is not folded. The axial planes of these folds are parallel to the bedding, and the axes are parallel to the strike or they may plunge about 10 degrees to the northwest. In the crests of the folds cleavage cuts the bedding, but the two are parallel in the limbs. These structures are common in the slaty rocks and possibly similar but larger folds exist. In any event, such folds make an estimate of the thickness of the slate and phyllite section a very precarious guess at best. A few similar folds were observed in the lower Harvey group and in the Yukon group strata.

Foliation in Drury quartz monzonite is marked primarily by the parallel orientation of biotite flakes. In the small granitic bodies the foliation is, in general, parallel to the contacts and to the schistosity and bedding of the associated metamorphic rocks. Larger bodies of quartz monzonite seem to have similar relations, and even the core may conform to such a picture, but here the data are too few for a proper assessment. To some degree, then, the quartz monzonite seems to conform to the folding of the Yukon group strata. It may have been folded with these rocks or formed during or after the folds were formed.

Foliation in Peak granodiorite is also marked by the parallel orientation of biotite flakes, and to a lesser extent, by the elongation of lenticular dark inclusions. It was investigated only in certain sections. The foliation dips predominantly to the north at angles ranging from 10 to nearly 90 degrees and strikes range mainly between north 45 degrees east and north 45 degrees west. Along the southwest contact and at the southeast end of the batholith the attitude of the foliation becomes erratic; the dips are mostly very steep and the strikes range widely. There does not seem to be any tendency for the foliation to swing into parallelism with the contact, but the observations are too few to permit an accurate appraisal.

Faults and Joints: The inferred faults which bound Glenlyon Range have been mentioned. Within the range many more faults have been mapped, and probably there are many that have not been recognized. Where these faults intersect the contacts of the upper and lower members of the Harvey group or of the Harvey and Yukon groups they can be readily and accurately mapped. Where they occur in the complex of Yukon group schist and granitic rocks they may be difficult to recognize even where they cut the structural trends at a large angle, and where they lie parallel to the structure they may be nearly impossible to locate. Most of the faults mapped within the range cut the contacts mentioned, and they follow two general directions, north to northwest and about east-west. These will henceforth be designated the north-trending and the west-trending faults, respectively.

The north-trending faults change in strike from the north part of the area to the south (plate 1). Along the valleys of East Tummel River and the east branch of Little Sheep Creek they strike close to north 50 degrees west but farther south on the same faults, and on others along Pass Creek, they strike about north 10 degrees west.

Most of these faults have the same sense of movement in regard to the displacement of north dipping contacts; that is, the east side has moved, relatively, to the south. An exception is the fault crossing the hill immediately east of Fairway Hill; on it the apparent displacement of the contacts is opposite to the usual direction. Another exception is the fault which crosses the east slopes of Fairway Hill itself. This fault offsets the contact of the lower and upper members of the Harvey group in the normal direction but the contact between the Harvey group and the Yukon group appears to be offset in the opposite way. The complications introduced by the intrusion of the Fairway dyke probably account for this apparent anomaly, but the situation is not well understood.

The west-trending faults, of which three have been mapped, strike within 20 degrees of east-west. All three faults cross the east branch of Little Sheep Creek. They offset the north-trending faults, and the south side has moved, relatively, to the east.

All the faults in Glenlyon Range appear to have steep or vertical dips. Little direct evidence was found to indicate the actual direction of movement. On the north-trending faults the movement might have been mainly strike-slip (east side south) or dip-slip (east side down) or a combination of the two. There could, of course, be other combinations. The west-trending faults have a more certain component of strike-slip movement (south side east) because they have offset the steeply dipping faults of the other set. They may also have a component of dip-slip movement.

If it is assumed that all the movement on the north-trending faults is strike-slip (east side south) then the total movement on all this group of faults lying between Fairway Hill and lower Pass Creek is about 12 miles.

If there is added to these faults the apparent displacement of the fault which lies just east of Moraine Mountain the total apparent strike-slip displacement (east side south) becomes 20 miles or more. If all the movement is dip-slip (east side down) the total displacement would be about 7 miles in order to offset the contact of the Harvey and Yukon groups from the valley of Harvey Creek in the west to the valley of Jar Creek in the east, assuming an average north dip for the contact of 30 degrees.

If dip-slip and strike-slip movements had the opposite effects in displacing the contacts (i.e. east side south and up) the total absolute strike movement would be much greater than the figures given. The minimum possible movement to explain the offsets is about 3 miles of strike-slip (east side south) and 5 miles of dip-slip (east side down); an absolute oblique movement of close to 6 miles.

An argument in favour of a large component of strike-slip movement is found in the uniformity of the attitudes of the contacts that are offset. This is readily explained on the basis of strike-slip faults cutting and offsetting the strata on the limb of a fold. It is difficult to envisage the beds retaining their attitude, down-dip, for a distance of 14 miles (to a depth of 7 miles) which would be required if all the movement were dip-slip. If this is possible one might expect to find an increase in the metamorphic effects, but none occurs. A very large component of strike-slip movement is indicated.

A significant aspect of the faults has to do with their relation to the granitic rocks. An inspection of the map shows that the faults cut all the metamorphic rocks, Drury quartz monzonite, and the alaskite, but do not seem to offset the contacts of Peak granodiorite. The effects of faulting on Nub Hill granodiorite are obscure, and the contacts may be offset. Where north-trending faults approach the contact of Peak granodiorite they tend to swing into parallelism with it. The west-trending faults could not be traced to the contact, but they do not interrupt it along any reasonable projection of their strike. This indicates that Peak granodiorite is younger than Drury quartz monzonite though the age difference may not be very large. Possibly the faults which cut the quartz monzonite were, at the same time, partly responsible for the dilation into which Peak granodiorite was intruded at a very late stage in the history of the development of the granitic rocks.

The southwest contact of Peak granodiorite and the north-trending faults are all sub-parallel to the major faults which bound the range on the northeast and southwest sides. On the northeast, in Tintina Valley, the structure is known unofficially as the Pelly Fault, which, on the basis of topographic expression and some scattered geologic information, is several hundred miles long. Movement on this fault is evidently very large and may be inferred to be mainly strike-slip. In keeping with the tectonic picture of the Cordillera of North America it might be inferred that the movement is right lateral (east side relatively to the south). Such movement would be in agreement with the movement on the San Andreas Fault and that which is inferred for the Denali Fault by St. Amand (1957). It is also in agreement with the apparent strike-slip displacement on the faults within Glenlyon Range. There is, of course, nothing against the possibility that these faults may have a component of dip-slip movement as well.

If the movement on the faults bounding Glenlyon Range is indeed strike-slip with the east side moved relatively to the south then the axis of principal strain, or compression, would be roughly north-south. This is supported by the trend of the folding within the range and in at least some of the surrounding area in which the fold axes trend roughly east-west. If such is the case then the north-trending faults in Glenlyon Range conform neither to an ideal shear nor tensional fracture direction, but fall about between the two. Some of them change from what should be a shear direction to what should be close to the direction of tensional fractures. Factors introduced by such masses as Peak granodiorite must have a profound influence on the stress pattern and cause changes from the ideal directions of fracturing.

No detailed study was made of the jointing in the granitic or metamorphic rocks. In any given outcrop there are often five or six directions of jointing, and it is not always possible to determine which of them represent major sets; the pattern of jointing, from a casual inspection seems to be very confused.

THE TEXTURE OF THE GRANITIC AND METAMORPHIC ROCKS

Introduction

The purpose of this section is to describe comprehensively the textural features of all the quantitatively important minerals in the granitic rocks of Glenlyon Range. The textures of the metamorphic rocks are described only insofar as they are important as an aid in the interpretation of the granitic textures. In this way it is hoped that the granitic minerals, and through them the granitic rocks, will be adequately described so that the observational data might be of use to some one who may not entirely agree with the writer's interpretations. The descriptions are supplemented by photomicrographs to illustrate the textural features.

A description of this nature can be achieved in two ways. The textures can be described rock by rock with subdivisions for the details of each mineral, or they can be described mineral by mineral with subdivisions in which the characteristics of a given mineral are described in each of the various rock types. As many of the features of the minerals are common to several rock groups it was decided that the mineral by mineral description would be most suitable. There is a general description of the texture of each mineral and, under subheadings, that mineral in the various rocks is described. A reader interested in the texture of Peak granodiorite for example, can thus read the description of the texture of this rock by following the Peak granodiorite subdivisions under the various mineral headings. In general the differences in the overall texture from rock to rock are less important, for present purposes, than the differences in the texture in the individual minerals from rock to rock.

About 400 thin sections of specimens of the rocks of Glenlyon Range were examined in detail. Of these, 42 were of Peak granodiorite, 116 of Drury quartz monzonite, 31 of hornblende-biotite-quartz diorite, 13 of alaskite, 8 of pegmatite, 4 of the Fairway dyke, 4 of Nub Hill granodiorite, 84 of Yukon group quartz-mica schist, 32 of Yukon group limy rocks, 26 of Harvey group limy rocks, and 38 of Harvey group slate, phyllite, and hornfels.

Texture involves not only the internal and external features of the minerals but also their relations to other minerals. As a consequence of this some of the intermineral relations may not be found in the description of the texture of one mineral but will be found in that of another. Thus some of the relations of plagioclase to potash feldspar will not be found in the description of the texture of plagioclase but will be found in that of potash feldspar. In this way excessive duplication is prevented. In the description of each mineral the relations of that mineral to those previously described will be found. The section is arranged so that the description of potash feldspar, which has highly significiant relations to all the other minerals, comes last, and is, in a sense, a general textural description.

Hornblende

In the rocks of Glenlyon Range hornblende and other amphiboles occur in many localities, but they are restricted to certain quantitatively minor rock types. Hornblende was observed in small amount in only two thin sections of Peak granodiorite. Amphiboles are otherwise entirely restricted to hornblende-biotite-quartz diorite and its transitions to quartz monzonite, to amphibolite, and less commonly to other lime-silicate rocks.

In Hornblende-biotite-quartz Diorite: The hornblende is fine grained in the quartz diorite. Prism faces are well developed, but the crystal terminations are irregular. Sections cut perpendicular to the C axis usually produce euhedral outlines, and other sections may produce euhedral to anhedral forms. The colour varies in shades of yellowish green; no bluish-green hornblende was observed. The pleochroic formula is about as follows: X = pale yellowish green, Y = olive green, Z = dark green.

The hornblende is usually associated with biotite and may include or be included by that mineral. There are no apparent replacement relations between these two femic minerals. Hornblende is mutually interfering with the form of plagioclase; that is, either of these minerals may interfere with the euhedral form of the other.

The quartz diorite is not foliated, and hornblende and biotite do not fall in a pattern of preferred orientation.

<u>In Amphibolite:</u> Hornblende in the amphibolite is quite similar to that in the quartz diorite, and the two rocks are very often closely associated in the field. In the amphibolite it has the same colours as in the quartz diorite but is finer-grained on the average, and is less frequently euhedral. Some of the amphibolite is schistose, and the grains of hornblende are oriented with the C axes in a common plane, and in a common direction; in other cases the amphibolite is not schistose.

The amphibolite consists almost entirely of hornblende and plagioclase and, in rare cases, contains considerable diopside. The delicate layering which is common in some of these rocks is evidently produced by alternate layers being richer or poorer in hornblende with respect to plagioclase.

<u>In Other Rocks</u>: Hornblende and other amphiboles rarely occur in the lime-silicate rocks of the Yukon group other than in amphibolite. On Skarn Ridge there is a thin bed composed of rosettes of fibrous anthophyllite that is associated with amphibolite and other lime-silicate rocks. In some of the lime-silicate gneiss there is a small amount of hornblende with the diopside.

In the basal sections of the lower Harvey group, and along the Fairway dyke, the lime-silicate rocks are mostly thinly layered, and some of the layers are rich in very fine-grained pale-green actinolitic amphibole.

Biotite

Biotite is found in the vast majority of rocks in Glenlyon Range and is usually the only ferromagnesian mineral. The grains usually appear elongate in thin section, and the longest dimension ranges from about 0.1 mm to about 2 mm; rarely, in schist, it forms grains up to 3 mm in length.

When biotite grains have developed crystal faces, such faces are usually basal pinacoids. Grain boundaries parallel to the C axis are, as a rule, very irregular. In all the granitic rocks except quartz diorite the cleavage of biotite is bent or broken to some degree. This is not a common feature in the metamorphic rocks.

In Peak Granodiorite: The biotite grains in Peak granodiorite range in major dimension from 0.1 to 2 mm and average somewhat less than 1 mm. In rare cases it forms hexagonal books, but more generally the prism faces are not developed. In every section of this rock the biotite cleavage is bent or broken in at least some grains, and there are small displacements along some of the breaks. In Peak granodiorite biotite is dark olive-green or dark brown when it is oriented with the cleavage parallel to the vibration direction of the lower nicol, and pale greenish yellow in the perpendicular direction. The approximate pleochroic formula is X = pale yellowish brown or yellowish green and Y = Z = dark brown or olive green.

Probably in its most common occurrence in Peak granodiorite biotite is associated with plagioclase. These two minerals are mutually interfering in that grains of one may interrupt the outline of the other. The biotite is very commonly included in potash feldspar. In this occurrence it may occur as rectangular grains, but commonly it is patchy in that there are angular embayments of potash feldspar into it, and rather angular patches of parallel biotite isolated in the feldspar (figs. 7 and 54). The biotite is less commonly included by quartz and is rarely included by plagioclase. The mica may include small grains of plagioclase but does not include quartz or potash feldspar. Grains of biotite that are partly included by quartz and partly by potash feldspar are in places reduced in size in the potash feldspar relative to their size in the quartz, but this is not so everywhere.

A feature of the biotite that is included by potash feldspar is its relation to quartz. Small shardy bits of quartz occur in and around the biotite; they penetrate small embayments between the cleavage, fit around the grains, and adhere evenly to the exterior contacts. This quartz, in and around a single biotite grain or clot of several grains,

Figure 7

Drury Quartz Monzonite
Thin section 63-M; Specimen 23-M-53-4.

Photomicrograph. Biotite (speckled dark grey with good cleavage) is included by potash feldspar. Angular embayments of potash feldspar into the biotite and some isolated orientated patches of biotite in the potash feldspar are suggestive that biotite has been replaced by potash feldspar, but the evidence is not good. Where symbols are used to identify minerals in the photomicrographs potash feldspar, plagioclase, quartz, biotite, and myrmekite are indicated by KF, Pl, Q, Bi, and My, respectively.
Crossed nicols; x 90.

Figure 8

Drury Quartz Monzonite
Thin section 63-M; Specimen 23-M-53-4.

Photomicrograph. Biotite (dark with obvious cleavage) is included partly by quartz (white) and partly by potash feldspar (medium grey). The small quartz grains around the biotite within the potash feldspar all have the same optical orientation as the larger quartz grain which is not included by the potash feldspar. This suggests that quartz has been replaced, preferentially, by the potash feldspar.
Crossed nicols; x 90.

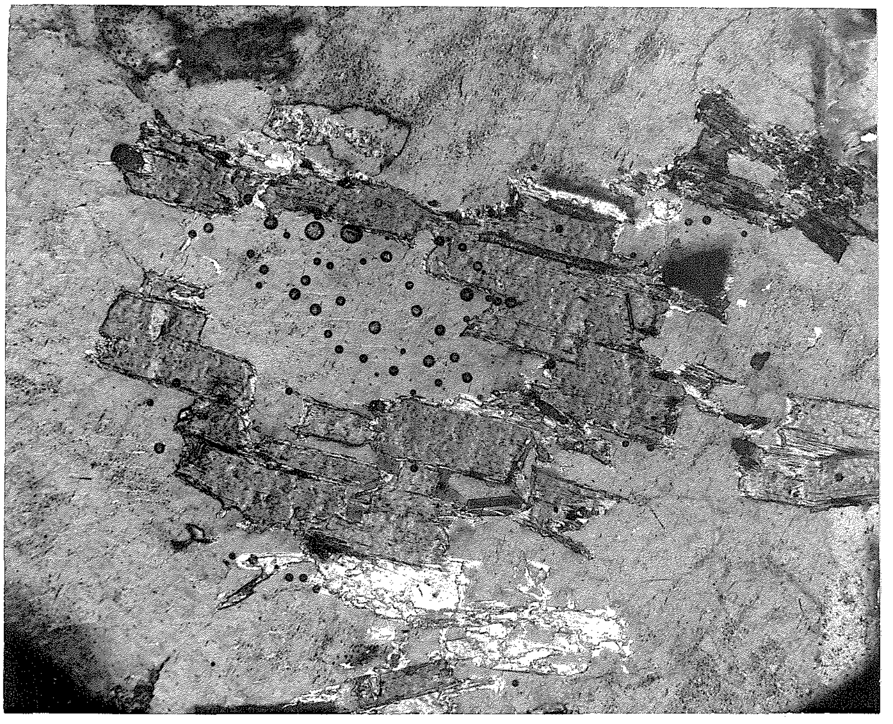

Figure 7

Figure 8

is generally all of one orientation and commonly is oriented parallel to an adjacent larger quartz grain which may not be included by the potash feldspar (fig. 8). The biotite included by quartz commonly is not engulfed by a single grain but tends to be on the contacts of quartz grains that are part of an aggregate.

Figures 7, 8, and 54 were taken from rocks in the core of Drury quartz monzonite but illustrate Peak granodiorite equally well.

In Drury Quartz Monzonite: The size, shape, colour, and relations of biotite are uniform within each of the individual zones of Drury quartz monzonite but differ from zone to zone.

In the core of the quartz monzonite biotite is similar in texture and colour to that in Peak granodiorite.

In the intermediate zone biotite is red-brown rather than olive-green and may be a little finer-grained but is otherwise similar to that in the core.

In the outer zone biotite is very fine-grained, has a strong preferred orientation, and is red-brown. In this zone the biotite is commonly included by plagioclase, an otherwise uncommon feature in Drury quartz monzonite. When biotite is included in plagioclase or potash feldspar in the rocks of the outer zone it is usually oriented parallel to the biotite of the matrix.

The most common occurrence of biotite in the outer zone of the quartz monzonite is in association with fine-grained quartz. The quartz grains are more or less elongate parallel to the long axes of the oriented mica grains. The feldspar grains tend to "float" in this fine-grained matrix of quartz and biotite, and the schistosity may curve around the feldspar grains.

In Hornblende-biotite-quartz Diorite: In the quartz diorite, biotite is fine-grained, irregularly shaped, and randomly oriented. It is most commonly associated with hornblende. The colour of biotite in the quartz diorite is similar to that in Peak granodiorite. The biotite in places includes small plagioclase grains and may include, or be included by, hornblende. There is no good evidence that biotite has replaced hornblende.

In Yukon Group Quartz-mica Schist: In the feldspathic quartzose schist of the Yukon group biotite is usually very fine-grained and has a strong preferred orientation. It is red-brown. Where muscovite occurs, it has similar textural features. A general view of the texture of the schist is shown in figures 9 and 10.

Where biotite is included in large feldspar grains in the schist it retains its preferred orientation, though the schistosity tends to bend around feldspar porphyroblasts.

Biotite in the schist is similar in texture and colour

Figure 9

Yukon Group Quartz-mica Schist
Thin section 96-M; Specimen 29-M-53-12.

Photomicrograph. Biotite (the dark grains) is moderately well oriented in the schist.
Plane light; x 30.

Figure 10

Yukon Group Quartz-mica Schist
Thin section 96-M; Specimen 29-M-53-12

Photomicrograph. This is the same picture as shown in figure 10 but with crossed nicols. This illustration gives a good general idea of the texture of the quartz-rich schist.
Crossed nicols; x 30.

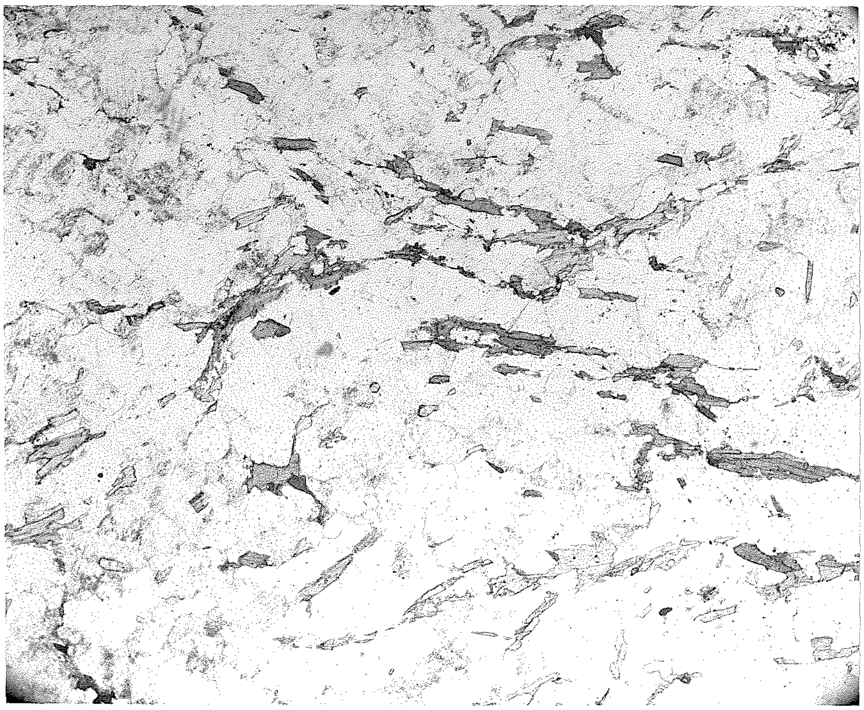

Figure 9

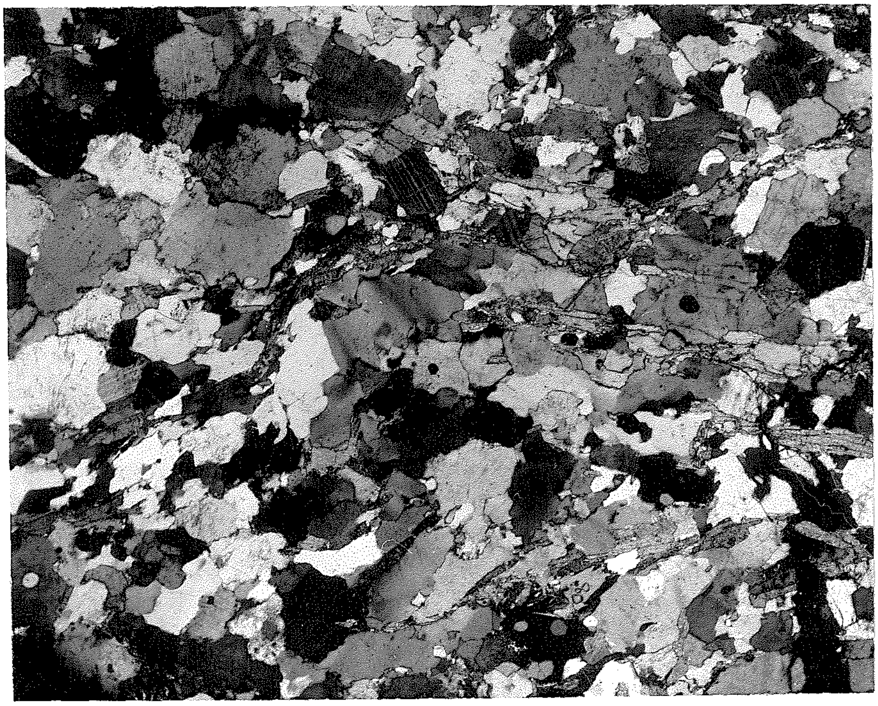

Figure 10

to that in the outer zone of Drury quartz monzonite.

In Other Rocks: The biotite that occurs in lime-silicate rocks of the Yukon group is greenish in colour as opposed to the red-brown biotite of the quartzose schist. Fine-grained biotite in the hornfels and phyllite of the upper member of the Harvey group is brown or red-brown in colour.

In Nub Hill granodiorite biotite is red-brown and is a little finer-grained than that in Peak granodiorite. It has the same relations to the other minerals as it has in Peak granodiorite.

There is a little shreddy red-brown biotite in the alaskite and in the Fairway dyke. In these rocks there is as much or more muscovite.

Plagioclase

Plagioclase has such varied textural characteristics in the rocks of Glenlyon Range that little of a general nature may be said of it. It is the most abundant mineral in all the granitic rocks with the exception of the alaskite and the alaskitic pegmatite and is the most common feldspar in the metamorphic rocks.

In Peak Granodiorite: The description of plagioclase in Peak granodiorite could, like that of other minerals, apply equally well to the core zone of Drury quartz monzonite. Reference may be made to photomicrographs of either rock.

In most samples of Peak granodiorite the composition of the plagioclase is between An 30 and An 40. In a few samples it is more calcic, and in four samples it is more sodic. The extreme range is from about An 10 to An 50. Commonly some grains appear to be more calcic than the rest in a single thin section.

In Peak granodiorite plagioclase grains are mostly between 2 and 3 mm in length, but they range from 0.1 mm or less to about 4 mm. Most grains are subhedral and a few are euhedral. Whether or not a given grain is euhedral depends to some degree on the mineral in contact with the plagioclase. Typically plagioclase in contact with plagioclase has irregular contacts; against potash feldspar it may be euhedral or extremely irregular; the most common occurrence of straight faces are those in contact with quartz. Grains of plagioclase are mutually interferring in form, and they may also interfere with the form of biotite.

Most of the plagioclase in Peak granodiorite occurs in complex clots with which a little biotite may be included (fig. 11). Clots or single grains of plagioclase are commonly included by potash feldspar (fig. 17, 30, 31, etc.).

Polysynthetic twinning on both the albite and pericline laws is apparent in many grains of plagioclase in Peak granodiorite. Regular well developed twinning patterns are unusual; rather one set of twins tends to be narrow and discontinuous relative to the other. Many individual

Figure 11

Peak Granodiorite
Thin section 41-M; Specimen 18-M-53-1.

Photomicrograph. A complex clot of plagioclase grains associated with an aggregate of quartz (Q) on the left and a large potash feldspar (K F) grain at the bottom right of the picture.
Crossed nicols; x 30.

Figure 12

Peak Granodiorite
Thin section 77-M; Specimen 25-M-53-15.

Photomicrograph. In the center of the picture is a plagioclase grain which contains remnants of strongly zoned plagioclase (dark grey) "floating" in more sodic unzoned plagioclase (light grey).
Crossed nicols; x 30.

Figure 11

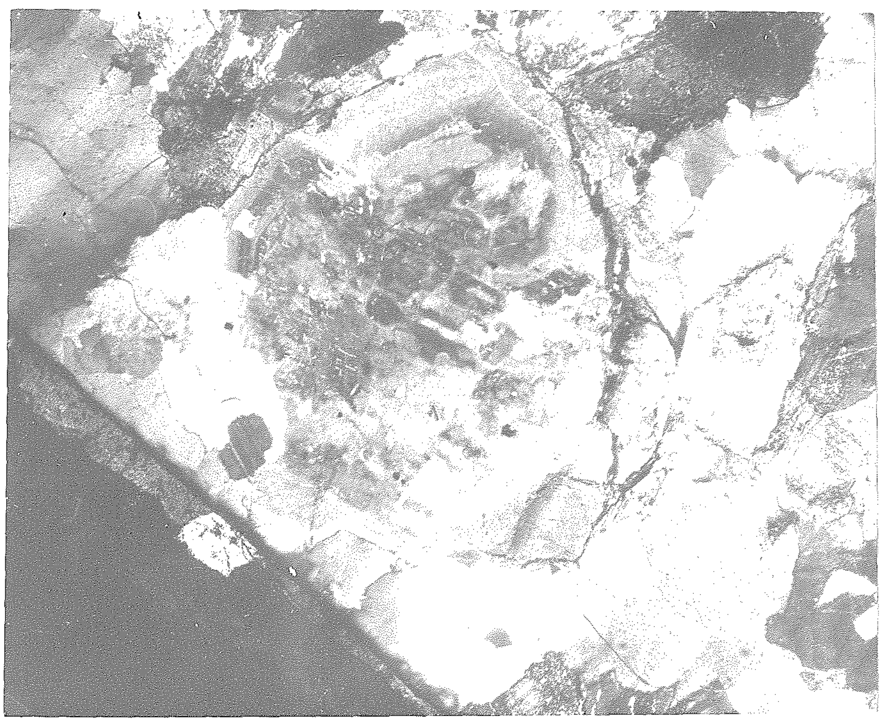

Figure 12

twins do not extend completely across a grain. Carlsbad twins also occur in the plagioclase.

Zoning is oscillatory, and the individual zones are characteristically extremely fine, delicate layers. There is not, as a rule, a strong change of composition from zone to zone, and while the oscillations may show a trend from more calcic plagioclase at the center of the grains to more sodic at the rims, there is not usually a compositional change from core to rim of greater than 10 per cent in anorthite content.

In some cases relatively sodic plagioclase forms the core (the innermost zone intersected by the plane of the thin section), or a zone near the core, and is connected by veinlets of similar sodic plagioclase to a zone or zones near the rim. Less commonly, but not rarely, there is a sharp compositional break between the core and the more sodic rim plagioclase. In such cases the core is apparently replaced by the rim plagioclase and may remain only as disconnected remnants within it. This sort of replacement has two types. Rarely the core is unzoned or weakly zoned calcic plagioclase and is surrounded and replaced by normal "rock" plagioclase with oscillatory zoning. This feature is more common in Drury quartz monzonite and will be discussed more fully. More usual in Peak granodiorite are the cases in which normal "rock" plagioclase is irregularly replaced by unzoned or weakly zoned sodic plagioclase (about

An 20 to An 25) (figs. 12 and 13). Veinlets and rims of sodic plagioclase which do not seem to be overgrowths, but are related to the type of replacement just described, run through and around plagioclase grains.

Another aspect of the texture of the plagioclase in Peak granodiorite is the complexity of the relations of one plagioclase grain to another. Commonly the grains are interrelated in such a way that the contacts transect zones, and as a result the contact between adjacent plagioclase grains may represent a surface against which the zones of one or both grains may be terminated (figs. 14 and 15).

The complexity between the plagioclase grains in a group is also shown by dislocations in the twinning that seem to have resulted, in some cases at least, by the fracturing of single plagioclase grains (fig. 16).

Complex plagioclase clots, involving grains with interrupted zones, may be completely included by a single grain of potash feldspar that exhibits no corresponding complexity (fig. 17). There is evidence that the plagioclase was fractured and that movement occurred on the fractures prior to the emplacement of the potash feldspar. An excellent example is shown in figure 18.

Many textural features of the plagioclase are dependent on the presence of potash feldspar and these are described in the section dealing with the texture of that mineral.

Figure 13

Peak Granodiorite
Thin section 14-M; Specimen 15-M-53-9.

Photomicrograph. Well twinned plagioclase (dark and light grey) corroded and replaced by more sodic untwinned plagioclase (light grey).
Crossed nicols; x 90.

Figure 14

Drury quartz monzonite
Thin section 52-M; specimen 21-M-53-6.

Photomicrograph. This illustration shows oscillatory zones of one plagioclase grain transected at the contact of another plagioclase grain.
Crossed nicols; x 90.

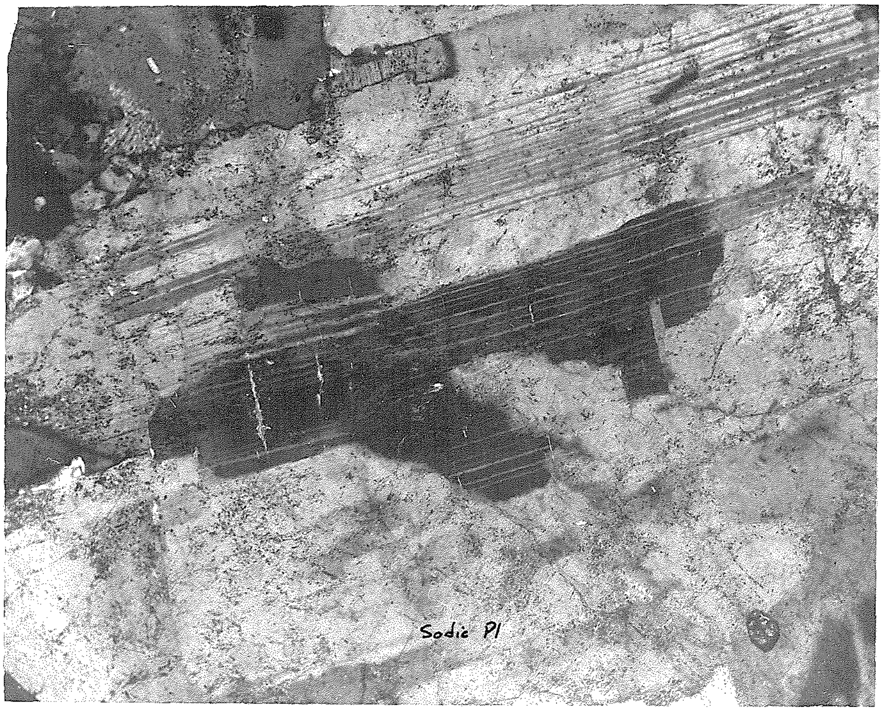

Figure 13

Figure 14

Figure 15

Core of Drury Quartz Monzonite
Thin section 41-C-54; Specimen 19-C-54-8.

Photomicrograph. This illustrates transected zones and the general complexity of relations between the plagioclase grains.
Crossed nicols; x 30.

Figure 16

Core of Drury Quartz Monzonite
Thin section 26-C-54; Specimen 18-C-54-7.

Photomicrograph. A further illustration of the complexity of plagioclase grains. The "dislocated" parts of the twinned plagioclase may represent the result of fracturing and movement of the broken parts or they may represent independently nucleated plagioclase grains.
Crossed nicols; x 90.

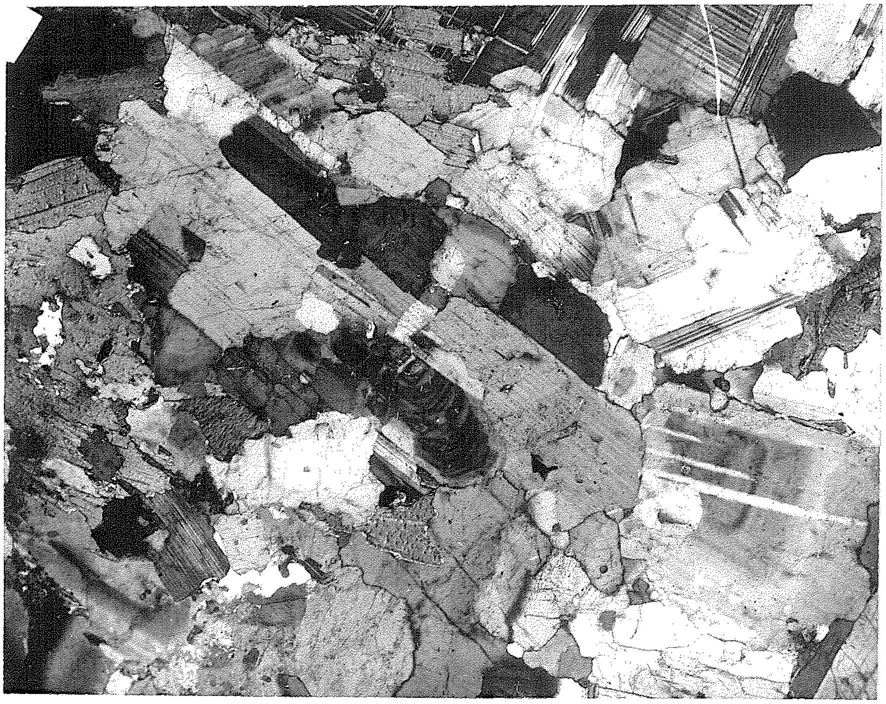

Figure 15

Figure 16

Figure 17

Core of Drury Quartz Monzonite
Thin section 35-C-54; Specimen 19-C-54-2

Photomicrograph. This shows a clot of plagioclase grains included by potash feldspar.
Crossed nicols; x 30.

Figure 18

Peak Granodiorite
Thin section 47-C; Specimen 27-C-53-5.

Photomicrograph. An excellent example of dislocation of a plagioclase grain which is included by potash feldspar. There is little doubt that the potash feldspar filled in after the plagioclase was dislocated. The characteristic sodic rim replacement of the plagioclase where it is in contact with potash feldspar is evident in the photograph.
Crossed nicols; x 90.

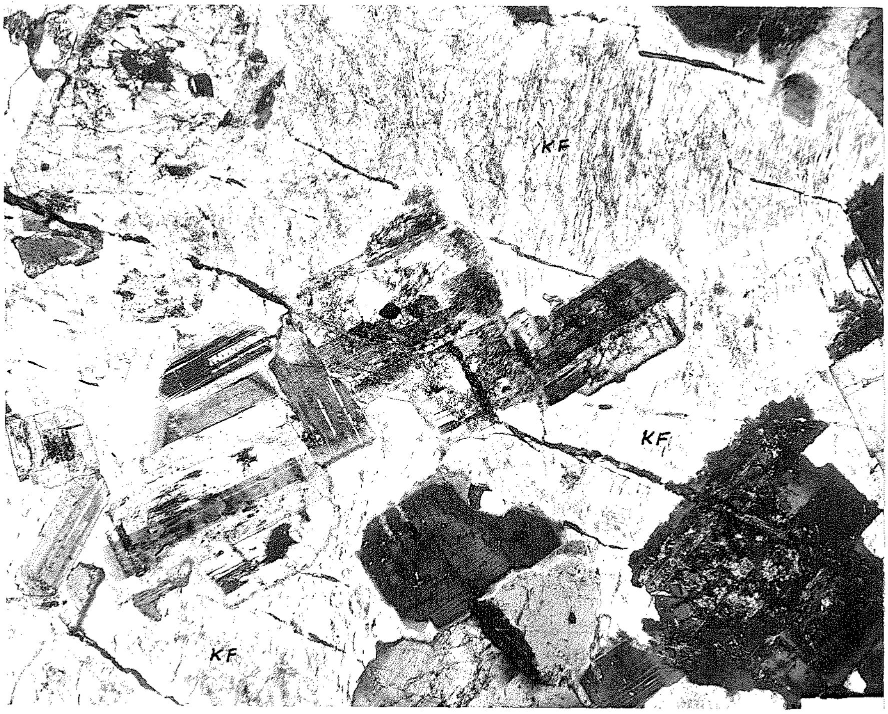

Figure 17

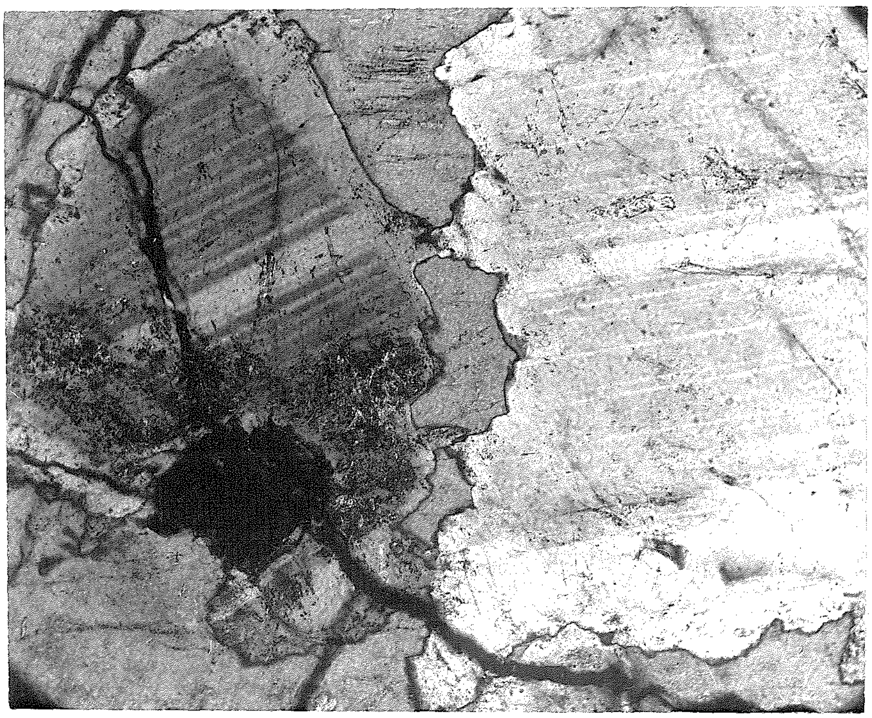

Figure 18

In Drury Quartz Monzonite: The description of the texture of the plagioclase in Peak granodiorite serves equally well for that in the core of Drury quartz monzonite and in most respects is adequate as a description of that in the intermediate zone as well. In the intermediate zone the plagioclase is a little more sodic.

In some localities, as at the north edge of the core and in the intermediate zone, the quartz monzonite passes gradationally into the hornblende-biotite-quartz diorite. In the transition phases the plagioclase shows some of the characteristics of each rock type. Highly calcic, weakly zoned or unzoned cores are surrounded by and may be partially replaced by more sodic plagioclase with oscillatory zoning (fig. 19). The cores are similar to the plagioclase in the quartz diorite and the rims like that in the quartz monzonite.

In the outer zone of Drury quartz monzonite the plagioclase is relatively sodic (An 25 to An 30) and is usually very weakly zoned. It rarely occurs in complex clots or grains; individual grains tend to "float" in a matrix of fine-grained quartz and biotite. In those cases in which zoning is apparent and the grains are in clots the relations do not seem to be as complex as those in the other zones of the quartz monzonite (fig. 20).

Another characteristic feature of the plagioclase in the outer zone of the quartz monzonite is that it includes

Figure 19

Transition Rock (between quartz monzonite and quartz diorite)
Thin section 109-M; Specimen 22-M-53-21.

Photomicrograph. In the center of the picture is a corroded weakly zoned calcic plagioclase core (light to medium grey) replaced by more sodic zoned plagioclase (dark grey).
Crossed nicols; x 90.

Figure 20

Outer Zone of Drury Quartz Monzonite
Thin section 80-C; Specimen 38-C-53-2.

Photomicrograph. One of the few cases in which plagioclase is zoned in the rocks of the outer zone of Drury quartz monzonite. The tendency to form clots of grains is much less marked than in the other parts of the quartz monzonite. Note the typical fine-grained matrix of quartz and biotite.
Crossed nicols; x 30.

Figure 19

Figure 20

quartz and biotite. This relationship is, otherwise, extremely rare in Drury quartz monzonite. All the quartz in small groups of inclusions may be in parallel optical orientation (fig. 21). The biotite inclusions are commonly sub-parallel to the oriented biotite in the matrix. This sodic, anhedral plagioclase with quartz and biotite inclusions is similar to the plagioclase in the associated schist.

In Hornblende-biotite-quartz Diorite: The plagioclase in the quartz diorite is fine to medium-grained and averages about 1 mm in length. No accurate average composition can be given, because the plagioclase occurs in two phases. Very highly calcic cores are separated by an abrupt compositional break from more sodic rims or overgrowths. The cores are unzoned or weakly zoned and range in composition, from sample to sample, from An 50 to An 74. The rims, which may be progressively zoned, range in composition from An 30 to An 40.

The calcic cores have two forms; they may be essentially complete euhedra (fig. 22), or they may merely be remnants of such euhedra which are heavily replaced by more sodic plagioclase extending into them from the rim (fig. 23). Where the cores appear to be severly replaced, discontinuous sections of the euhedral outline commonly remain and form a boundary within which are scattered remnants of the calcic plagioclase. Where the euhedral outline of the core can be

Figure 21

Outer Zone of Drury Quartz Monzonite
Thin section 89-M; Specimen 28-M-53-11.

Photomicrograph. Quartz grains (light grey), all in precisely parallel optical orientation, are included in plagioclase (medium and dark grey). Crossed nicols; x 90.

Figure 22

Hornblende-biotite-quartz Diorite
Thin section 111-M; Specimen 22-M-53-23.

Photomicrograph. At the top of the picture are two euhedral to subhedral calcic plagioclase cores which are separated by an abrupt compositional break from much more sodic plagioclase rims. A biotite grain covers most of the bottom part of the view. Crossed nicols; x 90.

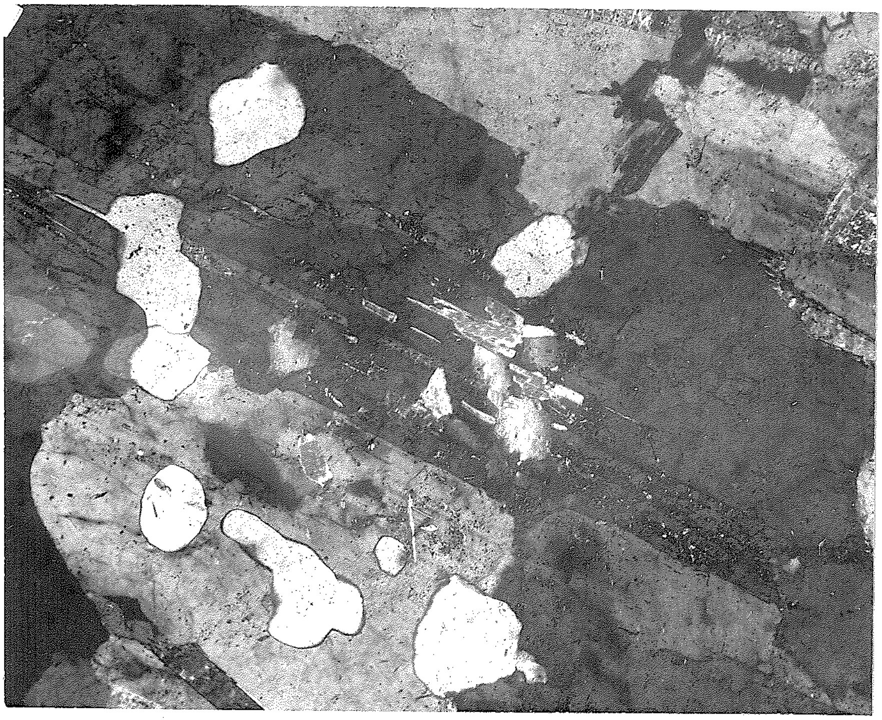

Figure 21

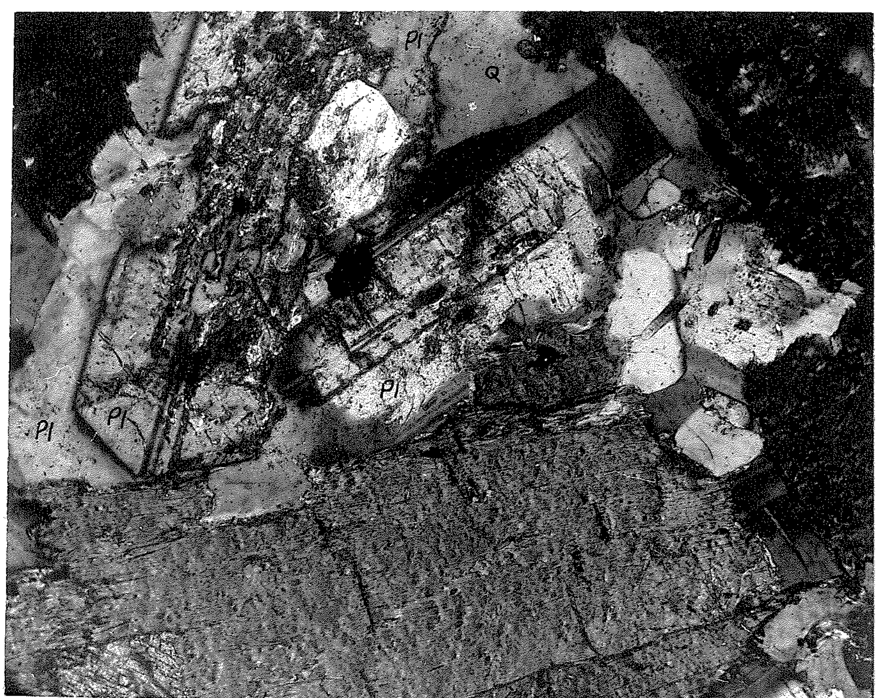

Figure 22

seen, it is apparent that the calcic plagioclase occupied a space almost as large as the present rim and core combined. The zoned rims, which are not usually very wide, may be overgrowths on the cores, or they may be reaction rims and replacements of the original core plagioclase.

In those samples of the quartz diorite in which little remains of the core plagioclase, there may be a little potash feldspar in the rock, and quartz monzonite is not far away in space.

The complex clots of grains and interrupted zones which are common in the plagioclase in Drury quartz monzonite and Peak granodiorite are not found in the quartz diorite. The grains may be mutually interfering in form, but this is mainly restricted to the sodic rims. Hornblende and biotite have mutually interfering relations with the form of plagioclase in the quartz diorite.

In Yukon Group Quartz-mica Schist: Most of the plagioclase in the Yukon group quartz-mica schist ranges in composition from An 25 to An 30; some is more sodic (An 10) and in rare cases is much more calcic (An 75). All the plagioclase in schist is anhedral and generally is fine-grained, though in some places porphyroblasts may reach 5 mm in length.

Universally the porphyroblasts contain inclusions of quartz and biotite. A few adjacent quartz inclusions may be optically parallel, and the biotite is sub-parallel to the oriented mica in the schistose matrix. The schistosity may be deformed around the porphyroblasts (fig. 24).

In Amphibolite: In the amphibolite plagioclase is irregular in shape and is fine-grained. The composition ranges from An 55 to An 65 from sample to sample, and the plagioclase is not appreciably zoned. It commonly includes and may be included by hornblende.

In Alaskite: The plagioclase in the alaskite is more sodic than in any of the other granitic rocks; it ranges from An 10 to An 25 and averages about An 20. It is not euhedral, though it may be subhedral, and it is unzoned or very weakly zoned. The grains do not usually occur in clots, hence they do not have the complex interrelations of the plagioclase in Peak granodiorite. In every thin section of the alaskite that was examined the plagioclase includes small grains of quartz but rarely includes any other mineral.

In Other Rocks: In the layered lime-silicate gneisses of the Yukon group the plagioclase of the diopside-rich layers ranges from An 50 to An 60 from sample to sample. In the alternate layers, which contain quartz and biotite, the plagioclase is between An 40 and An 50 in composition. It is all unzoned, anhedral, and fine-grained.

In the lime-silicate rocks at the base of the lower

Figure 23

Hornblende-biotite-quartz Diorite
Thin section 98-M; Specimen 29-M-53-16(2)

Photomicrograph. The light coloured almost white "rim" in the euhedral plagioclase grain in the center of the picture is a remnant of a calcic core that has been replaced by much more sodic plagioclase. The sodic plagioclase (dark grey) shows some zoning beyond the limits of the core, and within the remnant rim of the core it contains fragments of the core material that show up as rather diffuse white spots in the photograph.
Crossed nicols; x 90.

Figure 24

Yukon Group Quartz-mica Schist
Thin Section 29-C; Specimen 24-C-53-4.

Photomicrograph. A plagioclase porphyroblast in schist containing many inclusions of quartz (white). It also contains biotite inclusions, but these do not show up in the photograph. The schistosity of the rock is clearly deformed around the large grain. Small groups of quartz grains tend to be in optical parallelism, and the biotite inclusions are parallel to the oriented biotite in the enclosing schist.
Crossed nicols; x 30.

Figure 23

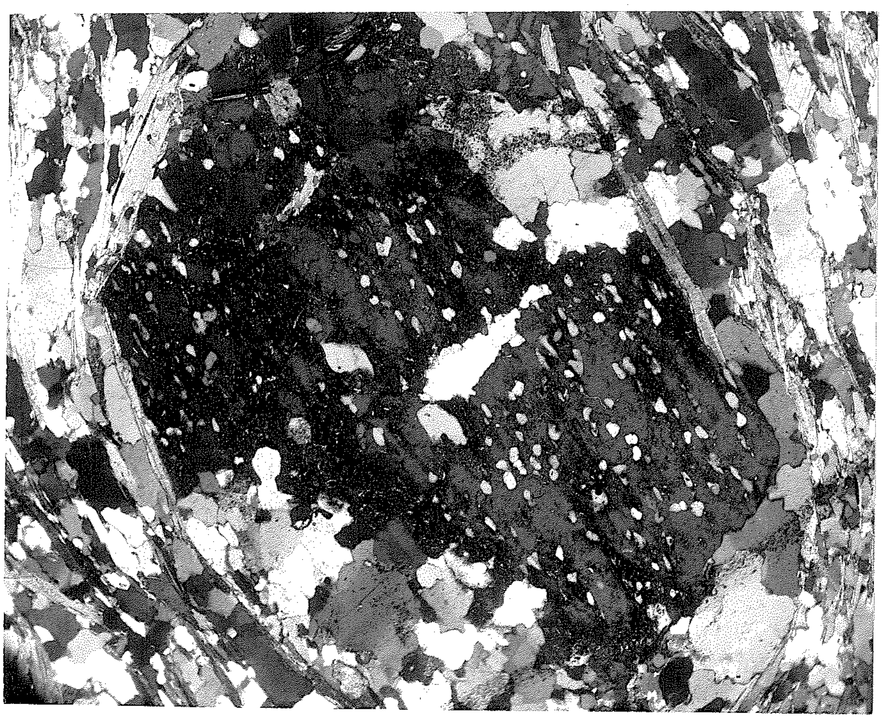

Figure 24

member of the Harvey group the plagioclase ranges from An 30 to An 40, but in the silicated zone along the Fairway dyke it is about An 50.

The plagioclase in the Fairway dyke is similar to that in the alaskite but is a little more noticeably zoned.

In Nub Hill granodiorite plagioclase is identical to that in Peak granodiorite.

In the hornfels related to the two granodiorite bodies unzoned plagioclase is about An 30 in composition.

Quartz

General Remarks: An important aspect of the quartz in all the rocks of Glenlyon Range is the degree of granularity of the mineral. Granular aggregates of quartz are the rule rather than the exception though locally there are single, non-granular grains.

A method to compare the granularity from sample to sample is necessary. A system was devised that can be applied rapidly and gives a comparative idea of the degree of granularity from rock to rock. The system is based on the premise that the maximum and minimum numbers of grains that fall under a line of prescribed length in a thin section are an index of the degree of granularity. The dimensions of the aggregates of quartz (or of single grains if the quartz is not granular) for any rock upon which measurements are to be made must be characteristically greater than the length of the line selected. Measurements were made only when the total line fell entirely on quartz, and if the quartz grains showed elongation measurements were made perpendicular to that direction. Several carefully selected measurements made on a thin section should give the desired values.

For the granitic rocks a line 2 mm long was used, but for the schist, in which the sizes of individual grains and aggregates of grains are much smaller, a line 0.5 mm long was used. When measurements on a number of thin sections of a given rock have been made the average maxima and minima can be calculated, and these values, when divided by the length of the line used, give an average maximum and minimum grain size of the granular quartz. Thus the results are directly comparable irrespective of the length of line used.

These measurements do not give the maximum size of quartz grains when the largest grains are greater in dimension than the length of the line used, and they do not indicate the size of quartz aggregates. These factors are specified in the descriptions of the various rocks in the succeeding sections.

No attempt was made to assess statistically the degree of strain in the quartz. In general all the quartz is strained and has undulatory extinction; the degree of strain does not seem to be more in one place than in another in the larger masses of granitic rocks. In detail the strain appears to differ from grain to grain in a single thin section.

In Peak Granodiorite: A few individual grains of quartz in Peak granodiorite reach 8 mm in diameter; the average diameter, however, is less than 2 mm. Aggregates of grains reach 8 to 10 mm but the average is about 4 mm. In 27 of 31 thin sections upon which measurements were made the minimum number of grains under a 2 mm line is 1 and the maximum ranges from 2 to 13 and averages 5.5 for the 31 samples. Thus the average maximum grain size in a sample is greater than 2 mm and the average minimum is about 0.4 mm.

The quartz of Peak granodiorite characteristically forms complex granular aggregates of grains. Sutured contacts are rare; the quartz in the aggregates forms irregular angular grains that sometimes are almost rectangular. The aggregates are not made up of a group of randomly oriented grains. In a restricted area of an aggregate there may be only three or four optical orientations of grains, so arranged that grains of one orientation may be isolated in any or all of the others (fig. 26). There is a crude intergrowth pattern.

Straight contacts of quartz are most common against subhedral to euhedral plagioclase (fig. 25) and biotite. In such cases the straight faces are controlled by the euhedral form of the minerals in contacts with the quartz. The rather rare straight contacts of quartz against potash

Figure 25

Core of Drury Quartz Monzonite
Thin section 35-C-54; Specimen 19-C-54-2.

Photomicrograph. The regular contacts of the quartz (light grey and white) against plagioclase (twinned and medium grey) are controlled by the form of the plagioclase.
Crossed nicols; x 30.

Figure 26

Peak Granodiorite
Thin section 16-C; Specimen 21-C-53-6.

Photomicrograph. This is a good illustration of the granular texture of quartz in Peak granodiorite and the southern parts of Drury quartz monzonite. The individual grains tend to be in angular shapes, and grains of any one orientation may appear, isolated, included by those of any or all of the other orientations.
Crossed nicols; x 30.

Figure 25

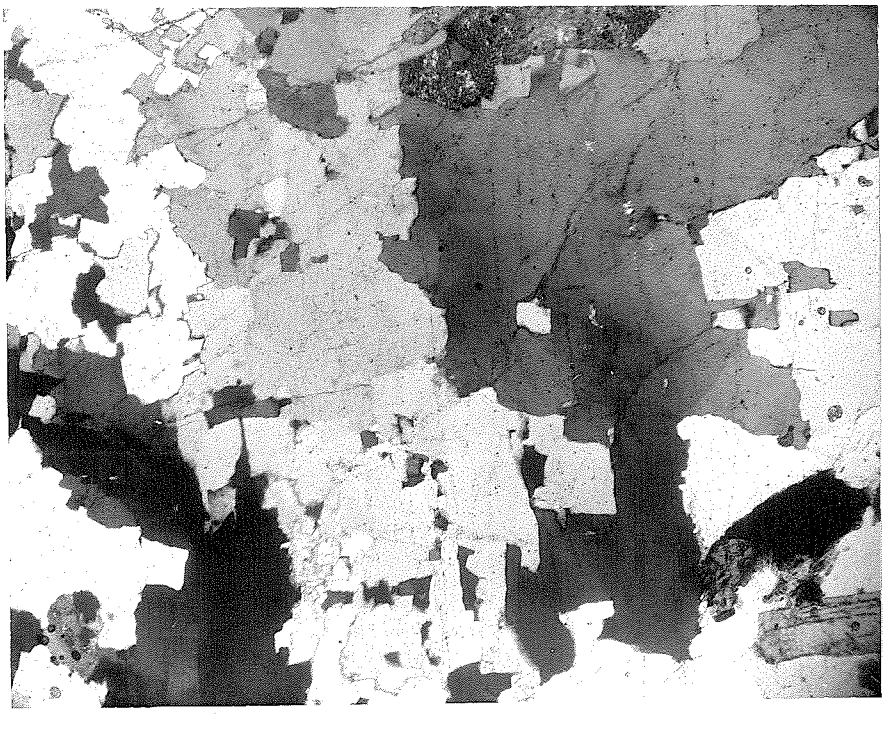

Figure 26

feldspar, however, must have a different origin. Potash feldspar is anhedral in all the rocks of Glenlyon Range, thus its rare straight contacts against quartz must reflect euhedral quartz faces or be inherited from a previously existing mineral that has been replaced. In figure 27 two slightly different orientations of quartz have nearly parallel straight contacts with potash feldspar. One of the quartz grains has similar straight contacts against a euhedral plagioclase crystal that is partly included in the potash feldspar. It is possible that the contacts of the quartz against the potash feldspar are inherited from pre-existing plagioclase and do not depend on the structure of the quartz. A highly irregular and apparently partly replaced plagioclase grain included by the potash feldspar can be seen in the lower right corner of the picture. In some cases biotite takes the role of the plagioclase of this illustration.

The contacts of quartz against potash feldspar are usually smooth. They may be curved or nearly straight across several completely different orientations of quartz in a single aggregate. In some cases the contact may change direction slightly from grain to grain of quartz.

In Peak granodiorite quartz commonly includes a few small grains of plagioclase and biotite. These inclusions, which vary from anhedral to subhedral forms, may be completely enclosed by a single grain or they may lie between grains

Figure 27

Core of Drury Quartz Monzonite
Thin section 35-C-54; Specimen 19-C-54-2.

Photomicrograph. Two slightly different orientations of quartz (white and light grey) have sub-parallel straight contacts with potash feldspar (mottled medium grey). Slightly below and to the right of center is a small euhedral plagioclase grain (speckled dark grey and rectangular) that is in contact with one of the quartz grains (white). The straight contacts of quartz against potash feldspar very nearly parallel those of quartz against plagioclase. Note the myrmekitic overgrowths on the ends of the plagioclase grain (light grey). (Figure 47 is an enlargement of this grain.)
Crossed nicols; x 30

Figure 28

Hornblende-biotite-quartz Diorite
Thin section 72-M; Specimen 24-M-53-10(1)

Photomicrograph. This is an excellent illustration of the texture of quartz in quartz diorite. The quartz (very light grey or white) is almost all in a single optical orientation and fills in between and includes plagioclase, biotite, and hornblende. The quartz grain is larger and the proportion of quartz is greater than normal in the quartz diorite.
Crossed nicols; x 30.

Figure 27

Figure 28

of a quartz aggregate. The quartz may also include small grains and veinlets of potash feldspar, but these are usually either directly connected with an adjacent large potash feldspar grain or are associated with and apparently replace small plagioclase inclusions. The form and other characteristics of the potash feldspar inclusions in quartz indicate that they have invaded the quartz and were not included by it.

In a few thin sections there are small shear zones cutting all the minerals in the rock. Adjacent to the shears the minerals are no more bent, broken, or granular than in unsheared rocks. Quartz grains that are cut on one edge by the shears are no more granular or strained than normal. The cataclasis or protoclasis that may have caused the development of the granular texture of the quartz, and perhaps produced some of the textural features of plagioclase and biotite, must have been pervasive throughout the rock.

In Drury Quartz Monzonite: The texture of quartz is distinct in each of the three zones of Drury quartz monzonite.

The quartz in the core of the quartz monzonite is identical to that in Peak granodiorite.

The difference in the quartz texture between the core and the intermediate zone is one of grain size. In the core, as in Peak granodiorite, granular aggregates of quartz average about 4 mm in diameter. Individual grains average less than 2 mm in diameter; the average maximum grain size of single grains is greater than 2 mm, and the average minimum is about 0.4 mm.

In the intermediate zone the size of granular aggregates of quartz grains also averages about 4 mm in diameter, and there are rather rare single grains greater than 2 mm. The minimum number of grains intersected by a 2 mm line in the thin sections ranges from 1 to 10 and averages about 3, and the maximum number ranges from 6 to 40 and averages about 15. These figures give average maximum and minimum grain sizes of 0.66 and 0.13 mm respectively. Thus the quartz in the intermediate zone is much more highly granular than that in the core of Drury quartz monzonite. Its other textural relations are very similar.

The occurrence of fine-grained quartz and biotite as a schistose matrix for the feldspars is the characteristic feature of the quartz in the outer zone of Drury quartz monzonite. Single grains of quartz larger than 1 mm are rare, though aggregates may be quite large and in some cases extend, in strips with fine-grained biotite, completely across a thin section. Quartz and biotite may also form garlands around coarser feldspar grains. The intergrowth pattern of granular quartz does not occur.

The minimum number of grains, in aggregates of quartz, that are intersected by a 2 mm line in thin sections of rocks of the outer zone ranges from 1 to 15 or more and averages about 10. The maximum number ranges from 10 to 40 or more and averages at least 17, and may be 20. Thus in the outer zone the average maximum and minimum grain sizes are about 0.2 and 0.1 mm respectively.

The nature of the fine-grained quartz of the outer zone of the quartz monzonite is illustrated in figures 20, 55, 56, and 57.

The inclusions of quartz in plagioclase are another distinguishing feature of the quartz in the outer zone of Drury quartz monzonite compared to the other zones and to Peak granodiorite.

In Hornblende-biotite-quartz Diorite: In the quartz diorite quartz textures are different from those in any of the other rocks in Glenlyon Range. The quartz may be fine or medium-grained and is very irregular in shape. The distinguishing characteristics are that it is not granular and that it is rich in inclusions of all the other minerals. The quartz is so full of inclusions that parts of a single grain may appear in many isolated places in the plane of a thin section (fig. 28). The form of the quartz is determined entirely by the shape and arrangement of the other minerals in the rock.

In Alaskite: The quartz of the alaskite is generally fine-grained and may or may not form granular aggregates.

Single grains larger than 1 mm are rare, though aggregates may be 2 or 3 mm in diameter. The minimum number of grains which fall under a 2 mm line ranges from 2 to 15 and averages about 5, and the maximum number ranges from 6 to 25 or more and averages about 11 (for 5 thin sections). Thus in the alaskite the average maximum and minimum grain sizes are 0.5 and 0.2 mm respectively. In grain size the quartz in the alaskite is similar to that in the intermediate zone of Drury quartz monzonite. In some of the pegmatitic phases of the alaskite in the area southwest of Jar Mountain quartz is considerably coarser grained.

Small grains of quartz are commonly included by plagioclase, a feature otherwise restricted to the outer zone of the quartz monzonite among the granitic rocks.

A quartz texture unique to the alaskite and the alaskitic pegmatite among the granitic rocks of Glenlyon Range is the micrographic intergrowth with potash feldspar (figs. 52 and 53).

In Yukon Group Quartz-mica Schist: In the Yukon group schist the size, shape, and relations of quartz are similar to those in the outer zone of Drury quartz monzonite except that the size of uninterrupted granular aggregates is smaller. Because of this a line 0.5 mm long was used for grain size measurements. The textures are illustrated in figures 9 and 10.

The minimum number of grains per thin section intersected by a line 0.5 mm long ranges from 1 to 3 and averages about 1.5 and the maximum number ranges from 4 to 12 and averages about 7. On the average grains range from a maximum of 0.3 to a minimum of 0.07 mm. This range in size, as an expression of the granularity of quartz, encompasses the range in grain size in the outer zone of the quartz monzonite (maximum of 0.2 and minimum of 0.1 mm).

The quartz grains are very irregular in shape. They may be elongate parallel to the schistosity expressed by the preferred orientation of biotite, and they do not show "intergrowth" textures.

In Other Rocks: The quartz in the Fairway dyke and in the alaskite is similar.

In Nub Hill granodiorite the quartz occurs mainly as single grains with an average diameter of about 1 mm.

In the limy metamorphic rocks of the Yukon group and in the rocks of the Harvey group there seems to be nothing unusual about the occurrence of quartz, and the textures do not appear to be significant in regard to the origin of the granitic rocks.

Potash Feldspar

General Remarks: Potash feldspar is found, in one place or another, in almost every rock type in Glenlyon Range. Its texture and occurrence are of considerable interest and importance.

The name potash feldspar is used advisedly in this text. It is not always possible to name the mineral as being either microcline or orthoclase on the basis of the presence of polysynthetic twinning. A single grain may be partly twinned and partly not, or one grain in a sample may be twinned and an adjacent one not. All the grains may be triclinic but the twinning may be submicroscopic in some portions, as has been suggested by Laves (1950, p. 550). In view of the later work of Goldsmith and Laves (1954), however, it may be that some parts of a grain are triclinic and other parts are monoclinic. Because of these conditions the inclusive name of potash feldspar is used. The important features of the mineral in this work are its textures and variations in amount within the rocks studied. The nature of the mineral does not seem to change within the granitic and closely associated metamorphic rocks.

In regard to the textures of potash feldspar some important generalizations can be made for all the rocks of Glenlyon Range, granitic and metamorphic alike.

Potash feldspar seems to have been the last major constituent to form in all the rocks in which it occurs, exclusive of alteration products. The older minerals appear to have been in disequilibrium with the conditions under which potash feldspar formed, and they are corroded and replaced.

Potash feldspar is perthitic in all the granitic rocks and in some of the metamorphic rocks. It is not perthitic in the rocks of the Harvey group except in the contact zone of the Fairway dyke. The main difference in potash feldspar from rock to rock is in grain size.

Perthite: All the perthite in the rocks of Glenlyon Range is microperthite, which is, in rocks at large, probably as common as true perthite is rare. The word perthite as used henceforth in this report designates microperthite. Most of the names proposed and defined by Alling (1938) to describe various sizes and shapes of plagioclase perthitic lamelli do not seem to be directly applicable to the perthite in the rocks of Glenlyon Range. Some of the names, however, are used and must be considered as rather general terms. All the variations in shape and size would require a multitude of terms to describe them adequately.

The problems of the origin of perthite have been the subject of speculation and discussion for many years. The writer accepts the broad definition of Alling (1936, p. 69) that

> "perthites are intergrowths of a potash-rich feldspar and a soda-rich feldspar."

with the reservation that inclusions left by the partial replacement of plagioclase by potash feldspar may not properly be included and should be distinguished by the term "remnant" perthite. This distinction is based on the premise that the type of perthite with which Alling's definition is mainly concerned originated in a different way from the remnant perthite. It is recognized that remnant perthite may be indistinguishable from true perthite in some cases, but in the rocks of Glenlyon Range at least, there is usually sufficient evidence for a distinction to be made.

To facilitate description the width of the plagioclase elements in perthite are arbitrarily divided into three groups; fine (less than 0.01 mm), medium (between 0.01 and 0.02 mm), and coarse (greater than 0.02 mm). No reasonable limits could be placed on the length of the lamelli but in general the thicker they are the longer they are. The length is variable.

Three descriptive terms are also used but not in the rigid sense of Alling's definitions. These are film, vein, and patch perthite.

Film perthite refers to the regular, spindle-shaped plagioclase lamelli which, when well developed, look superficially like albite twins in the potash feldspar. The films are very fine (0.001 mm or less in width) and, in swarms, are from 0.005 to 0.01 mm apart. They range in length from little more than their width to almost 1 mm. The films are usually very straight, though some bend abruptly, then resume their original direction; rarely they are branching.

The films are composed of sodic plagioclase whose precise composition is not known. The birefringence and refractive index are higher than those of potash feldspar.

They are never obviously twinned and do not seem to be readily altered. The physical orientation of the films is always different from any other linear perthitic elements; some appear to lie parallel to the basal cleavage of the host potash feldspar. Similar lamelli not parallel to a cleavage direction were noted by Goldich and Kinser (1939). The crystallographic orientation of the plagioclase in the films is parallel to that in the other types of perthite.

Film perthite is not uniformly distributed in a single grain of potash feldspar. The films occur in local swarms, and they do not intersect other types of perthite. Where veins pass through there are gaps in the film swarms, and where there are a number of veins there are larger gaps in the swarms.

Vein perthite, as used here, applies to all the linear types of plagioclase elements that do not have the regimented regularity of form and physical orientation of the films. The veins occur in many sizes and shapes and comprise fine to medium perthite in the rocks of Glenlyon Range. No twinned vein perthite was observed.

There are two general types of vein perthite, each of which is distinct from the other. Flat S-shaped veins are parallel to or make a small angle to the films, have clear cut and regular boundaries, are spindle shaped, but are thicker than the films. These veins are associated with film perthite and more closely resemble the films than they do other types of veins.

The majority of the veins are not regular in form or in physical orientation, though they maintain a consistent crystallographic orientation. They may have a definite trend, but in detail they change direction abruptly, their contacts are irregular, they pinch and swell, and they are commonly intricately branching. The general trend of these veins may be up to 30 degrees from the direction of the films.

Rectangular networks of the irregular veins seem to be a transitional stage between vein and patch perthite. The plagioclase in patch perthite in places is twinned and in that regard is unique in the perthite of the rocks of Glenlyon Range. Both irregular vein and patch perthite plagioclase elements may be more or less altered.

General views of most of the types of perthite are shown in figures 29, 44, and 53.

Several features of potash feldspar apparently indicate strong variations in the soda-feldspar content in parts of single grains. These features suggest that certain parts of the grains contain abnormally high contents of soda feldspar and may, in fact, be metastable and represent potential perthite zones. Such features are not truly perthites but they seem to be closely related; hence they are included in this section.

Very commonly in irregular vein or patch perthite the plagioclase elements are surrounded by a zone, commonly much wider than the vein or patch, in which the extinction position and birefringence of the potash feldspar grades from approximately that of the plagioclase to that of the mass of the host crystal. There is, however, an abrupt change of relief at the edge of the plagioclase.

Some rectangular zones, much like the shape of a plagioclase crystal, are marked by anomalous extinction and birefringence in the potash feldspar. Such zones in places contain small plagioclase blebs all in parallel orientation and parallel to other perthitic elements. In some cases these zones are connected with large plagioclase grains included in the potash feldspar. These zones may be the site of much more intense alteration than is normal in the potash feldspar. Where the rock plagioclase is intensely altered, the zones if present are intensely altered, but always to clay minerals, not sericite. There seems to be every gradation from potash feldspar containing no anomalous zones, through anomalous zones with or without included plagioclase, to included solid plagioclase grains.

Some perthite veins are surrounded by thin zones of "microcline-twinned" potash feldspar in otherwise untwinned material. In some cases there are only the twinned zones with no veins.

Figure 29

Alaskitic pegmatite
Thin section 6-C-54; Specimen 16-C-54-1.

Photomicrograph. Several types of perthitic plagioclase elements can be seen in this picture. Fine films are oriented diagonally across the view and are parallel to one of the cleavage directions. Spindle-shaped regular veins, some of which are S-shaped, are, in this case, about parallel to the films. Irregular veins do not have clear-cut contacts. They lie at an angle to the films and form, locally, rather vague patches. All the perthitic elements have the same optical orientation.
Crossed nicols; x 90.

Figure 30

Peak Granodiorite
Thin section 48-C; Specimen 27-C-53-6

Photomicrograph. A plagioclase grain in two parts lies in the center of the photograph and is an inclusion in potash feldspar of two orientations that also include other plagioclase grains. The plagioclase grain in the center has evidently been replaced by potash feldspar. Note that the zoning in the plagioclase, where it is visible, is transected at one of the contacts with potash feldspar.
Crossed nicols; x 30.

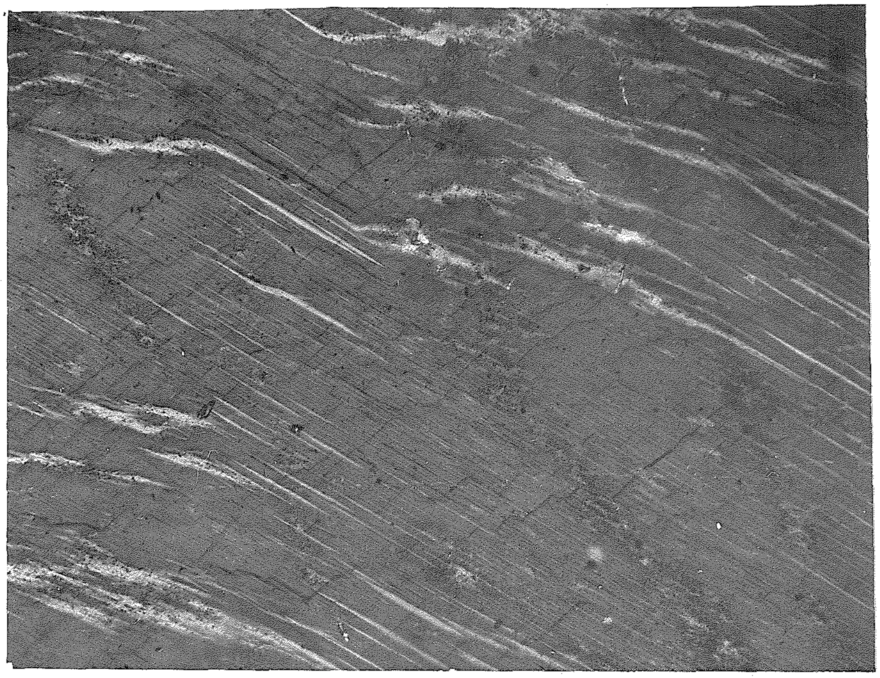

Figure 29

Figure 30

Relations to Plagioclase: The potash feldspar in the granitic rocks of Glenlyon Range is commonly rich in inclusions of other minerals, and plagioclase is the most abundantly included mineral. The most striking feature of the relations between the two feldspars is the apparent replacement of plagioclase by potash feldspar.

The textures that suggest that plagioclase is replaced by potash feldspar are varied in form and appearance (figs. 30 to 33). In these illustrations the plagioclase grains are included by or are in contact with grains of potash feldspar that may be larger than any plagioclase grain in the rock. These large grains of potash feldspar may contain plagioclase that shows no evidence of corrosion and replacement as well as corroded and replaced grains. Some included grains may be euhedral.

The replacement textures illustrated in figures 30 to 33 are characteristic of Peak granodiorite and the core and intermediate zones of Drury quartz monzonite. In these rocks the plagioclase is, on the average, more calcic than An 30. In the outer zone of the quartz monzonite, in the alaskite, and in the Yukon group schist the plagioclase is generally more sodic than An 30, and the replacement textures are different. This is the "pseudomorphic" replacement of plagioclase by potash feldspar, in which the orientation of the replacing mineral apparently is controlled by the structure of the replaced mineral. The control is not

Figure 31

Drury Quartz Monzonite (transitional phase to quartz diorite)
Thin section 109-M; Specimen 21-M-53-21.

Photomicrograph. In the upper right part of the picture are remnants of a twinned plagioclase grain (medium grey) enclosed by potash feldspar (light grey). It seems that the plagioclase has been replaced by the potash feldspar.
Crossed nicols; x 90.

Figure 32

Peak Granodiorite
Thin section and specimen 21-C-52-3

Photomicrograph. This is another example of apparent replacement of plagioclase (light grey) by potash feldspar (medium and dark grey).
Crossed nicols; x 90.

Figure 31

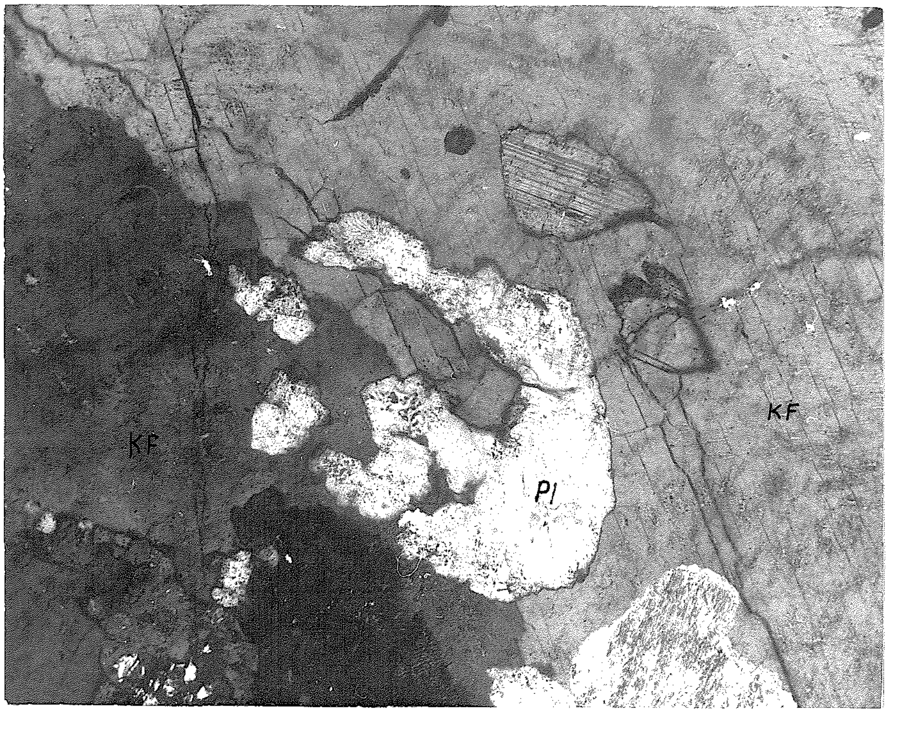

Figure 32

Figure 33

Peak Granodiorite
Thin section and specimen 21-C-52-3

Photomicrograph. This view shows an irregular contact of plagioclase (twinned) against potash feldspar and is suggestive of replacement of plagioclase by potash feldspar. Note the irregular sodic zone (dark) at the contact of the plagioclase grain.
Crossed nicols; x 90.

Figure 34

Peak Granodiorite
Thin section 20-M; Specimen 18-M-53-2.

Photomicrograph. A sodic plagioclase grain (weakly twinned and medium grey) differentially and "pseudomorphically" replaced by potash feldspar (dark). At one end (right) the plagioclase contains a few angular and rounded blebs of potash feldspar (antiperthite), and toward the left the amount of potash feldspar progressively increases until plagioclase remains only as disconnected perthite elements.
Crossed nicols; x 30.

Figure 33

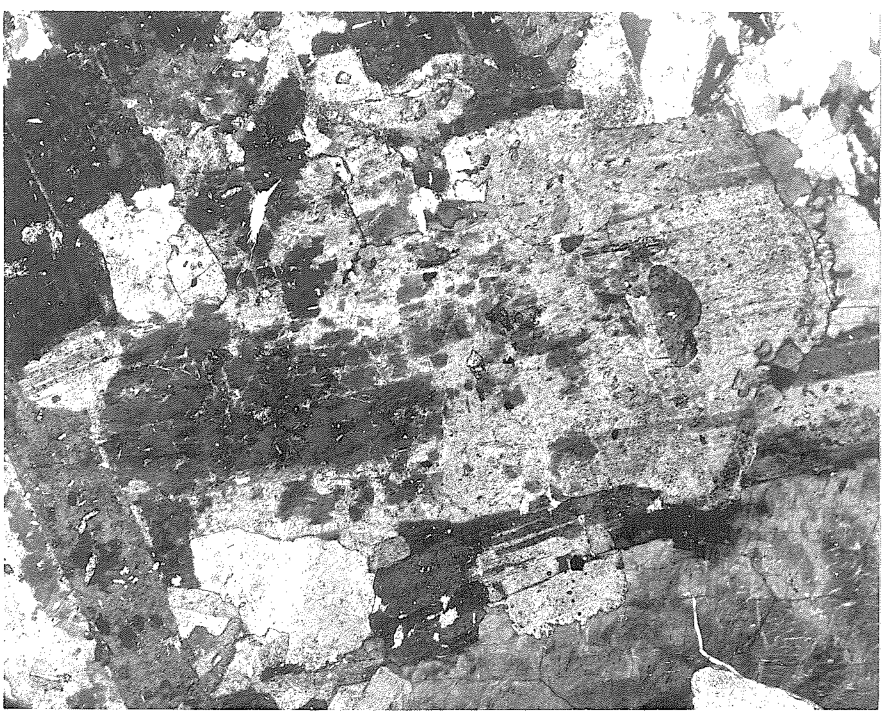

Figure 34

necessarily one of form, so the pseudomorphism is structural but may not be morphological.

Pseudomorphic replacement of plagioclase by potash feldspar is the process which most commonly produces remnant perthite. No case was observed in which film or regular vein perthite could be interpreted as having formed in this way.

A single plagioclase grain may be partially pseudomorphically replaced by potash feldspar so that part of the grain is untouched, part is antiperthite, and part is remnant perthite (fig. 34). In places a whole grain is replaced, leaving remnant perthite and, perhaps, a rim of plagioclase at the contacts (fig. 35). If the plagioclase is twinned on the Carlsbad law each twin is replaced by differently oriented potash feldspar (fig. 36). The orientation of potash feldspar does not seem to change in imitation of albite twins. Similar replacements are found in the schist (figs. 37 and 38). The example in figure 37 is about 4 feet from a granitic contact, and that in figure 38 is from another sample which is a mile or more from the nearest known granitic rock.

As mentioned, the pseudomorphic replacement is not everywhere a morphological pseudomorphism, though in places it approaches this condition as shown in some of the illustrations. Only very rarely does the potash feldspar significantly exceed the size of the replaced plagioclase grain. In any given thin section in which this type of replacement

Figure 35

Outer zone of Drury Quartz Monzonite
Thin section 67-C; Specimen 33-C-53-6.

Photomicrograph. The large grain in the picture contains potash feldspar (dark grey) and sodic plagioclase (light grey) in a perthitic intergrowth. Most of the plagioclase is in the form of small perthitic elements, but near the top and bottom of the photograph there are larger masses of it. On the basis of incomplete stages seen in other grains in the same thin section it is apparent that the perthite has developed by the replacement of plagioclase by potash feldspar. This is the "pseudomorphic" replacement in which the structure of the plagioclase apparently controls the orientation of the replacing potash feldspar.
Crossed nicols; x 30.

Figure 36

Peak Granodiorite
Thin section 20-M; Specimen 18-M-53-2

Photomicrograph. In this example of "pseudomorphic" replacement a Carlsbad twin pair of plagioclase has been partially replaced by potash feldspar, and remnant perthite has resulted. At the top of the grain in the center of the photograph is unreplaced plagioclase and below it, to the edge of the black portion of the grain, are remnants of plagioclase of the same orientation in potash feldspar (medium grey). The black part of the grain is potash feldspar in the other twin in which the remnant plagioclase is differently oriented from that above.
Crossed nicols; x 30.

Figure 35

Figure 36

Figure 37

Yukon Group Quartz-mica Schist
Thin section 57-C; Specimen 31-C-53-1.

Photomicrograph. The view shows "pseudomorphic" replacement of sodic plagioclase (white) by potash feldspar (medium grey). The plagioclase is a porphyroblast in schist about 4 feet from a granitic body of the outer zone of Drury quartz monzonite. The locality is close to the junction of the main branches of Little Sheep Creek. Crossed nicols; x 90.

Figure 38

Yukon Group Quartz-mica Schist
Thin section and specimen 15-C-50-8.

Photomicrograph. "Pseudomorphic" replacement of plagioclase (light grey and twinned) by potash feldspar (dark grey). This is a sample of schist at least a mile from the nearest known granitic rock. The locality is toward the south end of Bon Ridge.
Crossed nicols; x 90.

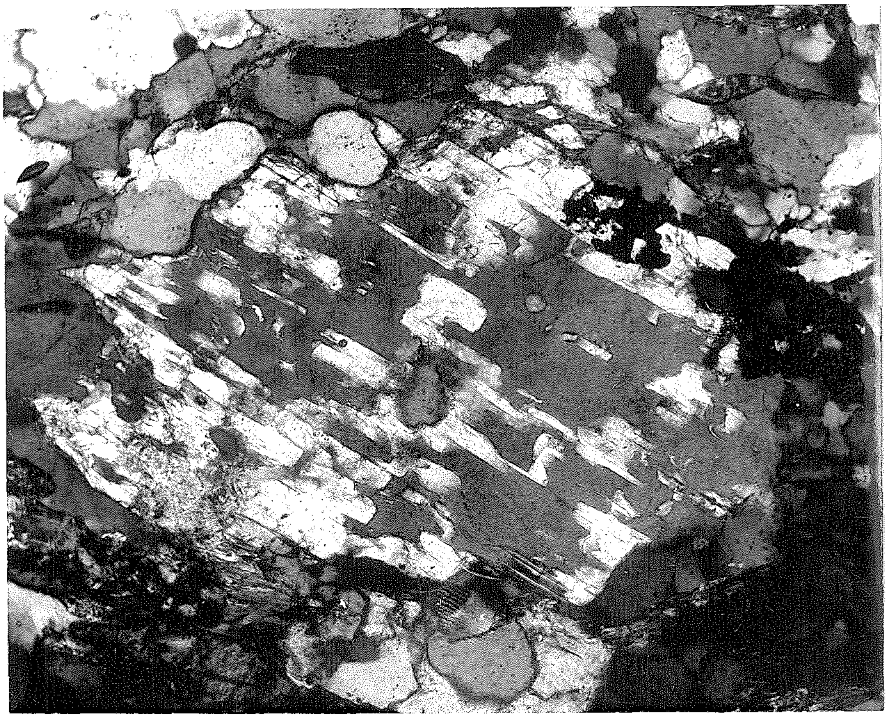

Figure 37

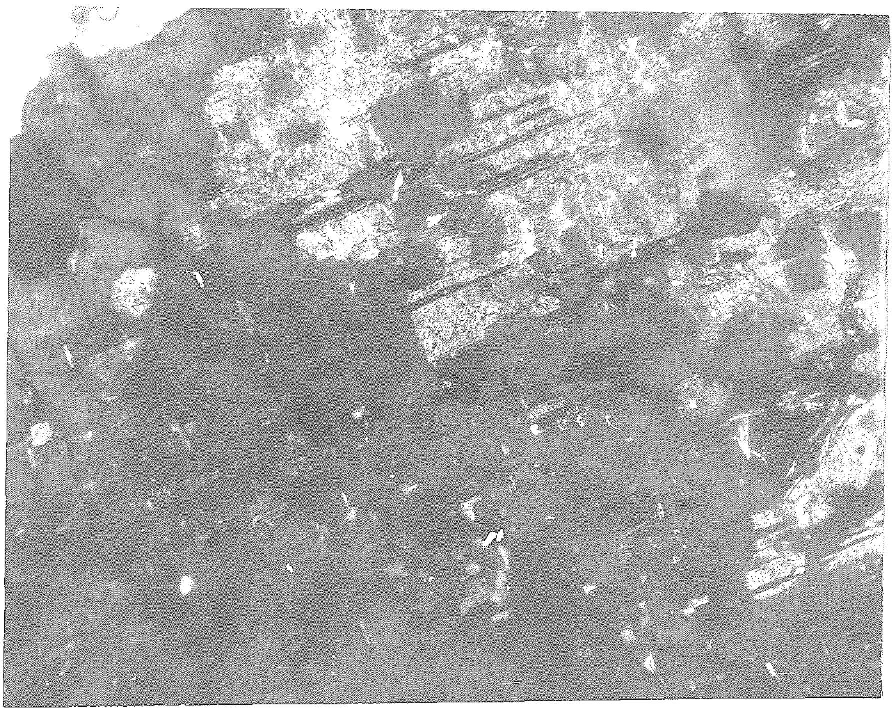

Figure 38

occurs it is usually possible to see various stages of the replacement in different grains. In some cases the stages are seen in a single grain (fig. 34). It seems evident, though it has not been proved, that there is a constant relationship between the orientations of the two feldspars involved in this type of replacement. This is suggested by the fact that the cleavage of the two feldspars always seems to be perfectly parallel and even continuous from one to the other. The plagioclase cleavage apparently controls the form of the angular antiperthite blebs in the early stages, and of the remnant plagioclase inclusions in the later stages of the replacement. The imitation of Carlsbad twins is another indication of the pseudomorphism (fig. 36).

The parallel orientation of disconnected "antiperthite" blebs is also an indication of the control the plagioclase exerts on the orientation of the replacing potash feldspar. A particularly striking example was observed in one case in which "antiperthite" blebs occur in several adjoining plagioclase grains. A single thin veinlet of potash feldspar cuts several of the plagioclase grains, and in each grain the optical orientation of the potash feldspar in the veinlet is parallel to the "antiperthite" blebs in that grain whether or not it connects with them. Evidently the veinlet formed by the replacement of plagioclase along a fracture.

In some places where there is apparent replacement of plagioclase by potash feldspar the latter shows a vague lamellar twinning that may be relict from the plagioclase. Another rare occurrence is zoning in potash feldspar which might reflect the zones of replaced plagioclase but could be some unusual zoning that originates in the potash feldspar (fig. 39).

In Peak granodiorite and in the core and intermediate zones of Drury quartz monzonite pseudomorphic replacement of plagioclase by potash feldspar may occur if the plagioclase is sufficiently sodic (figs. 34 and 36), but potash feldspar in those rocks characteristically forms very large grains that may include and replace various orientations of plagioclase. Grains limited in size by pseudomorphic replacement and larger grains may occur in the same thin section.

An interesting feature of the relationships of plagioclase and potash feldspar in the large masses of granitic rocks are the small grains of plagioclase that commonly occur on the contacts of adjacent potash feldspar grains. These may be long narrow strings of grains of one or more orientations, or they may be long narrow single grains. In this thesis these features are called plagioclase strips.

The plagioclase in the strips may be twinned and it may be similar in composition and degree of alteration to the rock plagioclase. On either side of a line representing the contact of two potash feldspar grains the plagioclase in the strips may be in different orientations; in places there are several orientations of plagioclase in the strips. In a few cases the plagioclase in the strips is myrmekitic (fig. 40).

There does not seem to be any fixed relationship between the plagioclase in the strips and that of either of the adjoining potash feldspar grains; in fact plagioclase of a single orientation may form a strip between any two of three adjacent potash feldspar grains (fig. 41).

There are many good examples of plagioclase strips optically parallel to and showing the same degree of alteration as adjacent apparently partially replaced plagioclase grains. A good illustration is shown in figure 42, in which the plagioclase grain is separated from the strip by "perthitic" potash feldspar. The grain, the "perthitic" elements (remnants), and the strip all are optically parallel.

More impressive are the rare cases in which a strip is actually joined to a corroded and replaced plagioclase grain (fig. 43). There are all gradations in terms of plagioclase strips from several sizeable grains of plagioclase on a contact between two potash feldspars, through narrow strips, to contacts with no strips at all.

Plagioclase strips may occur around inclusions of potash feldspar in potash feldspar, and even though they are discontinuous they may be in parallel orientation throughout

Figure 39

Drury Quartz Monzonite
Thin section 34-M; Specimen 16-M-53-11.

Photomicrograph. Zoning in potash feldspar that may be relict after replaced plagioclase. There is a plagioclase strip on one side of the grain (upper right). Crossed nicols; x 90.

Figure 40

Drury Quartz Monzonite
Thin section 98-C; Specimen 15-C-53-1.

Photomicrograph. Plagioclase grains, one of which is myrmekitic, distributed along the contact of adjoining large potash feldspar grains. This is an example of the features that are termed plagioclase strips.
Crossed nicols; x 90.

Figure 39

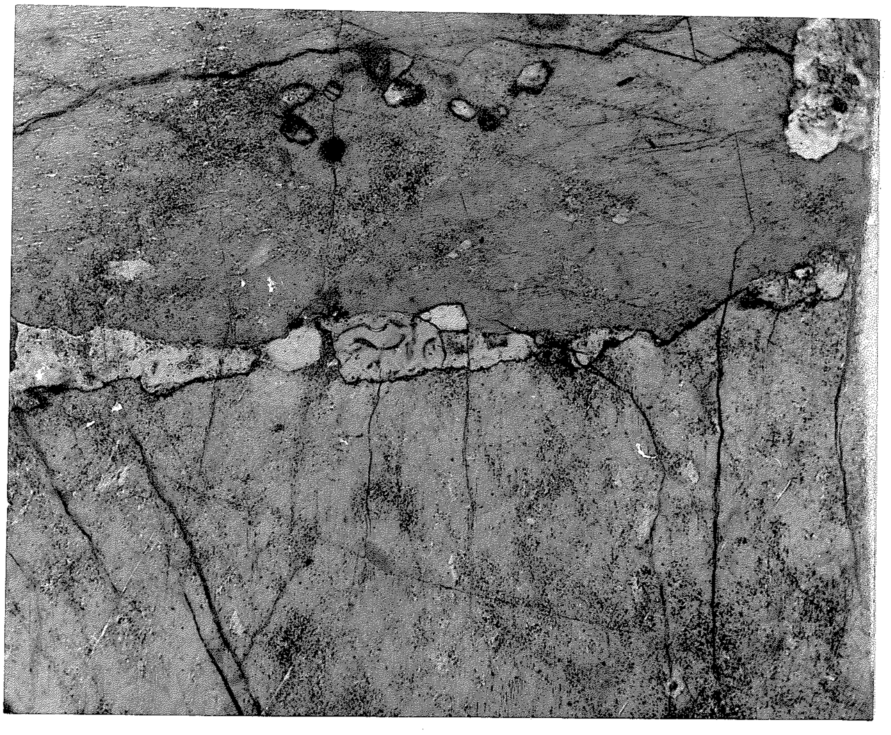

Figure 40

Figure 41

Drury Quartz Monzonite
Thin section 22-C-54; Specimen 18-C-54-3.

Photomicrograph. A plagioclase strip (medium grey, Y-shaped) lies about in the middle of the photograph at the contacts of three adjoining potash feldspar grains. Crossed nicols; x 90.

Figure 42

Drury Quartz Monzonite
Thin section and specimen 8-M-50-3.

Photomicrograph. A plagioclase strip (light grey, bottom) on a contact between two potash feldspars (black and dark grey). At the top is a "rock" plagioclase grain (light grey) of identical orientation to the strip, and between the two is remnant perthite in which the plagioclase elements are also optically parallel to that in the strip.
Crossed nicols; x 90.

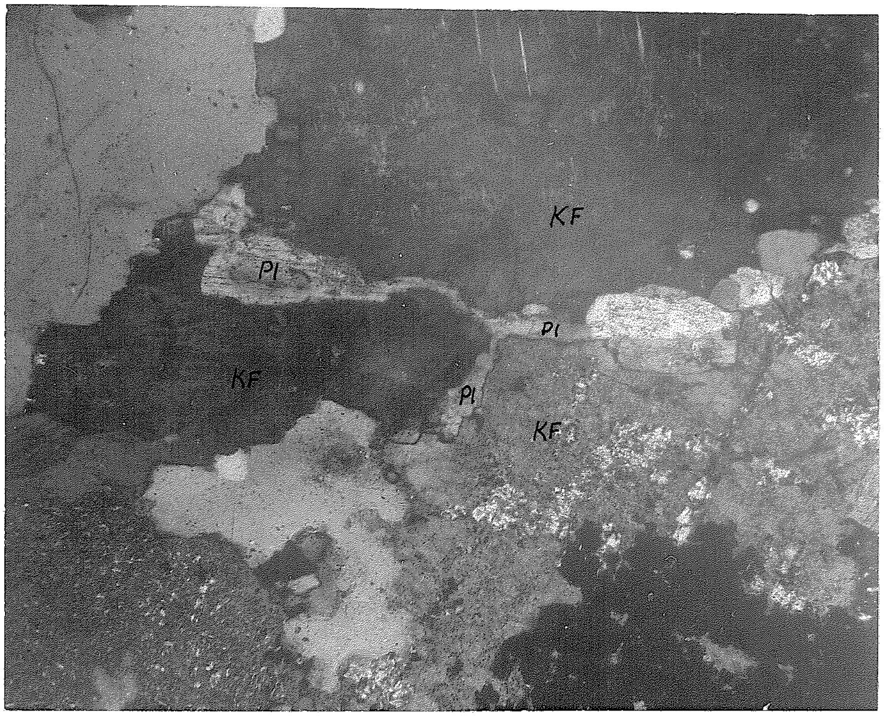

Figure 41

Figure 42

Figure 43

Drury Quartz Monzonite (intermediate zone)
Thin section 10-C-54; Specimen 16-C-54-5.

Photomicrograph. The central part of a plagioclase grain (light grey, marked Pl) is replaced by potash feldspar so that the two sides are isolated except for a narrow plagioclase strip along the contact with another grain of potash feldspar.
Crossed nicols; x 90.

Figure 44

Drury Quartz Monzonite
Thin section 80-M; Specimen 27-M-53-6.

Photomicrograph. A plagioclase strip around an inclusion of potash feldspar (rounded and very dark grey) in potash feldspar (dark grey and perthitic). The plagioclase in the strip and the perthitic elements are not in parallel optical orientation. The perthite in this example is not remnant perthite.
Crossed nicols; x 90.

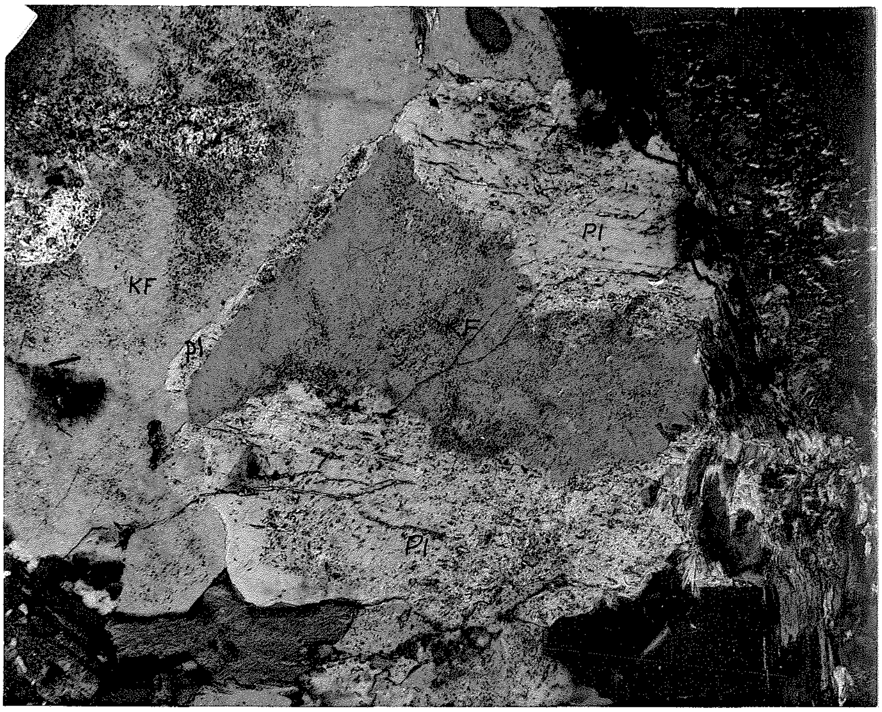

Figure 43

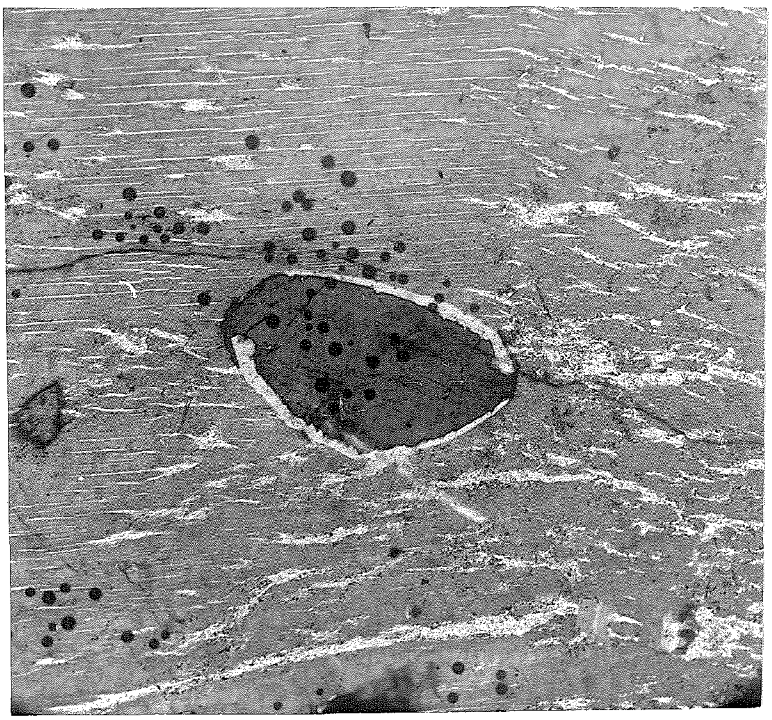

Figure 44

(fig. 44). Such strips as these become smaller and disappear on the one hand or merge with plagioclase inclusions partly replaced by potash feldspar on the other (fig. 45). The potash feldspar within the included plagioclase grain may have a different orientation from the enclosing potash feldspar, as in figure 45, or the orientation may be the same.

The plagioclase in strips is rarely, if ever, in optical parallelism with true perthitic plagioclase elements in the associated potash feldspar. It may be parallel to remnant perthite elements, however.

Characteristically the contact of plagioclase with potash feldspar in the granitic rocks is marked by a narrow zone of plagioclase which is more sodic than the remainder of the grain. This sodic rim faithfully follows the contact whether it is corroded or euhedral. The thickness of the zone may be irregular; it may be very thin in one place, and in another it may extend into the body of the plagioclase grain. These sodic rims may be related to the sodic replacements previously described (in the section dealing with plagioclase texture), which show no necessary relation to the presence of potash feldspar. The rims are illustrated in figures 33 to 46.

Distinct from the sodic rims are sodic overgrowths on plagioclase which are also found only at contacts with potash feldspar. In most cases these overgrowths are

Figure 45

Peak Granodiorite
Thin section 20-M; Specimen 18-M-53-2.

Photomicrograph. The central part of an inclusion of plagioclase (light grey, center) is replaced by potash feldspar (medium grey), and the grain is included by potash feldspar (dark grey, grid twinning). The two potash feldspars are of different orientation.
Crossed nicols; x 90.

Figure 46

Peak Granodiorite
Thin section 48-C; Specimen 27-C-53-6.

Photomicrograph. A distinct sodic plagioclase rim (light grey) replaces a zoned "rock" plagioclase along its contact with potash feldspar (medium grey, top left). The zoning is cut by the sodic replacement.
Crossed nicols; x 90.

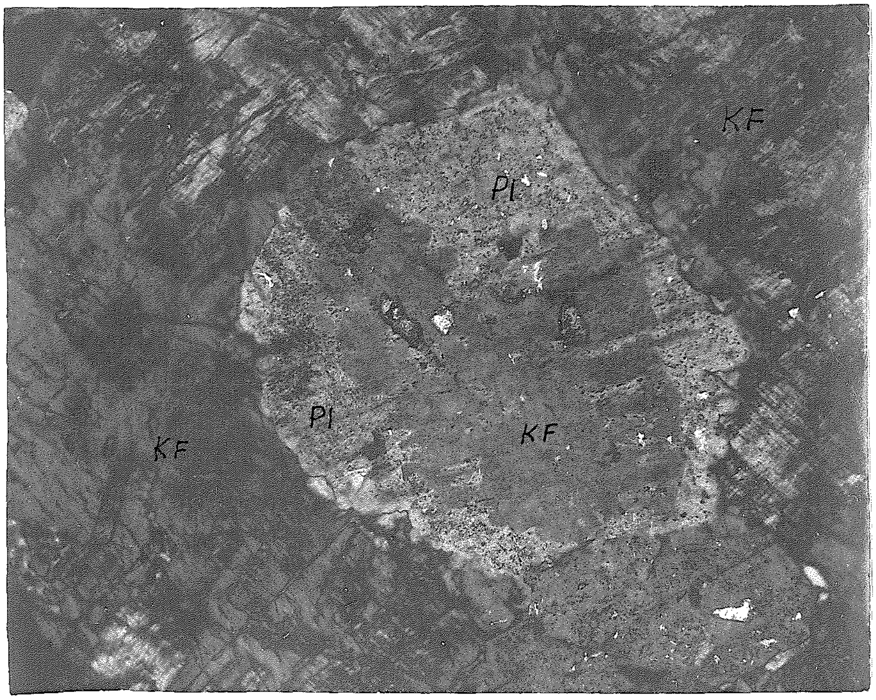

Figure 45

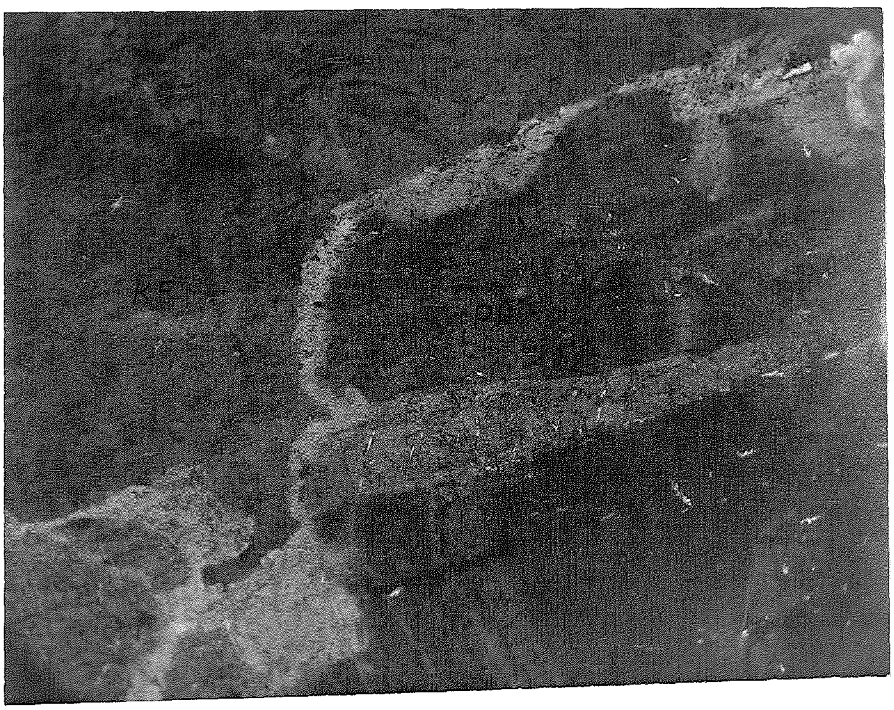

Figure 46

myrmekitic, and where they form there may be a soda-enriched rim inside them.

The myrmekite is an intergrowth of quartz and sodic plagioclase and might have been included in the section dealing with the textures of either of those two minerals. Myrmekite, where present, is invariably on the contact of plagioclase and potash feldspar grains, hence it might be considered as one of the characteristics of the occurrence of potash feldspar in the rocks of Glenlyon Range. Potash feldspar is described last of all the quantitatively important minerals, and as it seems to be one of the components necessary for the formation of myrmekite the description of that intergrowth is included in this section.

Figure 26, or the enlarged portion of it, figure 47, show that myrmekite does form as overgrowths. In these illustrations a euhedral plagioclase grain is included partly by quartz and partly by potash feldspar. A straight euhedral face of the plagioclase extends from the quartz into the potash feldspar. Against the quartz there is no overgrowth, but against the potash feldspar there is a myrmekitic overgrowth (at the right end of the plagioclase grain, fig. 47).

The overgrowths are unusual but do occur on irregular corroded and replaced plagioclase grains. Most commonly they occur on euhedral faces. The contact of the overgrowth and the plagioclase is, thus, very straight, and is marked by an abrupt change in refractive index, birefringence, and extinction position. The overgrowths may be weakly zoned but are in perfect crystallographic parallelism with the host grain even to the extent that albite twins are continuous from one to the other. This fact leads to an interesting situation in which one set of twins may be in extinction in the grain and illuminated in the overgrowth. The grains are more calcic than An 20, and the overgrowths are more sodic.

The quartz vermicules in the myrmekite are very small and are long relative to their width. They are usually arranged perpendicular to the contact of the plagioclase grain. In rare cases they project into the potash feldspar, and Roddick (1955) reports cases of the quartz vermicules being isolated in the potash feldspar.

If the rock plagioclase is between An 20 and An 30 an overgrowth may be developed on it or the quartz vermicules may be formed in the body of the plagioclase grain in a slightly more sodic rim. If the plagioclase is more calcic than about An 30 myrmekite always forms overgrowths, and if the plagioclase is more sodic than about An 20 overgrowths do not form and the quartz vermicules appear with the grain.

<u>Relations to Quartz:</u> The textural relations of potash feldspar to quartz are more difficult to interpret than are those of potash feldspar to plagioclase, though certain facts are quite clear.

The nature of the contacts between potash feldspar and quartz have been described. They may be straight or smoothly curving even where the quartz is highly granular and complexly intergrown within itself. Some of these may be explained as relict contacts that originally existed between plagioclase or biotite and quartz, the plagioclase or biotite having been replaced by potash feldspar. In many cases there is no supporting evidence of such a process, and the straight contacts appear to represent euhedral faces of quartz that formed prior to the emplacement of the potash feldspar or developed during the replacement of anhedral quartz by the potash feldspar. Characteristically contacts between quartz and potash feldspar are not straight, nor are they highly irregular; they are rather regular anhedral contacts.

Inclusions of quartz in potash feldspar are common but are much less abundant than are those of plagioclase. Good evidence of the replacement of quartz is hard to find. In all the rocks in which potash feldspar occurs it appears to be later than quartz, and there is usually suggestive evidence that it replaces quartz to some extent.

The age relationship is shown by the inclusions of quartz in potash feldspar, by veinlets of potash feldspar in quartz that are commonly connected to adjacent large potash feldspar grains (figs. 26, 47, and 48), and by the partial replacement of plagioclase included in quartz.

Figure 47

Core of Drury Quartz Monzonite
Thin section 35-C-54; Specimen 19-C-54-2.

Photomicrograph. A euhedral rectangular plagioclase grain (speckled dark grey) is in contact with potash feldspar (black) and quartz (white). At each end of the plagioclase (right and left) myrmekitic overgrowths have developed. The myrmekite is lighter grey in colour than the plagioclase, and in some of it faint dark lines are perpendicular to the contact. The lines are quartz vermicules. At the right end of the plagioclase the overgrowth is on the contact between plagioclase and potash feldspar but not on the same euhedral face of plagioclase where it is against quartz. This is an enlargement of the plagioclase grain shown in figure 27.
Crossed nicols; x 90.

Figure 48

Peak Granodiorite
Thin section 72-C; Specimen 35-C-53-2.

Photomicrograph. A veinlet of potash feldspar lies between various orientations of quartz. Beyond the limits of the picture the veinlet joins and is optically parallel to a large grain of potash feldspar.
Crossed nicols; x 90.

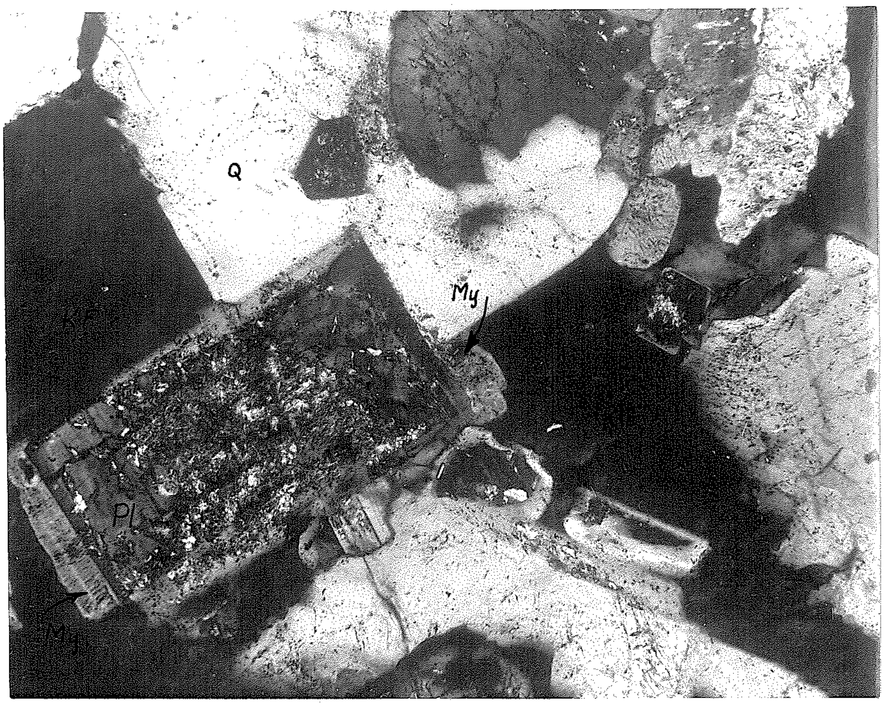

Figure 47

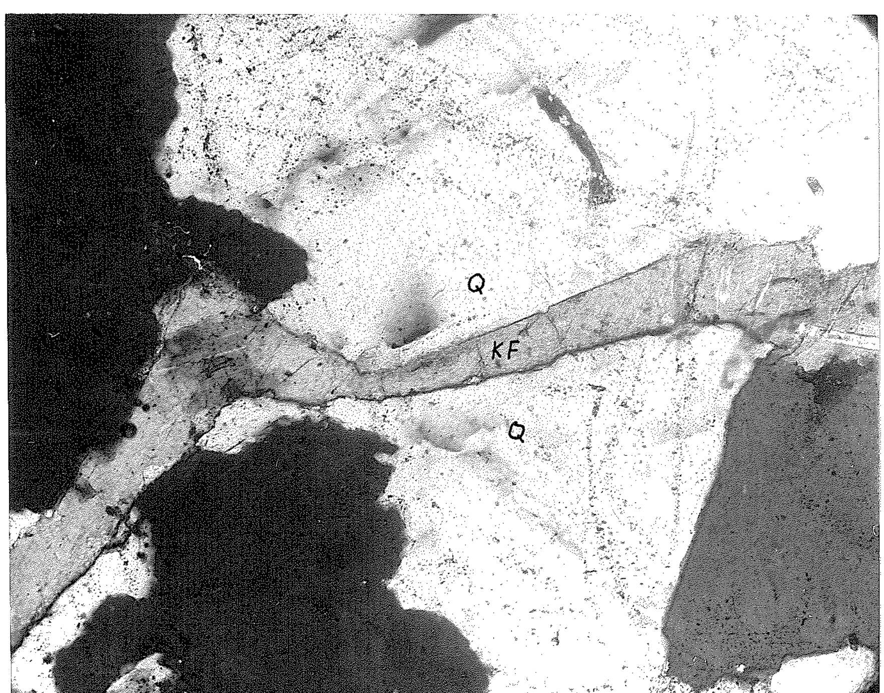

Figure 48

No evidence was observed to indicate that quartz might be later than potash feldspar or even that the two minerals might have crystallized simultaneously. The lack of such evidence, however, does not rule against such possibilities.

One type of evidence pointing to the replacement of quartz by potash feldspar is rather rare (fig. 49). In this example the quartz is severely corroded and many tiny "islands" of it are isolated in two grains of potash feldspar. A wave of undulatory extinction passes evenly through the quartz grain and the "islands."

Another example (fig. 50) involves less complex relationships. In this case a grain of potash feldspar is nearly surrounded by strips of quartz that occur in four separate grains and some tiny "islands." All of the quartz is in perfect parallel orientation, allowing for strain shadows.

Figure 51 shows a number of rounded quartz inclusions in potash feldspar. The difference of illumination of the inclusions is quite obvious in the photograph and is caused by undulatory extinction passing evenly from grain to grain.

Fragments of quartz around biotite inclusions in potash feldspar are common, and such fragments around a single group of biotite grains may be in parallel orientation. They are often parallel, also, to an adjacent larger quartz grain that may not be included by the potash feldspar (fig. 8).

Figure 49

Peak Granodiorite
Thin section 20-M; Specimen 18-M-53-2

Photomicrograph. Quartz (white), corroded and replaced at the contact, lies against two orientations of potash feldspar. Strain shadows pass evenly through the grain of quartz and all the "islands."
Crossed nicols; x 90.

Figure 50

Peak Granodiorite
Thin section 20-M; Specimen 18-M-53-2.

Photomicrograph. Strips of quartz in four separate grains (white) with some isolated "islands" surround a grain of potash feldspar (dark grey). The quartz grains and the "islands" are in perfect optical parallelism, allowing for strain shadows which pass evenly through them.
Crossed nicols; x 90.

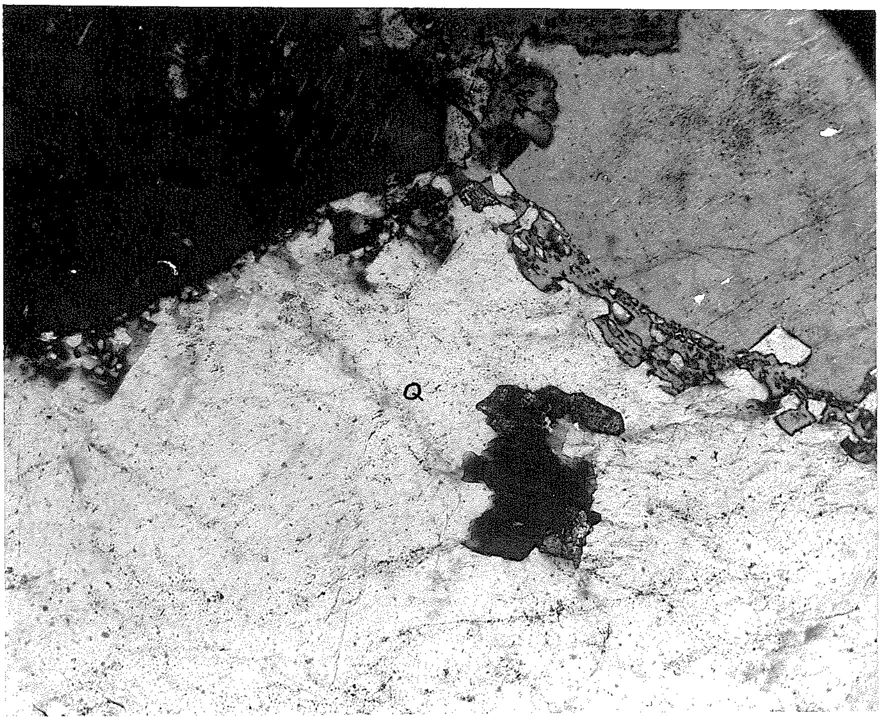

Figure 49

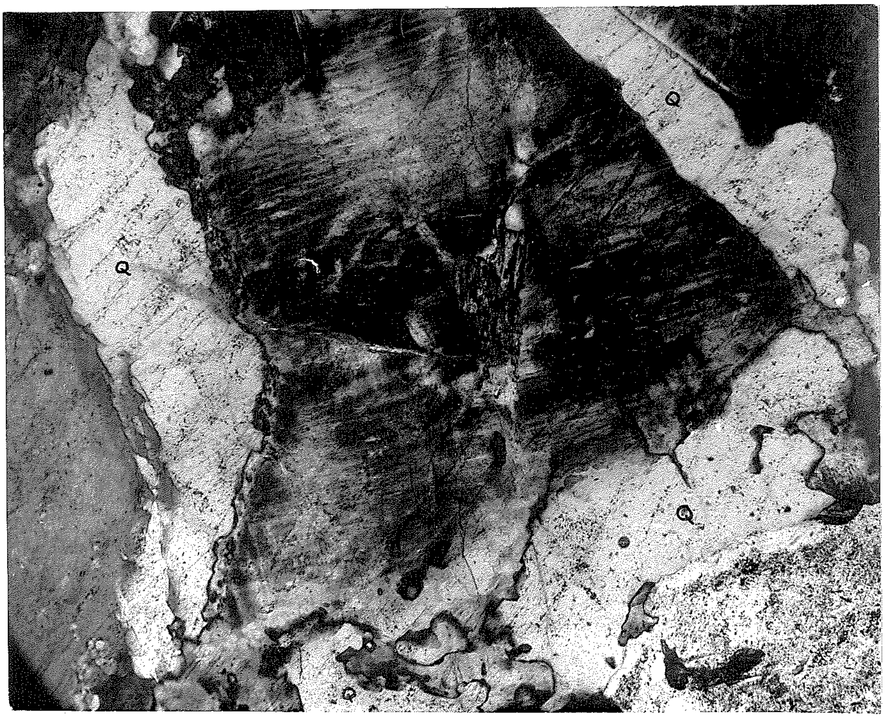

Figure 50

Micrographic intergrowths of potash feldspar and quartz are common in some of the alaskite dykes and the alaskitic pegmatite (figs. 52 and 53). In the example in figure 52 the amount and coarseness of the quartz in the intergrowth increases outward from the center of the potash feldspar grain. Near the margins, in some places, the quartz is almost solid and, while it is not obvious in the photograph, quartz of the same optical orientation is completely beyond the confines of the potash feldspar grain.

The intergrowth illustrated in figure 53 is confined to one edge of a very large potash feldspar grain and is made up of patches of differently oriented quartz. The intergrowth gives way to potash feldspar containing no intergrowth along a remarkable regular line. Some of the groups of quartz inclusions that are not in an intergrowth pattern contain grains all in parallel orientation.

A general feature of these zones of intergrown quartz and potash feldspar is that the perthitic plagioclase lamelli become fewer (or do not exist) in the potash feldspar involved in the intergrowth as compared to that outside.

Chayes (1952) found a relationship between the degree of granularity of quartz and the development of perthite in potash feldspar, and he and others have concluded that stress, as indicated by the granularity of quartz, is a prerequisite in the formation of perthite. He found that alkali feldspar associated with unstrained or mildly strained

Figure 51

Drury Quartz Monzonite (intermediate zone)
Thin section 15-C-54; Specimen 17-C-54-4.

Photomicrograph. Rounded quartz grains (light grey) are included by potash feldspar (dark grey to black). The difference in illumination in the quartz grains is due to undulatory extinction. Strain shadows pass smoothly from grain to grain.
Crossed nicols; x 90.

Figure 52

Pegmatitic alaskite
Thin section 6-C-54; Specimen 16-C-54-1

Photomicrograph. Quartz (light grey) is in a micrographic intergrowth with potash feldspar (medium grey). The quartz increases in coarseness and amount toward the margins of the grain. Beyond the limits of the picture other quartz not included in the potash feldspar is optically parallel to the quartz in the intergrowth.
Crossed nicols; x 30.

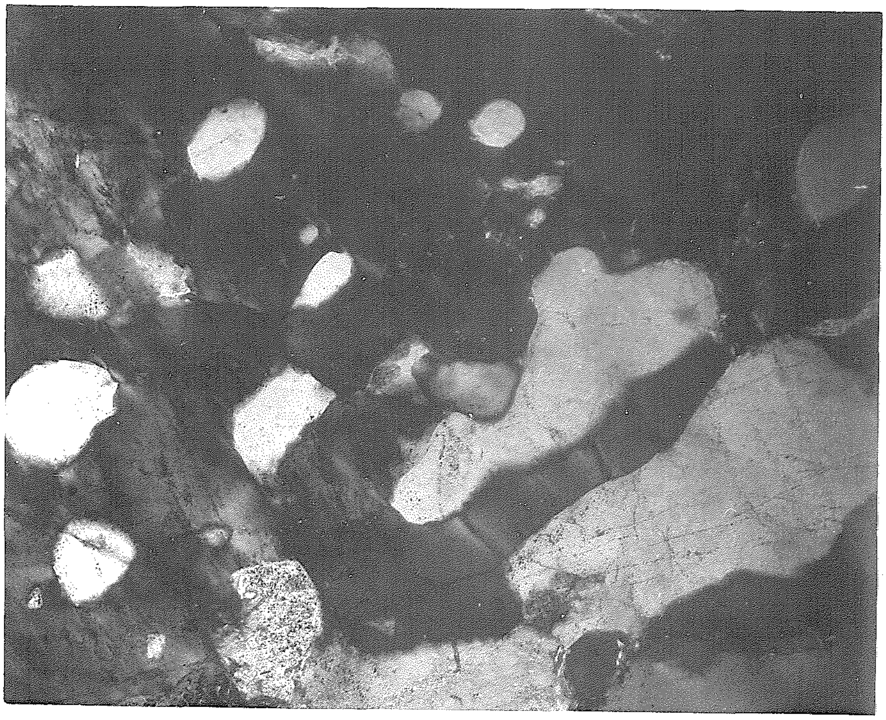

Figure 51

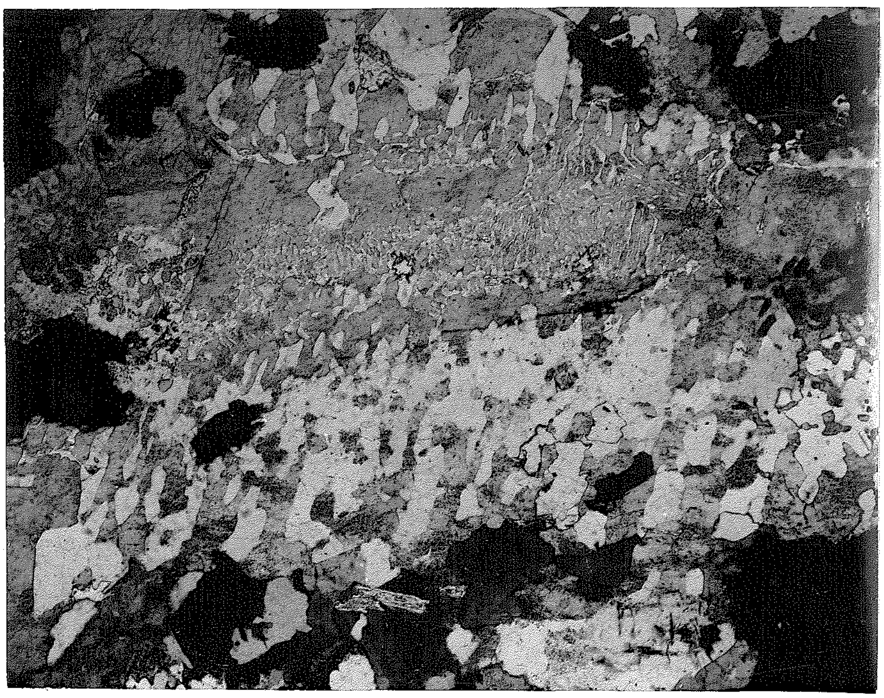

Figure 52

non-granular quartz is not perthitic; if the quartz is highly strained but not granular the alkali feldspar may or may not be perthitic; and if the quartz is granular the feldspar is always perthitic.

In the granitic rocks of Glenlyon Range the degree of strain in quartz, as shown by undulatory extinction, and the degree of granularity do not seem to correspond; very highly granular quartz may be less strained than non-granular quartz. In 100 thin sections of the granitic rocks of Glenlyon Range, measurements were made of the width of perthitic plagioclase elements and the degree of granularity of quartz. The amount of perthitic plagioclase in the potash feldspar was estimated. No correlation between the granularity of quartz and the development of perthite was recognized. Perthite is rather uniformly developed in all the granitic rocks irrespective of the degree of granularity of the quartz.

Relations to Biotite: The relations of potash feldspar to biotite are quite completely described in the section dealing with the texture of biotite. The main points are that biotite is commonly included by potash feldspar and that potash feldspar may replace it to some extent (fig. 54). Included biotite grains may be bent and broken, and there might be relative movement along the breaks, but there may be no corresponding fractures in the enclosing potash feldspar.

Figure 53

Pegmatitic alaskite
Thin section 6-C-54; Specimen 16-C-54-1

Photomicrograph. Along the left side of the picture is a micrographic intergrowth in which groups of quartz grains have different optical orientation. The zone containing the intergrowths ceases abruptly along a straight line in the potash feldspar. The string of quartz inclusions (white) beyond the intergrowths are in optical parallelism. The potash feldspar is less perthitic in the zone of the intergrowths than it is in the "quartz free" part.
Crossed nicols; x 30.

Figure 54

Drury Quartz Monzonite (core)
Thin section 35-C-54; Specimen 19-C-54-2.

Photomicrograph. Biotite (medium grey with good cleavage) is included in potash feldspar and may be partly replaced by it.
Crossed nicols; x 90.

Figure 53

Figure 54

In Peak Granodiorite: Most potash feldspar in Peak granodiorite forms large inclusion-rich grains which range in diameter from about 1 to over 20 mm and average from 6 to 8 mm. Potash feldspar forms the largest grains in the rock. They are very irregular in shape and vary from small angular forms that occupy the interspaces between plagioclase grains to large, roughly circular inclusion-rich phenocrysts or oikocrysts.

Plagioclase is the most commonly included mineral, and it has the same composition, twinning, zoning, and complex textures within itself as it has when not included (fig. 17). Potash feldspar includes, fits around, and replaces complex clots of plagioclase grains in such a way that it is apparent that the plagioclase was in its present form when it was engulfed and included. The included grains in places have a rather vague progressive zoning which reflects the present shape of the grain and which is superimposed on the original zoning.

The relationships of potash feldspar to quartz in Peak granodiorite indicate that the quartz was in its present form even to the extent of having the same undulatory extinction prior to the crystallization of potash feldspar. The feldspar replaced quartz to some extent at least.

The cleavage of the biotite included in potash feldspar may be bent and broken, and there may have been movement on the breaks, but there are no corresponding fractures in the potash feldspar. The biotite, too, was apparently in its present form prior to the formation of potash feldspar, exclusive, of course, of the textures produced in it through replacement.

The extinction of potash feldspar may be irregular and patchy as though the mineral has been strained. Parts of a single grain may show grid twinning and other parts may not, but adjoining grains in the same thin section may have uniform extinction and show no evidence of strain. Potash feldspar does not seem to have been involved in a stress environment which strained, bent, and broke the other minerals. Rather it seems to have been formed during or after a period in which the other minerals were generally recrystallized.

In Drury Quartz Monzonite: In general the potash feldspar in Drury quartz monzonite is similar to that in Peak granodiorite and has similar relationships to the other minerals. There are some differences, however, in the outer zone where the potash feldspar is finer-grained and, like plagioclase, tends to form rectangular to round masses that "float" in the matrix of fine-grained quartz and biotite. In the outer zone the plagioclase is more sodic than in the other zones and, consequently, "pseudomorphic" replacement of plagioclase by potash feldspar is more common. General views of the textures of the rocks of the outer zones are shown in figures 55 and 56.

Figure 55

Outer zone of Drury Quartz Monzonite
Thin section 63-C; Specimen 31-C-53-10.

Photomicrograph. This is a general view of the texture of rocks of the outer zone of the quartz monzonite. All the large grains are plagioclase or potash feldspar. The fine-grained matrix is quartz and biotite.
Crossed nicols; x 30.

Figure 56

Outer zone of Drury Quartz Monzonite
Thin section 85-C; Specimen 39-C-53-5.

Photomicrograph. This view shows part of a large potash feldspar grain and smaller plagioclase grains associated with fine-grained quartz and biotite. This is typical of the outer zone of the quartz monzonite.
Crossed nicols; x 30.

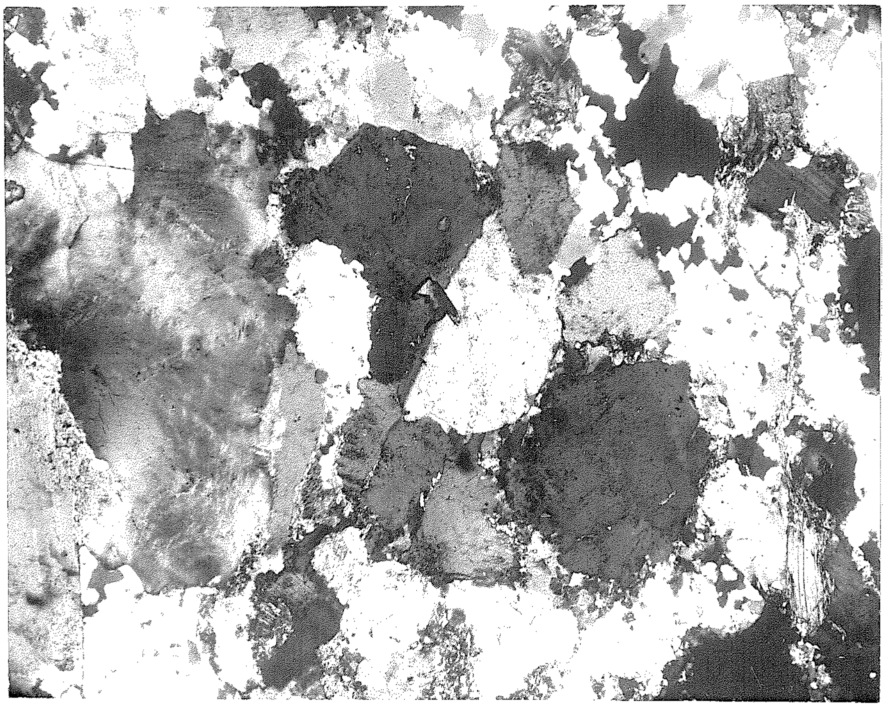

Figure 55

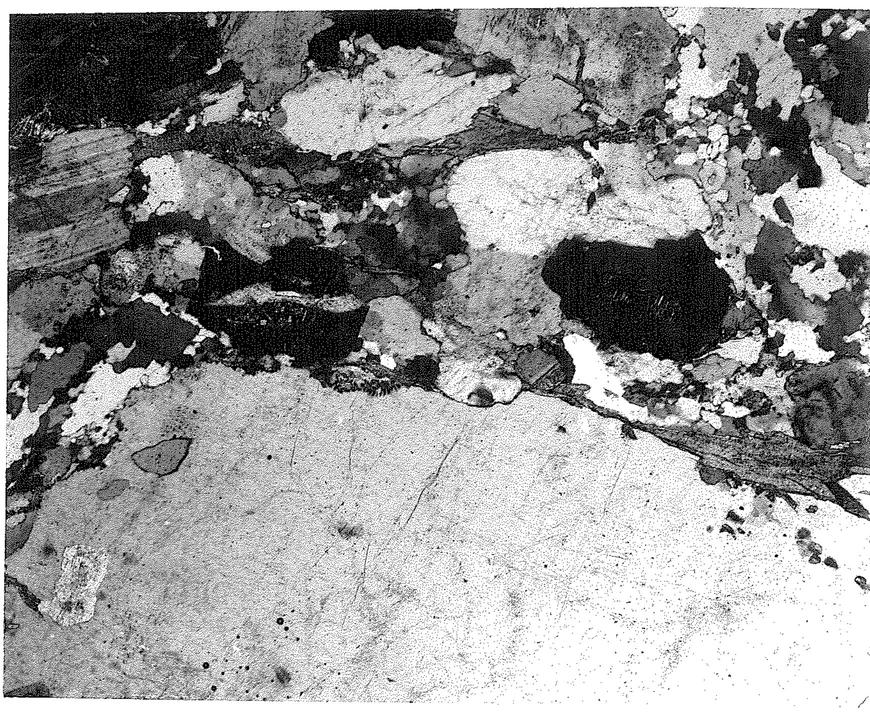

Figure 56

In the pegmatitic selvages that occur on some of the small bodies of Drury quartz monzonite in the intermediate and outer zones, large grains of perthitic potash feldspar and smaller grains of sodic plagioclase are associated with a groundmass of finely granular quartz and a little fine-grained biotite and muscovite (fig. 57). In this occurrence the potash feldspar is less rich in inclusions than in any of the other granitic rocks. Its contacts with the fine-grained groundmass, while in places irregular in detail, are regular overall.

In Alaskite and Alaskitic Pegmatite: In the alaskite the potash feldspar is similar to that in other granitic rocks except that it locally forms micrographic intergrowths with quartz and, except in pegmatitic phases, is finer-grained.

In Yukon Group Quartz-mica Schist: Potash feldspar is a minor constituent of the schist of the Yukon group except in the proximity of granitic rocks, where it may form as much as 30 per cent of the rock. In the schist in general potash feldspar may be absent, it may form tiny veinlets, or it may form discrete fine grains. It may or may not be perthitic.

Almost every relationship and feature of potash feldspar in the granitic rocks is duplicated, in one place or another, in the schist. Potash feldspar in the schist

Figure 57

Outer zone of Drury Quartz Monzonite
Thin section 68-C; Specimen 33-C-53-7.

Photomicrograph. Large grains of potash feldspar are associated with fine-grained quartz and micas in a pegmatitic selvage of a quartz monzonite sill in the outer zone.
Crossed nicols; x 30.

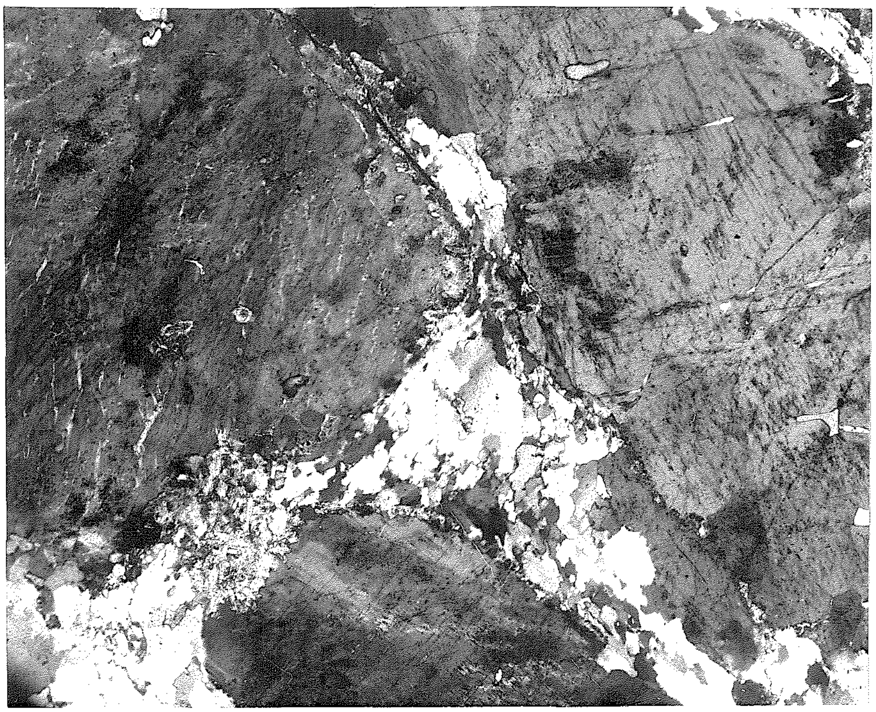

Figure 57

may include and replace any of the other minerals; the replacement of plagioclase is most obvious (figs. 37 and 38). It may form true perthite, may have plagioclase strips on contacts between potash feldspar grains, may form remnant perthite by the partial replacement of plagioclase, and the associated plagioclase may have myrmekitic overgrowths or myrmekitic quartz within the grains.

True perthite, plagioclase strips, and myrmekite occur in the schist only where granitic rocks are close by. These features reflect the highest degree of "granitic environment" in the metamorphic rocks.

<u>In Other Rocks</u>: Potash feldspar occurs in only a few samples of the hornblende-biotite-quartz diorite. When it is found in these rocks the highly calcic cores of the plagioclase are absent or remain as scattered remnants in more sodic plagioclase. It is similar in nature to the potash feldspar in Drury quartz monzonite.

Potash feldspar is rare in the lime-silicate rocks of the Yukon group but, as in the schist, it does occur in them where granitic rocks are close by. It is usually associated with the layers containing quartz, andesine, and biotite, but in some cases it invades the layers rich in calcic plagioclase and diopside, where it replaces the plagioclase. In the less calcic layers of the lime-silicate rocks the potash feldspar may be perthitic and may have plagioclase strips on its mutual contacts.

Small non-perthitic grains of potash feldspar occur quite commonly in the lime-silicate rocks and, rarely, in the limestone at the base of the Harvey group. Coarser perthitic potash feldspar is found in the limy rocks along the north contact of the Fairway dyke.

In the contact-metamorphic zone in the upper Harvey group fine grains and veinlets of non-perthitic potash feldspar are quite common but are not abundant.

Accessory Minerals

In the granitic rocks and quartz-mica schist of Glenlyon Range apatite is, by all odds, the most widespread accessory mineral. It forms fine grains which may be anhedral or euhedral and may be included by any of the other minerals. It is common in the schist and in the granitic rocks with potash feldspar, but is subordinate to sphene in the quartz diorite and amphibolite. Some zircon and a few grains of allanite were observed in the granitic rocks.

Various other minerals occur in small amounts. Fine, fibrous sillimanite is found here and there in schist and is common in alaskite. Andalusite and cordierite are very common in hornfels, and andalusite also appears rarely in schist and was observed in one sample included by potash feldspar in the pegmatitic selvage of a quartz monzonite sill. Staurolite was found in a single sample of schist. Garnet is fairly common in the schist of the Yukon group in the ridge between Pass and Jar Creeks but rarely occurs in schist in close association with granitic rocks. Garnet occurs in some of the lime-silicate rocks, closely associated with granitic rocks. There is a little garnet in the Fairway dyke, but otherwise none is found in the granitic rocks. Very fine-grained tourmaline was observed in a few samples of schist, and in all the rocks there are opaque minerals, mainly pyrrhotite and magnetite.

Alteration Minerals

Alteration in the rocks of Glenlyon Range is not uniform; the intensity differs greatly from place to place. It is, however, similar in type wherever it occurs. The minerals most affected by alteration are plagioclase and biotite. Potash feldspar and hornblende, if altered at all, are usually not severely changed.

The alteration of plagioclase and biotite evidently occurs under the same conditions and at the same time; the alteration of one can be taken as an index of the alteration of the other. When plagioclase is intensely altered it contains a heavy uniform dissemination of clay minerals and sericite. Zoning, if it ever existed, is no longer apparent, and twinning is difficult or impossible to find. The composition of such plagioclase as remains is hard to determine, but it always seems to be more sodic than about An 20. Less severe alteration of the plagioclase in the granitic rocks does not obliterate the zoning and twinning. The relatively calcic cores are most affected and contain disseminated clay minerals and fine sericite. In the unzoned or weakly zoned sodic plagioclase in the Yukon group schist, alaskite, and the outer zone of Drury quartz monzonite, a uniform dissemination of alteration minerals may be more or less intense. The highly calcic plagioclase in the lime-silicate rocks may be mildly sercitized but is not, as a rule, much altered. Corresponding to the alteration of plagioclase is that of biotite. Where plagioclase is mildly affected biotite is partly chloritized, and where plagioclase is intensely altered biotite is completely chloritized. The chlorite ranges from masses of fine grains to single pseudomorphic grains. It is pale green and slightly pleochroic, and may show anomalous purple interference colours. In some places green pleochroic epidote occurs with the chlorite, and some sericite forms from the alteration of biotite.

Potash feldspar is apparently not easily altered and may be clear and fresh in a rock in which the plagioclase and biotite are intensely altered. Grains of relatively fresh potash feldspar may include grains of plagioclase which is little more than a mass of clay minerals and sericite, and of completely chloritized biotite. Where potash feldspar is altered, either in granitic or metamorphic rocks, the alteration takes the form of a uniform dusting of fine clay minerals or iron oxide or both. Rarely this alteration is sufficiently intense that the mineral becomes almost opaque. Not a single case was observed in which disseminated sericite was produced by the alteration of potash feldspar. Some veinlets of sericite occur in the feldspar, but these do not necessarily originate from its alteration.

In a few samples hornblende has been altered to chlorite, but it is usually unaltered even in rocks in which biotite is heavily chloritized.

DISCUSSION OF THE STRUCTURAL, TEXTURAL, AND MODAL DATA

Introduction

The significance of the various structural, textural, and modal features and their implications as to the ultimate origin and mode of emplacement of the granitic rocks is discussed in this section. This is followed by a discussion of the crystallization of granodiorite magma based on available experimental data, and the relation of such crystallization to granitic rocks in general, and to the granitic rocks of Glenlyon Range in particular. The final result, it is hoped, gives a logical and comprehensive explanation of the origin of the features of these granitic rocks in terms of a single, controlling process, the crystallization of granitic magma. In the past the writer seriously considered theories of granitization but has abandoned them because they cannot provide a single, logical control for the origin of all the features even though they are attractive as an explanation of many things.

Structural Geology and General Field Relations

General Remarks: Field studies may reveal that a granitic body is intrusive or that it formed by the transformation of other rocks in situ. Field work will not, ordinarily, show that an intrusive granitic body originated, ultimately, by crystallization of the minerals from a magma; it may show only that mobile material was intruded at a given place. In Glenlyon Range field work indicates that some of the granitic masses are intrusive (Peak and Nub Hill granodiorite, the Fairway dyke, and most of the alaskite); some may or may not be intrusive (the core and intermediate zones of Drury quartz monzonite and some alaskite); and some appear to be formed by the transformation of metamorphic rocks in situ (some of the small bodies in the intermediate and outer zones of Drury quartz monzonite). Drury quartz monzonite, in terms of field relations and structure, will be discussed as to the possibility of its being a metamorphic rock formed by transformation in situ, and as to the possibility of its being intrusive. Peak granodiorite and the other intrusive rocks need be discussed only in terms of their being intrusive as one factor in their origin.

Granitic rocks are concentrated in the core of an apparent large anticlinal structure in Glenlyon Range. For several miles on either side of the east-west trending axis the rocks are essentially completely granitic. On either flank, beyond the granitic core, are areas of complexes of granitic and metamorphic rocks. On the north limb of the fold the complex area is succeeded by a "granite-free" zone which is cut, here and there, by intrusive granitic rocks. On the north limb of the fold the grade of metamorphism decreases progressively outward from the complex zone. The metamorphic rocks change from representatives of the amphibolite facies in most of the Yukon group strata to the green schist facies in the upper part of the Harvey group (excluding, of course, the hornfels zones related to local intrusive bodies). If the northern margin of the core of Drury quartz monzonite retains the same stratigraphic position down dip to the north that it has on the surface then it underlies all the other zones at depth, and presumably is intersected by the Pelly Fault.

<u>Intrusion of Peak Granodiorite</u>: As stated, Peak granodiorite must be regarded as an intrusive body. Its southwest contact (which is the only one exposed) is extremely sharp, relatively straight, and essentially vertical. It is strongly discordant to the invaded rocks, which are more or less deformed along the contact as is the foliation within the granodiorite itself. Only argillaceous rocks (slate and phyllite) are known along the contact of the batholith, and these are characteristically changed, over a variable width, to hornfels. There is no evidence to indicate that these rocks have any tendency to be converted to a granitic composition or texture. The writer believes that these factors indicate that Peak granodiorite is an intrusive mass though in part it may have fault relations to the Harvey group.

Peak granodiorite is exposed for about 20 miles in the area mapped in detail (plate 1); altogether its exposure may be 30 miles long (see plate 2) and about 3.5 miles wide, covering about 100 square miles in area. It is known to be at least a mile deep and is certainly very much deeper, hence it represents several hundred cubic miles of material. As with all large intrusive bodies we are confronted with the room problem, and that is the subject of some speculation in the next paragraphs.

Peak granodiorite is elongate parallel to the trend of the fault in Tintina Valley (the Pelly Fault). Far to the north near Dawson City early Tertiary (possibly Eocene) rocks have been found in the trench of Tintina Valley (Bostock, 1948, p. 62). In the Rocky Mountain Trench far to the south Roots (1954, p. 194) found evidence that the valley marks a line of faulting which he believes to have been active throughout much of the history of the Cordillera. These two trenches probably are related in origin, and the occurrence within them of early Tertiary rocks suggests that they may be very old physiographic features; the controlling structures may have developed, initially, well before the Tertiary period, but this is not known with certainty for Tintina Valley at least. It is possible that the form of Peak granodiorite was controlled by the fault structure, but it is also possible that the pluton is part of a larger mass which was intersected and displaced by the fault.

The faults within Glenlyon Range seem more definitely to be related to the period of formation of the granodiorite. Many of these faults approach but do not offset the southwest contact; some of the north-trending faults seem to merge with the contact. It may be that this contact shows both intrusive and fault relations whereby space for the intrusion was provided by movements on the faults. Under such circumstances of intrusion and fault movements the contact would be an intrusive one even though it may in part be formed by fault surfaces.

The dilation of space to allow the intrusion of the known bulk of Peak granodiorite could be provided entirely by strike-slip movements on the north trending faults within Glenlyon Range. This may be demonstrated by a simple geometric model. Consider two north trending faults lying at an angle of 30 degrees to the trend of the present southwest contact of the granodiorite. Southward movement of the block between these two faults could provide the space into which the intrusive was injected. A movement of 7 miles could provide an opening 3.5 miles wide measured perpendicular to the trend of the contact. Apparent strike-slip movement on the faults within Glenlyon Range is far in excess of 7 miles and in the correct relative direction as required by the geometry. The movement on the single fault just east of Moraine Mountain may be in excess of 7 miles. Vertical movements on the faults may also have played a part in providing space for the intrusion. Dilation of a fracture of the Pelly Fault may have been the mechanism whereby the intrusion occurred, but the lack of evidence on the relative ages of this fault and Peak granodiorite make such a possibility entirely speculative.

Obviously the situation was much more complex than suggested by any simple geometric model. Whatever mechanism is invoked it must explain the two large inclusions of Harvey group rocks, and if the foliation is a result of flowage that too must be explained. The complexity introduced by the existence of many faults rather than two may help explain these features in that the batholith may have developed as a composite though very nearly simultaneous series of intrusions.

The conditions outlined above do offer a possible mechanism to provide space into which Peak granodiorite was intruded. The north-trending faults apparently merge with the contact of the granodiorite, and the possibility that the contact is a combination of intrusive and fault surfaces which may have formed simultaneously could provide an explanation for the variable width of the hornfels and contorted zones along the contact and may also explain the lack of irregularities or apophyses from the granitic body. That is not to say that Peak granodiorite is in contact with the Harvey group only by the accident of faulting. The two large inclusions of Harvey group strata indicate that the pluton intrudes these rocks, and the fact that the inclusion of the argillaceous upper member is a hornfels identical to that along the contact also indicates that the thermal metamorphism of the Harvey group rocks has resulted by direct contact with the intrusive body.

Intrusion of Nub Hill Granodiorite: Nub Hill granodiorite is very similar in texture, composition, and associated rocks to Peak granodiorite, and it may well be connected directly to the larger body. This mass may be nearly concordant to the structure of the surrounding rocks. There are no chilled selvages at the contacts, which are extremely sharp. The complete similarity of the hornfels zones on the contacts of Nub Hill and Peak granodiorite suggests that if one mass is intrusive then both are. It is difficult to explain the smaller body as anything but intrusive, hence indirectly this implies that Peak granodiorite is intrusive.

Intrusion of the Fairway Dyke and Alaskite: The Fairway dyke is in contact for much of its length with the limy beds of the lower Harvey group. The contacts are poorly exposed, but the limestone near it has been converted to massive and layered diopside-garnet-plagioclase rocks into which perthitic potash feldspar is locally introduced. The dyke includes similar lime-silicate rocks in one place.

The Fairway dyke may be concordant to the structure of the surrounding rocks, but the exact relationships are obscure. If the alaskite east of the fault that intersects the east end of the dyke is part of the same body then the dyke is not concordant. The relation between these bodies is not proved, although it seems to be a reasonable supposition that they are part of the same intrusion. If the dyke is not intrusive, but has originated by the transformation of certain strata in situ, it seems unlikely that such strata would be limestones of the lower Harvey group. A tremendous compositional change would be involved in the transformation of lime-rich sedimentary rocks to lime-poor and alkali-rich granitic rock, and the lower Harvey group does not contain any appreciable thickness of rocks of more favourable composition. These factors, plus the fact that the Fairway dyke is similar to the alaskite, which is more definitely intrusive to the metamorphic rocks, suggest that the dyke is an intrusive body.

Clear-cut, sharp, cross-cutting contacts and displaced angular inclusions which obviously fit irregularities in the wall rocks demonstrate that the alaskite is intrusive at least into the metamorphic rocks of the Yukon group. Where alaskite dykes cut Drury quartz monzonite the contact is megascopically sharp, but in thin section there is no sharp contact. Probably the alaskite intrudes the quartz monzonite, but the contact has been blurred by reactions. The alaskite is definitely intrusive to the limy metamorphic rocks and probably to the quartz diorite. The metamorphism and the development of the quartz diorite were apparently simultaneous with the formation of the quartz monzonite, thus the alaskite may be considered to be later than all the other rocks. This, however, does not obviate the possibility of some alaskite forming by the transformation of Drury quartz monzonite along fracture zones.

Field Evidence Related to the Mode of Emplacement of Drury Quartz Monzonite: The core of Drury quartz monzonite is the focus of increasing grade of metamorphism, of increasing proportion of granitic relative to metamorphic rocks, and apparently of increasing stratigraphic depth. This situation might occur with either a metamorphic or an intrusive origin for the granitic rocks.

Many relationships point to an origin by granitization of rocks in situ. On a large scale, bodies of the quartz monzonite seem to be concordant to the structure of the metamorphic rocks; that is, the contacts and foliation are generally parallel to the bedding and schistosity. Many small-scale features are suggestive of such an origin. There are a few gradational contacts between schist and granitic rocks; isolated pods of granitic rock are found in the schist; there are inclusions of schist structurally parallel to the foliation and contacts of the enclosing rocks and to the bedding and cleavage of adjacent metamorphic rocks; the schist may contain large and numerous feldspar porphyroblasts in the vicinity of granitic contacts; and the granitization of schist inclusions involves all stages of transformation to granitic material. These and other small scale features suggest that granitization may be an important process in the origin of these rocks.

There are definite discordant relationships of Drury quartz monzonite to the Yukon group metamorphic rocks, and some of these may be on a very large scale but are not obvious because of lack of information. In general the contacts of the granitic rocks and the schist are sharp, and while they are generally concordant, they may cross-cut the metamorphic structures in detail. Locally there are strongly discordant dykes, which are most common in the limy metamorphic rocks.

The field evidence pertaining to the origin of Drury quartz monzonite is contradictory and in part supports the process of granitization of rocks in situ, and in part supports an origin by the intrusion of mobile granitic material. Whatever origin is invoked it must explain the mobilization and intrusion of at least small amounts of the quartz monzonite. An origin entirely by the transformation of rocks in situ is not consistent with all the facts. Nothing observed in the field obviates the possibility of an origin for Drury quartz monzonite by the intrusion of mobile granitic material with intense and large scale contact effects.

The Textures of the Rocks

General Remarks: Many papers in the geologic literature deal exhaustively with the problems of the origin of this or that granitic rock, or with the origin of granites in general. It is remarkable how few describe in any but cursory terms the details of the texture of the rocks with which they are concerned. In many cases in which texture is studied in detail the main emphasis is on grain size rather than on other textural features (van Biljon, 1939; Feniak, 1944). Some studies have been made of the inclusions within minerals (Mackie, 1909), and there has been much work on specific features of texture such as perthite, myrmekite, quartz and potash feldspar intergrowths, plagioclase zoning, etc. Few authors, however, have treated the texture of a group of granitic rocks in a detailed and comprehensive way; exceptions are Rogers (1955) and Roddick (1955). Such terms as typically granitic, granitoid, hypidiomorphic granular, and so forth are often the only reference to texture other than routine mention of the grain size and a few of the obvious characteristics of the various minerals. Apparently textures are considered to be unimportant or much less important than other features.

A study of textures probably cannot reveal the complete history of a given granitic rock, but unless the rocks have been violently affected by later non-granitic events, much of the history may be recorded in the textures. The difficulty lies in reading the record. The possibility of igneous granitic textures being converted to metamorphic textures by subsequent autometamorphism or independent regional metamorphism has been discussed (Tuttle, 1952). Here, however, much of the argument deals with the fact that the minerals are metamorphic by virtue of their low temperature state which could not have developed by direct crystallization from a magma. Transformations of minerals from high to low forms need not change the textural relations, so even if Tuttle is right in assertions in this regard some of the history of the rock, as recorded in the texture, may remain.

Tuttle (1952) and Tuttle and Bowen (1958) argue that in two-feldspar granite the plagioclase has originated by exsolution and migration of albite from a single alkali feldspar. They do not precisely define granite, but they are speaking of alkaline granite low in lime content although they make use of analytical data from Washington's tables (Washington, 1917) and apparently include as granite all plutonic rocks in which the normative albite, orthoclase, and quartz is in excess of 80 per cent. This would seem to allow a great leeway for the normative anorthite content within the classification of granite. It certainly allows room for enough anorthite that in some of these "granites" the two feldspars can be expected to have originated as independent phases in view of the work of Yoder, Stewart, and Smith (1957). None of the granitic rocks of Glenlyon Range, with the possible exception of the alaskite, fall in this category if the modal composition may be taken as a close indication of the norm. In the main masses of granitic rocks the sum of normative albite, orthoclase, and quartz would be around 75 per cent, and the normative anorthite would be about 15 per cent. The textural features of the granitic rocks of Glenlyon Range, and of other similar rocks, and the experimental work of Yoder et al (if the rocks have a magmatic origin) show conclusively that the two feldspars originated as independent phases. Both lines of evidence indicate that a very considerable proportion of the bulk of the plagioclase was crystalline before any potash feldspar formed. Tuttle's explanation of the origin of two-feldspar granites does not apply to the granitic rocks of Glenlyon Range.

The texture of large plutonic granitic masses is generally very similar and typically granitic; that is there may be differences between the texture of granite and granodiorite, but there is a characteristic texture of plutonic granodiorite from place to place, and the same applies to granite. This is not to say that every plutonic granodiorite must be texturally identical to every other one. There must be gradations from type to type and there must be unusual types just as there are in modal and chemical compositions. In generalizing the textures one must consider the average or usual case just as is necessary in considering the average chemical composition. If this generalization can be made, and the writer believes that it can, the notion of a characteristic texture for the granitic rocks of similar composition from place to place suggests that there is a uniform physical environment under which the texture originated. Independent metamorphism of an originally magmatic rock may produce such uniformity, but this would be highly coincidental. The process of granitization involving intense metamorphism with delicate chemical exchanges could produce such a uniform texture, but this too would seem to be a remarkable coincidence of circumstances. Magmatic crystallization, however, might very well be expected to produce similar conditions from place to place in similar compositions of rock, assuming that the magmas all crystallize under plutonic conditions. By the same token one might expect, and can find, uniformity in the texture of extrusive magmatic rocks.

The writer believes that the uniformity of the texture of plutonic granitic rocks of similar composition implies, but does not prove a magmatic origin for these rocks. If late stage processes or autometamorphism affect the texture then they do so to a similar degree in many localities, and they occur in response to common conditions. The identical texture of Peak granodiorite, which is intrusive into greenschists, and the core of Drury quartz monzonite, which may or may not be intrusive and is associated with rocks of the amphibolite facies, suggests that the conditions under which a single texture may develop might have a rather wide range.

<u>The Texture of Potash Feldspar</u>: The texture of potash feldspar involves all the other minerals in the rocks in which it occurs. As a consequence of this a discussion of its texture involves the texture of the rocks as a whole if supplemented by brief discussions of the textures of the other minerals.

Potash feldspar has what seem to be obvious replacement relations to the other minerals. These relations are so general that in the descriptive section of this thesis there were described as being replacements in spite of genetic implications. It is part of the purpose of this section to discuss the pros and cons of replacement versus other mechanisms in the production of the observed textures.

The mineral most obviously replaced by potash feldspar is plagioclase. The textures which indicate this are very common in granitic rocks though they are seldom mentioned in textural descriptions. The writer has observed them in granodiorites and quartz monzonites from other parts of Yukon, British Columbia, and California. They are reported in the literature from the Orofino region, Idaho (Johnson, 1947), from the islands of southeastern Alaska (Kennedy, 1953), from the southern end of the Coast Range, British Columbia (Roddick, 1955), and from the Sierra Nevada, California (Hamilton, 1956 and Sherlock and Hamilton, 1958). They are probably much more common features of granitic rocks than has been suggested in the literature.

Generally speaking potash feldspar in the Glenlyon granitic rocks has two rather distinct textural relations with plagioclase that suggest replacement; these involve plagioclase of different compositions. Most common in the large masses of granitic rocks (Peak granodiorite and the core and intermediate zones of Drury quartz monzonite) are large grains of potash feldspar which are rich in inclusions of all other minerals, particularly plagioclase, and which irregularly "replace" some of the plagioclase grains and leave others untouched. In the outer zone of Drury quartz monzonite and in the alaskite plagioclase is more sodic than in the larger masses of granitic rocks, and here "pseudomorphic replacement" is characteristic. This type of replacement occurs in the massive granitic bodies in the few cases where the plagioclase is sodic.

"Pseudomorphic" replacement does not occur if the plagioclase is more calcic than about An 30. It is characteristic when the composition is more sodic than about An 20. This type of replacement evidently involves little more than ion exchanges whereby potassium replaces sodium with resulting relatively minor adjustments in the lattice. It can occur in fairly low temperature environments. This will be discussed at greater length.

In the large masses of granitic rocks the plagioclase is more calcic than An 30 (it ranges generally from An 35 to An 40). Grains included in potash feldspar are identical in zoning, composition, and alteration to the "rock" plagioclase though they may be a little smaller in average grain size. Some plagioclase inclusions are essentially euhedral or have regular boundaries, but others are highly embayed and apparently replaced.

Some of the potash feldspar in these rocks may have crystallized directly from a liquid in space free of other minerals and some appears to have replaced other minerals. No estimate of the proportions of one to the other can be made for where replacement was an active process it tended to erase the evidence as it progressed. It may be useful to discuss the textural relations from the two extremes; first on the basis that all the potash feldspar formed by replacement, and second that it formed by crystallization from a cooling liquid. This should permit an appraisal of which better fits the observed features.

If potash feldspar formed directly by crystallization from a silicate melt and did not react with or replace other minerals (as it cannot do by crystallization at the liquidus in investigated silicate systems), then euhedral and unreplaced plagioclase grains are readily explained. There may be several explanations for the grains which are apparently corroded and replaced. They might result from intergrowth during simultaneous crystallization as suggested by Rogers (1955). In this case isolated patches of plagioclase in potash feldspar must be interconnected outside the plane of the thin section.

If the crystallization history of a granodiorite magma is approximately correct (as outlined in a later section) then at the beginning of the crystallization of potash feldspar the plagioclase would already have crystallized from 60 to 80 per cent of its final bulk. If the grains of plagioclase all nucleate simultaneously and grow uniformly then intergrowth by simultaneous crystallization with potash feldspar could occur only on narrow peripheral zones of the grains. If the final grain of plagioclase forms a cube 3 mm to a side the side would be 2.53 and 2.79 mm when the crystallization of the grain was 60 and 80 per cent complete, respectively. If the tabular form of the plagioclase crystals is such that the sides are in the ratio of 3:2:1 at all stages in the grain growth, and the sides are 3, 2, and 1 mm when the grain is completely grown, the sides would be 2.25, 1.68, and 0.84 mm when the growth is 60 per cent complete, and 2.79, 1.86, and 0.93 mm when 80 per cent complete. Under these conditions there is no possibility of an intergrowth into the core of the plagioclase grains, though this is a common feature of the granitic rocks.

There is the possibility that plagioclase grains nucleated over a long range of time in the magma so that some grains may not have begun to grow until potash feldspar began to crystallize. In this way intergrowths by simultaneous crystallization could be produced. Plagioclase nucleated at this time in the crystallization history should be extremely sodic throughout, and could not be in the range of the plagioclase generally found in the rocks. Much of the "replaced" plagioclase is too calcic to have originated under these conditions.

The plagioclase may have simply been resorbed due to changes in conditions in the magma, and subsequently the corroded and resorbed grains may have been engulfed by potash feldspar, and appear to be replaced by that mineral. This does not offer a very good explanation for the fact that some grains included by potash feldspar are euhedral whereas others of similar composition are included by the same grain and apparently are replaced.

The inadequacy of the explanation in the preceding paragraph is a difficulty also in an explanation of the apparent replacement textures by a potash metasomatism which is independent of a magmatic history. If the potash feldspar grew entirely by replacement in solid rocks it might happen that some plagioclase grains engulfed in the growing potash feldspar are replaced and others not, but the reasons for such circumstances are rather obscure. It might be that plagioclase grains within a certain range of crystallographic orientation relative to the encroaching potash feldspar grain can be replaced and others not. A grain of plagioclase which cannot be replaced by one orientation of potash feldspar may be replaced by another. In this manner, perhaps, inclusions of potash feldspar within plagioclase within potash feldspar may develop, and may reach the stage in which potash feldspar is included in potash feldspar with the two grains separated by an incomplete plagioclase strip.

Replacement of plagioclase grains by potash feldspar may be differential because of more fracturing in some plagioclase crystals than in others. It may be related to the proximity of the plagioclase grains to the center of nucleation of the potash feldspar, or to the source of the replacing material.

The possibility of simultaneous crystallization producing the textures through intergrowths seems to be rather implausible. The textural relations illustrated in figures 30, 31, 32, and particularly 43 seem to demand a replacement of plagioclase by potash feldspar and indicate that the potash feldspar is a very much later mineral in the crystallization sequence. Whether or not the potash feldspar crystallizes under conditions in which the plagioclase is corroded is difficult to prove, but such features as the plagioclase strips strongly indicate that it does.

In the writer's opinion the most comprehensive and logical explanation of all the textural relations of potash feldspar and plagioclase involves non-reactive magmatic crystallization of the two feldspars together during the early part of the crystallization of the potash feldspar. This is followed by a period in which the relatively calcic plagioclase becomes progressively more unstable in the magma (possibly because of the concentration of water in the magma as discussed in a later section), and in which the potash feldspar remains as a stable phase and continues to crystallize. Under these conditions some plagioclase may be mantled by a protective armour of potash feldspar in the early stages and some may be replaced in the later stages. The two sets of conditions are assumed to have merged smoothly so that the second is a direct descendant of the first and may occur uniformly throughout the rock mass. An independent potash metasomatism could not be expected to produce such a uniform texture (and mode) throughout the rock.

Under these conditions a granitic magma may produce a uniform and predictable modal composition throughout the rock even though evidence of replacement of minerals by potash feldspar is found everywhere from contact to contact.

Several features of the interrelations of orthoclase, albite and anorthite may be important in the "pseudomorphic" replacement of the relatively sodic plagioclase mentioned above. The solid miscibility of potash feldspar and soda feldspar is well known, and even at low temperatures the content of one in the other may be a very significant amount (Bowen and Tuttle, 1950, Yoder et al, 1957, and Tuttle and Bowen, 1958). At high temperatures they are miscible in all proportions except at high water vapour pressures. In contrast to this, under plutonic conditions at least, is the extremely limited mutual solid solubility of potash feldspar and anorthite (Yoder et al, 1957). Thus it is apparent that potassium may proxy for sodium in albite but cannot substitute for calcium in anorthite; nor will the lattice of plagioclase containing appreciable anorthite tolerate potassium.

There is evidence to support the belief that low temperature albite and anorthite have limited mutual solid solubility (Bowen and Tuttle, 1950; Laves, 1954). It was found that plagioclase in the compositional range An 30 to An 70 is made up of submicroscopic intergrowths of An 30 and An 70. Laves believes, further, that plagioclase in the range An 5 to An 17 is made up of two phases with compositions close to An 0 to An 30.

These factors are evidently important in regard to the replacement of plagioclase by potash feldspar. The replacement of albite need involve little more than the substitution of potassium for sodium, with only minor lattice reconstruction. On the other hand, the replacement of anorthite by potash feldspar would involve essentially complete destruction of the lattice in order that the Si to Al ratio be changed from 1:1 to 3:1.

Several features of the pseudomorphic replacement of plagioclase by potash feldspar suggest that the orientation of the replacing mineral is rigidly controlled by the structure of the replaced mineral. The fact that cleavage seems to be continuous from one mineral to the other is one such feature. Perhaps more convincing are the replacement blebs of potash feldspar in an antiperthitic pattern in the sodic plagioclase. The evidence also suggests that the orientation of the potash feldspar may change in imitation of Carlsbad twins in the plagioclase. It is not proved that there is a constant crystallographic relationship between the two minerals, but this is suggested; in fact it is implied if the replacement takes place by the simple substitution of ions with but minor lattice reconstruction. The possibility of such a relationship is the basis for the use of the term pseudomorphic replacement.

The structure of plagioclase more sodic than An 30 is basically that of albite, and replacement by potash feldspar need not involve major reconstruction of the lattice. The replacement may be further facilitated by the fact that, at the elevated temperatures involved, the potash feldspar may retain considerable sodic plagioclase in solid solution. Some of this may later be exsolved in what amounts to a reversal of the replacement process.

"Pseudomorphic" replacements of this type are typical of the occurrence of potash feldspar in Yukon group rocks high in the section and far removed from any known granitic rocks. It seems reasonable to assume that the temperature was lower there than deeper in the section in close association with the granitic rocks. In higher grade metamorphic rocks and in the granitic rocks similar replacements are common wherever the plagioclase is sufficiently sodic.

In the outer zone of Drury quartz monzonite in which the plagioclase is sodic and is commonly "pseudomorphically" replaced the potash feldspar could also replace plagioclase without regard to orientation. A single grain of potash feldspar may partly replace one plagioclase grain "pseudomorphically" and partially replace another of completely different orientation. In the rare cases in which plagioclase more sodic than An 30 is found deep in the zones of continuous granitic rocks potash feldspar may occur as both the typical large inclusion-rich grains and as pseudomorphic replacements.

There is considerable evidence that quartz as well as plagioclase is replaced by potash feldspar in the granitic rocks of Glenlyon Range. Biotite may also be replaced, but the evidence is not so conclusive. It does seem, however, that all three minerals (plagioclase, quartz, and biotite) were unstable and subject to replacement by potash feldspar during part of the crystallization of the rock.

Tuttle (1952) and Tuttle and Bowen (1958) suggest that the exsolution and migration of sodic plagioclase from potash-rich alkali feldspar is responsible for the formation of perthite, plagioclase strips on the mutual contacts of adjacent potash feldspar grains, and independent albite grains in two-feldspar alkali granites. Such a process might logically be extended to include the origin of some of the features of rocks in which the plagioclase is more calcic and in which the feldspars can definitely be considered to have formed as independent phases. In the more calcic rocks analogous features to those described by Tuttle are common; that is potash feldspar is usually perthitic and has plagioclase strips on its contacts. In addition there are the sodic replacements of plagioclase which are independent of the proximity of potash feldspar and the sodic rim replacements and sodic myrmekitic overgrowths which are characteristic of contacts between potash feldspar and plagioclase.

There is little reason to doubt that the exsolution of sodic plagioclase from alkali feldspar is the origin of film, regular vein, probably most irregular vein, and some of the patch perthite. In the large, inclusion-rich potash feldspar grains which contain and partially replace many orientations of plagioclase, and may also replace quartz and biotite, the perthitic elements cannot be regarded as remnants of a single plagioclase orientation. In general, perthitic plagioclase is much more sodic and much less altered than "rock" plagioclase; this is particularly true of films and regular veins. The plagioclase elements of perthite were not observed to cross grain boundaries or even, except in rare and exotic "flame" perthite, to accumulate in abnormally large amounts at the boundary of a potash feldspar grain. The lamelli rarely cross the composition plane of Carlsbad twins in potash feldspar. It seems that the plagioclase might most reasonably be expected to have originated from within the host crystal. This conclusion is supported by many petrologists (Alling, 1938; Emmons et al, 1953; Goodrich and Kinser, 1939; etc.). Experimental evidence is also in accord with this view (Tuttle and Bowen, 1958).

The higher the temperature the greater the mutual solid solubility of the two alkali feldspars. This is true regardless of the origin of the feldspar, be it igneous or metamorphic. It is important to note that the slope of the solvus curve, or curves, is steeper in the lower temperature regions (Tuttle and Bowen, 1958), hence alkali feldspar formed at relatively low temperature in metamorphic rocks may remain as a single phase upon cooling, and potash feldspar formed in such an environment may be non-perthitic. This is the case in Yukon group schist far removed from the granitic rocks.

In the granitic rocks of Glenlyon Range potash feldspar which is partly perthitic and partly not could probably be shown by X-ray to be all perthitic with some of the plagioclase lamelli of submicroscopic size (Tuttle, 1952). In general all the potash feldspar of the granitic rocks is perthitic. If plagioclase is replaced by potash feldspar at a sufficiently high temperature the replacing mineral may retain considerable amounts of albite in solid solution. In some of the potash feldspar crystallized directly from a liquid it may also contain a significant quantity of albite. If the conditions responsible for the two occurrences occur simultaneously, or merge smoothly, then the permissible albite content of each may be about the same.

In the rocks of Glenlyon Range the plagioclase strips on the contacts between potash feldspar grains are in many cases remnants of partially replaced plagioclase (e.g. fig. 43). They are found in both metamorphic and granitic rocks. Some of these strips may form by exsolution and migration of albite from within the potash feldspar grain as has been suggested by Tuttle (1952 and 1958). Where this is the case one might expect to find that the plagioclase in the strips is in parallel optical orientation to the perthitic plagioclase lamelli in one or other of the adjoining potash feldspar grains. This is so because the plagioclase in the strips must replace one or other of the potash feldspar grains in the same sense that the perthitic plagioclase must replace its host. One would also expect that the plagioclase in the strips would be compositionally similar to that in the perthitic intergrowths. Neither of these conditions holds in the rocks of Glenlyon Range. The plagioclase in the strips is rarely if ever optically parallel to true perthitic lamelli, and it is seldom if ever compositionally similar. The plagioclase in the strips is similar in composition and alteration to the "rock" plagioclase in contrast to the more sodic perthitic plagioclase, and it is sometimes optically parallel to "rock" plagioclase grains and may even be physically connected to them (fig. 43).

Some of the plagioclase strips are certainly remnants left by partial replacement of plagioclase. In many cases there is no clear evidence, but the nature of the plagioclase in the strips as outlined above indicates that most if not all of it has a common origin.

The discussion of myrmekite is included in this section for the same reasons that its description was included with that of the texture of potash feldspar. Though myrmekite involves an intergrowth of quartz and plagioclase it occurs only where plagioclase is in contact with potash feldspar in the rocks of Glenlyon Range, and hence the presence of potash feldspar is evidently required for its formation. Myrmekite seems to reflect the environment of the formation of potash feldspar rather than that of plagioclase.

The writer has no definite opinion regarding the origin of myrmekite in the granitic and metamorphic rocks. In those rocks in which the plagioclase is more calcic than An 30 a definite overgrowth of sodic myrmekitic plagioclase develops, and these overgrowths do not involve replacement of the original plagioclase grain. In those rocks in which the plagioclase is less calcic than An 30 and more calcic than An 20, an overgrowth may form or the quartz vermicules may develop directly in the original plagioclase. When the plagioclase is more sodic than about An 20 no overgrowths develop and quartz forms directly in the grains.

In some cases the contacts of myrmekitic overgrowths and potash feldspar are intricately embayed, which suggests that one has replaced the other. Roddick (1955) found cases in which quartz vermicules extended into the potash feldspar and, rarely, were isolated in it. This implies that potash feldspar may replace myrmekitic plagioclase. Rogers (1955) considered myrmekite to have formed by crystallization of albite and quartz, simultaneously, with the final crystallization of potash feldspar from a magma. This view is not in accord with the facts that myrmekite may develop in metamorphic rocks and that the quartz vermicules may develop within the body of the "rock" plagioclase. Neither does it support Roddick's observations.

The evidence indicates that myrmekite develops altogether later than the "rock" plagioclase, but it may form simultaneously with potash feldspar. There is apparently a necessity for myrmekite to form at the contacts of potash feldspar and plagioclase except where solid plagioclase is "pseudomorphically" replaced. In those cases where the plagioclase is more calcic than about An 30 myrmekite cannot form without the development of a sodic plagioclase overgrowth. These factors show that the common features of all the myrmekite are that it forms on the mutual contacts of potash feldspar and plagioclase and that in order for it to form the plagioclase actually involved in the intergrowth must be more sodic than about An 30. The development of overgrowths is not a necessary condition.

Myrmekite may develop on contacts where the plagioclase has been replaced and also where it has not. The former of these, at least, suggests that it forms as some sort of a reaction between solid crystals, perhaps aided by the action of intergranular solutions. That the conditions may be essentially metamorphic is shown by the occurrence of myrmekite in metamorphic rocks. This is in general agreement with the conclusions of Drescher-Kaden (1948) expressed in an English summary of his work by Rogers (1953).

The ubiquitous sodic rims that are a replacement of relatively calcic plagioclase on its contacts with potash feldspar seem to be a "front" ahead of replacement. They are best developed on those contacts where plagioclase is replaced even though a myrmekitic overgrowth may be formed. The replacement of plagioclase seems to be a two-stage process whereby it is first replaced by more sodic material, then by potash feldspar.

Large grains of potash feldspar in Peak granodiorite and in the core and intermediate zones of Drury quartz monzonite may include grains of any of the other minerals. These inclusions may show any or all of the textural features, between themselves, and within themselves, that they do when not included. Where these minerals show evidence of strain the enclosing potash feldspar may appear to be unstrained. This suggests that the potash feldspar crystallized at a later time than the bulk of the other minerals.

The best explanation of these circumstances is that the minerals were strained during the period when the granitic masses were mobile and intruding into their present sites. Potash feldspar, or most of it, evidently was not crystallized at this time; it presumably was retained in the fluid fraction that allowed the mobility of the rock masses. When potash feldspar began to crystallize the mass lost its mobility or could no longer cause protoclastic textures to develop. Indeed the period of crystallization of potash feldspar might have been one of recrystallization and annealing of the strained early minerals.

The final stage of the development of the texture of the granitic rocks was essentially metamorphic and extended into the associated metamorphic rocks. All the important features of the texture of potash feldspar in the granitic rocks can be duplicated, in one place or another, in the metamorphic rocks of the Yukon group. Thus there is evidence that the final stage of crystallization of the granitic rocks involves a metamorphic or metasomatic process even though it may, and probably does, have a magmatic ancestry.

The Texture of Biotite: The texture of biotite in Peak granodiorite and the core and intermediate zones of Drury quartz monzonite is uniform throughout. In all these rocks biotite seems to have begun to crystallize very early in the sequence and may be included by grains of quartz or potash feldspar. It may be replaced by potash feldspar in some places. Nothing about the texture of biotite seems to favour any one particular origin for the large masses of granitic rocks.

In the outer zone of the quartz monzonite the biotite is finer grained, has a strong preferred orientation, and with quartz forms a matrix for the feldspars. Here the biotite may be included by plagioclase, which is unusual in other parts of the quartz monzonite. In the outer zone the biotite is similar to that in the associated schist in every respect.

The Texture of Quartz: The "intergrowth" relationship between the quartz grains of an aggregate (fig. 25) in the large masses of granitic rocks in Glenlyon Range is a very characteristic feature. The degree of granularity of the quartz in Peak granodiorite is about the same as that in the core of Drury quartz monzonite. In the quartz monzonite the degree of granularity of the quartz is greater in the intermediate zone than in the core and still greater in the outer zone. This increase in granularity is part of, and parallels, a general increase in the "metamorphic look" of the quartz monzonite from zone to zone.

The present texture of the quartz may be one of recrystallization and grain growth of more highly granular material, or it may be one of the granulation of less granular material. The intergrowths might have developed under either set of conditions and there is no apparent convincing evidence favouring one origin over the other. In the granitic rocks quartz grains which have been involved in minor shear zones are granulated and do not show any intergrowth patterns. Highly granular and non-granular quartz may fit around and include plagioclase and biotite grains that show no more than normal effects of stress in either case. Quartz inclusions in potash feldspar may be granular or non-granular indicating that it was at least as granular as it is now when it was included. These factors might suggest, but do not prove, that the present texture of quartz in the large masses of granitic rocks reflects a most recent history of recrystallization and grain growth.

The granular texture, as such, plus the common strain shadows in quartz suggest that there was a period of stress and granulation at one time in the history of the mineral. The fact that strain shadows in isolated quartz inclusions in potash feldspar may be seen to pass evenly from inclusion to inclusion implies, as does other evidence, that the quartz was strained prior to the formation of potash feldspar but also suggests that there has been little subsequent recrystallization.

Aside from the inclusions of granular and non-granular quartz in potash feldspar, the age relation of these two minerals is shown by the veinlets of potash feldspar which cut the quartz and may connect with large potash feldspar grains which include quartz. The assertion by Chayes (1952) that the granularity of quartz, as an index of strain, can be related to the degree of exsolution of albite from alkali feldspar does not appear to hold for the granitic rocks of Glenlyon Range.

The straight contacts of quartz against potash feldspar may be inherited from other minerals since replaced by potash feldspar. There is no evidence, however, that many of such contacts originated in this way. Some may have developed during the process of replacement of quartz by potash feldspar as suggested by Stringham (1953) who concluded that quartz, when replaced by potash feldspar, could assume euhedral outlines. This conception is supported to some degree by the relation of potash feldspar to granular quartz in which, while the contacts are nearly straight, there are small changes of direction from grain to grain of quartz. If such a process is operative, it certainly is not in all cases, for locally the contacts of the two minerals are very complex. Perhaps some of the straight contacts are crystal faces of quartz which formed in open space prior to or during the early stages of the crystallization of potash feldspar. There is little evidence to support this possibility. Such faces are common only in the large masses of granitic rocks where the degree of granularity is least. They do not occur in the outer zone of the quartz monzonite or in the alaskite.

In the hornblende-biotite-quartz diorite quartz is not granular. It forms grains which fill in around the other minerals in such a manner that a single grain may appear in several isolated places in a thin section. It has no apparent replacement relations to the other minerals and is quite evidently the youngest mineral in the rock. Its texture suggests that it crystallized in open spaces.

The Texture of Plagioclase: In Peak granodiorite and in the core and intermediate zones of Drury quartz monzonite plagioclase characteristically occurs in clots of randomly oriented grains. Zones may be transected by the contacts of the grains. The termination of zones at the grain boundaries, however, is not necessarily evidence of fracturing and breaking of the grains because in almost every case that was observed the zones are terminated only where the plagioclase is in contact with another plagioclase grain (exclusive of those cases in which replacement by potash feldspar is a factor).

The termination of zones at grain boundaries in clots of plagioclase grains might have been produced by the growth of grains in contact. At the common boundary of two plagioclase grains no zones will develop, but they will develop around the free faces of each grain. In some cases one grain of a pair in contact may gradually engulf the other and produce an even more complex relationship. If the clots of plagioclase grains formed in this way they indicate, in concert with other factors, that the plagioclase formed very early in the sequence and probably at the beginning of crystallization. Such a relationship between the plagioclase grains suggests that they formed in an environment in which they could move about freely and become aggregated into clots, and having done so could grow freely without interference from other minerals, with the possible exception of biotite. These features, and the zoning itself, are most reasonably explained on the basis of a magmatic origin for the rocks.

Plagioclase grains are commonly decidedly bent and broken, and there may have been movements on the breaks. Some and perhaps all of the discontinuous zones may have been formed by dislocations of plagioclase grains.

In the large masses of granitic rocks in Glenlyon Range clots of plagioclase grains with terminated zones may be included within a single grain of potash feldspar. Obvious fracturing in included plagioclase may not be reflected in the enclosing potash feldspar. As is the case with quartz and biotite the plagioclase seems to have been in essentially its present form prior to the crystallization of the bulk of the potash feldspar. These factors suggest that plagioclase, quartz, and biotite were involved in a stress environment that had ceased to exist, or in which the stresses were much less intense, when the bulk of the potash feldspar was formed. Intrusion of mobile granitic magma during which protoclastic textures were developed in the early minerals provides a logical explanation for the observed relationships.

The plagioclase of the outer zone is unique in the rocks of Drury quartz monzonite. It is weakly zoned or unzoned, does not commonly occur in clots of grains, characteristically contains inclusions of quartz along with biotite, and "floats" in a matrix of schistose fine-grained quartz and biotite. If the rocks in this zone originated by the crystallization of magma then it is evident that quartz and biotite were the first phases to crystallize, and they developed their present form prior to the crystallization of plagioclase. It also implies that the plagioclase crystals grew from the magma and were able to include the older minerals without disturbing their orientation. Another and perhaps more reasonable explanation is that the plagioclase grew as porphyroblasts in a schistose matrix of quartz and biotite as it undoubtedly did in the associated metamorphic rocks.

Field relations, plus the fact that plagioclase and other minerals in the hornblende-biotite-quartz diorite show no evidence of having been subjected to severe stresses, indicate that this rock, in its many occurrences, was never mobile and intrusive, but formed primarily by reactions in the solid state with, perhaps, a minor amount of pore magma or fluid.

The plagioclase of the intrusive alaskite dykes forms weakly zoned grains which do not occur in clots and do not seem to have been distorted and fractured although the evidence would be hard to detect. This plagioclase commonly includes grains of quartz and in this regard is similar to that of the outer zone on the quartz monzonite. It is suggested that the quartz that is partly granular and partly non-granular was the dominant crystalline phase at the time of the intrusion of the dykes and that most of the plagioclase crystallized after the intrusive activity had ceased.

Granitic rocks may form by granitization and may never be mobilized and intrusive. Where this happens one would expect that the minerals in the granitic rocks and in the immediately associated metamorphic rocks of similar bulk composition would be almost identical in composition and texture. In the core and intermediate zones of Drury quartz monzonite the plagioclase is strongly zoned and occurs in complex clots, but in the "granitic" schist associated with these rocks the plagioclase is more sodic, is unzoned, does not occur in complex clots, and shows little evidence of distortion and fracturing. Even if delicate oscillatory zoning can develop in a metamorphic environment, which is doubtful, one still must conclude that the two types of plagioclase have had a different origin. It is concluded that the quartz monzonite is intrusive, and this conclusion is strengthened by the fact that the texture of the core, and to a lesser extent of the intermediate zone, can be duplicated in every detail in the texture of Peak granodiorite which is more obviously an intrusive mass.

The situation of the outer zone of the quartz monzonite, however, is different. Here the plagioclase in the granitic and metamorphic rocks is very similar in composition and texture. On this basis it is possible that the granitic rocks of this zone could have formed by the transformation of metamorphic rocks in situ.

In Peak granodiorite and the core and intermediate zones of Drury quartz monzonite there is much evidence that the crystallization of plagioclase was interrupted by abrupt changes in conditions. The crystallized plagioclase seems suddenly to have been involved in an environment in which the plagioclase in equilibrium was very much more sodic. This led to sharp compositional changes far in excess of the normal changes from zone to zone in the early more calcic plagioclase. Furthermore the late sodic plagioclase is not zoned and may irregularly replace the zoned grains to the extent that the original material remains only as disconnected remnants.

Sodic replacements of this type are independent of the occurrence of potash feldspar but may very well be related to the ubiquitous sodic replacement rims in plagioclase that is in contact with potash feldspar. These sodic replacements are difficult to assess in terms of abundance, and they may amount to a very significant proportion of the total plagioclase.

Another type of compositional discontinuity occurs in the plagioclase of the hornblende-biotite-quartz diorite, less commonly in Drury quartz monzonite, and rarely in Peak granodiorite. Highly calcic weakly zoned or unzoned plagioclase may be replaced or engulfed by distinctly zoned, more sodic, material. In Drury quartz monzonite the zoned plagioclase is identical to the bulk of the "rock" plagioclase. In the quartz diorite, oscillatory zones do occur in the more sodic plagioclase, but progressive zoning is more common. These features may be readily explained on the basis that highly calcic plagioclase was suddenly placed in an environment with which it was violently out of equilibrium. In the quartz monzonite and granodiorite the calcic plagioclase crystals might have been zenoliths in a magmatic environment, or they may have formed from the magma at the beginning of crystallization, and because of some special conditions, did not react and become progressively more sodic for a considerable period.

In the quartz diorite the calcic plagioclase is quite evidently similar to that in the amphibolite. The quartz diorite is believed to have formed by the reaction of rocks similar to amphibolite with quartz monzonite magma, and it is quite possible that partial melting took place. The calcic plagioclase might have been violently out of equilibrium with a pore magma or with emanations from the adjacent quartz monzonite melt. The quartz of the quartz diorite is believed to have crystallized directly from a small fraction of melt developed in these rocks. Most of the unzoned calcic plagioclase in the quartz monzonite occurs in rocks that are transitional to the quartz diorite, and it may be inferred that these transitional rocks originated either by the more complete fusion of limy metamorphic rocks or by the contamination of quartz monzonite magma;

they may well represent a combination of these two circumstances. The calcic plagioclase is readily explained under either of these circumstances.

Summary of Some of the Important Aspects of the Textures: The textures of the large masses of the granitic rocks of Glenlyon Range indicate that a significant proportion of the potash feldspar originated by the replacement of other minerals. The best evidence is for the replacement of plagioclase, but quartz and possibly biotite may have been replaced also. A good explanation for all the features observed is that potash feldspar began to crystallize as a normal magmatic mineral under conditions with which all the other minerals were in equilibrium, and continued to crystallize from the magma under conditions with which the other minerals were no longer in equilibrium. The above statement does not imply that all the minerals came into disequilibrium with the magma at the same time.

A significant part of the plagioclase of these rocks also originated by the replacement or reaction with early formed minerals, particularly calcic plagioclase. The textures indicate that there was a rather sudden change in conditions in the magma whereby the early plagioclase, with oscillatory zones, was replaced, probably by magmatic reaction, by much more sodic unzoned plagioclase. It is presumed that this sodic replacement is related to, and developed simultaneously with the sodic rims on plagioclase in contact with potash feldspar. In the late stage of crystallization it seems that only potash feldspar and soda feldspar were stable phases though quartz may also have been stable for a very long period in the crystallization history. The crystallization of plagioclase does not reflect a continuous series of reactions. It must be emphasized that there appears to have been a discontinuity in the reaction series.

There is much evidence that potash feldspar began to crystallize very late in the sequence. The other minerals apparently were involved in a stress environment prior to the formation of potash feldspar. A period of intrusion during which protoclastic textures were developed seems to offer the best explanation of this relationship.

Replacement of plagioclase more calcic than about An 30 by potash feldspar involves major reconstruction of the replaced lattice, but the replacement of more sodic plagioclase need involve little more than the substitution of potassium for sodium in the lattice with little reconstruction necessary. The replacement of calcic plagioclase by potash feldspar must be accompanied by very considerable changes in composition, as the amount of anorthite that can be retained in solid solution in the potash feldspar is negligible. On the other hand the replacement of calcic plagioclase by sodic plagioclase may involve much less transfer of material in that there may be a compromise in composition between the replacing and the replaced material.

The complete identity in texture between Peak granodiorite and the core of Drury quartz monzonite leads to the conclusion that both have a similar history and originated in a similar way. Thus, because Peak granodiorite is intrusive, it is concluded that the core and probably the intermediate zone of the quartz monzonite are intrusive. This is supported by the fact that the minerals, particularly plagioclase, in the quartz monzonite core and intermediate zones are different from those in the immediately associated "granitic" schist. If the quartz monzonite formed by the transformation of rocks in situ then the minerals in the two rocks should reflect a similar history. Mineralogical and textural similarities to schist are consistent with a granitization origin for some of the small bodies in the outer zone of the quartz monzonite.

The texture of the hornblende-biotite-quartz diorite can be interpreted, in harmony with field relations, as being the product of reactions between amphibolite or limy metamorphic rocks and quartz monzonite magma.

In the alaskite only quartz shows evidence of having been severely stressed. If the strain is the result of stresses set up during intrusion then it can be inferred that the alaskite was largely fluid when intruded, and that quartz was a dominant phase of the crystals which existed. The alaskite normally forms clear-cut intrusive dykes, but in a few places it seems to pass gradationally into quartz monzonite. This may be the result of interactions caused by the intrusion of fluid material into incompletely crystallized quartz monzonite.

Summary of the Paragenetic Sequences Indicated by the Textures of the Various Granitic Rocks: The paragenetic sequence of the minerals is of some importance in the discussion of the mode of origin of the rocks. It is presented below in summarized form for the various rock types.

1. Peak granodiorite and the core and intermediate zones of Drury quartz monzonite:

a. Plagioclase and biotite have mutually interfering contacts, and one may include the other. Neither includes quartz or potash feldspar (except as obvious replacements). These are the oldest minerals, and they seem to have begun to crystallize about simultaneously.

b. Quartz fits around the euhedral outlines of plagioclase and biotite and may include them. Quartz began to crystallize after plagioclase and biotite and before potash feldspar. The three older minerals show possible protoclastic textures that do not occur in potash feldspar.

c. Potash feldspar replaces, veins, and includes all the other minerals. It is youngest.

2. Outer zone of Drury quartz monzonite:

a. Quartz and biotite form a fine-grained schistose matrix which is commonly deformed and curved around grains of both plagioclase and potash feldspar. Quartz and biotite appear to be the oldest minerals. They are similar, in every respect, to the same minerals in the associated schist.

b. Plagioclase includes both quartz and biotite and the included minerals show the same textural features as when not included. There seems little doubt that plagioclase is younger than the matrix minerals.

c. Potash feldspar replaces and includes all the other minerals; it is youngest.

3. Hornblende-biotite-quartz diorite:

a. Plagioclase rarely includes hornblende or biotite, but its form is mutually interfering with them. It may have been the first mineral to begin crystallization in the rock as it now exists.

b. Both hornblende and biotite may include plagioclase, though biotite more commonly does so; also one of these minerals may include the other. It would seem that plagioclase, hornblende, and biotite crystallized together for a considerable period.

c. Quartz fits around and includes the other minerals. It formed very late in the sequence.

4. Alaskite:

a. Quartz is granular in part and is included by the two feldspars. It may have begun to crystallize before or about simultaneously with plagioclase.

b. Plagioclase includes quartz, but the two minerals may have had a long history of simultaneous crystallization. Plagioclase does not show much evidence of strain.

c. Potash feldspar includes and replaces the other minerals and formed late in the sequence.

Modal Compositions

Accuracy of Modal Analyses: The validity of petrographic modal analyses on thin sections combined to give a measure of the true mode of large bodies of granitic rocks is open to some question. The problems involved have been discussed at considerable length by Chayes (1956). He shows that the coarser the effective grain size of the rock the larger the number of thin sections that must be analysed in order to obtain the true mode of a single sample of the rock. He also gives evidence to show that the larger the areas of the individual thin sections used the fewer the number that must be analysed to obtain a significant mode of the sample.

When one is faced with the problem of determining the modal composition or compositions of large, medium-grained, inequigranular, granitic masses such as those of Glenlyon Range, the number of individual analyses becomes prohibitive if one follows the recommendations of Chayes. If the rocks are compositionally homogeneous in any given mass the number of analyses required is greatly reduced, but one cannot tell if the mass is homogeneous without making a large number of analyses from many samples.

Chayes' recommendations are undoubtedly based on sound statistical principles, but one is forced to compromise in terms of practical application. The method used by the writer is, perhaps, best explained along with the results obtained as discussed in the succeeding pages.

Of first concern is the reproducibility of analyses on single thin sections. This was tested on two thin sections, one of Peak granodiorite and one of the intermediate zone of Drury quartz monzonite. Three point count analyses were made on each thin section. In two of the analyses the traverses were along the length of the thin sections but were begun at different points; in one of the analyses on each section the traverses were made across the length. Different traverse spacings were used in the analyses of one of the thin sections. The results of these tests are shown in table 1.

The average modal composition for each thin section was determined from the total points counted in the three runs. The deviations for individual runs are the differences between the results of each run and the appropriate average composition.

From the table it can be seen that the maximum deviation, for any one mineral in thin section 4, is 1.6 per cent. Of the 12 deviations of the minerals in this section, 6 are less than 1 per cent. In thin section 22, none of the deviations is as large as 1 per cent; the maximum

TABLE 1

	Potash feld. %	Dev.	Plag. %	Dev.	Quartz %	Dev.	Biotite %	Dev.	Total Pts.
Run 1	23.1	0.4	41.5	0.2	24.7	1.2	9.8	1.5	1432
2	21.6	1.1	43.3	1.6	22.9	0.6	11.3	0.0	1322
3	23.3	0.6	40.5	1.2	23.0	0.5	12.4	1.1	1710
Average	22.7	0.7	41.7	1.0	23.5	0.8	11.3	0.9	4464
Thin section 4, Specimen 9-C-49-1; Peak granodiorite									
Run 1	36.2	0.3	27.4	0.8	29.0	0.5	6.6	0.1	1325
2	37.1	0.6	25.5	0.9	29.7	0.2	7.2	0.5	1438
3	36.1	0.4	27.1	0.5	29.8	0.3	6.2	0.5	1392
Average	36.5	0.4	26.6	0.7	29.5	0.3	6.7	0.4	4155
Thin section 22, Specimen 21-M-53-6; Drury quartz monzonite									

Thin section 4,
Run 1 across section, traverse spacing 1.25 mm
2 along section, " " 1.50 mm
3 " " " " 1.25 mm

Thin section 22,
Run 1 along section, traverse spacing 1.50 mm
2 " " " " 1.50 mm
3 across " " " 1.50 mm

The results of reruns of point count modal analyses on two thin sections are shown. The deviations listed with the mode of each run are from the average modes of the three runs. The deviations listed with the average modes are the mean deviations of the three runs.

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is 0.9 per cent. The data show that the deviations are not least for biotite which is the least abundant mineral in the rock; they are about the same for all the minerals. Thus the deviation of reproducibility for biotite is a much greater percentage of the abundance of that mineral than it is for the other minerals.

For the average number of points counted in these tests, and with the traverse spacings used, one can expect to be able to reproduce the results of point count modal analyses on thin sections of the granitic rocks of Glenlyon range within 1 per cent, on the average, for each major mineral.

The variation of the mode of the granitic rocks within a single thin section is of interest in this study. To investigate this the tally may be taken and the mode calculated at various stages in the analysis of a thin section. This was done for two of the runs on thin sections 4 and 22 and was also done on 14 other thin sections. The plotted results of these analyses are shown in Appendix figures A1 to A5. In Appendix figure A6 the differences in mode between roughly half and complete analyses are shown for 8 other sections.

As a test of the differences in mode at various stages in the analysis of single thin sections the differences for counts of from 600 to 800 points (about half analyses) to those of completed analyses were determined for the 26 thin sections tested. The arithmetic means of these differences or deviations for the four major minerals are 2.04, 2.49, 1.82, and 0.89 per cent for potash feldspar, plagioclase, quartz, and biotite respectively. If the differences are summed according to sign and averaged for the 26 analyses they are 0.27, 0.28, 0.35, and 0.07 per cent for the minerals in the same order as above. While this is not a valid method of determining the average difference or mean deviation to be expected, it does show that the differences tend to compensate.

In these analyses the spacing of the traverses was 1.5 mm, and the points were spaced 0.25 mm apart; the area of the sections is such that a total of from 1300 to 1400 points could be counted on most of them. This test indicates that one might expect the average mode determined from a group of thin sections, each of which is only half the area of those used in the test, will not be significantly different from the average mode determined from the analyses of full sized sections. This point is important because many of the analyses in this work were made on small thin sections upon which an average of about 800 points could be counted with the traverse and point spacing as specified.

One might expect that there will be large differences in the modes of thin sections cut from the same specimen of the granitic rocks of Glenlyon Range. To check this, 5 thin sections were made from each of two specimens, one from Peak granodiorite and one from the intermediate zone of Drury quartz monzonite. The sections were made from parallel slices cut from the specimens so that for each group of 5 slices the most distant would not be over 1.5 inches apart (the slices were cut from a block measuring about 1.5 x 1.5 x 0.75 inches). The results of these analyses are shown in table 2.

The deviation of each analysis from the average of the appropriate group of 5 can be determined and these too are shown in table 2. The mean deviations for each mineral in the 10 analyses combined are 3.4, 4.3, 4.8, and 1.0 per cent of potash feldspar, plagioclase, quartz, and biotite respectively. These mean deviations are much larger than those found for the modes of half analyses as compared to completed analyses. This supports the validity of the use of analytical data from small thin sections.

Presumably the differences in mode found in thin sections cut from the same hand specimen is a function of texture. Consider a grain of potash feldspar, or a clot of plagioclase grains, or an aggregate of quartz grains in a square area 7 mm to a side. The maximum number of points that could be counted on such an area is 145 (with traverse spacing of 1.5 mm and point spacing of 0.25 mm). In an analysis in which the total points number 1300 this represents 11.15 per cent of the total. If there is one too many or one too few of such masses in a thin section the mode may deviate from the true value by as much as 12 per cent for any mineral except biotite which is fine grained and uniformly distributed (as is indicated by its mean deviation of 1 per cent). Thus in a group of thin

TABLE 2

Thin Sect	Potash feld. %	Dev.	Plag. %	Dev.	Quartz %	Dev.	Biotite %	Dev.	Total Pts.
4	22.7	3.6	41.7	1.2	23.5	3.8	11.3	1.4	1450
4A	22.0	2.9	42.9	0.0	23.9	3.4	10.3	0.4	1071
4B	14.6	4.5	37.2	5.7	36.3	9.0	11.2	1.3	1471
4C	21.2	2.1	49.2	6.3	19.5	7.8	9.2	0.7	1271
4D	16.0	3.1	44.7	1.8	31.4	4.1	7.3	2.6	1464
Average	19.1	3.2	42.9	3.0	27.3	5.6	9.9	1.3	6727
Specimen 9-C-49-1; Peak granodiorite									
22	36.5	9.8	26.6	10.1	29.5	1.8	6.7	1.3	1450
22A	24.0	2.7	40.8	4.1	24.5	3.2	9.5	1.5	1611
22B	25.3	1.4	36.4	0.3	29.5	1.8	7.9	0.1	4153
22C	24.1	2.6	32.3	3.9	34.5	6.8	7.8	0.2	1175
22D	23.5	2.6	46.1	9.4	21.8	5.9	7.6	0.4	1364
Average	26.7	3.8	36.7	5.6	27.7	3.9	8.0	0.7	7053
Specimen 21-M-53-6; Drury quartz monzonite									

Two sets of data are shown for point count modal analyses made on different thin sections cut from the same hand specimen. The deviations listed for each single analysis are from the average mode of the group of five and the deviations shown with the average are the mean deviations.

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sections cut from a single specimen the modal abundance of any of the more coarse-grained minerals (e.g. plagioclase) may differ by as much as 24 per cent from one section to another. Generally, in the granitic rocks of Glenlyon Range, deviations from this cause will be less than the theoretical maximum because the minerals do not usually form individual grains or aggregates 7 mm square, and potash feldspar, even though it may form large grains, is usually rich in inclusions.

The tabulated data for all the modal analyses made in this study are shown in Appendix table 1, and for each group of modes the averages are shown. The averages of the 5 analyses made on the single sample of Peak granodiorite are, for each mineral, within 2.3 per cent of the averages of all the analyses made on thin sections from the pluton. Similarily the averages of the 5 analyses made on sections from the single sample from the intermediate zone of Drury quartz monzonite are all within 2.7 per cent of the averages of all analyses made on thin sections of that mass. This suggests, but certainly does not prove, that the average mode of 5 thin sections cut from a single hand specimen is a good approximation of the true mode of the specimen, and that the granitic rocks in Glenlyon Range in any one unit may be sufficiently homogeneous that a small specimen is a good sample of the whole. A great deal more information is required before these conclusions are proved.

The data discussed above indicate that insofar as specimens are taken at random and sections are cut from them at random the average mode of all analyses on an apparently homogeneous granitic rock, from a single body or group of closely related bodies in Glenlyon Range, is a good approximation of the average mode of the rock. Extremely detailed sampling would be required to show minor changes in the mode of the rocks within one group, and a large number of analyses would have to be made. This is so because only the average of many analyses is significant, hence minor changes, or even more important progressive changes from one part of a body to another, may be obscured.

Modes calculated from counts taken at various stages in the analyses of two thin sections of hornblende-biotite-quartz diorite are very uniform throughout (Appendix fig. 7A). The mode of completed analyses (about 1300 points) is indicated within 1.5 per cent when only 500 points are counted. This information indicates that the use of small thin sections for modal analyses of this fine-grained rock is a valid procedure.

The Calculation of Average Modal Compositions: As has been mentioned, the granitic rocks of Glenlyon Range fall into distinct groups such as Peak granodiorite and Drury quartz monzonite, and these in turn fall into subsidiary groups based on geographic position and geologic relations.

The average modes as listed in Appendix table 1 were determined by summing the points for each mineral species from all analyses made of each group or sub-group. This method is based on the premise that the bigger the thin section the larger the volume of rock it accurately represents, though as has been shown the differences involved are apt to be small.

The averages were computed initially from small thin sections (33 of Peak granodiorite and 53 of Drury quartz monzonite) which gave an average of about 800 points each. There is doubt that such small sections give significant analytical data, and because of such doubt some of the tests described in the preceding section were made. As a further test of the validity of the use of the small thin sections additional modal data were added by the analyses of larger thin sections (giving an average of 1300 points each). These thin sections were cut from specimens that had already been used for the purpose. These duplicate analyses were incorporated in the final averages for each rock group. In no case did the addition of data make large changes in the average modes. The effect of the duplication is distributed because the samples used were selected at random and from all rock groups. The actual changes are discussed in the succeeding sections.

The Modal Composition of Peak Granodiorite: Peak granodiorite was sampled most heavily in the vicinity of Glenlyon Peak hence the data discussed below represent the modal composition of a sample area (plate 3). The modal data of Peak granodiorite are summarized in table 3. The table shows the average mode of each sub-group of samples and of all the samples combined. The averages of the original analyses are given separately from those of the duplicate analyses for each group and for the whole

TABLE 3

PEAK GRANODIORITE MODAL DATA

		Potash feld. %	Plag. %	Qtz. %	Biot. %	Total Points
S.W.Contact						
Orig. mean;	7 anal.	17.1	38.6	32.0	11.5	5830
Dupl. mean;	3 "	14.2	43.2	28.1	13.1	4534
Final mean;	10 "	15.8	40.6	30.4	12.2	10364
Median	10 "	15.2	40.6	30.4	12.1	
Mean Dev.	10 "	4.1	4.1	3.7	2.6	
Std. Dev.	10 "	4.9	4.5	4.5	3.0	
Mean Dev. S.W.Cont. from all Pk. Gd.		4.9	4.3	3.7	2.9	
S.W.Slope						
Orig. mean;	8 anal.	18.8	40.5	30.6	10.0	5675
Dupl. mean;	3 "	17.8	42.0	26.4	12.8	4086
Final mean;	11 "	18.4	41.7	28.8	10.7	9761
Median	11 "	18.4	41.5	29.1	9.0	
Mean Dev.	11 "	8.0	6.2	8.6	2.9	
Std. Dev.	11 "	9.2	7.8	11.9	3.4	
Mean Dev. S.W.Slope from all Pk. Gd.		8.0	6.3	8.4	2.8	
Central Zone						
Orig. mean;	10 anal.	20.4	43.1	26.4	9.2	8045
Dupl. mean;	3 "	15.7	42.8	31.2	9.1	4129
Final mean;	13 "	18.8	43.0	28.0	9.2	12174
Median	13 "	17.3	42.3	29.2	9.3	
Mean Dev.	13 "	6.7	5.8	5.4	0.8	
Std. Dev.	13 "	7.7	7.1	6.2	1.0	
Mean Dev. Cen. Zone from all Pk. Gd.		6.6	5.9	5.3	1.0	
N.E. Slope						
Orig. mean;	8 anal.	21.2	38.1	30.9	8.8	6899
Dupl. mean;	3 "	20.9	40.2	30.0	7.0	3680
Final mean;	11 "	21.1	38.8	30.6	8.2	10579
Median	11 "	17.7	36.3	28.2	9.1	
Mean Dev.	11 "	6.5	4.1	7.2	1.9	
Std. Dev.	11 "	7.0	4.5	7.8	2.6	
Mean Dev. N.E.Slope from all Pk. Gd.		5.9	4.3	7.0	2.1	

TABLE 3
(Continued)

			Potash feld. %	Plag. %	Qtz. %	Biot. %	Total Points
Peak Granodiorite overall							
Orig. mean;	33	anal.	19.5	40.5	29.7	9.6	26449
Dupl. mean;	12	"	17.0	42.2	28.8	10.6	16429
Final mean;	45	"	18.5	41.2	29.3	10.0	42878
Median	45	"	17.4	41.0	29.1	9.8	
Mean Dev.	45	"	6.4	5.3	6.1	2.1	
Std. Dev.	45	"	7.7	6.5	8.2	2.9	
Duplicate Data							
Mean Dev.	12	anal.	4.0	3.1	3.2	2.8	
Std. Dev.	12	"	5.3	3.6	4.3	3.5	

The table shows the average modes of the four groups of Peak granodiorite and of all the data combined. The medians are also listed. The averages are given for original data and the additional or duplicate data. For each group the mean and standard deviations are given along with the mean deviation of the analyses of each group from the average of all the groups. Finally the mean and standard deviations of the duplicate data are given separately.

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mass. The medians are also given, and these are merely the middle analysis of any one group, or the arithmetic mean of the two middle analyses if there is an even number.

The mean deviations are given for each group, for all the data combined, and for the duplicate analyses treated as a separate mass of data. The mean deviation is the arithmetic mean of the difference or deviation for any one mineral from the average of that mineral in all the data. The standard deviation, also listed, is calculated from the formula $D = \sqrt{\frac{\Sigma x^2}{N}}$; where x is the deviation for any one mineral in a single analysis and N is the number of analyses. If the data have a normal frequency distribution, 68 per cent falls within a distance equivalent to one standard deviation on either side of the arithmetic mean. The deviations give a measure of the spread of the data.

Point count modal analyses were performed originally on 33 thin sections of Peak granodiorite, from which a total of 26,449 points were counted. Subsequently 12 more thin sections were analysed and these were cut from samples from which 12 of the original 33 thin sections had been made. The averages of the groups of data differ by 1.5, 1.7, 0.9, and 1.0 per cent for potash feldspar, plagioclase, quartz, and biotite respectively (table 3). In the sub-groups some of the differences are larger, though many are very small. The differences in the sub-groups can be attributed mainly to the fact that the additional or duplicate data involves too few analyses to give a meaningful average.

The mean and standard deviations show, as is verified by the frequency distribution curves for the minerals in the analyses (figs. 58 and 59), that the spread of the values of modal abundance for all the minerals is rather large. The deviations for potash feldspar and quartz are largest and are the least for biotite. The data are not uniformly distributed across a given range, however, rather they are grouped (the curves are peaked), and the averages appear to be significant quantities in terms of the real modal composition of Peak granodiorite. This is shown by the fact that the original and duplicate data give very similar average abundances and that all the averages of the sub-groups fall within a narrow range of the combined averages. The greatest deviation for any mineral in any sub-group from the combined averages is 2.7 per cent. Only 4 of the 16 deviations are over 2 per cent and 5 are between 1 and 2 per cent. The average modes of any one sub-group could be changed by at least the amount of the deviations by the addition of about 30 per cent more duplicate data. On this basis it could be argued that the deviations result from sampling error alone and do not represent real differences in composition from group to group.

The mean and standard deviations of the duplicate analyses considered as a separate mass of data are relatively small (table 3). The implication of this is that those data may more accurately represent the true average mode of the sample area of Peak granodiorite than do the original data. It is interesting that there are certain consistent changes brought about by the addition of data. In each sub-group and in the overall data the average abundance of potash feldspar is reduced and in all but one sub-group (in which there is little change) the average of plagioclase is increased. The average for quartz varies up and down and in the final average changes very little, and that of biotite generally is increased.

In general the addition of data tends to bring the average values closer to the median values. The median is not much affected by the unbalance of extreme ranges in values, and it may provide a better approximation of the true mode of Peak granodiorite than does the average. The main difference between the median and average values in the combined data is the reduction in the value for potash feldspar.

There may be real changes in composition within Peak granodiorite, but if so they are not systematic. The effect of such changes (if they exist) is to produce a wide range in the data. It seems that extremely detailed sampling would be required to outline zones of distinctly different composition from the main mass of the pluton.

Within the area sampled in detail the average (or perhaps the median) composition determined from all the analyses made of Peak granodiorite seems to be a good approximation of the effective modal composition of that body. It cannot be denied that there may be real changes from place to place.

<u>The Modal Composition of Drury Quartz Monzonite:</u>

Table 4 is a summary of the modal data of Drury quartz

TABLE 4

DRURY QUARTZ MONZONITE MODAL DATA

			Potash feld. %	Plag. %	Qtz. %	Biot. %	Total Points
Core							
Orig. mean;	15	anal.	20.2	39.4	30.0	9.3	12320
Dupl. mean;	3	"	14.0	42.9	31.2	11.0	3752
Final mean;	18	"	18.8	40.2	30.3	9.7	16072
Median	18	"	20.3	40.3	30.0	9.1	
Mean Dev.	18	"	4.5	4.4	3.6	2.0	
Std. Dev.	18	"	6.0	5.5	4.6	2.6	
Intermediate Zone							
Orig. mean;	25	anal.	26.9	34.3	30.3	7.6	22299
Dupl. mean;	6	"	26.2	35.4	29.9	7.6	7525
Final mean;	31	"	26.7	34.6	30.2	7.6	29824
Median	31	"	27.1	35.4	30.2	7.1	
Mean Dev.	31	"	6.4	3.9	3.0	2.6	
Std. Dev.	31	"	7.6	4.7	4.0	3.2	
Intermediate Zone Divide Ridges only							
Orig. mean;	14	anal.	27.8	33.9	30.2	7.3	12254
Dupl. mean;	4	"	26.7	35.4	28.9	8.1	5043
Final mean;	18	"	27.5	34.4	29.8	7.5	17297
Mean Dev.	18	"	7.5	4.2	3.3	3.2	
Std. Dev.	18	"	8.5	5.0	4.5	3.8	
Intermediate Zone Duplicate Data only							
Mean Dev.	6	anal.	5.4	4.1	1.7	2.3	
Std. Dev.	6	"	6.2	4.7	2.2	2.9	
Outer Zone							
Orig. mean;	9	anal.	23.7	33.9	32.6	8.1	7054
Dupl. mean;	3	"	18.6	35.9	30.5	13.8	3717
Final mean;	12	"	22.0	34.5	31.9	10.1	10771
Median	12	"	23.2	35.2	32.2	9.9	
Mean Dev.	12	"	6.5	3.8	3.8	3.5	
Std. Dev.	12	"	7.6	4.4	4.1	4.1	
Drury Quartz Monzonite Overall							
Orig. mean;	53	anal.	24.2	35.9	30.6	8.2	44964
Dupl. mean;	13	"	20.8	37.3	30.6	10.3	16062
Final mean;	66	"	23.2	36.2	30.7	8.7	61026
Std. Dev.	66	"	9.5	5.1	4.3	3.4	

The table shows the modal averages for the three zones of Drury quartz monzonite broken up in terms of original, duplicate, and final averages. Also shown are mean and standard deviations for each group and the overall average of the quartz monzonite with the standard deviations calculated from grouped data.

monzonite and gives information similar to that given for Peak granodiorite in table 3. The standard deviations for the combined data of the quartz monzonite are calculated from grouped rather than individual values.

Both the original and duplicate data of the core of the quartz monzonite contain analyses from an apparently anomalous sample. The effect of this sample is very pronounced in the additional data from 3 thin sections, and is primarily responsible for the large difference between the original and duplicate averages. It may be that this sample should have been included with the rocks thought to be a transitional phase between the quartz monzonite and the hornblende-biotite-quartz diorite, but no definite evidence of this was found. Other than these 2 analyses the data for the core are extremely well grouped and cover a narrow range. The average and the median values differ by 1.5 per cent (for potash feldspar) and one or the other is considered to be a good representation of the composition of this mass, though it must be admitted that the sampling is inadequate.

The averaged results of the original and duplicate data of the intermediate zone of Drury quartz monzonite are almost identical; the largest difference is 1.1 per cent. This fact, coupled with the similarity in average mode of four of the five sub-groups (see Appendix table 1), strongly suggests that the determined average from all the data is a good approximation of the true modal composition of the intermediate zone.

There is good reason to believe that there is a real compositional difference between the core and the intermediate zone of Drury quartz monzonite. Quartz shows very little change, but the other minerals all differ by significant amounts. The average modes differ by 7.9, 5.6, 0.1, and 2.1 per cent for potash feldspar, plagioclase, quartz, and biotite respectively. There is a rather striking difference in the frequency distribution of the minerals in the two zones (figs. 58 and 59).

The medians are the middle analyses in each group. None of the analyses of the core contains potash feldspar above the median value of the intermediate zone, and only 19 per cent of the intermediate zone analyses have potash feldspar less than the median for that mineral in the core. This offset in concentration of values is shown in the frequency distribution curves, which show the proportion of the data within 5 per cent intervals. The proportions of the data within 5 per cent intervals were taken at 2.5 per cent divisions so that each curve is determined by points at distances representing 2.5 per cent. For biotite the intervals are 2 per cent and the distance between points represents 1 per cent. The curve for potash feldspar in the intermediate zone shows the wide range of values, but the main bulk is well offset from the sharp peak of the curve for the core.

Plagioclase also shows an offset in concentration of values, although the difference is not so wide as for potash feldspar. None of the analyses of the intermediate zone has plagioclase in greater amount than the median for the core, and only 22 percent of the core analyses have it of smaller amount than the median for the intermediate zone. There is considerable overlap in the values, but the offset is obvious in the curves.

Quartz is similar in average amount, median value, and deviations in the two zones.

There are differences in biotite. In the analyses of the core only 11 per cent (2 of 18 analyses) contain biotite of smaller amount than the median of the intermediate zone, and 26 per cent of the intermediate zone analyses have it greater than the median of the core. There is considerable overlap, but the peaks of the curves seem definitely to be offset.

If the computed average compositions for the core and intermediate zones of Drury quartz monzonite could be incorrect by the amount of the mean or standard deviations then possibly there might be no difference in mode between the two zones. On the other hand the true values could be farther apart than the determined averages. The rather distinct offset of data seems to show conclusively that there is a difference in modal composition between the two zones. It is quite possible, however, that the core passes gradationally and erratically into the intermediate zone. That this is the case may be shown by the wide range of values in the analyses of the intermediate zone, which leads to low rather than high "peaks" in the frequency distribution curves for potash feldspar, plagioclase, and biotite.

Perhaps there are discrete masses, essentially identical to the core, in the intermediate zone. The granitic rocks in the small area on the northeast ridge of Skarn Ridge (toward Canyon Mountain) may provide an actual illustration of this. Only 3 samples and 4 sections of this rock were available, so the data are too few to be conclusive; however, the average mode of the 4 analyses made is very close to that of the core, and the rock may be more closely related to the core than to the intermediate zone with which it is included.

Another body of doubtful affiliations is the quartz monzonite which underlies the southern portion of Caribou Ridge. At its northern contact with Yukon group schist this rock is, texturally, very similar to the outer zone of Drury quartz monzonite on Canyon Mountain, whereas near its southern boundary, south of Caribou Ridge, the texture and mode of the only specimen available (thin section 18-C-54) is much more typical of the intermediate zone. Again the data are too few for a sound conclusion, but the suggestion of a transition from the intermediate to the outer zone is certainly supported by the location and geologic relations. Because of the uncertainty regarding this body it is not placed with either zone. It seems to be more closely related to the outer zone, but this is probably due to the fact that 3 of the 4 samples are from the northern part; a sampling in proportion to bulk might show a definite affiliation to the intermediate zone.

The outer zone of Drury quartz monzonite is known, in terms of its modal qualities, entirely from samples collected from the vicinity of Canyon Mountain (plate 4). Probably some of the small bodies farther west and southwest are similar; they are similar texturally. The possibility of the rocks on Caribou Ridge being of similar nature has been discussed. Unfortunately, little is known of the granitic body which evidently underlies the valley of East Tummel River and its surrounding hillsides directly east of Fairway Hill. What little is known of this body suggests that it is not similar to the outer zone, at least in texture. It may be an intrusive of material similar to the core. It seems to grade upward into alaskite and may be related to the Fairway dyke. This body is classed as Drury quartz monzonite but is given no affiliations to any of the zones.

The modal data of the outer zone is rather unusual in respect to the rest of Drury quartz monzonite. Only 9 samples were used for analyses and 3 duplicate sections were made. The outstanding feature of the data is that the deviations for potash feldspar and biotite are very large and encompass almost the whole range found in the core and intermediate zones combined. Plagioclase and quartz, on the other hand, are well "peaked" in distribution. The frequency distributions show some similarities to the intermediate zone, but it seems certain that the outer zone does not represent the end stage of a continuous change from the core through the intermediate zone. The two peaks in the potash feldspar and biotite curves suggest that there may be an admixture of two rocks of different modes; one rich in potash feldspar and poor in biotite and the other reversed. This may be shown, also, by the fact that the average of biotite changed by a rather large amount from the addition of data from duplicate thin sections. The duplicates do not represent the whole range of composition.

The core of Drury quartz monzonite is a large mass and certainly has been inadequately sampled if its true modal composition is to be determined with confidence. The samples collected are from widely scattered localities, but because of the rather narrow frequency distribution of the minerals in the modes, and the apparent homogeneity of the rocks in the field, it may be that the core is well represented by the 15 samples and 18 analyses. If the average composition of Drury quartz monzonite was calculated by combining the three zones in terms of their relative bulk, then the composition, overall, would be similar to the average of the core. This average is very close, in feldspar ratio, to the division between granodiorite and quartz monzonite (taken to be potash feldspar: plagioclase as 33.3:66.7), and it may be that the small effects of the intermediate and outer zones, which qualify as quartz monzonite, would bring the whole mass into that range. Within the area of interest, at least, the overall rock is definitely quartz monzonite.

Comparison of the Mode of the Core of Drury Quartz Monzonite to that of Peak Granodiorite: In Appendix table 1 it will be seen that the average modes of the core of Drury quartz monzonite and of Peak granodiorite are remarkably similar. The largest difference, for any one mineral, is 0.8 per cent for plagioclase. This must be regarded as highly coincidental, but it does imply that the two bodies have very similar modal compositions. The chemical composition of the plagioclase and the texture in each are also similar.

The frequency distribution curve for potash feldspar in the granodiorite is much less peaked and more widely spread than is that for the core of the quartz monzonite. If the two anomalous analyses of the core of the quartz monzonite are neglected then all the analyses contain potash feldspar in the range between 14.6 and 26.7 per cent. This same interval contains 47 per cent of the values for potash feldspar in the analyses of Peak granodiorite. Of the analyses of the granodiorite, 22 per cent have potash feldspar above this range and 31 per cent have it below. If there is a real difference in the content of potash feldspar one would expect the granodiorite to contain less of it than the core. In general the two groups of analyses are well centered around a common peak value.

The frequency distribution curve for potash feldspar in Peak granodiorite suggests that the rock has a bimodal character at least in the content of potash feldspar. It seems at least as likely that the shape of the curve results from the accident of sampling. The low in the curve which causes the secondary peak exists mainly because one 5 per cent interval (20 to 25 per cent) contains very few values. Whether or not Peak granodiorite is bimodal, its content of potash feldspar is, in bulk, very close to that of the core of Drury quartz monzonite.

The distribution of plagioclase in the two masses is more similar than is that of potash feldspar. The range of plagioclase in the core is from 30.5 to 52.0 per cent and this range includes 93 per cent of the results of analysis on Peak granodiorite. Fifty-five per cent of each group of data lies between 36 and 46 per cent in plagioclase abundance (roughly 5 per cent above and below the medians). The average values, the medians, and the shape of the frequency distribution curves are almost identical, thus the assumption seems warranted that the two masses have essentially identical quantities of plagioclase in their respective modes.

As can be seen in the frequency distribution curves the modal abundance of quartz in all the granitic rocks is heavily concentrated in the range 25 to 35 per cent. The quartz in the analyses of Peak granodiorite shows the greatest spread in values, and this may be a reflection of true modal variations or of larger deviations resulting from the sampling techniques. As the average quartz abundance in the combined data and in all the sub-groups of Peak granodiorite is very close to 30 per cent (i.e. in the middle of the 25 to 35 per cent range), it would seem that sampling error is as likely a cause of the wide spread of the data as modal variation. There is no apparent reason for a greater sampling error in the granodiorite than in other rocks. The samples of the granodiorite were analysed first, and perhaps personal errors occurred. One factor in support of the contention that the wide deviation results from sampling error alone (and this applies to potash feldspar and plagioclase as well) is that the mean and standard deviations of the duplicate data are much smaller than are those for all the analyses combined. The duplicate analyses were made long after the original ones and were performed on larger and better thin sections. The quartz in all the granitic rocks averages close to 30 per cent; thus one might expect little real change within Peak granodiorite.

The frequency distribution curves for biotite in Peak granodiorite and in the core of Drury quartz monzonite are very similar. About 50 per cent of the analyses of each mass contain biotite between 8 and 11 per cent, though the total spreads are very much larger. The narrow distribution and highly peaked curve of the biotite in Peak granodiorite is perhaps the best indication that the mass has effectively a single modal composition and is neither bimodal nor polymodal.

The modal data consistently indicate that Peak granodiorite and the core of Drury quartz monzonite have essentially identical modal compositions. Some evidence suggests that they are very uniform in composition from place to place, but this is difficult to prove.

<u>The Modal Composition of Hornblende-biotite-quartz Diorite</u>: The average grains in the quartz diorite are one millimeter long or less and as is shown in Appendix figure A7 the rock is uniform in composition on the scale of a single thin section. Changes in composition indicated by analyses of different sections from a single specimen are likely to be small.

The frequency distribution curves of the minerals in the analyses of 14 thin sections are shown in figure 60. Significant features of these curves are the high narrow peaks of plagioclase in the range 50 to 55 per cent and of biotite in the range 15 to 20 per cent. The quartz curve

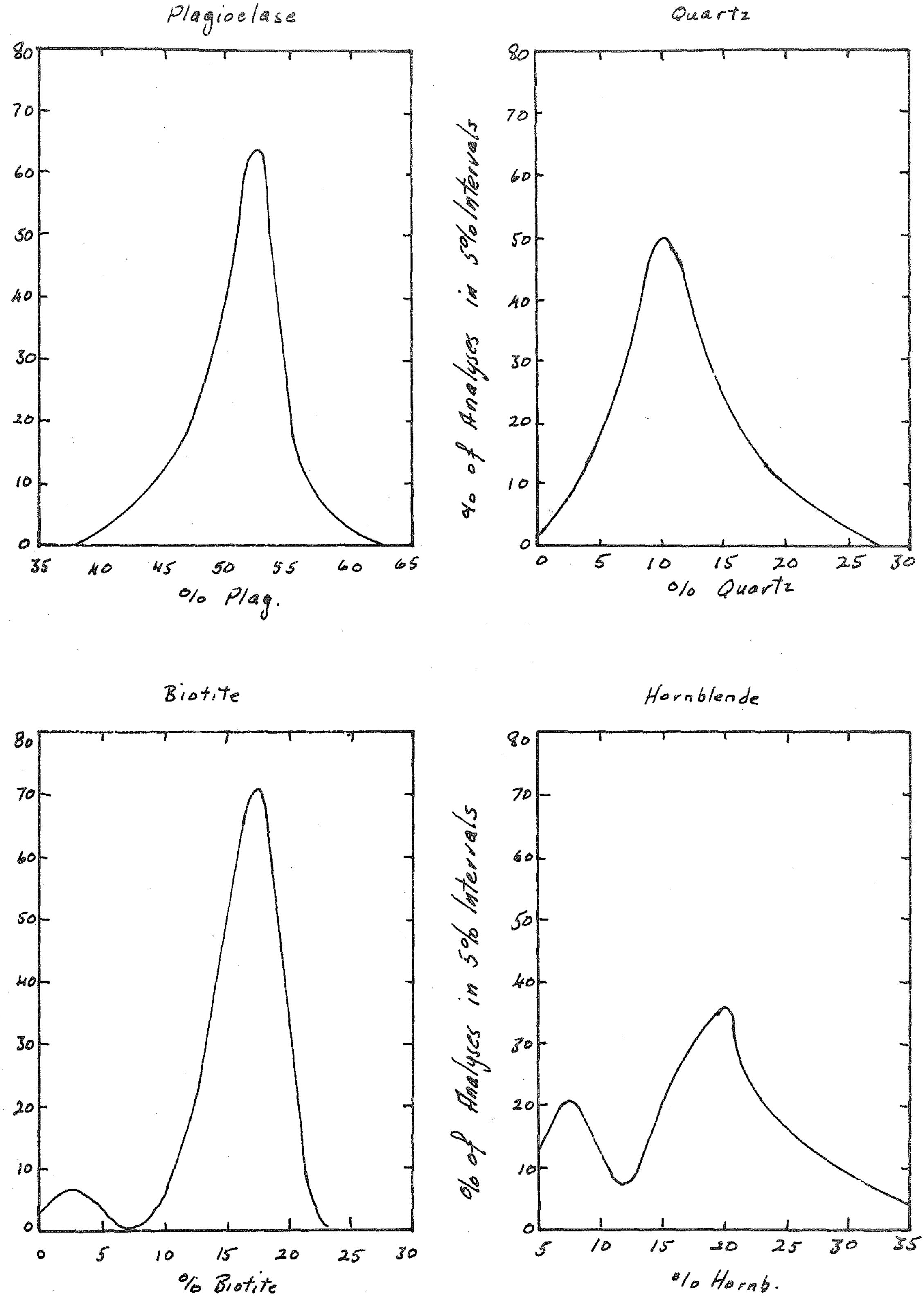

Figure 60

Frequency distribution of minerals in modal analyses of hornblende-biotite-quartz diorite, Glenlyon Range.

also has a pronounced peak in the range 7.5 to 12.5 per cent, but the spread is much wider. Hornblende, as indicated by its curve, varies over a wide range and has a much less pronounced peak than those of the other minerals.

The hornblende-biotite-quartz diorite is a fine-grained rock, and deviations in the analytical results owing to the inadequacy of a thin section as a sample of a hand specimen should be very small; they should be a small fraction of those from the same cause in Peak granodiorite or Drury quartz monzonite. The frequency distributions of the minerals in the analyses of the quartz diorite suggest that plagioclase and biotite differ little from place to place; that quartz differs a little more but is of a nearly constant amount; and that the true mode of hornblende differs appreciably from sample to sample. The uniformity in the modes for plagioclase, biotite, and quartz is remarkable in that the quartz diorite occurs in numerous small bodies, commonly between limy metamorphic rocks and quartz monzonite, and is believed to be a hybrid that resulted from the interaction of quartz monzonite magma and limy metamorphic rocks. If it is a hybrid rock it must have formed under very uniform conditions and by the interaction of essentially identical materials from place to place.

<u>The Modal Composition of Transition Rocks:</u> Analyses were made on 7 thin sections of rocks which are believed to represent transitions between biotite-quartz monzonite and

hornblende-biotite-quartz diorite. The minerals in these analyses cover extremely wide ranges in an erratic fashion. Inspection of the data in Appendix Table 1 shows that modal features which seem to distinguish these rocks are the range of quartz content between 15 and 30 per cent and the presence of hornblende between 0 and 8 per cent. Potash feldspar, plagioclase, and biotite cover wide ranges.

Mineralogically these rocks are distinguished by calcic cores in the plagioclase and by the presence of hornblende. In the field they are associated with both quartz monzonite and quartz diorite. As in the quartz diorite sphene is a common accessory, and the amount of accessory minerals is relatively high.

<u>The Modal Composition of Amphibolite</u>: Only four thin sections of the amphibolite were analysed. One of these contained appreciable diopside and a correspondingly smaller amount of hornblende. The other three are composed almost entirely of hornblende and plagioclase in which the amount of the former averages almost twice that of the latter. Here again sphene is a common accessory.

The delicate layering, parallel to bedding, and the close association with limy metamorphic rocks leaves little doubt that the amphibolite formed from sedimentary rocks by metamorphism or metasomatism or both.

Possible Transition in Mode from Amphibolite Through Quartz Diorite and Transition Rocks to Quartz Monzonite: The modal data of these groups of rocks suggest the possibility of a transition relationship.

Hornblende, the dominant mineral in the amphibolite, is of smaller and variable amount in the quartz diorite, is still less in the transition rocks, and is not found in the quartz monzonite. Quartz does not occur in significant quantities in the amphibolite, is of appreciable but variable quantity in the quartz diorite, is variable, in a higher range, in the transition rocks, and attains a still higher and uniform amount in the quartz monzonite. The anorthite content is probably similar in the amphibolite and quartz diorite, but decreases, through the transition rocks, into the quartz monzonite. Albite seems to increase progressively from the amphibolite to the quartz monzonite. If the end members of the plagioclase series change in this way the quantity of plagioclase would be highest in the quartz diorite (as it is in the modal data). Biotite first appears in the quartz diorite, becomes less as the femic constituents decrease in the transition rocks, and is the only mafic mineral in the quartz monzonite. Potash feldspar does not appear in the amphibolite or the quartz diorite in significant quantities; it is extremely variable in the transition rocks though generally of lower range than it is in quartz monzonite.

The modal data, in harmony with field and mineralogical relations, suggest that a transition could exist across these four rock types, a transition which involves continuous enrichment, from the amphibolite to the quartz monzonite of soda, silica, and potash (but not, necessarily, of potash feldspar), and a nearly continuous impoverishment of lime, iron, magnesia, and probably alumina. Enrichment in potash feldspar, as such, does not seem to begin until a definite point in the transition has been reached; potash is fixed in biotite at first. Potash feldspar apparently cannot occur in this transition until the ratio of potash, soda, and silica to lime, iron, and magnesia reaches a certain value. This relationship may be even more refined and may be a function of the ratio of soda to lime (or albite to anorthite) in the system, assuming that potash is available. It seems that the quartz diorite must have become completely crystalline before potash feldspar was a stable phase in the adjacent quartz monzonite magma.

The Modal Composition of Alaskite: Only five analyses were made of the alaskite, hence the averages are probably not very significant numbers. The analyses are consistent, however, in some important respects. First they show a small amount of biotite (hence the name alaskite). Muscovite is a common constituent; it is very uncommon in other granitic rocks except as an obvious alteration mineral. Quartz seems to be characteristically higher than 30 per cent, and perhaps the average of 35 per cent is a good approximation of its true amount. Plagioclase and potash feldspar are more widely variable, but the variations are such that the range of the former seems to be lower, and of the latter, higher, than in other granitic rocks.

These data suggest but do not prove that alaskite is richer in potash feldspar and quartz, and poorer in plagioclase, than any parts of Drury quartz monzonite. It is definitely poor in biotite.

<u>The Modal Composition of the Fairway Dyke</u>: Only four thin sections from two samples were available for modal analyses of the Fairway dyke, hence, again, the data can be considered as suggestive only.

The modes do show some definite similarities to those of alaskite in the small amount of biotite and the occurrence of muscovite. It is probably more than coincidence that quartz has a similar range to that in the alaskite. The range of variation of plagioclase and potash feldspar, however, is not different from what might be expected for any part of the intermediate or outer zones of Drury quartz monzonite. Small garnets are a common accessory mineral in this rock. The environment of the Fairway dyke, in association with the limy beds of the Harvey group, is one in which no other granitic rocks are known to occur. At the eastern end the dyke is intersected by a fault, and its continuation may be the alaskite immediately across the fault, which seems to be the upper phase of a large quartz monzonite body. The modal analysis of a single section of this alaskite gives a result almost identical to the average mode of alaskite in general.

It seems possible that the difference in mode, if there is a difference between the two parts of the dyke, might be explained on the basis of the different geological environments.

<u>The Modal Composition of Nub Hill Granodiorite</u>: Four analyses of two samples were made on this body. The range of deviations and the average mode are entirely consistent with the possibility that Nub Hill granodiorite had a similar and synchronous origin with Peak granodiorite.

<u>The Modal Composition of the Yukon Group Strata</u>: The sampling and analysis of a thick section of metasedimentary rocks in the hope of arriving at a significant average mode is probably a futile task. Such rocks might best be considered in terms of the range in the modal amounts of the minerals.

Eight analyses were made on samples of Yukon group schist from Bon Ridge in the southeastern part of the area. Here there are no closely associated granitic rocks, and because of faulting these strata may be completely removed from the influence of granitic activity. These rocks are all very low in potash feldspar content and may contain as much as 18 per cent muscovite. Garnet and apatite are the most common accessories.

The schist in association with the outer zone of Drury quartz monzonite might be thought of as being in a middle zone of granitic influence. If the six analyses made on samples from this zone represent modal differences resulting from this cause rather than normal differences in the rocks, then there is a very small increase in potash feldspar and an increase in plagioclase; muscovite is essentially absent. Accessories are rare, apatite is most common, and there is a little garnet and sillimanite, and one grain of staurolite was noted. Three samples from Divide Ridges represent the schist in an intensely granitic environment. If the changes are significant they show an increase in potash feldspar and in plagioclase over the other samples. Again muscovite is nearly absent. Thus, if the samples do show the effects of the proximity of granitic rocks on schist there is first an increase in plagioclase, and then in potash feldspar, and a rapid decrease in muscovite. No changes in quartz and biotite are obvious.

The best estimate that can be made of the "average" schist is probably the average mode of the 8 samples from Bon Ridge. In respect to the "average" mode of the Yukon group as a whole it must be remembered that an appreciable quantity of limy rocks have to be considered.

Based on field observations and the rather inadequate modal data an estimate of the modal range of all Yukon group strata might be about as follows: potash feldspar 1-3 per cent, plagioclase (An 25) 15-20 per cent, quartz 35-45 per cent, biotite 20-25 per cent, muscovite 7-12 per cent, and calcite (considering lime-silicate rocks as limestone) 2-4 per cent.

Summary of the Important Aspects of the Modal Data: For the granitic rocks of Glenlyon Range tests show that the probable deviation of half-completed point count modal analyses from completed analyses is very small for thin sections about 2 by 3 cm in area, if the traverse and point spacings are 1.5 and 0.25 mm respectively. This result is important in this work because many analyses were made on small thin sections upon which about 800 points were counted. The deviations to be expected between the modes of thin sections cut from the same small hand specimen may be very much larger.

The average modes of Peak granodiorite and the core of Drury quartz monzonite are essentially identical. Though the samples give a rather small representation of the bulk of each mass they were collected at random, and the similarity of the averages is presumably more than coincidence. If the medians give a better estimate of the true modes, the core of the quartz monzonite may be a little richer in potash feldspar than the granodiorite.

The modal data for all the minerals in Peak granodiorite covers a wide range of values, and it cannot be proved with present information if this is caused by sampling errors alone or by true changes of mode from place to place. The fact that the average modes of the sub-groups are very close to that of the combined data suggests that any real changes in mode are erratic, and within the mass no one zone can be delimited as being appreciably different in mode from the average. The duplicate data, which are about 36 per cent of the original in terms of thin sections analysed, have much smaller mean and standard deviations than the original analyses but do not differ appreciably in average mode. This also favours the argument that the wide spread of data is caused by sampling errors. It is believed that the final averages give a good approximation of the bulk modal composition of Peak granodiorite. The data of the sub-groups suggest that there may be a slight increase in potash feldspar progressively from the southwest contact toward the northeast. The median values do not show this change and it is concluded that the granodiorite is effectively very uniform in modal composition though there may be erratic changes. The immediate southwest contact may be a little poorer in potash feldspar and richer in biotite than the remainder of the mass.

There is good evidence of a change in mode between the core and the intermediate zone of Drury quartz monzonite.

This change involves an increase in potash feldspar and a decrease in plagioclase and biotite in the intermediate zone compared to the core. The change may be gradational and erratic, and masses identical to the core may occur in the intermediate zone. The gradational change is believed to be responsible for the rather wide range of the data for the intermediate zone, although again this could be a reflection of sampling errors.

The modal data of the outer zone of the quartz monzonite show that these rocks are not the end stage of a progressive change from the core through the intermediate zone. They seem to be an admixture of two compositions.

The mode of the hornblende-biotite-quartz diorite differs considerably, from sample to sample, in hornblende, differs less widely in quartz, and is very uniform in plagioclase and biotite. The data indicate that there could be a transition from the amphibolite through the quartz diorite and transition rocks, to the quartz monzonite. This transition involves enrichment in soda, silica, and potash, and removal of lime, iron, magnesia, and alumina. Potash feldspar apparently does not appear until the ratio of albite to anorthite reaches a certain value.

The alaskite is low in biotite and contains appreciable muscovite. These are definite characteristics. It may be higher in quartz than the other granitic rocks and also may be richer in potash feldspar and poorer in plagioclase. Plagioclase is definitely sodic. The definite characteristics of alaskite are reflected in the Fairway dyke.

Sampling of the Yukon group strata in the attempt to arrive at a significant average mode would be a major and, perhaps, impossible undertaking. The available data suggest that the effects of the proximity of granitic rocks are an increase in the quantity of plagioclase and finally of potash feldspar, and elimination of muscovite. Quartz and biotite seem to change little, if at all. A guess at ~~the~~ the "average" modal range of the minerals, in the Yukon group as a whole, can be made.

Variations in Mineral Abundance

General Statement: The study of the variations in mineral abundance is undertaken in an effort to determine, quantitatively, how changes in the quantity of one mineral, from sample to sample, are compensated, on the average, by changes in the other minerals in the plutonic granitic rocks of Glenlyon Range. It was hoped, originally, that this study would reveal which mineral, if any, is preferentially replaced by potash feldspar. The determined variations probably contain this information, but the result is obscured by the effects of sampling errors and real changes in modal composition.

Triangular diagrams are used for the purpose of plotting the raw modal data as the first step in the determination of the variations in mineral abundance. Each trio of the four major minerals in the granitic rocks ~~are~~ is brought to 100 per cent for all analyses and plotted on triangular diagrams. The points plotted in this manner are contoured in terms of the percentage of points per one per cent area of the diagram. If the contours show a definite linear trend then an estimated trend line is drawn through the plotted point for the average of the data used.

The data for Peak granodiorite (fig. 61), Drury quartz monzonite (fig. 63), and hornblende-biotite-quartz diorite (fig. 65) are plotted separately in this manner. Each set of data gives four triangular diagrams which, in fact, are the faces of tetrahedrons. The plotted data are projections on the faces from within the tetrahedrons. The lines representing the average trend in mineral abundance on the faces are also projections. They may represent the projections of a single line which shows the average variation in abundance in terms of all four minerals, or, if the data fall within a circular disc, then the lines are projections of various diameters of the disc, in which case the data on one of the four faces may show little or no trend.

The trend lines that may be projections of the line representing the average variation in mineral abundance can be plotted on the faces of a projection of a tetrahedron, and from them the single line within the tetrahedron can be determined, if one exists. Three-dimensional diagrams with the construction and final variation lines are shown in figures 62, 64, and 66 for Peak granodiorite, Drury quartz monzonite, and hornblende-biotite-quartz diorite, respectively.

A possible reason for the variations found in any granitic rock is sampling error. If the variations result entirely from sampling error they should, theoretically, be predictable; that is, if the true mode of the rock is known then the variations of one mineral should be compensated, on the average, in a definite ratio by the other minerals. In Peak granodiorite, in which plagioclase, quartz, potash feldspar, and biotite are about in the ratio of 40:30:20:10, a given variation of potash feldspar should be compensated, on the average, by plagioclase, quartz, and biotite in the ratio of 4:3:1. This concept assumes that all the minerals are subject to the same degree of sampling error, which is very probably not the case. Potash feldspar forms the largest grains and should be most susceptible to sampling error, quartz next, then plagioclase, then biotite. Thus variations in potash feldspar from sampling error alone should be compensated mostly by quartz, a little less by plagioclase, and little, if at all, by biotite.

If variations by any one of potash feldspar, plagioclase, and quartz are compensated on the average about equally by the other two minerals, and little, if at all, by biotite (because biotite in all analyses is close to its true modal abundance), then the data will fall on the potash feldspar-plagioclase-quartz face of the tetrahedron within a roughly circular area and in terms of all four minerals will be in a flat disc within the tetrahedron. On the faces including biotite at one apex the data will fall in patterns showing strong linear trends and the lines representing these trends will be projections of various "diameters" of the disc. If all the samples were ideal, and there were no real variations in the mode, then all the data would plot at a single point.

Another effect will appear in these diagrams. There might be real changes in composition from place to place in the rock, and these changes, rather than being random, might involve, say, enrichment in potash feldspar and corresponding reductions in plagioclase and biotite with little change in quartz. In this case the data would plot, in three dimensions, within an elongate ellipsoid. The long axis of the ellipsoid, which is the trend line representing the average variation in abundance, will show that variations in potash feldspar are compensated mainly by plagioclase and biotite and very little by quartz. In this case, if all samples were ideal, the data should fall along a straight line.

Another feature of the variation in mineral abundance diagrams is that they show, perhaps more convincingly than the frequency distribution curves, that the analyses for Peak granodiorite and Drury quartz monzonite are not just a random scattering of values. They show strong concentrations of points. This is true also for hornblende-biotite-quartz diorite for which the diagrams, while not contoured, show good concentrations of values either around a point or along a line.

Variations in Mineral Abundance in Peak Granodiorite: The study of the modal data of Peak granodiorite indicates that the pluton is effectively homogeneous in modal composition, but there may be erratic and local compositional variations which could be detected only by extremely detailed sampling. Within the area sampled there does not appear to be any systematic and large scale compositional variation. Differences between the average modes of the sub-groups within the granodiorite can be explained entirely on the basis of deviations to be expected from sampling errors.

The mineral abundance variation diagram (fig. 61) shows that the modal data are concentrated within rather narrow limits around the average values, although the total spread of the data is quite large. The maximum concentration of points per one per cent of the total area of each face of the tetrahedron varies from 14 to 26 per cent of the total number of points. The maximum concentration

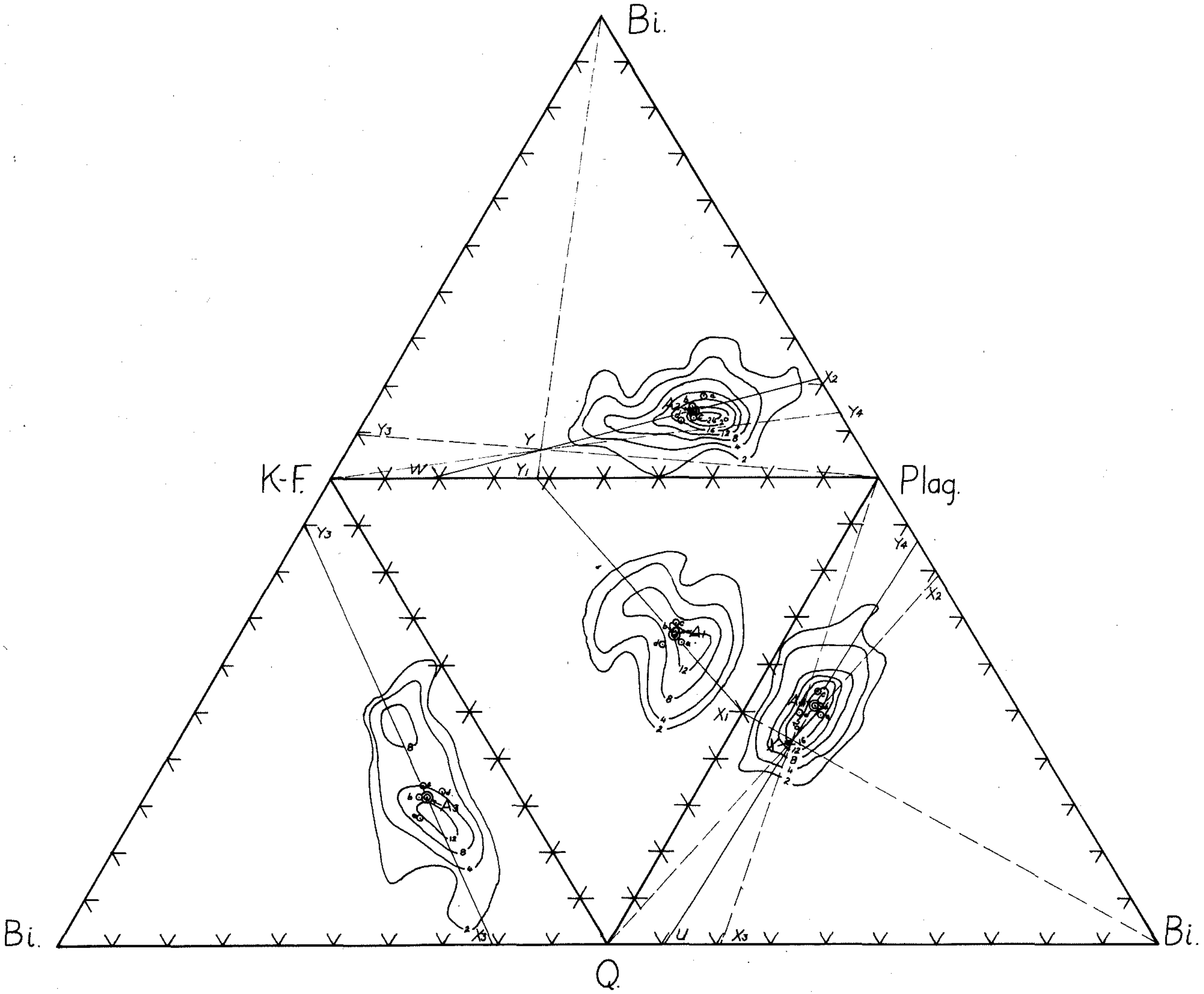

Figure 61

Variations in mineral abundance: Peak Granodiorite.

Opened tetrahedron representing the four mineral phases. The contours represent the percentage of the total of 49 points in 1% areas of the total area of each face. The points (not shown) are the locations of 49 modal analyses plotted in terms of each three of the four mineral phases. A_1, A_2, etc. represent the computed average modal composition plotted on each face; a, b, c, and d represent the average modes of the southwest contact, southwest slope, central zone, and northeast slope respectively. Solid lines $X_1A_1Y_1$, X_2A_2YW, etc. are the estimated trends of the average variation on each of the four faces. The dashed lines are construction lines from which the terminations, X and Y, of the trend line, in terms of all four phases, are determined.

within 4 per cent of the total area varies from 38 to 60 per cent. The total spread of the data varies from 14 to 19 per cent of the total area. The average distribution of data on the four faces is as follows: the average maximum proportion of points per one per cent area is 20 per cent; the average maximum proportion of points per 4 per cent area is 50 per cent; and the average total spread of the data is 17.5 per cent of the total area. On the average, 20 per cent of the data lies in 5.7 per cent of the area covered by data and 50 per cent lies in 22.8 per cent. The modal data show a rather wide spread of values but also indicate a strong concentration.

The base of the tetrahedron in the opened form (fig. 61) and in the projection (fig. 62) is the potash feldspar-plagioclase-quartz face. Biotite is at the apex of the tetrahedron.

The contours on the basal face do not show a strong linear trend, and the line drawn to represent the average variation in mineral abundance may be considerably in error; indeed, possibly no such line exists. The contouring on the base suggests that variations of potash feldspar are compensated by quartz only slightly more than by plagioclase. It may be more correct to say that variations in any one of the three minerals are compensated by the other two in roughly equal proportions. The contours on the side faces of the tetrahedron (which include biotite) all show well

Variations for a + 20 % variation in K-Feldspar

	Average	Expected
Plag.	- 3.0 %	- 10.2 %
Quartz	-14.9 %	- 7.3 %
Biotite	- 2.1 %	- 2.5 %

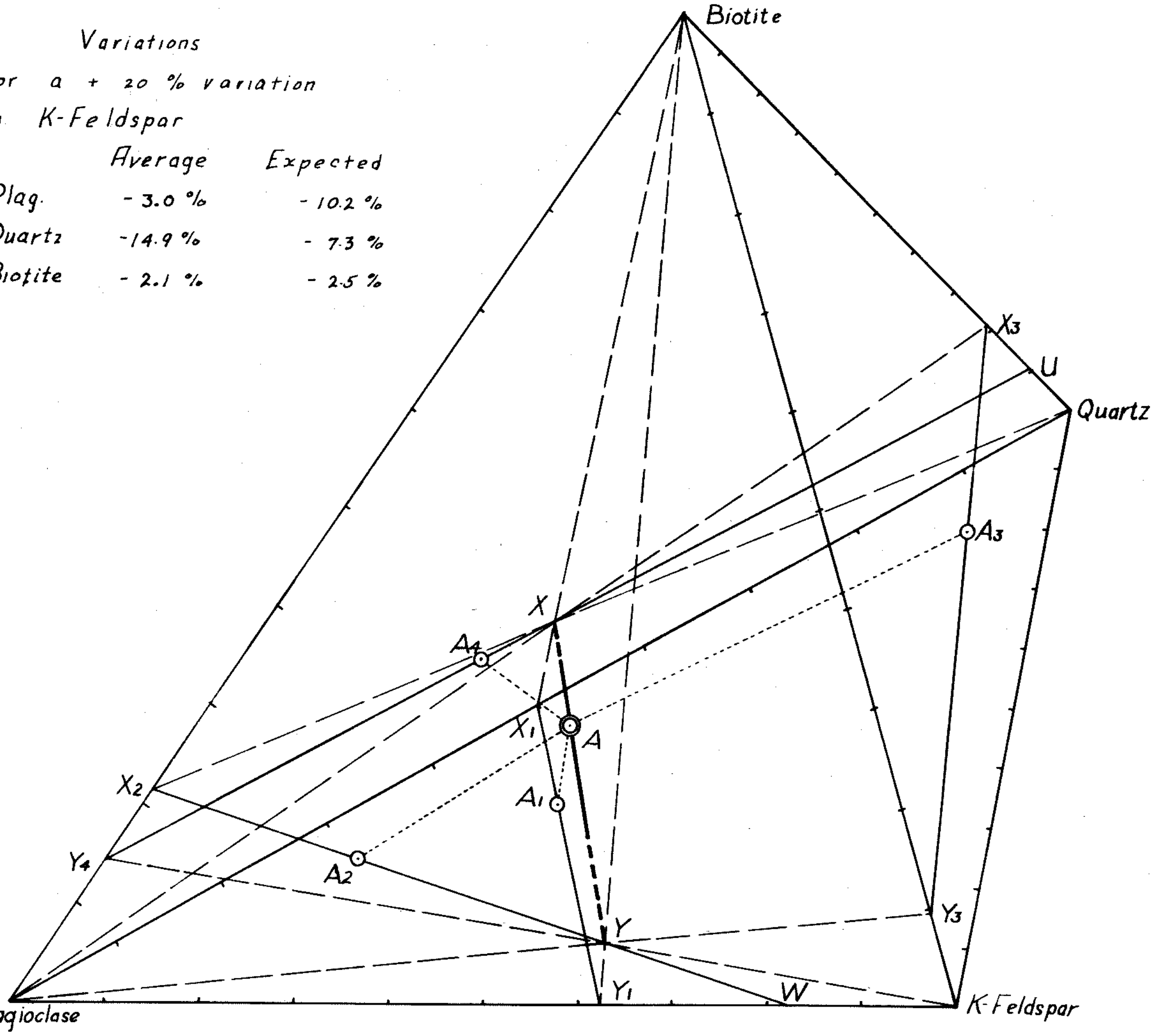

Figure 62

Variations in mineral abundance: Peak Granodiorite

Isometric projection of tetrahedron representing the four mineral phases. Trend lines, averages, etc. on the faces derived from Figure 61. A is the average mode; XAY is the trend line representing the average variation in mineral abundance.

Average variation is derived from line XY. Expected variation is based on the assumption that all variations result from sampling error alone; i.e. if one mineral varies the others will, on the average, compensate in the ratio in which they occur in the average mode.

defined linear trends. The data on the faces fall within the tetrahedron within a flat disc, which may be slightly ellipsoidal. The trend lines on the side faces are projections of various "diameters" of the disc rather than of a single line.

The lines as drawn can be used to determine a single line within the tetrahedron and still be reasonable representations of the trends of the data on the faces. The single line shown in figure 62 may be accepted as real with the reservation that it indicates a weak tendency for quartz to compensate for variations in potash feldspar slightly more than does plagioclase. The line indicates that biotite differs little with respect to the variations of the other minerals. It does differ slightly in antipathy with respect to variations of potash feldspar and in sympathy with those of plagioclase and quartz.

This interpretation of the variation in mineral abundance diagrams indicates that Peak granodiorite is effectively modally homogeneous insofar as the abundance of biotite may be accepted as an index of compositional variation in the analysed rocks. Assuming that deviations resulting from sampling errors are a function of the grain size of any particular constituent, the variations in abundance, as indicated by the diagrams, are precisely what would be expected.

The total spread of the data is so large, however, that the conclusion seems inescapable that there are real compositional variations within Peak granodiorite. These variations must be erratic and do not involve large masses of the pluton.

The conclusion seems justified that Peak granodiorite is effectively a modally homogeneous mass.

Variation in Mineral Abundance in Drury Quartz Monzonite: Data from all the analyses of thin sections of Drury quartz monzonite are plotted in the diagrams.

The contoured diagrams on the faces of the opened tetrahedron (fig. 63) show that the modal values for minerals in Drury quartz monzonite tend to concentrate within narrow limits even though the total spread is fairly wide.

The maximum concentration of points per one per cent area, on each of the four faces, ranges from 17 to 26 per cent of the total points. The maximum proportion of points within 4 per cent of the total area ranges from 48 to 71 per cent, and the total area covered by all points ranges from 11 to 18 per cent.

The average distribution of data on the four faces is as follows: the average maximum proportion of points per one per cent area is 22.5 per cent; the average maximum proportion of points per 4 per cent area is 57.7 per cent; and the average total spread of the data is 15.5 per cent of the area of a face. Thus on the average 22.5 per cent of the data lies in 6.5 per cent and 57.7 per cent lies in

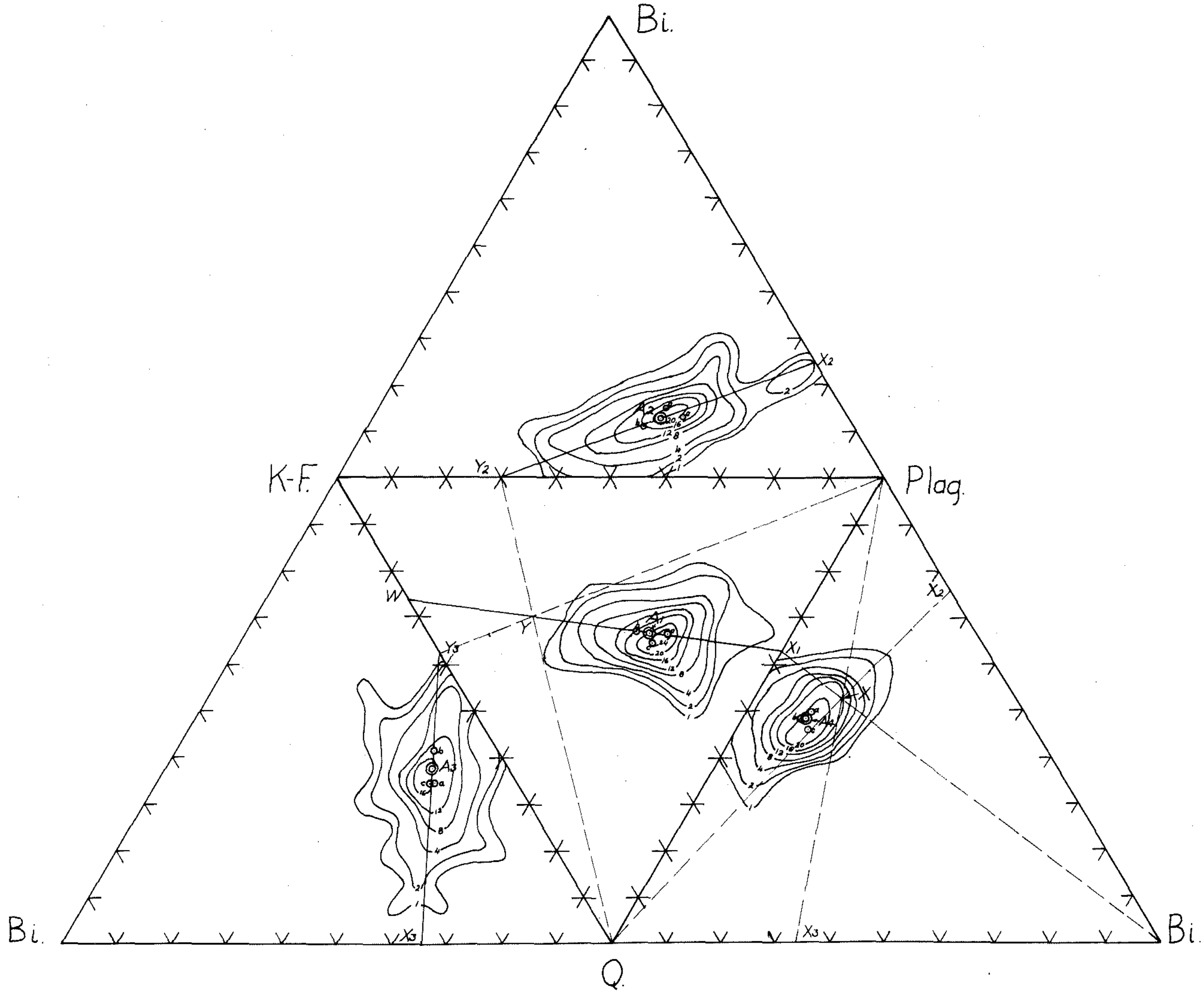

Figure 63

Variation in mineral abundance: Drury Quartz Monzonite.

Opened tetrahedron representing the four mineral phases. The contours represent the percentage of the total of 70 points in 1% areas of the total area of each face. The points (not shown) are the locations of 70 modal analyses plotted on each face. A_1, A_2, etc. represent the computed average modal composition; a, b, and c represent the average modes of the core, intermediate, and outer zones respectively. Other lines and points derived and lettered as in Figure 61.

25.8 per cent of the area covered. The data are well concentrated around the average values.

The contoured diagram on the basal face of the opened tetrahedron (fig. 63) shows a rather pronounced linear trend particularly if the 1 and 2 per cent contours are not considered. The line drawn as the average trend of the variation in mineral abundance on this face indicates that variations in potash feldspar are compensated almost entirely by plagioclase (and vice versa) and that quartz differs little, if at all. The width of the contours perpendicular to the trend line represents the variation of quartz which may result from sampling error alone.

The diagrams on the two side faces that include potash feldspar at one corner have strong linear trends, but that on the other side face has a weaker trend (the plagioclase-quartz-biotite face). These factors show that the data lie, inside the tetrahedron, within an ellipsoid. The long axis of the ellipsoid is projected onto the three faces on which the data show a strong linear trend. The axis is nearly perpendicular to the fourth face, and the weak trend exhibited by the data on that face is the projection of the intermediate axis of the ellipsoid. The intermediate axis is a measure of the degree of sampling error for quartz, and the minor axis measures that for biotite. The sampling errors of potash feldspar and plagioclase are incorporated in the major axis along with the effects of real changes in composition.

The single trend line in the three dimensional diagram (fig. 64), which is derived from the lines on the faces, thus has real significance and represents changes in modal composition to be expected from place to place in Drury quartz monzonite. The variations in compensation for a 20 per cent variation in potash feldspar are shown with the diagram and are probably a good approximation of real variations. These values indicate that variations of potash feldspar are compensated, on the average, 65 per cent by plagioclase and 34 per cent by biotite; changes in quartz are negligible, thus quartz, in any part of Drury quartz monzonite, will have about the same value. These values are in such strong contrast to those listed as expected from sampling error alone that it seems that the change in mode, from place to place, is real.

A real change in mode is also indicated by the positions of the averages of the core and intermediate zone as plotted on the faces of the tetrahedron (fig. 63). On all faces these averages lie on opposite sides of the overall average and both are reasonably close to the average trend lines. The change from one to the other seems to be real and gradational. It will be noted, however, that the plotted positions of the average of the outer zone are erratic. The outer zone does not seem to represent a gradational change from either of the other zones.

Variations
for a + 20 % Variation
in K-Feldspar

	Average	Expected
Plag.	- 12.4 %	- 9.6 %
Quartz	- 0.8 %	- 8.1 %
Biotite	- 6.8 %	- 2.3 %

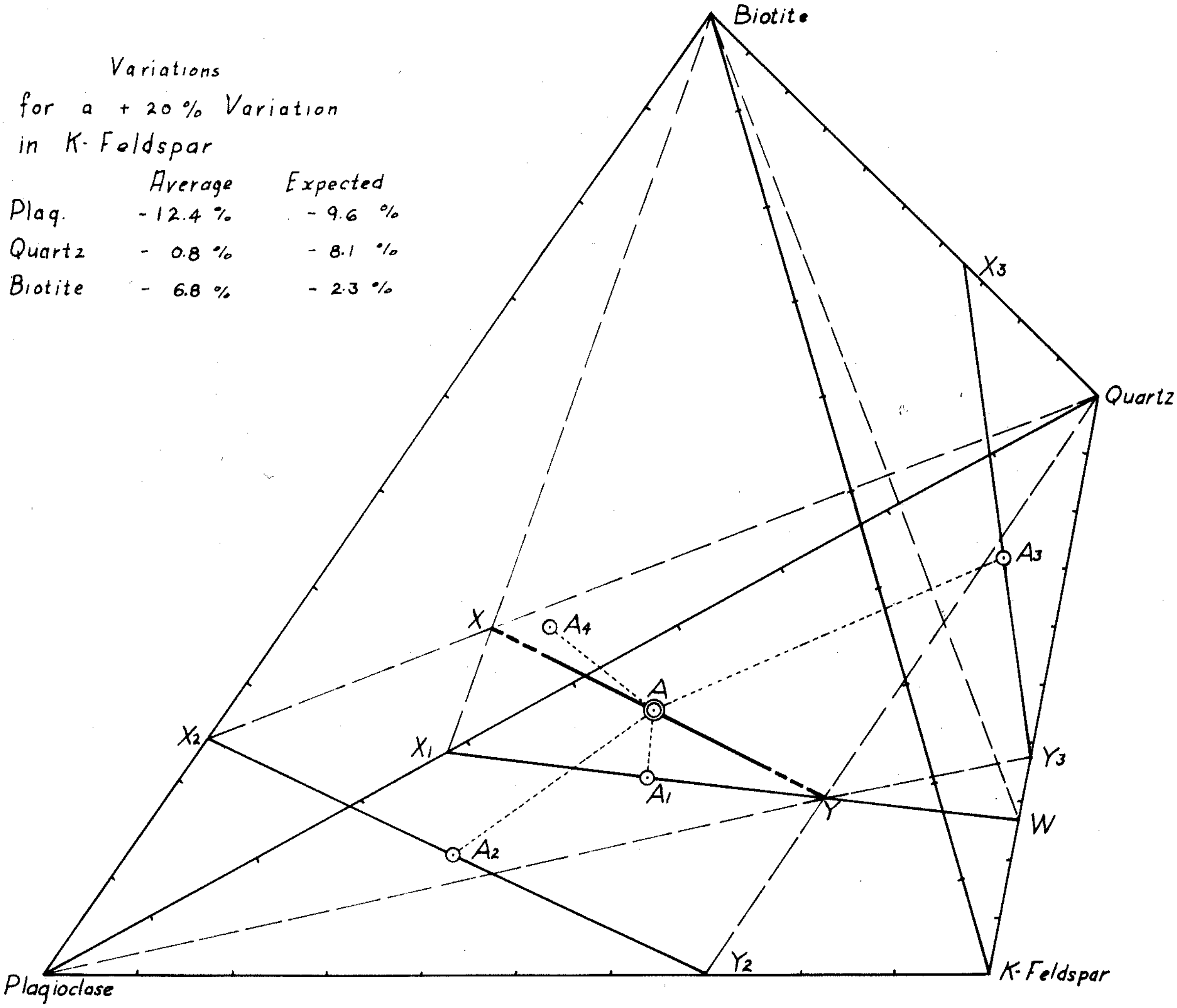

Figure 64

Variations in mineral abundance: Drury Quartz Monzonite

Isometric projection of tetrahedron representing the four mineral phases. Trend lines, averages, etc., on the faces derived from Figure 63. A is the computed average mode; XAY is the trend line representing the average variation in mineral abundance.

Average and expected variations as in Figure 62.

Variation in Mineral Abundance in Hornblende-biotite-quartz Diorite: No attempt was made to contour the modal data of the hornblende-biotite-quartz diorite as plotted on the faces of an opened tetrahedron (fig. 65). Only 14 thin sections were analysed, compared to 49 of Peak granodiorite and 73 of Drury quartz monzonite. The points show, however, rather good grouping either clustered around a point or spread along a line.

The data evidently fall in an ellipsoid inside the tetrahedron (fig. 66). The long axis of the ellipsoid represents the average variation in abundance. The diagram shows that variations in hornblende are compensated by quartz (64.5 per cent) to a far greater degree than can be expected from sampling error alone. Plagioclase compensates less than expected (35 per cent) and biotite differs slightly in sympathy with changes in hornblende.

Sampling errors are unlikely to be a significant cause of variation in the quartz diorite, hence the results of this treatment of the data are probably valid, at least for the samples analysed.

Summary and Conclusions Regarding Variations in Mineral Abundance: Diagrams depicting variations in mineral abundance show that the modal data for Peak granodiorite, Drury quartz monzonite, and the hornblende-biotite-quartz diorite are not an indiscriminant scattering of points. The data are shown to be well concentrated though the total

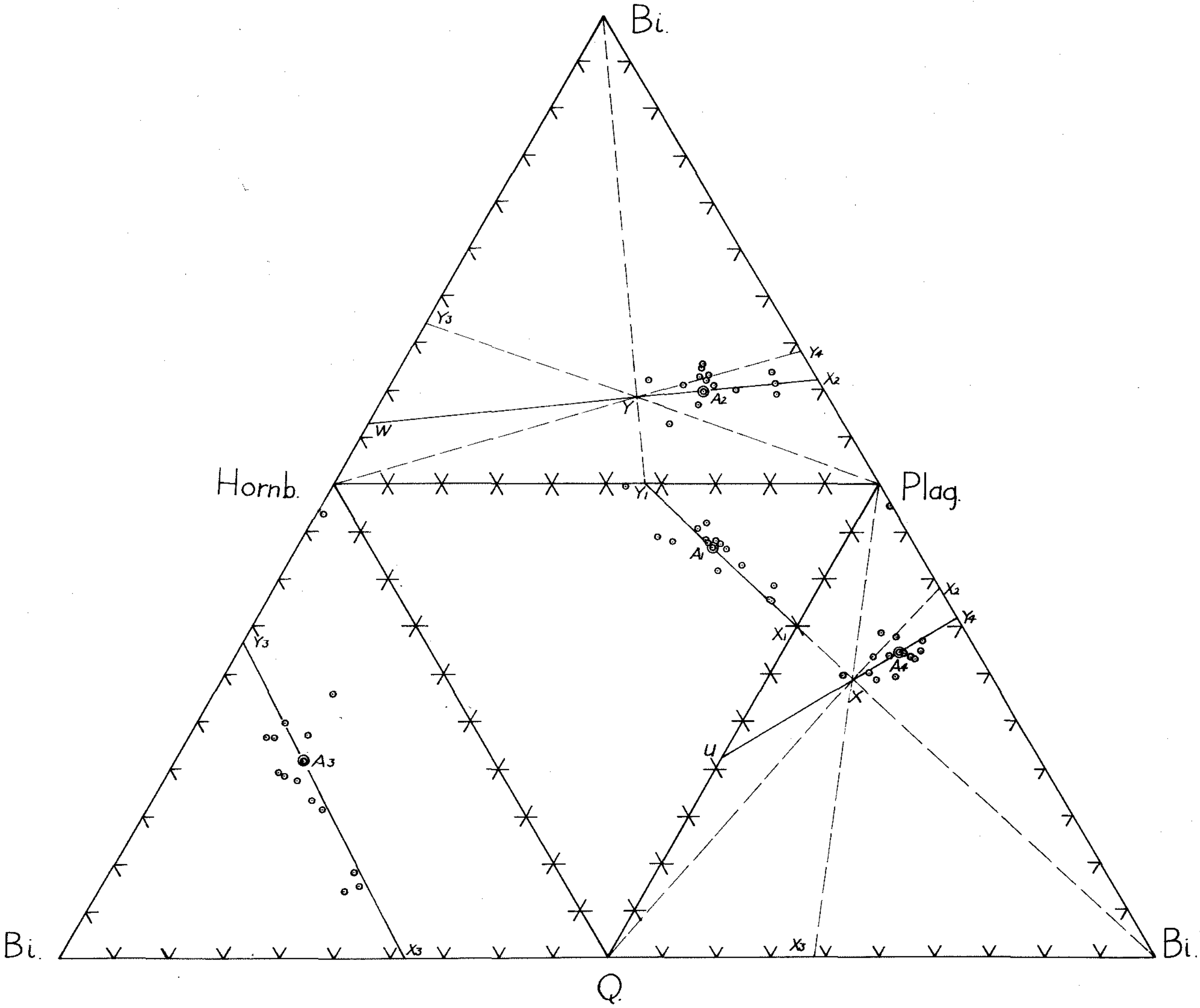

Figure 65

Variations in mineral abundance: Hornblende-biotite - quartz Diorite.

Opened tetrahedron representing the four mineral phases. Points in single circles are the locations of 14 modal analyses plotted on each face in terms of each three of the four phases. A_1, A_2, etc. are the averages of the 14 analyses on each face. Lines and other points derived and lettered in same manner as those in Figure 61.

Variations
for a +20 % Variation
in Hornblende

	Average	Expected
Plag.	- 7.0 %	- 12.9 %
Quartz	- 14.5 %	- 2.9 %
Biotite	+ 1.5 %	- 4.2 %

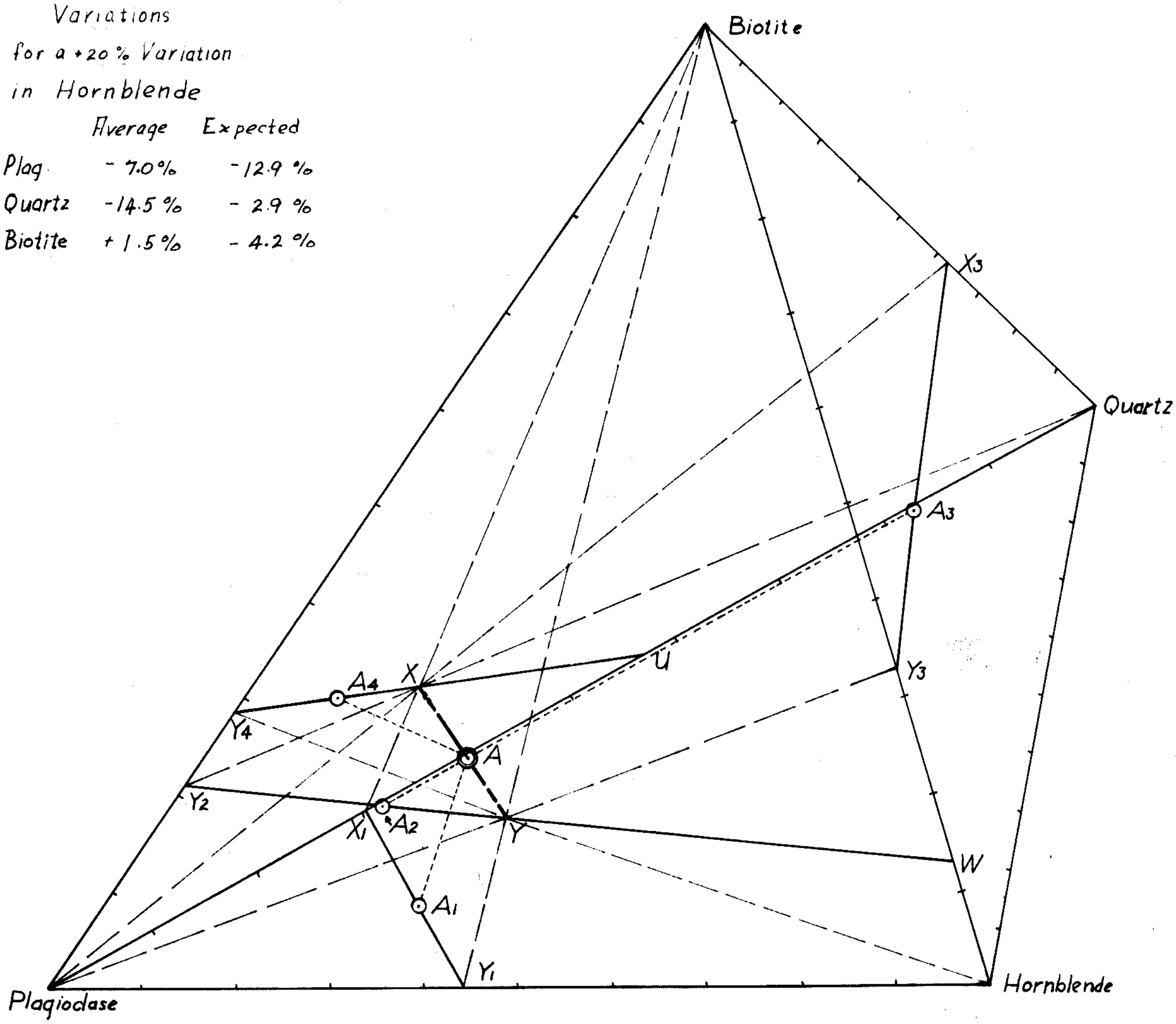

Figure 66

Variations in mineral abundance: Hornblende-biotite-quartz Diorite
Isometric projection of tetrahedron representing the four mineral phases. Trend lines, averages, etc. derived from Figure 65. A is the computed average mode; XAY is the trend line representing the average variation in mineral abundance. Average and expected variations as in Figure 62.

spread may be relatively great. This is in accord with conclusions reached from a study of the modal data alone.

The variation diagrams for Peak granodiorite show that there may be real compositional changes from place to place in the pluton. This is indicated by the modal data alone and by the frequency distribution curves, but there are no apparent systematic changes. Compositional variations, if they exist, are apparently erratic and do not involve any large masses of the granodiorite. Peak granodiorite is believed to be a compositionally homogeneous mass within which there may be local and small-scale variations that occur frequently enough to affect the analytical results. The average modal composition is believed to be a good approximation of the mode of the pluton as a whole.

The variation diagrams for Drury quartz monzonite show stronger trends than do those of Peak granodiorite, and this is believed to be a reflection of real and systematic compositional changes within the quartz monzonite. Although the variations are no greater than those in Peak granodiorite, in Drury quartz monzonite the analyses give significantly different averages for definite groups (e.g., the core and intermediate zones). The probability of a real change from the core to the intermediate zone is shown by the fact that their average modes lie on the variation line on opposite sides of the average of all analyses of the quartz monzonite. The average of the outer zone, however, is erratic, and this zone does not appear to be directly gradational from either of the others.

Variations in the mineral abundances in the hornblende-biotite-quartz diorite are confined, primarily, to hornblende and quartz, hence variations in one are mainly compensated by variations in the other.

If the variations indicated by the average trend line for Drury quartz monzonite are approximately correct, then, at the composition at which there is no potash feldspar in the rock the mode would be about 51, 32, and 17 per cent of plagioclase, quartz, and biotite, respectively. Similarly, if there is no hornblende in the quartz diorite the modal composition would be about 57, 25, and 18 per cent of plagioclase, quartz, and biotite, respectively. These figures are remarkably close considering their derivation. While the trend lines may be accurate within the compositional ranges of the samples analysed there is no assurance that they retain the same direction outside those limits. The extrapolations could be even closer than indicated.

At the composition at which there is no quartz in the quartz diorite the average mode would be 45, 18, and 35 per cent for plagioclase, biotite, and hornblende, respectively, or if all the biotite was converted to hornblende it would be 45 and 53 per cent for plagioclase and hornblende respectively. This is certainly not an unrealistic composition for the amphibolite, which has not been adequately sampled in the area.

The variations in mineral abundances lend support to the concept that there is a transition from the amphibolite through the quartz diorite and transition rocks to the quartz monzonite, as is indicated by field relations, textures, and the modes themselves. In a reverse sense, this supports the validity of the variation diagrams and the trend lines.

In the average mode of the few analyses of alaskite potash feldspar is 30.8 per cent. The composition of a rock having 30.8 per cent potash feldspar calculated from the average variation in mineral abundance in Drury quartz monzonite is 30.8, 31.7, 30.4, and 6.0 per cent for potash feldspar, plagioclase, quartz, and biotite, respectively. This is too high in biotite and may be too low in quartz to qualify as a typical alaskite. The amount of plagioclase is about correct. The difference in the compositions is sufficiently small, considering that the average of alaskite is imperfectly known, to permit the assumption that the deviation of the alaskite from quartz monzonite magma is possible.

PROPOSED ORIGIN OF THE GRANITIC ROCKS OF GLENLYON RANGE

Theoretical Crystallization of Granodiorite Magma

Crystallization in the System $KAlSi_3O_8$-$NaAlSi_3O_8$-$CaAl_2Si_2O_8$-SiO_2-H_2O: The quarternary system $KAlSi_3O_8$-$NaAlSi_3O_8$-$CaAl_2Si_2O_8$-SiO_2 has not been investigated under high water vapour pressures. All the ternary systems comprising the quarternary system have been investigated in the dry way and there is sufficient information of the wet systems that, by analogy to dry conditions, and by extrapolation of known data from the wet systems, a reasonable "quaternary" diagram can be constructed.

The system $KAlSi_3O_8$-$NaAlSi_3O_8$-$CaAl_2Si_2O_8$ was investigated by Franco and Schairer (1951); the system $KAlSi_2O_6$-$CaAl_2Si_2O_8$-SiO_2 (which includes $KAlSi_3O_8$) by Schairer and Bowen (1947); and revised by Schairer (1957); the system $NaAlSi_2O_6$-$CaAl_2Si_2O_8$-SiO_2 (which includes $NaAlSi_3O_8$) by Schairer (1957); and the system $KAlSi_3O_8$-$NaAlSi_3O_8$-SiO_2 by Schairer and Bowen (1935). All the related binary systems are known.

The dry quarternary system in the form of an opened tetrahedron on the base $KAlSi_2O_8$-$NaAlSi_3O_8$-$CaAl_2Si_2O_8$ is illustrated in figure 67. The dry system is presented primarily as a model from which the wet system can be drawn for conditions where water vapour pressure is equal to total pressure of 5000 bars.

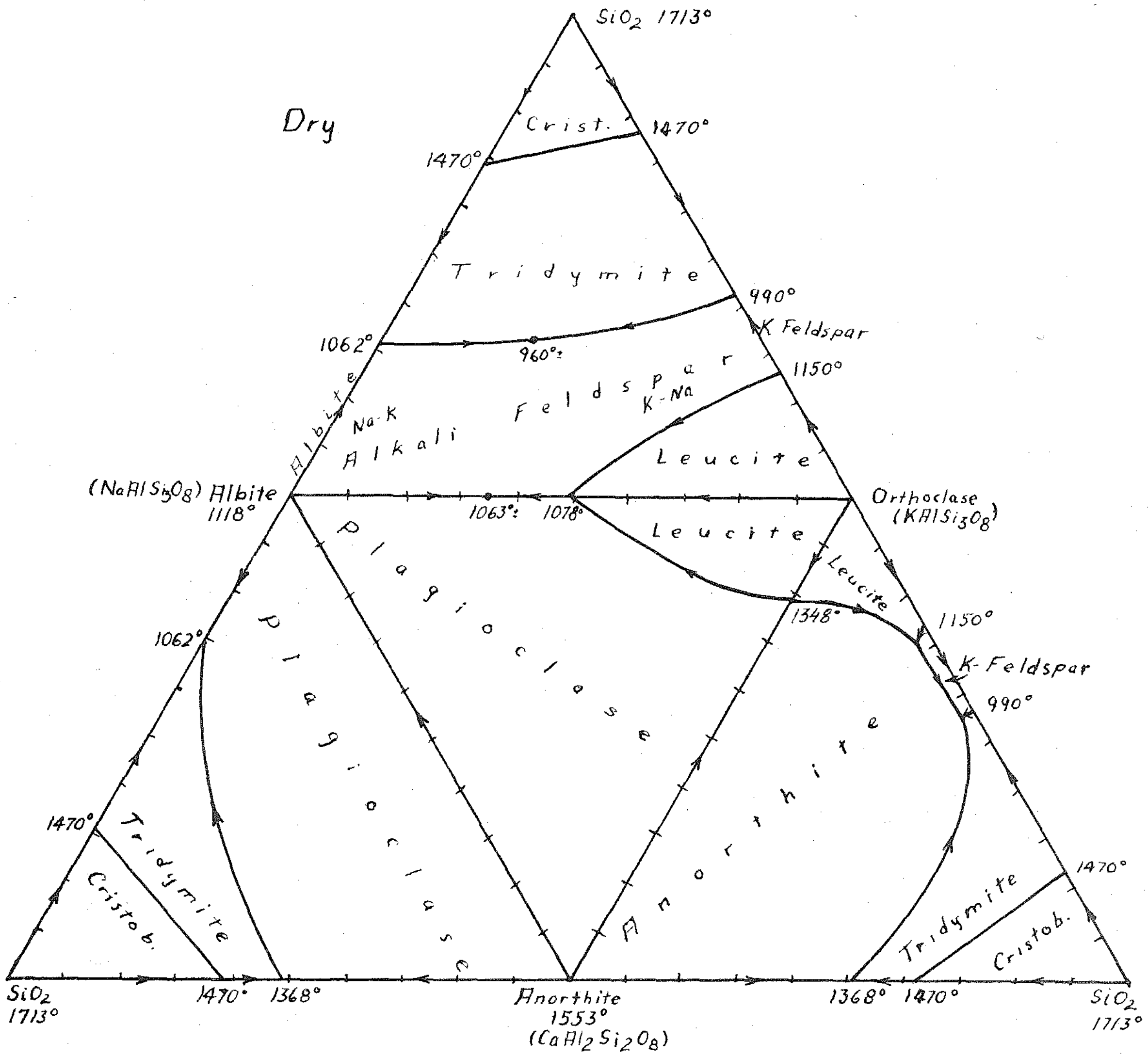

Figure 67

Quaternary system $KAlSi_3O_8$-$NaAlSi_3O_8$-$CaAl_2Si_2O_8$-SiO_2 as an opened tetrahedron.

The melting points of the four components are known at 5000 bars water vapour pressure as is the system $KAlSi_3O_8$-$NaAlSi_3O_8$-$CaAl_2Si_2O_8$ with its bounding binaries (Yoder, Stewart, and Smith, 1957). The system $CaAl_2Si_2O_8$-SiO_2 is also known at this pressure (Stewart, 1957). Tuttle and Bowen (1958) have investigated the system $KAlSi_3O_8$-$NaAlSi_3O_8$-SiO_2 and the related binaries at various water vapour pressures to 3000 bars, and to some extent to 4000 bars. The nature of this system can be extrapolated to represent conditions at 5000 bars with no possibility of the introduction of any gross errors.

Thus all the points are known in the wet "quaternary" system except the "ternary" eutectic in the $KAlSi_3O_8$-$CaAl_2Si_2O_8$-SiO_2 face; also the shape of the field boundaries in this and in the $NaAlSi_3O_8$-$CaAl_2Si_2O_8$-SiO_2 face are not known. These may be estimated, beginning with known points in the bounding "binary" systems, by analogy to established dry conditions. There is the possibility of the introduction of considerable error, but such errors are not likely to be of really large magnitude. Probably the four "ternary" systems illustrated in the opened tetrahedron (fig. 68) and in the isometric projection of the quarternary system (plate 4) give a good approximation of actual conditions.

The diagram shown in plate 4 is a schematic representation of the system. It actually represents a 5-component system which cannot be shown diagramatically. Each face of

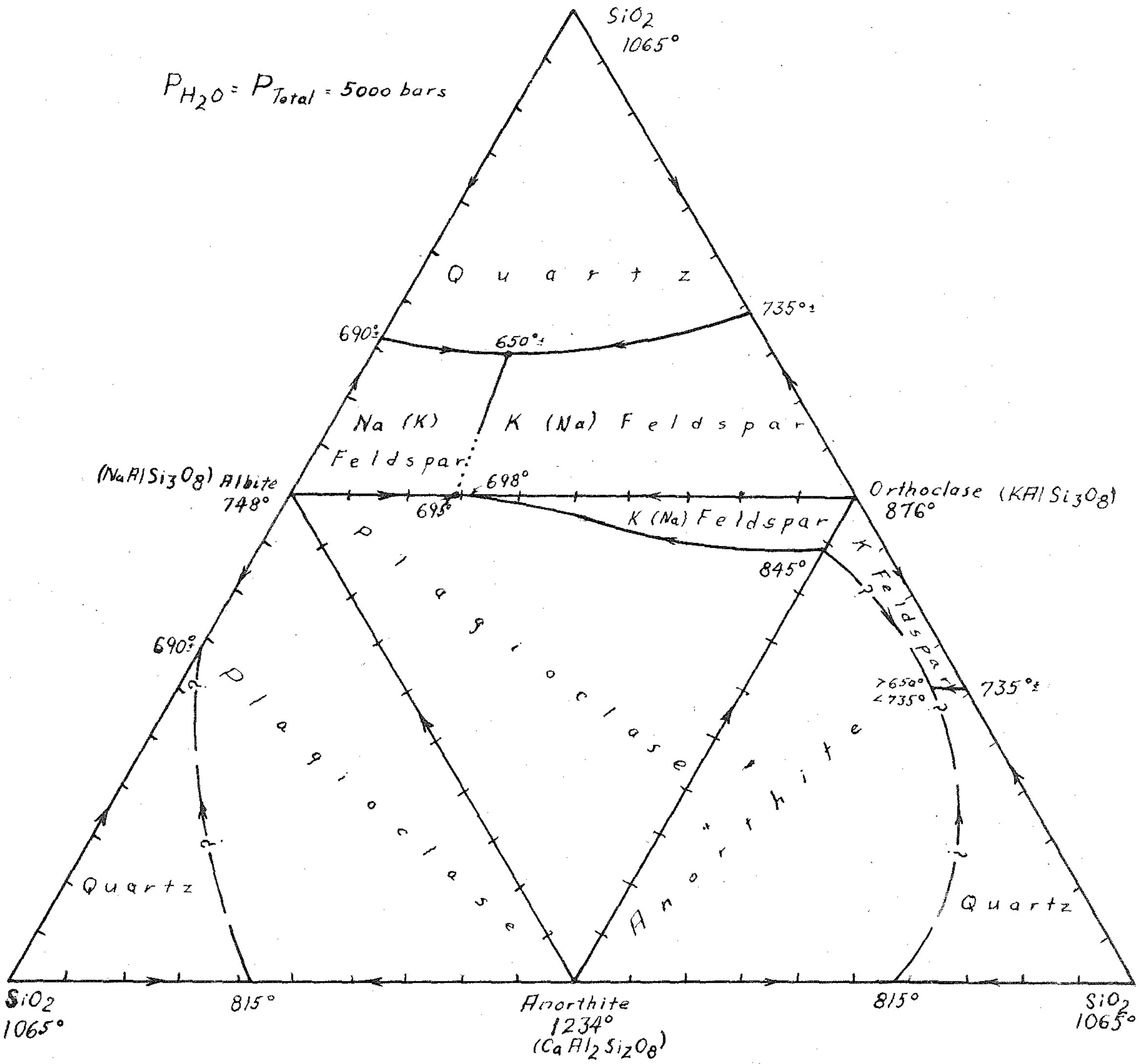

Figure 68

System $KAlSi_3O_8$-$NaAlSi_3O_8$-$CaAl_2Si_2O_8$-SiO_2 as an opened tetrahedron assuming water vapour pressure equal to total pressure of 5000 bars. Each terniary diagram is actually a projection of an appropriate quaternary system with water.

the tetrahedron is not truly a ternary system but is a projection of a quarternary system involving water unto the face opposite the water apex. The system shown in plate 4 should actually represent dry conditions only, and the tetrahedron is a framework by which the wet systems are related. However the quinary system can be represented by four components if water is neglected, in a sense the system illustrated is a projection of four bounding quaternary systems.

Water vapour pressure is defined as being equal to the total or confining pressure. This implies that the melt is saturated in water at all times. When anhydrous crystals separate a vapour phase must form. Throughout the crystallization of this system water vapour is present with the other phases. If the water in the vapour has a greater specific volume than the water in the melt, the vapour pressure must increase as crystallization proceeds or the volume of the system must expand. By definition the pressure is constant and if expansion is not possible, water vapour must escape, and the system is not closed. If vapour escapes, the composition of the system changes continuously. If there is no increase in specific volume of the water in the vapour as opposed to that in the melt, water need not escape as crystallization proceeds, and the bulk composition remains constant. Under either circumstance, however, a separate vapour phase will be present throughout the crystallization.

The diagram may not be precisely correct. The possibility of changes in the course of crystallization of a "granodiorite" magma caused by changes in the diagrams will be noted as the crystallization of such a magma is followed through.

The composition chosen for discussion is an approximation of the composition of Peak granodiorite and the core of Drury quartz monzonite in which the minerals plagioclase (An 35), quartz, potash feldspar, and biotite are close to the proportions of 40, 30, 20, and 10 per cent, respectively. Neglecting biotite the other minerals form 45, 33, and 22 per cent for plagioclase, quartz, and potash feldspar, respectively. Crystallization is assumed to proceed on the basis that there is no solid solution of potash feldspar in plagioclase or of anorthite in potash feldspar. The results of the work of Yoder et al (1957) in the three-feldspar system and their data on the chemical analyses of appropriate pairs of coexisting natural feldspars indicate that any such solid solution would be of very small amount in any event. Considering the qualitative nature of the present case such solid solution as there is can make no great difference to the trend of crystallization.

Yoder's results indicate that in coexisting synthetic and natural feldspars the potash feldspar in association with plagioclase of composition An 35 will be about Or 90 Ab 10.

Properly, then, the calculation of the four components of the quaternary system from the above mode should make allowance for this fact. The view may be taken, however, that since a certain proportion of the albite is, in a sense, earmarked to crystallize with potash feldspar to form an alkali feldspar, then that proportion of albite may be considered as behaving like orthoclase during crystallization. The writer has taken the latter view recognizing that it may introduce an error, but the error is quantitatively very small for the composition under consideration. Furthermore, if an error is introduced, then it is only necessary to consider that the discussion involves the crystallization of a slightly different composition from the one assumed.

On the basis of the assumptions outlined above the composition of the melt at the beginning of crystallization is 22, 33, 29, and 16 per cent of $KAlSi_3O_8$, SiO_2, $NaAlSi_3O_8$, and $CaAl_2Si_2O_8$ respectively. This composition is plotted as point A within the tetrahedron (plate 4) and as A1, A2, A3, and A4 on the faces, the latter in terms of each three of the four components. An inspection of the diagram shows that this composition lies well within the plagioclase field, hence plagioclase will be the first phase to separate. No tie lines are known that give the composition of plagioclase in equilibrium with melts in this system.

As a substitute for tie lines the curves of the solid solution series in the "binary" system $NaAlSi_3O_8$-$CaAl_2Si_2O_8$ at 5000 bars water vapour pressure (Yoder et al, 1957) may be used as an approximation. This method may be considerably in error but at least it adds some consistency to the postulated crystallization history. If the method is in error then the effects of substantial differences can be roughly estimated from a scrutiny of the diagrams. These effects will be pointed out, quantitatively, during the discussion.

From a trial section through the tetrahedron including the silica apex, point A, and the point Ab 40 An 60 on the $NaAlSi_3O_8$-$CaAl_2Si_2O_8$ join it was determined, from reasonably appearing field boundaries, that the amount of plagioclase to crystallize before quartz begins to form would be about 40 per cent of the total plagioclase in the system. Reference to the "binary" plagioclase system showed that when the plagioclase is 40 per cent crystallized it should have a composition of about An 60. Accordingly a similar section of the tetrahedron was drawn and includes the silica apex, point A, and the point Ab 40 An 60 on the $NaAlSi_3O_8$-$CaAl_2Si_2O_8$ join (fig. 69). All field boundaries were located as accurately as possible, and the line AB was drawn from A extending directly away from the plagioclase apex; B is the intersection of the line and the saturation surface of both quartz and plagioclase.

When plagioclase crystallizes the composition of the

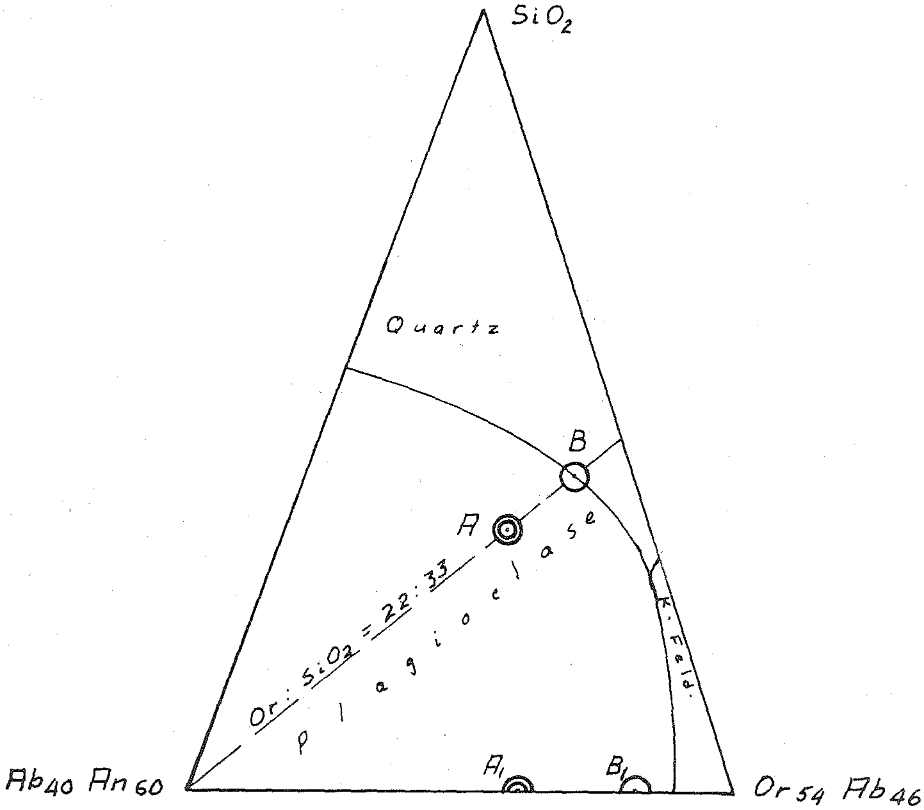

Figure 69

Section through tetrahedron of Plate 4. The section includes the SiO_2 apex, point A, and the point representing Ab 40 An 60 on the $NaAlSi_3O_8$-$CaAl_2Si_2O_8$ join.

liquid leaves the plane of the section at A, curves behind, and reenters it at B. This curved path lies in a plane that represents a constant ratio of SiO_2 (as a component) to $KAlSi_3O_8$ of 33 to 22. The line AB in the section is a projection of this path.

The composition of the liquid at B can be determined graphically and plotted in the tetrahedron in plate 4 along with its projections B1, B2 etc. on the four faces. The composition of the liquid at B is 27.0, 40.0, 26.8, and 6.2 per cent for $KAlSi_3O_8$, SiO_2, $NaAlSi_3O_8$, and $CaAl_2Si_2O_8$, respectively. The ratio of crystals to liquid can be determined, in this case 18 and 82, because the liquid contains the same absolute amounts of $KAlSi_3O_8$ and SiO_2 (as components) as it did at A.

If the field boundary should be closer to A than shown then the amount of plagioclase to separate between A and B would be less than shown, and it would be a little more calcic. In such a case the liquid would be a little richer in the plagioclase constituents and poorer in SiO_2 and $KAlSi_3O_8$ than the values determined for B in figure 69. If the field boundary should be farther from A than shown then the effects on the crystallization and the liquid would be opposite.

If the real tie lines require that the plagioclase during the early stages of crystallization should be more sodic than the values used (it seems very unlikely to be much more calcic) then a different section should be drawn through A. The change in the distance from A to B in a new section including the point Ab 50 An 50 on the edge of the tetrahedron, for example, would not be much different than that shown. The main effect of such a change would be to decrease the amount of $NaAlSi_3O_8$ and to increase the amount of $CaAl_2Si_2O_8$ in the melt at B. There would be little change in the amounts of the other components.

Biotite is also a component of the rocks studied. It is not possible to include it in the system under discussion, and in the natural magma its precise effect on the course of crystallization is unknown. Textural evidence in the rocks of Glenlyon Range indicates that biotite begins to crystallize early in the history of the minerals, probably at the beginning. It also seems to crystallize most of its final amount in the early stages. The assumption, which has no other basis than that mentioned above, might be made that biotite crystallizes at the same rate as plagioclase. The assumption must also be made that the addition of biotite, as a component, will not change the course of crystallization in the "quaternary" system. If all these assumptions are accepted then the composition of the liquid at B would be 25.0, 37.5, 24.5, 5.5, and 7.5 per cent for $KAlSi_3O_8$, SiO_2, $NaAlSi_3O_8$, $CaAl_2Si_2O_8$, and biotite, respectively. The crystal to liquid ratio would be 20 to 80, and the crystals would consist of 80 per cent plagioclase (An 60) and 20 per cent biotite.

Neglecting biotite again, at B in the quarternary system quartz begins to crystallize along with plagioclase, and the liquid changes in composition, in a curved path, on the saturation plane of plagioclase and quartz toward some point such as C. Point C is on the line of intersection of the stability fields of the three mineral phases (orthoclase, plagioclase, and quartz).

Again using the "binary" plagioclase diagram in place of proper tie lines a position of C on the line of intersection can be found, by trial and error, which gives an appropriate plagioclase composition with respect to the proportion of plagioclase that has crystallized. Point C, as shown in plate 4, was determined in this manner.

The liquid composition at C can be determined graphically and from it, since the absolute amount of $KAlSi_3O_8$ is the same as at A, the crystal to liquid ratio and the composition of the crystals can be found. In this case the ratio if 51 to 49 and the liquid consists of 44.5, 30.0, 23.0, and 2.5 per cent for $KAlSi_3O_8$, SiO_2, $NaAlSi_3O_8$, and $CaAl_2Si_2O_8$, respectively. The crystals consist of 36 per cent quartz and 64 per cent plagioclase (An 45). Quartz is 55 per cent crystallized and plagioclase 72 per cent. The percentage crystallized and the composition of the plagioclase are consistent with the "binary" plagioclase diagram.

If biotite is again considered on the same basis as before then the composition of the liquid at C would be 42.0, 28.5, 21.0, 2.5, and 6.0 per cent of $KAlSi_3O_8$, SiO_2, $NaAlSi_3O_8$, $CaAl_2Si_2O_8$, and biotite (as a component), respectively. The ratio of crystals to liquid would be 52 to 48 and the crystals would consist of 31.5, 54.5, and 14.0 per cent of quartz, plagioclase (An 45), and biotite, respectively. Quartz would be 55 per cent crystallized and plagioclase and biotite 72 per cent.

The location of the line of intersection of the stability fields is, of course, of vital importance in the determination of the composition of the liquid at C. The effects of possible changes in the position of this line are worth considering.

If the line should be closer to the silica apex than shown, but remains at the same distance from the alkali feldspar-silica face of the tetrahedron, then the amount of silica in the liquid should be increased and quartz in the crystals reduced. This change will be compensated by a reduction of all the other components in the liquid. There should not be gross changes in the effects on plagioclase. If the line should be farther from the silica apex the changes will be just the opposite. It seems that changes of this nature must be rather limited because of the proximity of the "ternary" minimum in the alkali feldspar-silica system with which the line must join.

The line could be farther away from the face of the tetrahedron than shown and to check the effect of this the "ternary" eutectic in the $KAlSi_3O_8$-$CaAl_2Si_2O_8$-SiO_2 face was moved, parallel to the base, to twice the distance from the $KAlSi_3O_8$-SiO_2 join as it is shown in figure 68 and plate 4. A reasonable curved line was then drawn between this point and the ternary minimum, and the data were measured for a point on this new line horizontally in from point C. This point, called X (plate 4), gave results as follows: the liquid composition is 40.0, 29.0, 24.5, and 6.5 per cent for $KAlSi_3O_8$, SiO_2, $NaAlSi_3O_8$, and $CaAl_2Si_2O_8$ respectively; the ratio of crystals to liquid is 45 to 55; the crystals are composed of 38 per cent quartz and 62 per cent plagioclase (An 44); and quartz is 52 per cent and plagioclase 62 per cent crystallized. The plagioclase composition, relative to the quantity crystallized, is not grossly inconsistent with the data of the "binary" plagioclase diagram, hence even large changes in the position of the line in this way do not seriously change the position of point C with respect to the alkali feldspar apeces. The line cannot be moved much closer to the face of the tetrahedron.

Another possibility is that the tie lines demand a more sodic composition for the plagioclase at the point of intersection of stability fields of the three mineral phases.

If this is the case then C must move along the line closer to the $KAlSi_3O_8$ apex to a point such as C' (plate 4). Here the composition of the liquid is 49.5, 30.5, 15.8, and 4.0 per cent for $KAlSi_3O_8$, SiO_2, $NaAlSi_3O_8$, and $CaAl_2Si_2O_8$, respectively. The crystal to liquid ratio is 56 to 44 and the crystals are composed of 35 per cent quartz and 65 per cent plagioclase (An 39). Quartz is 59.5 per cent and plagioclase 80.5 per cent crystallized. This would appear to be a reasonable extreme position for C in terms of distance from the ternary minimum. If biotite is considered as before then at C' the liquid would have the composition of 47.5, 29.0, 14.5, 4.0, and 5.0 per cent for $KAlSi_3O_8$, SiO_2, $NaAlSi_3O_8$, $CaAl_2Si_2O_8$, and biotite (component), respectively. The crystal to liquid ratio would be 58 to 42 and the crystals would consist of 30.5, 55.5, and 14.0 per cent of quartz, plagioclase (An 39), and biotite, respectively.

If point C should be closer to the ternary minimum than shown in plate 4 then the plagioclase would be more calcic. As an example consider C". Here the liquid composition is 39.5, 29.0, 30.0, and 1.5 per cent in the same order as used above. The crystal to liquid ratio is 44 to 56 and the crystals are 38 per cent quartz and 62 per cent plagioclase (An 55). Quartz is 51 per cent and plagioclase 61 per cent crystallized. If biotite is considered as before the composition of the liquid at C" would be

36.5, 27.0, 28.0, 1.5, and 7.0 per cent for $KAlSi_3O_8$, SiO_2, $NaAlSi_3O_8$, $CaAl_2Si_2O_8$, and biotite (component), respectively. The ratio of crystals to liquid would be 45 to 55 and the crystals would consist of 34, 55, and 13 per cent for quartz, plagioclase (An 55), and biotite respectively. Quartz would be 55 per cent crystallized and plagioclase and biotite 60 per cent.

It seems unlikely that C should be closer to the ternary minimum than the position of C" because the plagioclase would be extremely calcic. As an example consider C'". Here the liquid composition is 35.0, 28.6, 35.5, and 0.9 per cent for $KAlSi_3O_8$, SiO_2, $NaAlSi_3O_8$, and $CaAl_2Si_2O_8$ respectively. The crystal to liquid ratio is 37 to 63 and the crystals are 40.5 per cent quartz and 59.5 per cent plagioclase (An 70). Quartz is 45.5 per cent crystallized and plagioclase 49.0 per cent. This composition is unrealistic and is closer than a reasonable minimum distance from the ternary minimum. Even in this case, however, it is significant that both quartz and plagioclase are close to 50 per cent crystallized.

It seems that the most reasonable position of point C is within a fairly narrow range around the location as plotted in plate 4. It might be somewhat closer to C" than to C'. Changes in the location of the line of intersection of the stability fields of the three mineral phases will not grossly change this position with respect to the alkali feldspar apeces of the tetrahedron. Fractional crystallization would cause the point to move toward the ternary minimum.

During crystallization between C and D all three minerals crystallize. At some point such as D the last of the silicate melt is used up. At this point the composition of the liquid is 29.3, 28.3, 42.1, and 0.3 per cent for $KAlSi_3O_8$, SiO_2, $NaAlSi_3O_8$, and $CaAl_2Si_2O_8$, respectively.

This rather detailed analysis of crystallization in this system with consideration of the effects of changes in the diagrams is necessary in order that conclusions from this analysis may be significant.

The salient features of the crystallization of a liquid of composition A (plate 4) are as follows.

1. Before potash feldspar begins to crystallize the melt is already 50 per cent crystalline or more.

2. Before potash feldspar begins to crystallize quartz is from 50 to 60 per cent crystalline and plagioclase is from 60 to 80 per cent crystalline. If biotite is assumed to crystallize early then it might be from 60 to 80 per cent crystalline before any potash feldspar crystallizes.

3. The composition of the plagioclase crystals (An 35 in the melt as a whole) is between An 50 and An 40 at the point where potash feldspar begins to crystallize.

4. During the first half of the crystallization (A

to C in plate 4) $KAlSi_3O_8$ is concentrated in the liquid and $CaAl_2Si_2O_8$ is rapidly extracted. SiO_2 rises (at B) then falls back to near its original value in the liquid. The concentration of $NaAlSi_3O_8$ does not change by a large amount.

5. During the last half of crystallization (C to D) $NaAlSi_3O_8$ is concentrated in the liquid and $KAlSi_3O_8$ is extracted. SiO_2 and $CaAl_2Si_2O_8$ change very little.

6. Well over 50 per cent of the liquid during crystallization (from between B and C to D) lies in the compositional range to which Tuttle and Bowen (1958) would restrict the composition of true granite.

7. The amount of $NaAlSi_3O_8$ in the liquid, and in the crystals, does not vary far from between 25 and 30 per cent if any reasonable location of point C is assumed, until a very late stage.

8. The amount of SiO_2 in the liquid is close to 30 per cent during much of the crystallization. It is higher in the vicinity of point B. This quantity, of course, will vary directly as the line of intersection of the stability fields of the three mineral phases is raised or lowered (because it is incorrectly plotted in plate 4 or because of changing water vapour pressure). It might be expected, however, to center, in its variations, around 30 per cent.

<u>Application to the Geology of Plutonic Granitic Rocks in General</u>: If granitic rocks represent a differentiation series (either by fractional crystallization or partial fusion) of a common parent material, then some of the features of the above analysis should be seen in them. In any such treatment of course, the averaged characters of granitic rocks must be considered.

In Nockolds' tables of average chemical compositions and norms of granitic rocks (Nockolds, 1954), the normative albite is grouped around 30 per cent in tonalite, granodiorite, adamellite, and all granite but peralkaline types (in which it is about 35 per cent). This grouping is also found in diorite, monzonite, and some syenite, though in some of the latter it is very much higher. There is an abrupt break in normative albite between diorite (25 to 30 per cent) and gabbro and norite (17 to 19 per cent). This is in agreement with the findings of Poldervaart and Elston (1954) who believe that enrichment of basaltic liquid in soda occurs at a very late stage when the rock is about 95 per cent crystalline. On this basis there does not seem to be any direct descent from basaltic to plutonic granitic rocks or, perhaps, even to dioritic rocks.

Chayes (1952) and Tuttle and Bowen (1958) point out the uniformity in the amount of quartz in modal analyses of granites. Normative quartz does not differ greatly from between 25 and 30 per cent in all the over-saturated granitic rocks in Nockolds' averages. The variations in quartz content within any one group can be greater than the differences from group to group. The changes are erratic rather than progressive and it would seem that they result from inadequate sampling, and there is a good possibility that the average quartz content in each group of granitic rocks is relatively constant between 25 and 30 per cent. It may be a little lower in tonalite.

Nockolds' averages also show that orthoclase increases (as required by definition of the rocks) and that anorthite decreases, progressively, from tonalite to granite. The mafic minerals also decrease slightly, though in the norms they do not vary greatly from 10 per cent.

If, in the system discussed (plate 4), the liquid and crystals were separated when the liquid had a composition close to that of point C, or at any point between C and D, the composition of the liquid will be that of an alkaline granite and the crystals will range from tonalite to granodiorite depending on the point of separation. Both crystals and liquid will contain quartz and albite at close to 30 per cent. If the average rocks of the granitic family are derived by fractional crystallization or partial melting of essentially identical material the differentiation of such material is readily explained on the basis of crystallization discussed in the preceding section if coupled with assumptions regarding the mafic minerals.

Should identical material be, on the average, the ultimate source of granitic rocks, such material might be the bulk composition of the volcanic and sedimentary rocks accumulated in eugeosynclines where granitic complexes are subsequently best developed. A combination of Clarke's average shale and sandstone (Clarke, 1924) may give a good approximation of such a composition (carbonate rocks are generally not important in eugeosynclines) provided it is permissible to assume a higher content of soda than the averages indicate. According to the analyses of graywacke listed by Pettijohn (1949, p. 250) there is reason to believe that eugeosynclinal sediments, in bulk, may be relatively rich in soda compared to Clarke's averages (see table 5). The inclusion of volcanic material might also tend to enrich the bulk composition in soda.

If this idea has any validity it might be tested in respect to relatively young granitic rocks such as in the great Mesozoic plutonic granitic complexes. In general it can be said that these rocks have not been through multiple periods of granitic activity. This cannot be said, with certainty, for older granites, particularly those of Precambrian age. Large undifferentiated granitic complexes should be composed mainly of tonalite and granodiorite, with, perhaps, minor quartz monzonite. True granite should be rare or absent. This is the case in the Coast Range plutonic rocks of British Columbia and in the

Sierra Nevada. Differentiated complexes, on the other hand, might cover the spectrum of oversaturated granitic rocks but should be, in bulk, about the composition of granodiorite or tonalite. The batholith of Southern California may approach this condition (Larsen, 1948, p. 138).

Fifty per cent or more of a liquid of the composition of the "average" eugeosynclinal rock will, during equilibrium crystallization, lie in the compositional range of alkaline granite. Fractionation, however, will produce an even higher proportion of granite liquid. Repeated episodes of granitic activity with fractionation, or a single episode with intense fractionation involving the same parent material will ultimately produce true granite in the amount of possibly as much as 70 per cent of the original bulk. The principal substance rejected by this process is anorthite, and, to a smaller extent, ferromagnesian material. Thus relatively small quantities of gabbro, ultramafics, and even anorthosite might be expected to be associates of "multiple cycle" or highly fractionated granite. Intermediate rocks should be rare or absent.

Obviously fusion of rocks of varying composition may produce local aberrant rock types; aberrant in the sense that they are not representative of the large proportion of plutonic rocks as a whole. Unusual conditions of fractionation may lead to the development of relatively unusual rocks. In the general or average case, however, plutonic rocks are granitic and conform well, in composition, to what would be expected by the fusion and fractional crystallization of the "average" eugeosynclinal section in terms of crystallization in the system $KAlSi_3O_8$-$NaAlSi_3O_8$-$CaAl_2Si_2O_8$-SiO_2-H_2O. It is necessary to assume that the mafic minerals separate early in order to complete the picture.

The Role of Water

In the quinary system $KAlSi_3O_8$-$NaAlSi_3O_8$-$CaAl_2Si_2O_8$-SiO_2-H_2O, water does not enter into any of the crystalline phases produced by crystallization within the range of interest in granitic rocks. It acts as a flux that lowers the temperature of melting of the components but makes relatively moderate changes in the locations of the various field boundaries in the diagrams illustrated in figures 68 and plate 4. This last statement does not hold true for relatively low water vapour pressures (500 to 1500 bars), which cause more extensive changes in the positions of some of the field boundaries. For example, the ternary minimum in the alkali feldspar-silica system changes from 30, 40, and 30 per cent to 24, 28, and 48 percent for $KAlSi_3O_8$, SiO_2, and $NaAlSi_3O_8$, respectively when the water vapour pressure changes from 500 to 5000 bars. At 2000 bars the components at this point are in the ratio of 26, 34, and 40 per cent respectively. Thus the change in the position of the minimum is as much or more for the change in pressure of 1500 bars from 500 to 2000 bars as it is for the change in pressure of 3000 bars from 2000 to 5000 bars. The three binary eutectics involving silica all behave in a similar manner. All these points are closer to their compositional position in the dry system when the water vapour pressure is at 5000 bars than when it is at 500 bars. This does not apply, necessarily, to the points in the binary systems not involving silica of which those that are known change by rather small amounts, progressively, as the water vapour pressure increases. These facts suggest, though they certainly do not prove, that the location of the "ternary" eutectic in the system $KAlSi_3O_8$-$CaAl_2Si_2O_8$-SiO_2 as shown in figure 68 and plate 4 is not grossly in error for conditions at 5000 bars water vapour pressure.

The quantity of water in the magma will make a difference in the mafic phases which might occur. No biotite or hornblende can form from an anhydrous melt, and pyroxene will be the stable phase. There seems to be a specific water vapour pressure above which biotite is stable and below which hornblende is the stable phase. A plutonic granitic magma may have pyroxene as the stable mafic phase in the early stages of crystallization. As water is concentrated pyroxene will become unstable and will be replaced by hornblende and finally biotite may become the stable phase. If there is insufficient time for reaction all three minerals may occur in a single rock.

If biotite is an early mineral in the sequence of crystallization, and the rock contains no hornblende or any evidence that hornblende was ever present, the assumption seems warranted that even in the early stages of crystallization the magma was relatively "wet." The possibility of biotite forming, of course, presupposes the availability of potash.

If granitic rocks do indeed form by the fusion of eugeosynclinal sedimentary rocks, which may include great thicknesses of porous greywacke and also a large percentage of hydrous minerals, then the magma may contain 2 per cent and perhaps more water. Clarke's average shale contains 3.68 per cent water after heating above 100 degrees and the average "sandstone" contains 1.33 per cent (Clarke, 1924). Any reasonable combination of these averages to represent the bulk composition of eugeosynclinal rocks would involve between 2 and 3 per cent water.

Another indication of the original amount of water in granitic magmas is the content of water found in crystalline granitic rocks. This varies from 0.4 per cent in leucogranite to about 0.7 per cent in tonalite in Nockolds' averages (Nockolds, 1954). Clarke (1924) gives a water content of 1.15 per cent in his average igneous rock. It is generally believed that a considerable amount of water escapes from a crystallizing granitic magma prior to complete solidification, hence the original water content should be much higher than the amount found in solid rocks at the surface.

All these factors imply that the original water content of a granodiorite magma might be as high as 3 per cent and is probably well over 1 per cent.

If the water content is between 1.5 and 3 per cent at the beginning of crystallization the magma is undersaturated in water and the vapour pressure will be less than the total pressure. As crystallization proceeds water tends to be concentrated by the formation of anhydrous minerals and removed by the crystallization of hydrous phases. If the former more than offsets the latter then the net effect will be an increase in the proportion of water in the melt.

In the case of a rock of the average composition of Peak granodiorite in which biotite makes up 10 per cent and seems to have separated early from the melt and in which the original water amounted to 1.5 per cent, then when crystallization is 50 per cent complete, the water content of the liquid is 3 per cent less the water combined in biotite, provided none escapes from the system. If biotite is 100 per cent crystallized it will have removed only a small amount of water. According to the analyses of biotite from various granitic rocks in the batholith of Southern California by Larsen and Draisen (1950, p. 69) the water content of the mica varies from 0.60 to 1.98 per cent. If all the biotite has formed when the melt is half crystalline it would change the water content of the liquid from 3 to 2.6 per cent at the most.

When the melt is 75 per cent crystalline the water content would be 5.2 per cent if none escapes. This is nearly equivalent to the solubility limit of water in Stone Mountain granite melt at 2000 bars pressure as determined by Burnham and Jahns (1958, p. 40). Extrapolation of a curve drawn from their data gives a solubility of between 6.0 and 6.2 per cent at 5000 bars pressure. Jahns (personal communication) presents convincing reasons why these figures are likely to be more exact than those of Goranson (1931) and others who found much higher values.

When the melt under discussion is 80 per cent crystalline the water content is 6.5 per cent which probably exceeds the solubility at any reasonable confining pressure. When crystallization is 95 per cent complete the water content of the fluid phase (or phases) would be 26 per cent if none was able to escape the system. Even if the original water content was only 1 per cent the comparable figure at 95 per cent crystallization is 16 per cent water. It is thus reasonable to suppose that a water-rich phase will separate from a cooling magma similar in composition to Peak granodiorite when crystallization is from 80 to 90 per cent complete, and perhaps much sooner if the pressure is low or the original water content is higher than 1.5 per cent.

If it be assumed that all the minerals to crystallize between C and D in plate 4 do so at a uniform rate from their stage of crystallization at C to complete crystallization at D, then when the liquid is 80 per cent crystalline the minerals will comprise about 60, 80, and 80 to 90 per cent of their final bulks for potash feldspar, quartz, and plagioclase respectively. If biotite is assumed to crystallize at the same rate as plagioclase then it too will be 80 to 90 per cent crystalline. When the magma reaches this stage of solidification further crystallization will cause boiling and the appearance of an aqueous vapour phase. This composition would seem to be an upper limit in respect to the amount of crystallization necessary to produce boiling. If the confining pressure is less than 5000 bars, say 2000 bars, or if the original water content was 3 rather than 1.5 per cent then boiling will occur when the magma is from 50 to 75 per cent crystalline.

In view of the foregoing it is possible that water vapour was continually evolved from the melt during all or most of the period of crystallization of potash feldspar in a magma of the composition of Peak granodiorite. This would be even more true of tonalite which is poorer in potash feldspar. Thus at the beginning of or during the first half of the crystallization of potash feldspar there is an abrupt change in the physical conditions in the magma chamber; the magma becomes saturated in water and a separate aqueous vapour phase forms. During this stage the pressure must rise, or the vapour must escape continuously, or the magma chamber must expand if it be assumed that there is an increase in the specific volume of water in the vapour phase relative to that in the melt. There is little possibility of the pressure greatly exceeding the confining pressure, thus it seems that water vapour must escape from the system, either continuously or in surges, or that the chamber expands to accommodate the vapour phase and maintain the pressure. Possibly both operate together; expansion of the chamber and upward accumulation of the vapour followed by escape of the vapour and contraction of the chamber, then a repetition of the whole process.

During this process the magma will contain a multitude of vapour bubbles as the vapour phase is evolved. Jahns and Burnham (1958, p. 88) found that the presence of a vapour phase is evidently necessary for the growth of giant crystals in pegmatite. In a granodiorite magma the conditions might be termed pegmatitic, but the only mineral not already mostly crystallized is potash feldspar, and potash feldspar might be expected to form coarse grains that, of necessity, must be rich in inclusions.

Bowen (1933) discussed the evolution of a vapour phase from a magma. In regard to the concentration of hyperfusibles in the late stage liquid of a cooling magma he wrote

(p. 114):

> "In respect to the crystallization of gabbroic magmas in which pyroxene and calcic plagioclase have already crystallized and in which the hyperfusibles have become concentrated, the pyroxene and plagioclase are unstable in relation to the liquid with which other minerals are in equilibrium. The instability of plagioclase is characterized by the fact that one end-member, albite, is stable in contact with the liquid whereas anorthite enters into other combinations. The result is albitization of the plagioclase . . . "

In gabbroic magma, in Bowen's view, the late-stage volatile-rich melt, even prior to the evolution of a vapour phase, may cause the early formed minerals to become unstable, and they may be replaced by a phase in equilibrium with the liquid. If these conditions may be extended to granodiorite magma in which, under similar circumstances potash feldspar as well as albite is a stable phase, then it would seem possible that the calcic plagioclase might be replaced by potash feldspar as well as by albite. The lime released by this replacement might become fixed in epidote or carbonate. Both epidote and carbonates are found, commonly, though in small amounts, in the granitic rocks of Glenlyon Range.

The vapour produced by boiling must be in equilibrium with the minerals in the magma and with the magma itself. It will be made up of materials in proportion to the partial vapour pressures of the various constituents of the magma and will not be particularly corrosive toward the solid phases as pointed out by Bowen (1933, p. 124). Potash, which is highly concentrated in magma and which forms relatively volatile compounds (Bowen, 1933, p. 123), will be an important constituent of the vapour. As the mass cools entrapped vapour may condense, and the fluid so formed will be highly corrosive toward all the truly magmatic minerals, particularly those that formed early from the magma, but even quartz and alkali feldspar may be attacked. The implication here is that potash feldspar, because potash forms highly volatile compounds, may soon come into equilibrium with the liquid and may crystallize from it with continued cooling. At this stage it may replace any of the other minerals, even quartz and albite. The "pseudomorphic" replacement of sodic plagioclase may occur at this time, and the fluid which causes it may extend from the granitic into the metamorphic rocks, where similar replacements are found.

If these conditions are relatively uniform throughout a cooling magma then there will be produced, everywhere, a uniform texture and mode even though potash feldspar replaces the other minerals and seems to be the result of potash metasomatism. In actual fact it may be the result of both normal crystallization and potash autometasomatism and form under conditions which merge from the magmatic to the metamorphic. This might produce an entirely predictable modal composition throughout the rock if the original composition of the magma is known.

In the final stages of cooling both quartz and albite may become stable in the aqueous liquid, which is, by this time, an interstitial fluid. It may be at this time that myrmekite develops as the final episode in the production of the granitic texture. The writer does not know why these two minerals form as an intergrowth and why the occurrence of myrmekite is restricted to the contacts of potash feldspar and plagioclase. It seems apparent, however, that myrmekite stabilizes these contacts, and hence it must form. As myrmekite can be in the form of overgrowths, or the quartz vermicules may develop directly in the rock plagioclase if it is sufficiently sodic, there appears to be, first, a requirement that the plagioclase at the contact be sodic, and second, that the Si to Al ratio must be equivalent to or higher than that in potash feldspar, hence free silica must develop in the plagioclase. Possibly in those cases where the plagioclase is nearly pure albite no myrmekite will develop. The traditional explanation that myrmekite develops through the replacement of potash feldspar by plagioclase with the release of excess silica does not seem to be valid for many granitic rocks.

Still another possibility connected to the formation of a vapour phase in granitic magmas may provide part of the explanation of the replacement relations of potash feldspar to the other minerals. This is the effect of the change in water vapour pressure on the position of the boundaries of the stability fields of the mineral phases. If a change occurs rapidly, say by the sudden escape of vapour, then there may be resorption of some minerals and rapid precipitation of others. Whether this mechanism can ever be operative is problematical, but it is a possibility.

The Granitic Rocks of Glenlyon Range Considered in Terms of the Theoretical Crystallization of Granodiorite Magma

A good indication that Peak granodiorite and the core and intermediate zones of Drury quartz monzonite crystallized from a magmatic liquid is given by the textural study, from which a clear-cut paragenetic sequence can be deduced. In the large masses of granitic rocks the sequence began with the crystallization of plagioclase and biotite; quartz began to crystallize later than these minerals, and potash feldspar formed very late in the sequence. The differences in time of the beginning of crystallization of the minerals were great enough that one might think that there was no overlapping crystallization, though this obviously cannot be the case.

The paragenetic sequence of plagioclase, quartz, and potash feldspar is precisely what would be expected from the crystallization of "granodiorite" magma in terms of experimental data as discussed in the preceding sections. It was shown that plagioclase can be 40 per cent crystallized before quartz begins to form and 60 to 80 per cent crystallized before potash feldspar becomes a stable phase. The crystallization of quartz can be between 50 and 60 per cent complete before any potash feldspar begins to form. Potash feldspar will not begin to form until the melt is 50 per cent or more crystalline.

The calculated chemical compositions of the estimated "average" mode of all Yukon group strata and of the average mode of all analyses of Peak granodiorite and of the core of Drury quartz monzonite combined, are shown in table 5. These calculations give results which are strictly approximations of the true compositions but they should not be grossly different from the true values of the various oxides for the granitic rock at least. The theoretically ideal compositions of orthoclase, albite, anorthite, and muscovite as listed in Dana's Textbook of Mineralogy were used in the calculations. The average composition of biotite in the rocks of the batholith of Southern California as found by Larsen and Draisen (1950, p. 69) is used. Potash feldspar in the metamorphic rocks is considered as pure $KAlSi_3O_8$ and is taken as Or 90 Ab 10 in the granitic rocks. The modes used are, for the Yukon group 2, 18, 44, 23, 10, and 3 per cent of potash feldspar, plagioclase (An 25), quartz, biotite, muscovite, and calcite, respectively, and for the granitic rocks 18.8, 41.1, 30.1 and 10.0 per cent for potash feldspar, plagioclase (An 35), and biotite, respectively.

TABLE 5

CHEMICAL COMPOSITIONS FOR VARIOUS ROCKS

	1	2	3	4	5	6	7
SiO_2	71.0	70.3	67.0	59.5	63.8	68.2	70.2
TiO_2	0.3	0.8	0.5	0.6	0.5	0.6	0.4
Al_2O_3	15.6	12.1	11.4	13.3	14.0	15.2	15.0
Fe_2O_3	0.4	0.9	2.9	3.5	1.1	1.3	1.0
FeO	1.7	3.9	1.7	2.1	4.1	2.4	2.0
MgO	0.9	2.1	2.1	2.7	2.9	1.3	1.0
CaO	2.9	2.8	4.2	5.8	3.5	3.0	2.4
Na_2O	3.4	1.7	1.0	1.1	3.4	3.6	3.5
K_2O	3.7	3.4	2.5	2.9	2.0	3.8	3.9
H_2O	0.1	0.7	2.9	3.2	3.1	0.6	0.6
CO_2	--	1.3	3.8	5.3	1.6	--	--

1. Calculated from average modes of Peak granodiorite and the core of Drury quartz monzonite.
2. Calculated from "average" mode of Yukon group strata.
3. Combination of Clarke's average shale and "sandstone" in ratio of 60:40 (Clarke, 1924).
4. Average sediment listed by Pettijohn (1949, p. 82).
5. Average graywacke listed by Pettijohn (1949, p. 250).
6. Mean of Nockolds' average granodiorite and adamellite.
7. Mean of Nockolds' average biotite adamellite and average biotite granodiorite (Nockolds, 1954).

All compositions adjusted to total 100 per cent.

Considering the manner of derivation the composition of the Yukon group and of the granodiorite show some important similarities though the discrepancies in FeO, MgO, and Na_2O are large. The differences are not so great that they might not be removed by a proper sampling of the rocks, particularly the Yukon group. Also it may be that the effect of the granitic magma on the metamorphic strata has produced some of the discrepancies, possibly by basification, as is suggested by the production of amphibolite and lime silicate rocks from limestone, and by the possible introduction of iron in pyrrhotite in hornfels. The schist may be biotitized.

The remarkably close similarity of the calculated composition of the granodiorite and the mean of Nockolds' average biotite granodiorite and biotite adamellite (Nockolds, 1954) shows that the rocks of Glenlyon Range are quite average in composition. The combination of Clarke's average shale and sandstone and the composition of the average sediment and the average graywacke are listed to provide a basis of comparison for the Yukon group composition.

If it be granted that the granitic rocks of Glenlyon Range are of magmatic origin on the basis of the evidence cited in the preceding sections of this thesis, there is good reason to believe that the "parental" magma of the rocks which can be observed at the present surface crystallized to form the core of Drury quartz monzonite and the large intrusive of Peak granodiorite. The core of the quartz monzonite is much deeper in the section than the granodiorite and presumably represents rocks that are closer to the magma source than any others that can be observed.

The composition of any magma is directly dependent upon the composition of the material available for melting and upon the degree of fractionation which might result either by fractional crystallization or by partial melting. A magma which crystallized to form the core of Drury quartz monzonite (which in the core is actually granodiorite) could have resulted by fusion and homogenization of a section of rocks similar in bulk composition to the rocks of the Yukon group in Glenlyon Range. Toward the margins of such a zone of fusion the process would become more and more highly selective, and only rocks of favourable composition would be melted. In a section such as that of the Yukon group the rocks most resistant to melting would be the limy beds, particularly as these might be expected to be converted to refractory lime-silicates prior to being engulfed in the zone of fusion.

One result of a process such as this would be to cause changes in the composition of the magma outward from the zone of complete fusion and homogenization. Toward the margins of the melt the liquid should become progressively richer in silica and alkalies and poorer in lime and ferromagnesians. With this change there should be a continuous increase in the amount of unfused material beginning at the most refractory and progressively including material of less and less refractory nature.

In a gross way these features are reflected in the occurrence of Drury quartz monzonite. Near the margin of the homogeneous core the inclusions are, with but minor exceptions, limy metamorphic rocks which are surrounded by aureoles of hornblende-biotite-quartz diorite. The occurrence, texture, and mode of the quartz diorite all support the concept that it is the result of minor fusion and severe reactions between granitic magma and limy metamorphic rocks. It grades through rocks which are evidently the result of contamination of "normal" magma into those which are typical of Drury quartz monzonite. In the intermediate zone there are inclusions of schist as well as of limy rocks. These inclusions contain many small sills of quartz monzonite, and the schist is "granitized" to some extent.

If Drury quartz monzonite did form by the fusion of rocks in situ it is apparent that the melted material was mobile, and it developed intrusive relationships to the unmelted rocks. The intrusion might be in the same sense that porridge in a pot is intrusive to the pot.

There are some rather cogent arguments against the hypothesis that the quartz monzonite formed by the fusion of rocks in situ. One should find evidence of partial melting in the schist inclusions of the intermediate zone, but no conclusive evidence of this was observed. There should, perhaps, be a broad zone of migmatitic complex at the margins of such a fused zone, but nothing like this occurs. One is forced to consider the possibility of the introduction of magma from a source which cannot now be observed.

If the core of Drury quartz monzonite represents the intrusion of material from below it may have arched the surrounding rocks into an anticlinal structure or it may have been injected into a pre-existing structure. Under either of these circumstances the contacts might be roughly concordant to the structure of the invaded rocks. Outward from the main mass roughly concordant satellite intrusions becoming progressively smaller would occur with relatively more and more metamorphic rocks. At the outer limit of such activity there would be only small sills associated with rocks resulting from granitization of favourable strata. The general aspect of the intrusions would be one of concordancy though obviously their interconnections would be discordant.

Under these conditions reactions between the intrusive magma and the invaded rocks will be less and less intense from the core outward. At the margin of the core the temperature of the invaded rocks was, judging from their metamorphic condition, high enough that certain compositions could be partially melted given sufficient water content and confining pressure. Under these circumstances rocks of "granitic" composition in contact with an intrusive magma would be readily assimilated whereas those of non-granitic composition (e.g., limy rocks) would be involved in severe reactions but could not be melted unless the magma contained superheat or unless the reactions were so long-continued that the composition of the rocks was changed by exchanges with the magma. Superheat is unlikely to be a factor, and reactions cannot proceed without crystallization of the magma, thus the process which tends to assimilate material included in the magma is self-destroying. The more refractory the included material the less likely that assimilation will proceed to completion.

Under conditions such as these all the contact rocks that are of favourable composition at the margins of a large intrusion of magma may be assimilated, but those which are, in effect, supersaturated with respect to the magma will remain as inclusions if they contain more material than can be converted to phases in equilibrium with the magma before crystallization halts the process. Smaller intrusions above the main mass will become less able to assimilate material, and as a consequence the inclusions and contact rocks will become more and more "granitic" in composition as one moves from the center of most intense magmatic activity. The smaller the mass of the magma the less the volume of rock it can assimilate.

This will be accentuated if the intrusions are injected into progressively higher levels of the crust and at the same time become progressively smaller. The higher in the crust the lower the probable initial temperature of the surrounding rocks, hence the magma must crystallize more completely in order to assimilate material. The decrease in confining pressure may also be a factor. If the magma is assumed to be saturated in water it crystallizes at progressively higher temperatures as the confining pressure decreases; thus there is, in a sense, less time for assimilation by a magmatic mass high in the crust relative to an identical mass at greater depth or in a higher temperature environment.

The occurrence of Drury quartz monzonite can be well explained as resulting from a massive intrusion of magma in the core and a complex of intrusions above the core so that the proportion of granitic to metamorphic rocks decreases progressively from the core outward. The effects of assimilation as outlined above seems to account adequately for the change in the nature of the inclusions from exclusively limy rocks at the margin of the core to both limy rocks and feldspathic schist in the intermediate zone. There is no evidence against the possibility that this magma was formed by the fusion of strata of the Yukon group, so that the outer limit of the original melting coincided approximately with the present margin of the core. Under conditions such as these the volume of intrusive material is not large, and the problem of providing space is not a difficult one.

If, in the upward and outward intrusion of magma from the mass of the core, there was a slight tendency toward fractionation by the separation of crystals from liquid then the satellite bodies would be richer in potash feldspar and poorer in anorthite and probably in iron and magnesia than the source. The more selective nature of the assimilation in the smaller bodies would tend to produce the same compositional changes. This seems to provide a reasonable explanation for the compositional difference between the core and the intermediate zones of Drury quartz monzonite. There might have been, of course, injection of core-type material at any level into the intermediate zone or above.

The metamorphic rocks associated with and overlying the intermediate zone of the quartz monzonite would be recrystallized, and with the aid of magmatic emanations certain favourable strata may have been granitized. Rocks resulting from granitization in such an environment might be expected to differ widely in composition and to show similarities to both the metamorphic and magmatic rocks. If the zone containing granitized rocks is injected by small sills of relatively highly fractionated magma, an association such as is found in the outer zone of the quartz monzonite might be produced. The environment varies from purely magmatic in the core to primarily metamorphic in the outer zone, and the imprint of these changing conditions will be found in the textures of the rocks. The granitic rocks of the intermediate zone have a primarily magmatic texture, but they seem to show the effects of metamorphism more than do those of the core. The textures of the granitic rocks of the outer zone, be they magmatic or metamorphic, reflect an intensely metamorphic environment.

The possibility of a magma of the composition of the core of Drury quartz monzonite becoming saturated in water when crystallization is from 50 to 80 per cent complete has been discussed in a previous section. Saturation in water with the evolution of a vapour phase (which may eventually condense to an aqueous liquid) seems to provide the best explanation for the change of conditions in the magma which lead to the replacement of other minerals by potash feldspar and the apparent discontinuity in the plagioclase series whereby zoned, relatively calcic plagioclase is irregularly replaced by unzoned, more sodic material. The conditions under which these replacements occurred evidently extended into the surrounding metamorphic rocks and led to a general potash metasomatism and perhaps locally to granitization.

The possibility of the early evolution of a vapour phase may also be important in respect to the origin of the alaskite dykes. In any given magma chamber water vapour will be evolved when the vapour pressure exceeds the confining pressure. If the vapour cannot continuously escape the pressure may rise until the surrounding rocks fail. Magma in independent bodies but of the same composition (including water) and at about the same confining pressure, will reach saturation at the same time in the crystallization history. Fracturing of the chamber walls may then occur at about the same stage of crystallization though perhaps at different times from place to place. The material from the magma injected into fractures formed by this mechanism can thus be expected to be uniform in composition from place to place even though it may have had different sources. Material injected under these conditions will be water-rich and presumably would involve a high proportion of liquid relative to crystals. The composition would be rich in alkalies and silica and poor in anorthite and biotite. Within these limits the composition might be quite variable. The alaskite of Glenlyon Range seems to be well explained by an origin of this nature. That it was water-rich is suggested by the fact that it is locally pegmatitic and probably by the fact that it characteristically contains muscovite. It is everywhere low in anorthite content and poor in biotite. That it was highly liquid at the time of injection is suggested by the textures that do not show extreme protoclastic effects.

The pegmatitic selvages on the margins of some of the small sills of quartz monzonite in the intermediate and outer zones may be related to the evolution of an aqueous phase. There is no apparent explanation for such features on the basis of crystallization of silicates from the liquidus; rather one might expect chilled selvages. Perhaps under normal conditions in these small sills the water vapour continuously escapes into the surrounding rocks (and produces potash metasomatism), but locally the contact may be "tight," and the vapour or liquid may be forced to move along the contact or along a fracture within the body itself. This might produce a narrow zone of coarse potash feldspar by replacement. If a vapour forms, the transfer of material may be accomplished by diffusion set up by a temperature gradient. Jahns and Burnham (1958, p. 88) found that transport by this mechanism led to the formation of muscovite and potash feldspar under experimental conditions. Muscovite occurs in these pegmatitic zones. If a liquid is the medium involved it may transport the constituents directly.

Peak granodiorite shows a remarkable textural and compositional similarity to the core of Drury quartz monzonite. So similar are the two masses that one is forced to the conclusion that they have a common source. Faulting gives evidence, however, of an age difference; Peak granodiorite appears to be younger. The age difference may be very small, and the faults which cut the core of the quartz monzonite may have done so when the mass was still molten at depth (what better explanation is there of what happens to a fault at depth?). Under these circumstances the fault movements themselves may have permitted the dilation of the space into which Peak granodiorite was injected from the magma below.

If the textures that indicate that plagioclase, quartz, and biotite were strained prior to the formation of potash feldspar were developed by protoclasis during intrusion, it seems that a granitic magma which is much over 50 per cent crystalline is no longer mobile or that it has lost the character whereby protoclastic textures may be developed.

The intrusion of such a large mass as Peak granodiorite vertically upward would, in a sense, bring the environment of its origin with it. The temperature of the intruded greenschists would be raised and they would be converted to hornfels. The lack of chilled margins in such a disharmonious environment is difficult to explain. There is a possibility that the one contact of the granodiorite that can be observed is a combination of intrusive and fault surfaces, and this may be in some way connected with the lack of chilled margins. It may also be that the continuous upward intrusion of magma over a long period would tend to react with, recrystallize, and resorb such chilled margins as did form initially. When the intrusion became static, the temperature of the wall rocks may have been sufficiently high that no chilled margins developed during the final crystallization.

If the development of a vapour phase is needed for potash feldspar to replace the other minerals, this occurred from contact to contact in Peak granodiorite. There was evidently little chance for the vapour to escape into the relatively impermeable rocks across the vertical contact, and there has been little if any metasomatism in these rocks. However, the effects of metasomatism are well displayed in the inclusion of the limy lower Harvey group rocks on the north slopes of Glenlyon Peak. Obviously introduced potash feldspar is an important constituent of these rocks. Perhaps in the long-since eroded part of Peak granodiorite well above the present exposures the effects of the upward accumulation of aqueous vapour might have been more pronounced.

CONCLUSION

The origin of the granitic rocks of Glenlyon Range can be explained comprehensively on the basis of the crystallization of granitic magma. The magmatic origin proposed in this thesis neither denies nor minimizes the many features of occurrence and texture which seem to indicate a metamorphic origin for these rocks.

The basis of the proposed origin is provided in the discussion of the crystallization of "granodiorite" magma in the system $KAlSi_3O_8$-$NaAlSi_3O_8$-$CaAl_2Si_2O_8$-SiO_2-H_2O. This discussion is supplemented by consideration of the effects of hyperfusibles, principally water, during the crystallization sequence.

The main conclusions reached in these discussions are the following:

1. Prior to the crystallization of potash feldspar the melt will be 50 per cent or more crystalline; quartz will be between 50 and 60 per cent and plagioclase between 60 and 80 per cent crystallized. Presumably biotite also crystallizes early in the sequence.

2. It is reasonable to expect that soon after potash feldspar begins to crystallize an aqueous vapour phase will be developed in the magma and will cause the early formed minerals, particularly plagioclase, to become unstable so that they may be replaced by potash feldspar and albite.

The nature of the crystallization history is in agreement with the nature of the family of granitic rocks assuming that these rocks originated by the partial fusion or fractional crystallization of identical material from place to place. The composition of this material is assumed to be the bulk composition of the rocks characteristic of eugeosynclines.

The paragenetic sequence of the minerals in Peak granodiorite and in the core and intermediate zones of Drury quartz monzonite conform precisely to what would be expected from the theoretical crystallization of "granodiorite" magma. The evidence of the replacement of plagioclase by potash feldspar is found everywhere in the granitic rocks. The uniformity in texture and mode in large masses of granitic rocks in which replacement textures are common leads to the view that the replacement resulted from a change of conditions in a magma whereby the early formed minerals became unstable. The saturation of a magma in water and the evolution of a vapour phase seems to provide the best explanation of this uniformity. An independent potash metasomatism is unlikely to produce such uniform effects throughout large masses or from mass to mass in different environments.

Part of the core of Drury quartz monzonite may have originated by the fusion of rocks of the Yukon group in situ. The intrusive features may have been developed by movements of this melted mass but not necessarily by its large scale injection away from its place of origin. Near the margins of such a zone of fusion the most refractory rocks would remain as inclusions. This may be the reason that limy metamorphic rocks are the only large inclusions in the core of Drury quartz monzonite. The hornblende-biotite-quartz diorite that forms aureoles around the inclusions seems definitely to be the result of partial melting and interactions of the limy rocks and granitic magma. Higher in the zone of fusion less and less refractory rocks may remain as inclusions, and finally the effects may be predominantly metamorphic. The zones above the homogeneous core may be intruded at any level by core material.

These features can be explained equally well by the processes of selective assimilation on the contacts of a large intrusion of magma surrounded by satellite intrusions. There is no implicit solution of the room problem by this mechanism however.

At a late stage in the crystallization history of Drury quartz monzonite, fracturing, perhaps induced by a build-up of vapour pressure in the magma chambers, allowed the intrusion of magma rich in alkalies, silica, and water. This crystallized to form the alaskite dykes.

Finally, faulting displaced all these rocks, and from the still mobile interior of the core of the quartz monzonite (which is actually granodiorite) the mass of Peak granodiorite was intruded upward. Adjustments on the faults within Glenlyon Range could adequately provide the space into which this mass was injected.

All the many factors of the occurrence, textures, and modes of the granitic rocks of Glenlyon Range seem to be best explained on the basis of crystallization of magma as described in this thesis. Many but not all the features are consistent with an origin by granitization. The data were accumulated and much of the descriptive material written at a time when the writer was convinced that a granitization process and not magmatic activity was the primary origin of the rocks. Any prejudice that may have existed in the gathering of the data and in its presentation would thus be slanted away from the possibilities of an igneous origin. Because of this it is all the more remarkable that essentially every detail of this material fits the igneous origin proposed in this thesis. It is hoped that this is a favourable commentary on the writer's objectivity.

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APPENDIX

Figures and Tables

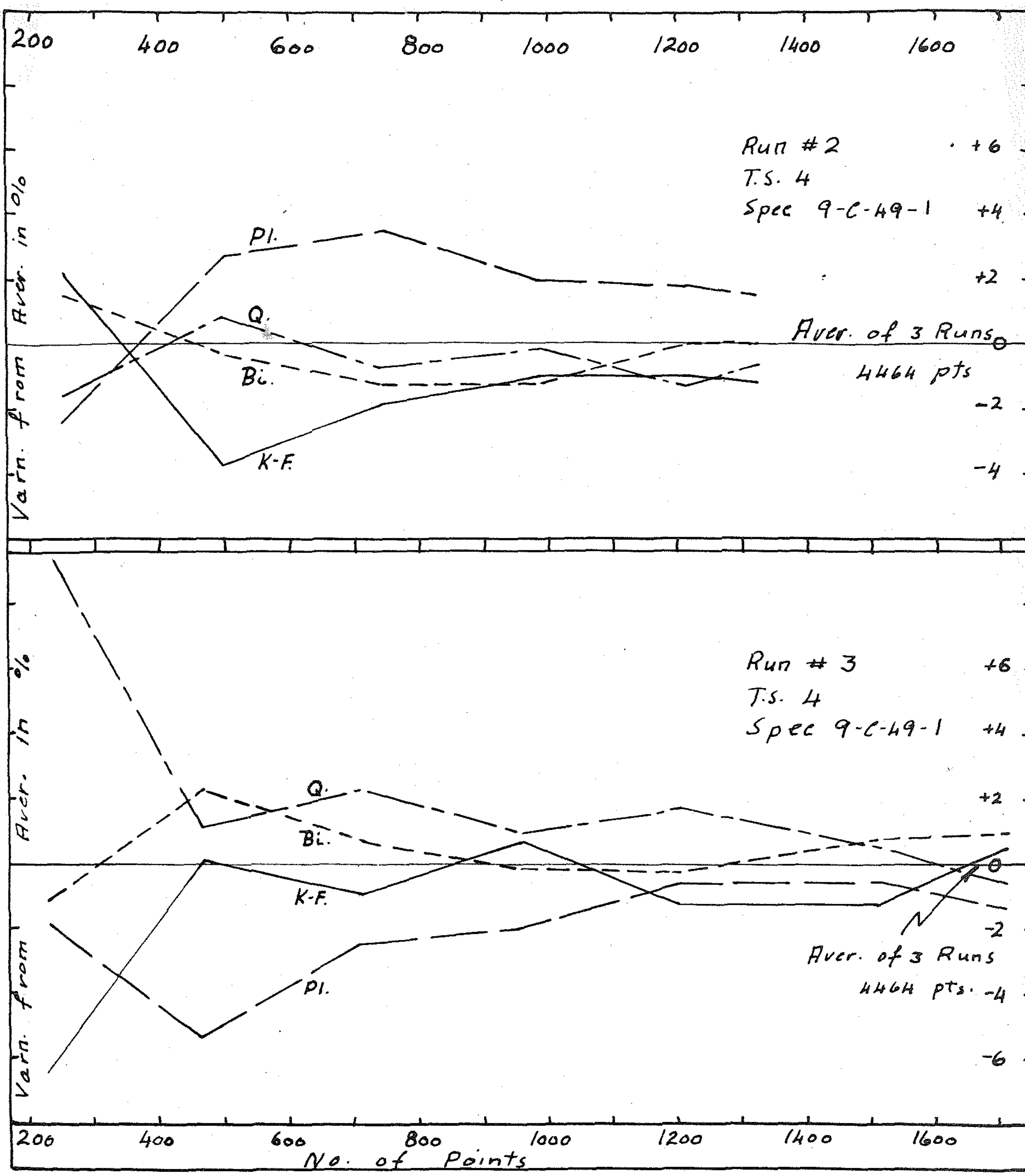

Figure A1

Modal analyses: variations in proportions of minerals with respect to number of points counted. Diagrams represent two runs on the same thin section of Peak granodiorite. Average determined from 3 runs using different traverses (No. 3 with closer spacing).

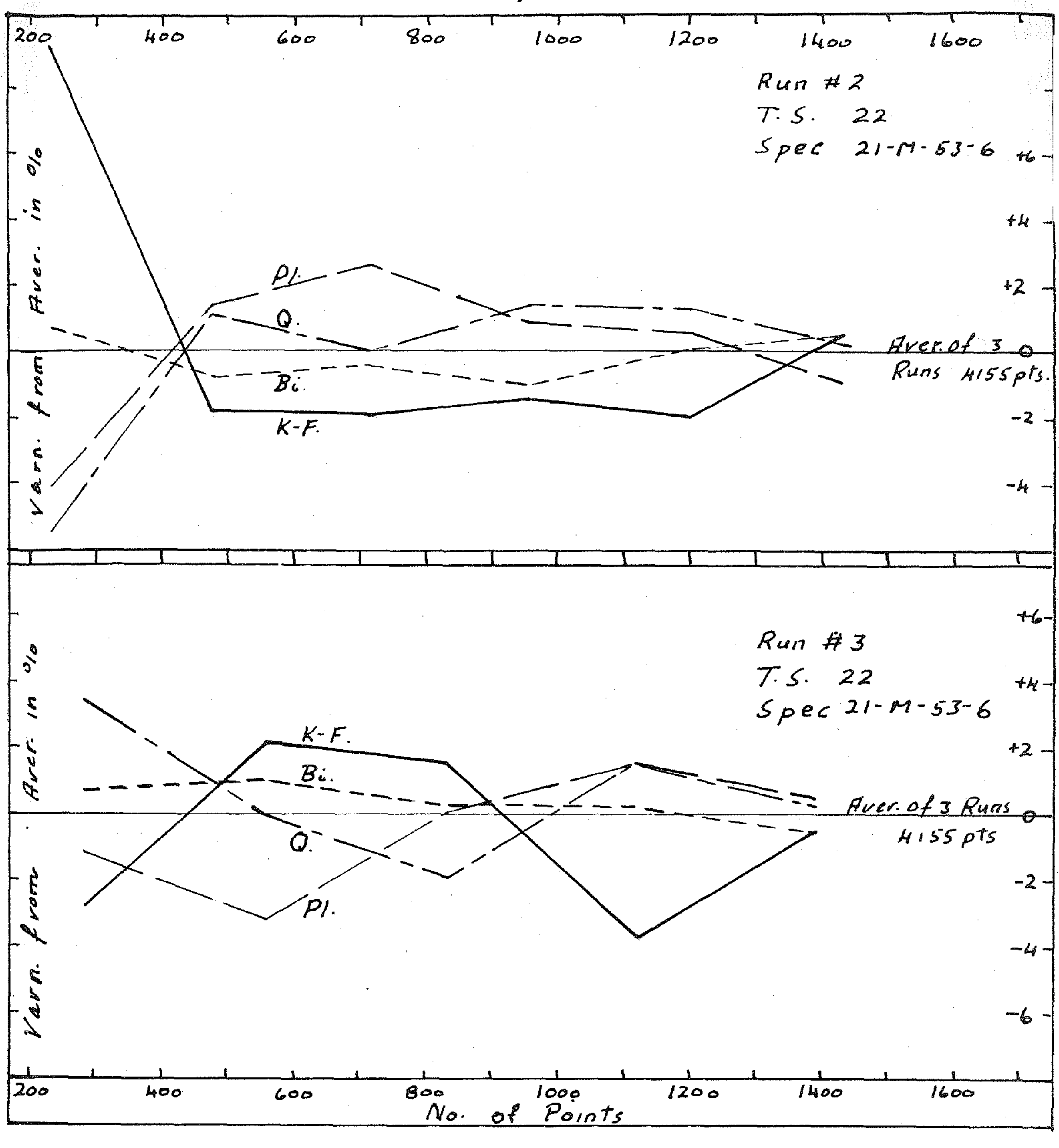

Figure A2

Model analyses: variations in proportions of minerals with respect to number of points counted. Diagrams represent two runs on the same thin section of Drury quartz monzonite. Average determined from 3 runs using different traverses.

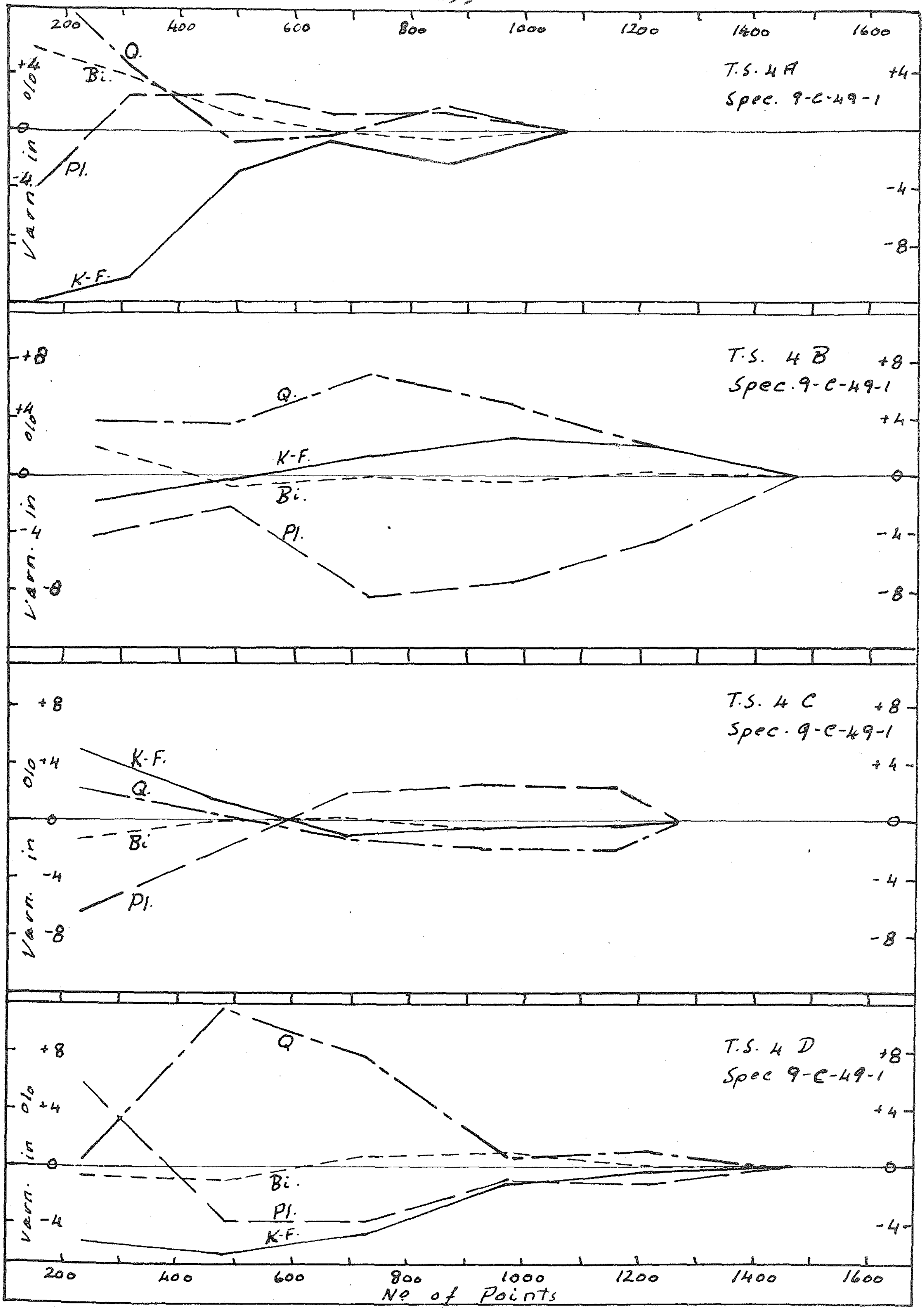

Figure A3. Modal analyses: variations in the proportions of minerals with respect to the number of points counted. The variation is zero for completed analyses.

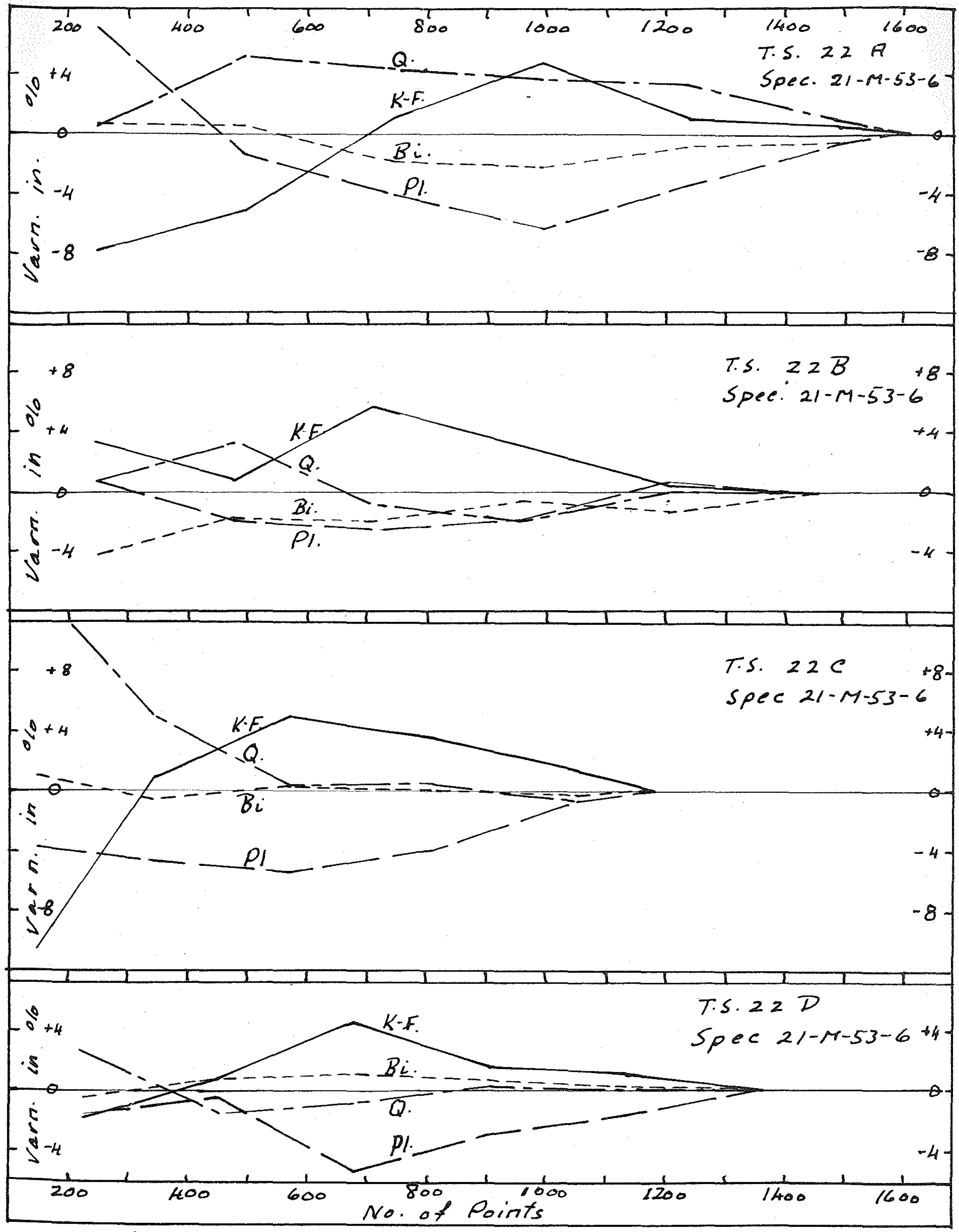

Figure A 4

Modal analyses: variation in proportion of minerals with respect to number of points counted. Variation of zero for completed analyses.

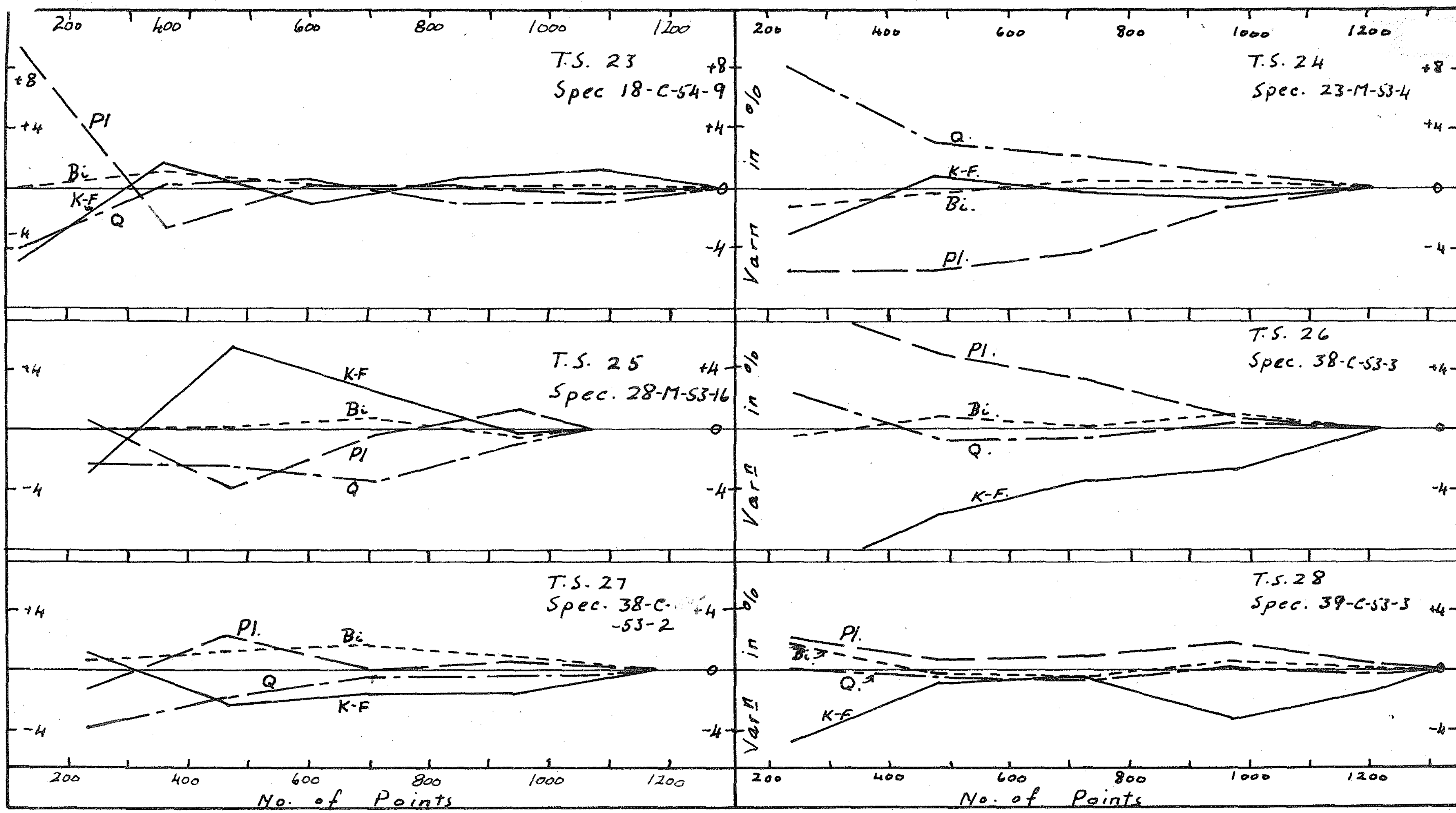

Figure A5

Modal analyses: variations in proportions of minerals with respect to number of points counted. Variation of zero for completed analyses.

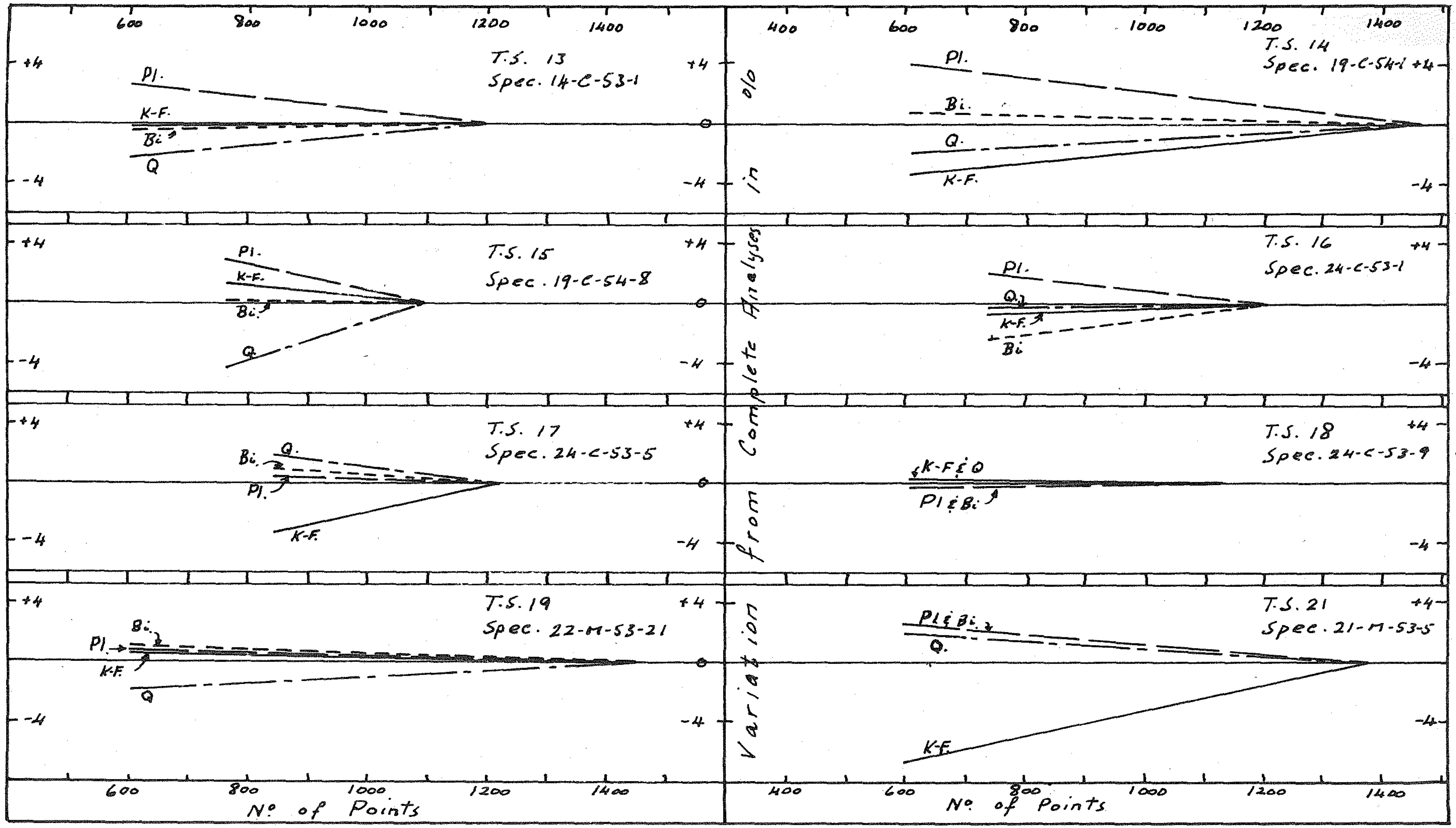

Figure A6

Modal analyses: variations in proportions of minerals between about half complete and completed analyses.

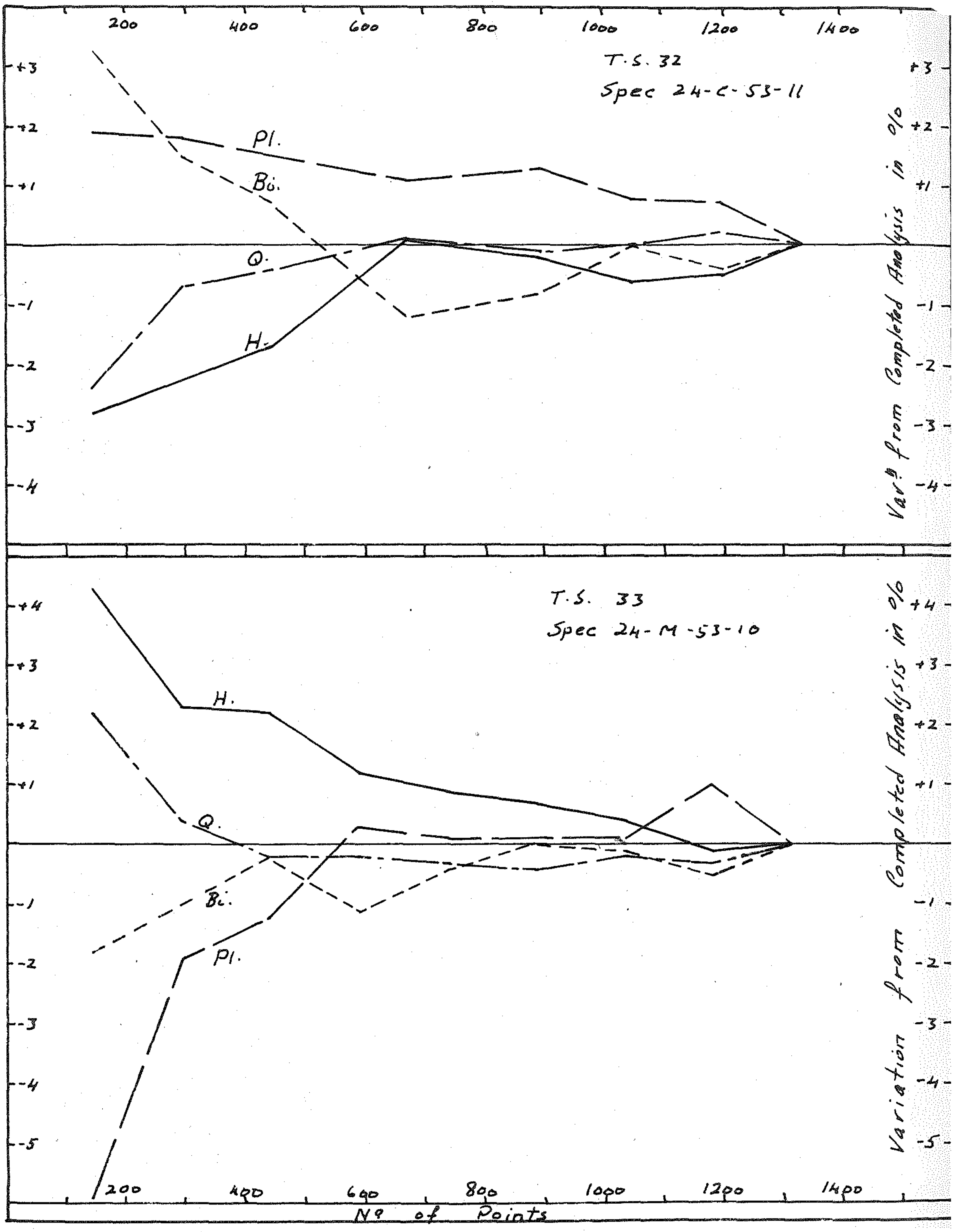

Figure A 7

Modal analyses: variations in proportions of minerals with respect to number of points counted. Variation of completed analyses is zero. Examples from hornblende-biotite-quartz diorite.