GEOLOGY OF THE MOUNT BRENNER STOCK
NEAR DAWSON CITY
YUKON TERRITORY

by

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ABSTRACT

The Mount Brenner stock has intruded folded sedimentary and metasedimentary rocks that lie 40 miles northeast of Dawson City, Yukon Territory. The stock consists of four major concentric zones: (1) an outer zone of fine- to medium-grained augite-biotite monzonite; (2) a zone of very coarse-grained monzonite porphyry; (3) an intermediate zone of porphyritic hornblende monzonite; and (4) a central zone of coarse-grained pink quartz monzonite porphyry. Except for the outer zone, all rock types are porphyritic and the alignment of feldspar phenocrysts gives the rocks a primary flow structure which conforms to steeply outward dipping gradational internal contacts. All external contacts are sharp. The regional structural trend is modified in the vicinity of the stock so that beds are generally conformable with the intrusive contact.

From structural evidence, it is concluded that at the present level of erosion, the stock was emplaced by forceful injection. The different rock zones of the stock can be accounted for by differentiation of an augite-biotite monzonite magma by a combination of crystal fractionation, volatile and alkali diffusion, and multiple intrusion.

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INTRODUCTION

LOCATION AND ACCESSIBILITY

The map-area lies in west-central Yukon Territory about 40 miles northeast of Dawson City and 3 miles north of the Tombstone River (fig. 1). The Demster Highway leaves the Taylor Highway 20 miles east of Dawson City and follows the North Klondike River. Both of these gravel highways are kept in excellent condition for summer travel. At mile 45 of the Demster Highway (in the vicinity of North Fork Pass) the North Klondike River swings southwestward along a broad valley. This valley leads to a low, flat pass into the valley of the Tombstone River at about 11 miles from the Demster Highway. The map-area is a two day walk from the highway by way of these valleys. The area is accessible by helicopter or, with difficulty by horses.

TOPOGRAPHY, DRAINAGE AND GLACIATION

The region lies within the physiographic unit known as the Ogilvie Mountains (Bostock, 1948). "The range has a rugged and mountainous aspect and consists of long, branching, knife-edge crests, with sharp and often

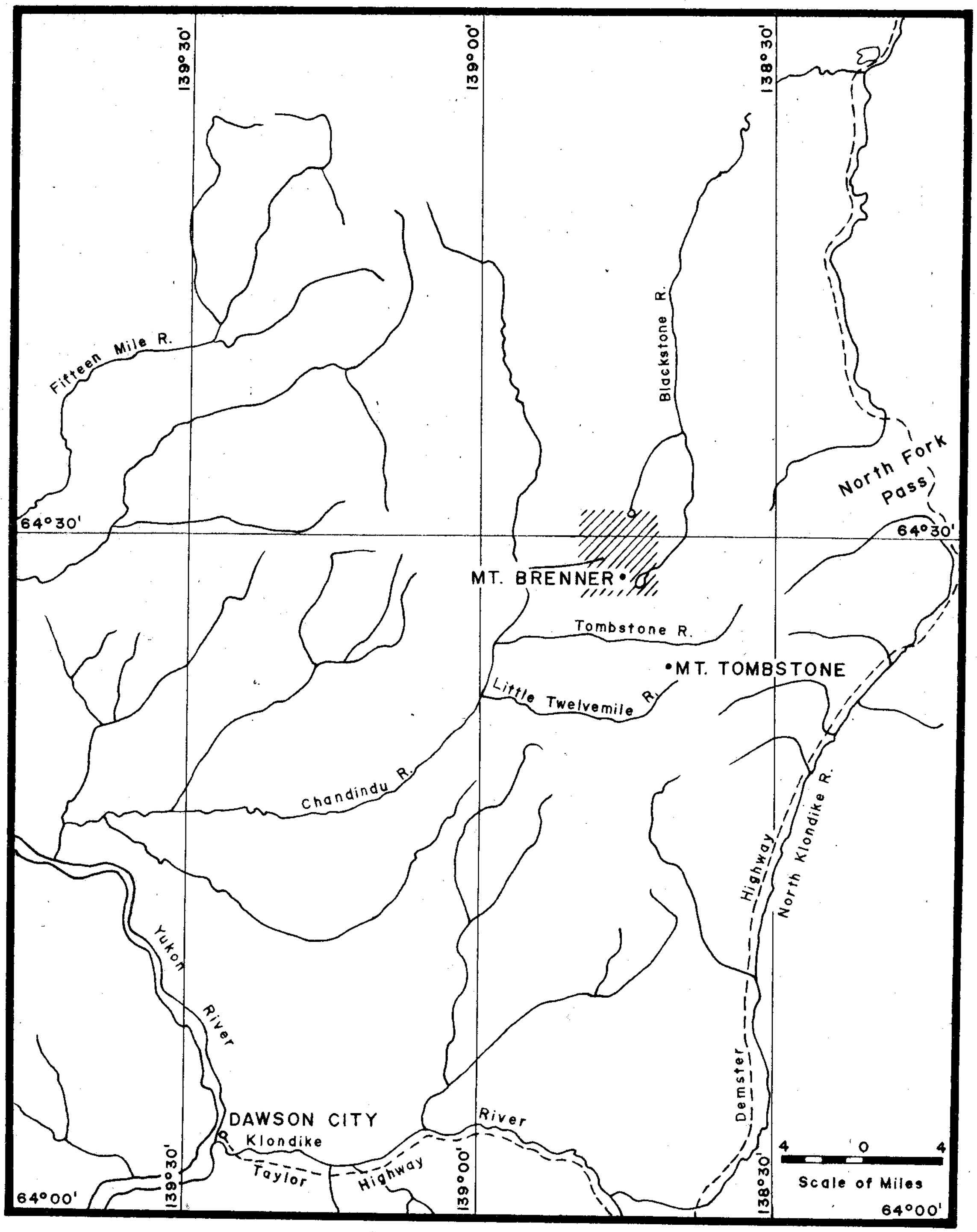

Figure I. Index map showing the Dawson City area and location of the Mount Brenner stock (lined pattern).

precipitous peaks, separated by deeply cut valleys." (Cockfield, 1919). The map-area is entirely above timber-line which is at an elevation of approximately 4000 feet. Average relief is 3500 feet and peaks reach a maximum elevation of 7500 feet. In areas of granitic rocks the topography has a unique character which has been described by McConnell (1903) in the following words.

> This rock is strongly jointed vertically and weathers into ruinous, wedge-shaped ridges, surmounted by lines of sharp pinnacles and lofty tower-shaped peaks. The pillared character of the region is so remarkable that the prospectors have given it the name of the tombstone country.

The area is drained by three river systems: in the west, the south flowing Chandindu River system with its main westward flowing tributaries, the Tombstone and Little Twelvemile Rivers; in the east, the North Klondike River system; and in the north, the Blackstone River system.

The Ogilvie mountains display considerable evidence of glaciation. Main valleys have U-shaped cross-profiles and the uppermost parts of tributary valleys generally terminate in glacial cirques, which commonly hold tarns. Arêtes, horns, and hanging valleys are common features. Small ice patches still occupy a few of the cirques on the north sides of some peaks north of

"Syenite Lakes". Valley glaciers emerged from the mountains and occupied the valleys of the North Klondike and Chandindu Rivers but extended only a short distance beyond the mountains (Green and Roddick, 1962). Since glaciation, streams have cut narrow trenches and canyons into older valley bottoms.

PREVIOUS GEOLOGICAL WORK

Early investigations in the Tombstone area were made by McConnell (1903) and Cockfield (1918 and 1929). The work consisted of reconnoitering the country and examining mineral deposits. Green and Roddick (1961) mapped the area at a scale of 1 inch to 4 miles as part of a project known as Operation Ogilvie. Vernon and Hughes (1961) mapped the surficial geology. Tempelman-Kluit (1964 and 1965) carried out mapping in the Tombstone map-area at a scale of 1 inch to 1/2 mile for eventual publication at 1 inch to 1 mile. The present field work was carried out by the writer during the months of July and August, 1964, while employed by the Geological Survey of Canada.

ACKNOWLEDGMENTS

The writer was ably assisted in the field by the late Mr. Bennie Lastiuka.

Thanks are due to Mr. D. J. Tempelman-Kluit for encouragement and stimulating discussion during the course of field work, and to Mr. E. Montgomery for preparation of thin sections.

I wish to express special appreciation to Professor K. C. McTaggart, of the University of British Columbia, under whose supervision this thesis was written.

GENERAL GEOLOGY

Rocks of Silurian age (Tempelman-Kluit, 1965) occupy the northwestern corner of the map-area (see map in pocket). These rocks consist mainly of interbedded black cherts and argillites and are here about 1000 feet thick.

In the northeastern and southwestern parts of the map-area, the black cherts and argillites are overlain conformably by a series consisting of black shale, argillite, slate, phyllite and thin bedded quartzite of Jurassic age. A continous thin bed of limestone, which contains Middle Permian fossils, marks the contact between these two rock units.

Dark blue-grey to grey quartzite of Lower Cretaceous age (Tempelman-Kluit, personal communication), occupies the southeastern part of the map area. Quartzites are massive and characteristically have thin partings of slate and phyllite (commonly graphitic) between thicker beds. The maximum thickness of this unit has been estimated to be 45,000 feet (Green and Roddick, 1962). Recent work, however, suggests that the rocks are isoclinally folded with steeply dipping axial planes and that the true thickness is in the order of 5000 feet.[1] The contact between the quartzite and the underlying rocks "is considered to be a gently southeast-dipping thrust surface upon which the quartzite has moved to the northwest." (Tempelman-Kluit, 1965).

Two large stocks that intrude the sedimentary and metamorphic rocks in the Tombstone map-area range in composition from diorite to syenite. Textures of these rocks range from fine-grained and equigranular, to coarse-grained and porphyritic. Foliation in the rock is shown by alignment of tabular feldspar phenocrysts. Inclusions are rare. Age of the granitic rocks is not known, though they are thought to be contemporaneous with granitic rocks far to the southeast which have been dated as Middle Cretaceous (Green and Roddick, 1962).

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[1] Tempelman-Kluit, personal communication

THE MOUNT BRENNER STOCK

GENERAL DESCRIPTION

Mount Brenner is the highest peak of the most northern granitic body in the Tombstone map-area. In this thesis the granitic body is referred to as the Mount Brenner stock. The intrusion occupies a roughly elliptical area with its long axis trending northeastward. It crops out over an area of about 17 square miles and exhibits a more or less concentric arrangement of its various subdivisions.

A segment of augite-biotite monzonite lies around the western part of the stock. A crescent-shaped, narrow band of monzonite porphyry lies along the inner contact of this segment. Inward from this band, and forming a broad irregular ring, is a body of porphyritic hornblende monzonite. The central part of the stock is composed mainly of pink quartz monzonite porphyry. A body of aplite lies near the eastern side of the pink quartz monzonite porphyry. The contacts between each of the rock types are in most places gradational, although the monzonite porphyry locally shows a sharp intrusive contact against augite-biotite monzonite. Modes of each rock type are shown in Table I.

Dykes are not common within the stock and very few of them were found in the adjacent country rocks. A series of dykes is found in the east central part of the pink quartz monzonite porphyry near where the porphyritic hornblende monzonite protrudes into the core. In this area aplite dykes, that range from a few inches to 20 feet thick, follow steeply dipping north to northeast trending joints. Dykes of pink quartz monzonite porphyry fill joints in pink quartz monzonite porphyry of approximately the same compositon and texture. No dykes were traced outward into the surrounding country rocks. Near the southeastern contact of the stock, however, a few sills of porphyritic hornblende andesite, that range from 0.5 to 15 feet wide intrude the shale. In the same area a feldspar porphyry dyke cuts across the foliation in black phyllite. Euhedral, thin-tabular potash feldspar phenocrysts are aligned parallel to walls of the dyke to give the rock a distinct foliation.

TABLE I

MODAL ANALYSES OF GRANITIC ROCKS
MOUNT BRENNER STOCK

Rock Type	Augite-Biotite Monzonite					Monzonite Porphyry	Porphyritic Hornblende Monzonite			Pink Quartz Monzonite Porphyry				Aplite	Hornblende-Biotite Pyroxenite
Specimen Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Plagioclase	42.5	34.6	41	38.8	42.6	39.8	50	24.1	35.7	29	39.2	34.9	34.3	38.0	2.9
Potash Feldspar	3.8	27.1	20.2	25.6	23.6	43.0	31.7	56.8	43.6	50.8	36.7	41.9	48.6	30.1	3.4
Quartz	26.4	7.2	1.2	2.6	---	1.4	2.3	1.0	5.3	10	13.8	13.7	11.3	27.5	---
Biotite	27.2	17.5	16.4	15.6	5.1	---	1.0	1.2	0.2	0.5	---	0.4	tr.	0.1	25.6
Hornblende	---	tr.	0.7	4.2	15.3	7.6	11.9	14.5	12.2	7.9	9.3	6.7	5.5	tr.	7.9
Augite	tr.	12.7	18.5	11.5	10.7	6.5	1.0	0.4	---	0.3	0.2	0.3	tr.	---	56.1
Muscovite(sericite)	tr.	---	---	---	---	---	1.0	---	---	0.5	---	---	---	2.7	---
Total Accessories	1.0	0.9	2.0	1.6	2.7	1.7	1.1	2.0	3.0	1.0	0.6	2.1	0.3	1.6	4.1
Apatite	tr.	0.2	1.1	0.8	0.9	tr.	0.4	0.2	0.3	0.3	0.2	0.1	0.2	tr.	2.0
Epidote	tr.	0.2	0.8	---	tr.	tr.	tr.	---	tr.	tr.	tr.	tr.	tr.	tr.	---
Allanite	---	0.1	---	---	---	---	---	---	tr.	tr.	0.1	0.4	tr.	tr.	---
Sphene	---	---	tr.	tr.	0.14	---	tr.	0.5	tr.	---	0.2	0.9	0.2	tr.	---
Zircon	tr.	0.1	tr.	tr.	---	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	---
Garnet	tr.	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Calcite	---	tr.	tr.	tr.	tr.	---	1.0	---	0.8	0.7	0.3	0.3	0.3	0.3	0.2
Chlorite	---	tr.	0.1	tr.	0.14	tr.	tr.	---	0.4	tr.	tr.	tr.	tr.	1	---
Myrmekite	1.5	1.6	tr.	tr.	---	1.4	---	---	2.7	1.0	tr.	tr.	tr.	---	---
Opaque	tr.	0.3	tr.	0.8	1.5	1.7	0.7	1.2	1.5	0.3	0.3	0.5	tr.	0.3	3.8
Average Percentage An in plagioclase	48	44	41	54	50	33	31	45	27	32	28	26	30	28	45
Ratio of K-feldspar:plagioclase	1:11	1:1.2	1:2	1:1.5	1:1.8	1:0.9	1:1.6	1:0.4	1:0.8	1:0.6	1:1	1:0.8	1:0.7	1:1	1:2.8

Modes are plotted in Figures 2 and 3, and location of specimens is shown in Figure 7.

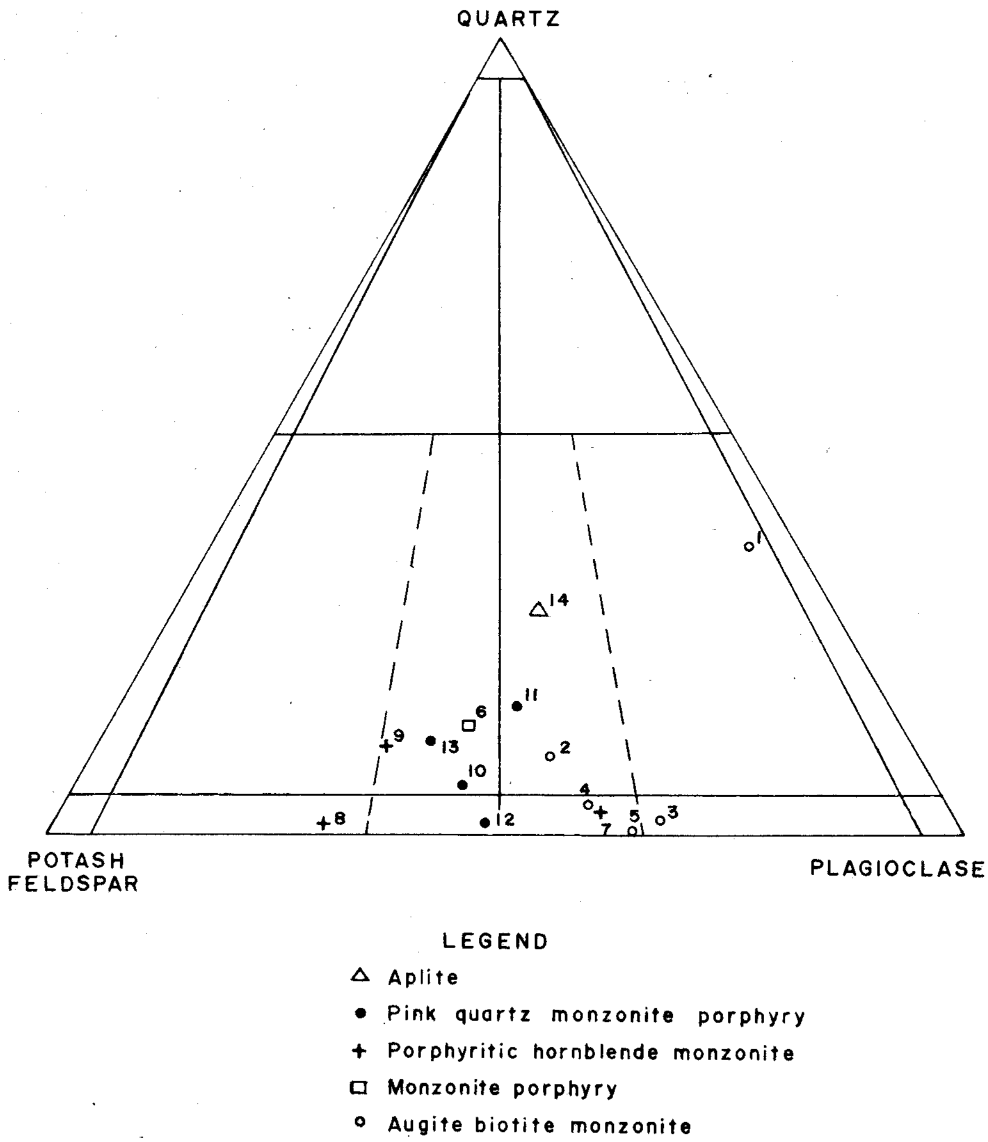

Figure 2. Modes of specimens from Mount Brenner Stock. Numbers refer to specimens in Table I and in Figure 4.

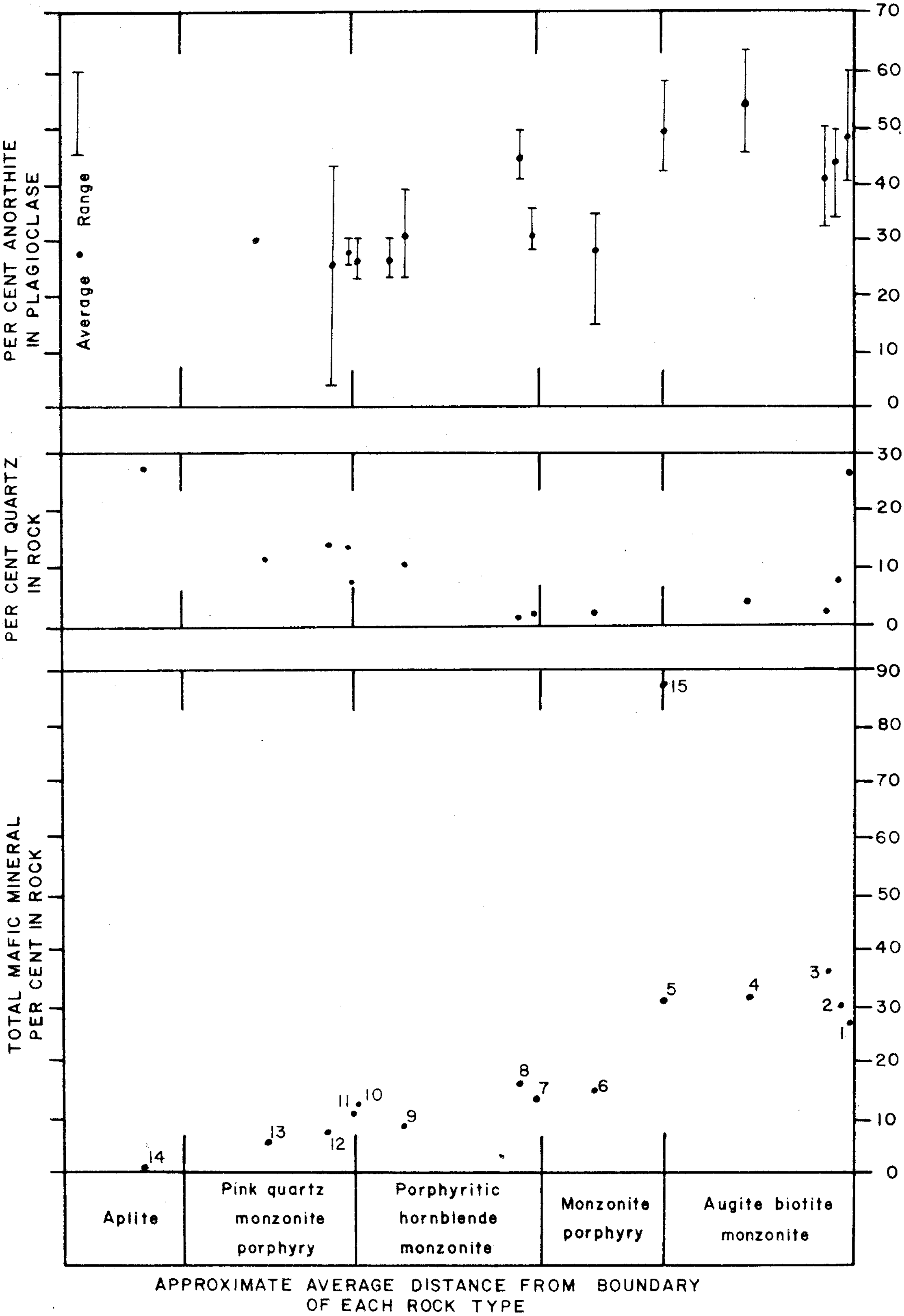

Figure 3. Variation in composition of granitic rocks with respect to distance from the margin of each rock type. Location of specimens shown in Figure 7.

PETROGRAPHY

Augite-Biotite Monzonite

The augite-biotite monzonite unit forms an irregular segment around the western and southwestern borders of the stock. A zone of dark-grey, fine-grained, garnetiferous biotite quartz diorite (1)[1], less than 1 foot wide, lies along the outer contact with hornfels. This zone grades into grey, fine-grained augite-biotite monzonite (2 and 3) that has a distinct foliation shown by trachytoid alignment of euhedral plagioclase crystals. The biotite forms hexagonal plates 1 to 2 mm. in diameter. Between 150 and 200 feet from the contact the texture of this rock grades from fine- to medium-grained (4) and the biotite occurs both as hexagonal plates and as platy aggregates. The platy aggregates, up to 2 cm. in diameter, lie along minute fractures in the rock (pl. I A).

A zone of dark-green, medium-grained, hornblende-

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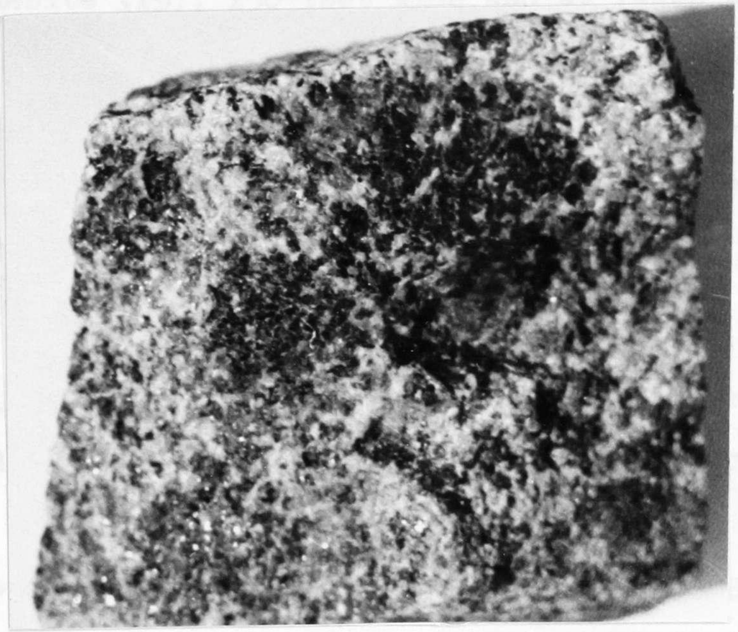
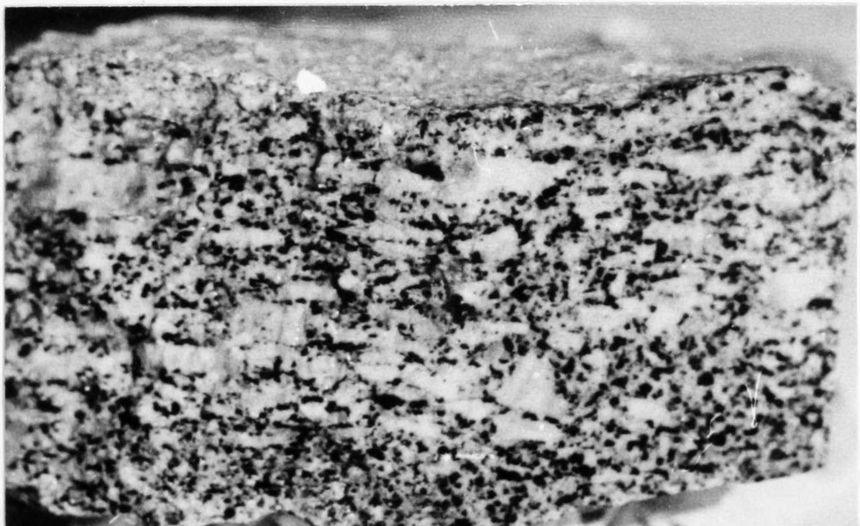
[1] Numbers in parentheses refer to specimens in Tables I and II and in Figures 2, 3, and 7.

Plate 1



A. Augite-biotite monzonite with rounded platy aggregates of biotite (X 1)



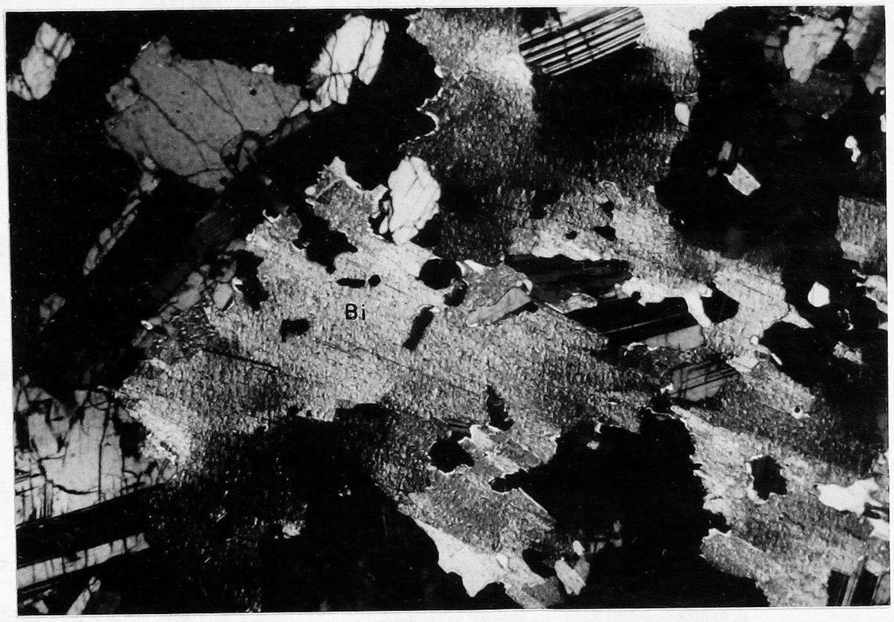
B. Porphyritic hornblende monzonite with distinct alignment of feldspar crystals (X 1) biotite pyroxenite (15), 150 feet wide and at least 2000 feet long, lies along the contact between the augite-biotite monzonite and the monzonite porphyry. The contacts between this rock and the surrounding rocks are gradational over a distance of about 5 feet.

In thin section, plagioclase from near the outer contact displays oscillatory zoning and broad, euhedral, saussuritized cores (pl. IIA), whereas plagioclase from the main part of this unit displays normal zoning and is relatively unaltered. The sub-trachytically aligned grains commonly are bent (pl. IIB) and show stress twinning (curved polysynthetic twin lamellae). Myrmekite occurs along some contacts between plagioclase and orthoclase. Weakly perthitic orthoclase ($2V_x$= 62 degrees) is interstitial to plagioclase and augite, or encloses and partly replaces plagioclase. A broad zone of randomly orientated inclusions of plagioclase, apatite, ziron, and biotite occurs in the cores of some orthoclase grains. Brown biotite (pl. IIIA) has the following pleochroic scheme: X, pale tan to yellowish-tan; Y, medium brown; Z, dark brown to dark reddish-brown. Bent cleavages are common. Zircon inclusions produce dark brown pleochroic halos. Green hornblende commonly forms rims around anhedral to subhedral grains of augite (pl. IIIB). Hornblende and

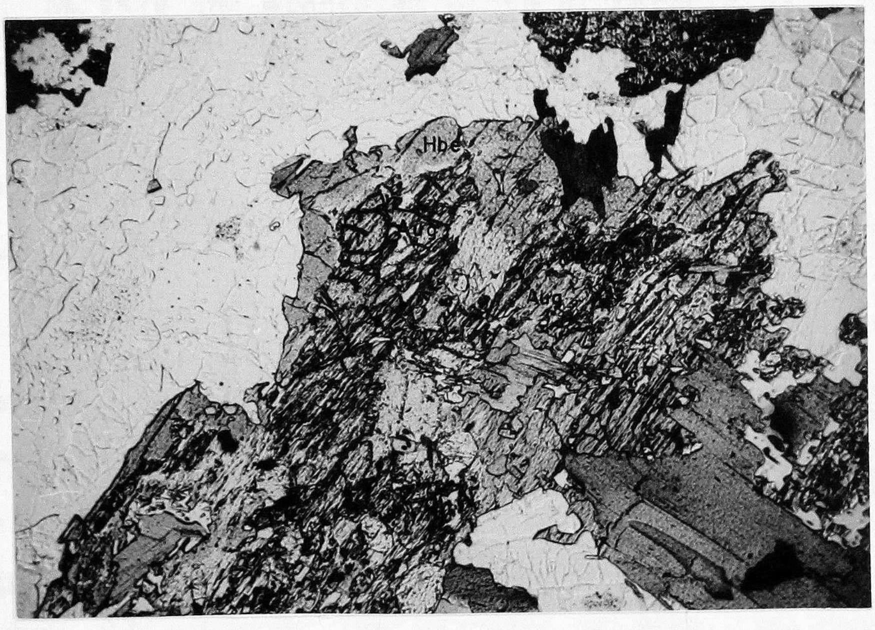
A. Zoned, twinned plagioclase with broad altered core in biotite quartz diorite (Crossed nicols X 10)

B. Bent plagioclase with stress twinning in augite-biotite monzonite (Crossed nicols X 10) biotite form small patches throughout augite giving it a mottled texture. Augite has an optic angle ($2V_z$) of 60±2 degrees and an extinction angle ($Z_\wedge c$) of 48 degrees. Quartz occupies irregular areas between almost all other minerals. Fractured grains and undulatory extinction are very common. In the garnetiferous biotite quartz diorite, quartz commonly contains inclusions of subrounded plagioclase laths.

Pale green, weakly pleochroic diopsidic-augite of the hornblende-biotite pyroxenite has an optic angle ($2V_z$) of about 60 degrees and an extinction angle ($Z_\wedge c$) of 45 degrees. Plagioclase, potash feldspar and biotite are interstitial to the euhedral pyroxene. Biotite commonly has bent cleavages. Green hornblende and biotite form irregular patches that have replaced pyroxene.



A. Texture of biotite (Bi) in augite-biotite monzonite (Crossed nicols X 10)



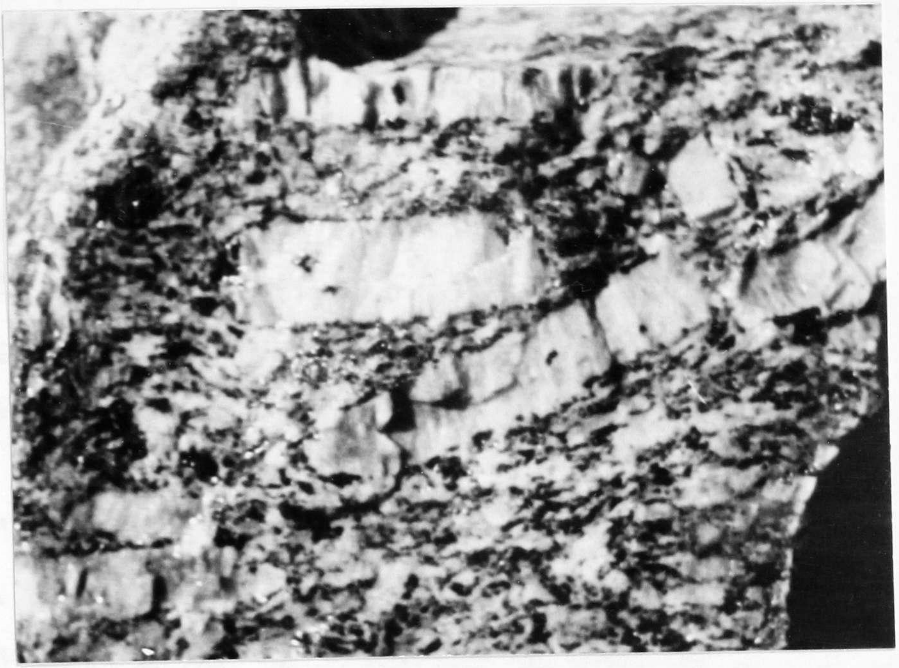
B. Anhedral augite (Aug) with rim of hornblende (Hb) in augite-biotite monzonite (X 10)

Monzonite Porphyry

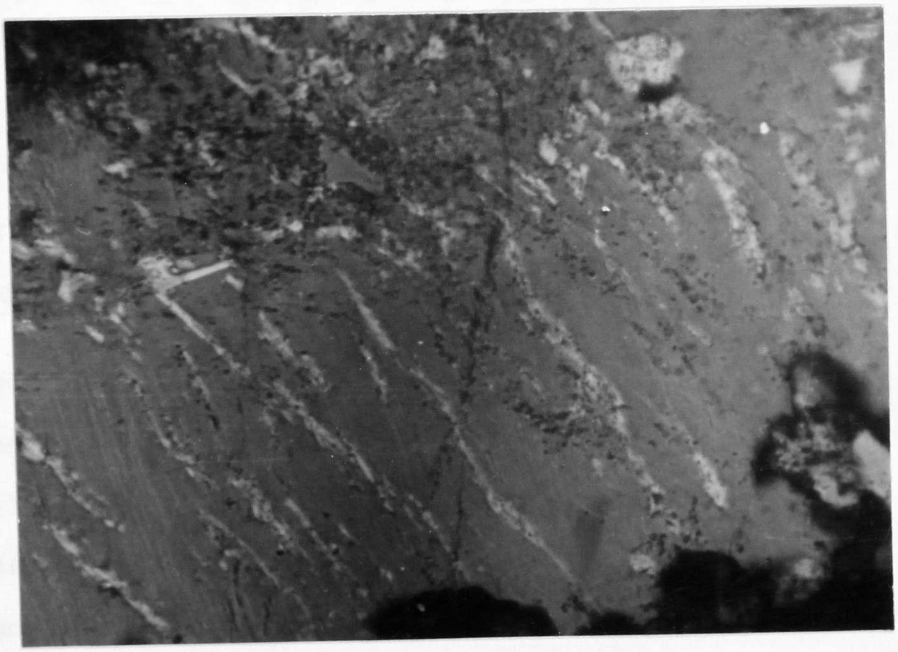
Monzonite porphyry (Plate IV) forms an arcuate band, 500 to 1000 feet wide, which lies between biotite-augite monzonite and medium-grained hornblende monzonite. Lenses of this rock also occur at the contact between the porphyritic monzonite and the pink quartz monzonite prophyry. Pale grey, euhedral, tabular phenocrysts of orthoclase microperthite, that average 6 cm. by 2 1/2 cm. by 1 1/2 cm., are set in a medium- to coarse-grained trachytoid monzonite matrix. Lustrous, dark-green hornblende prisms are interstitial to plagioclase and orthoclase. Streaks and elongated clots of hornblende crystals locally give the rock a weak lineation. The lenses of monzonite porphyry differ from the main band in that they have a coarse-grained matrix and the alignment of crystals is indistinct.

In thin section, the orthoclase microperthite phenocrysts have a euhedral general form, though the crystal boundaries are minutely irregular and the outermost portions partly or wholly enclose plagioclase, pyroxene and opaque minerals of the matrix. Oscillatory zoning is distinguished by variable concentrations of perthite and by difference in extinction angles. A great variety of

Plate 1V

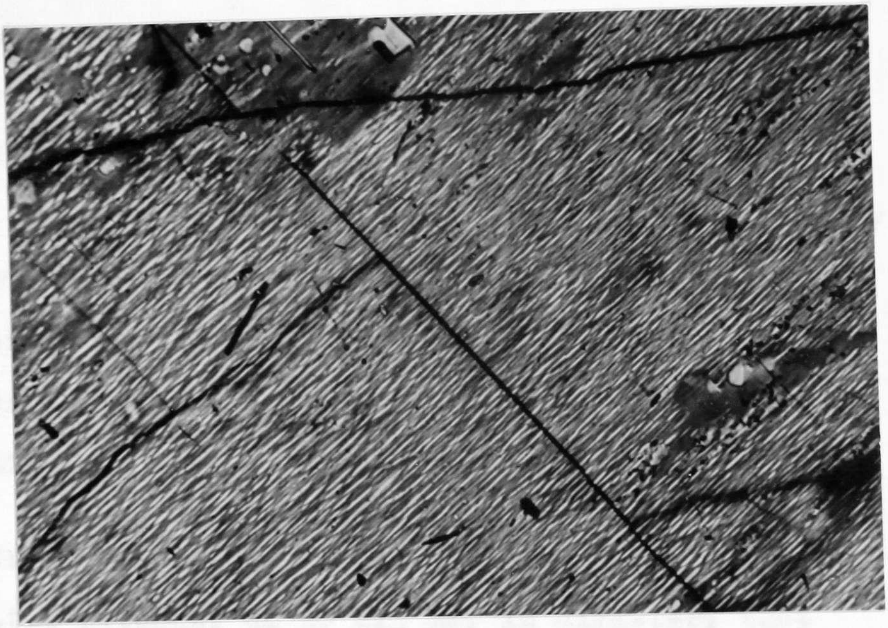


A. Monzonite porphyry (X 1/2)



B. Vein perthite in phenocryst of monzonite porphyry (Crossed nicols X 45) microperthitic textures that range from very fine films or strings, to veins or networks of veins (braid perthite) and irregular patches, (Emmons, 1953), may be displayed within a single phenocryst. Film perthite (pl. V A) is made up of a multitude of lensoid plagioclase segregations, averaging 0.05 mm. wide by 0.2 mm. long, that are orientated perpendicular to the (010) cleavage in orthclase. In some places, the lenses coalesce to form long narrow "strings" (pl. V B). Plagioclase in vein perthite (pl. IV B) occurs as long, narrow, locally branching forms, that are generally elongated in the same direction as film and string perthite. Orthclase between the veins, and around the edges of equant plagioclase grains (pl. V B), is almost non-perthitic. The very fine, regularly orientated perthitic intergrowths, the absence of cross-cutting relationships, and the gradational nature of the various types of perthite, suggest an exsolution origin.

Inclusions in the ortholase phenocrysts are mainly plagioclase but augite, hornblende, biotite, apatite and occasionally orthoclase are also present. Included plagioclase crystals are oriented most commonly with their long dimensions parallel to the (010) plane of orthoclase but also lie parallel to other crystal faces. The larger crystals, that range in length from 1 to 2 mm., are



A. Film perthite in orthoclase of monzonite porphyry (Crossed nicols X 45). Albite 'lenses' trend perpendicular to (010) cleavage in orthoclase

B. Non-perthitic areas around peripheries of plagioclase grains in orthoclase of monzonite porphyry (Crossed nicols X 45) euhedral whereas smaller crystals are subhedral to anhedral and have irregular boundaries. Almost all plagioclase inclusions display weak normal zoning and polysynthetic twinning. Subhedral inclusions of weakly zoned, sparsely perthitic orthoclase occur just within the borders of the phenocryst and are orientated parallel to a crystal face of the phenocryst. The included orthoclase is not in optical continuity with the orthoclase host.

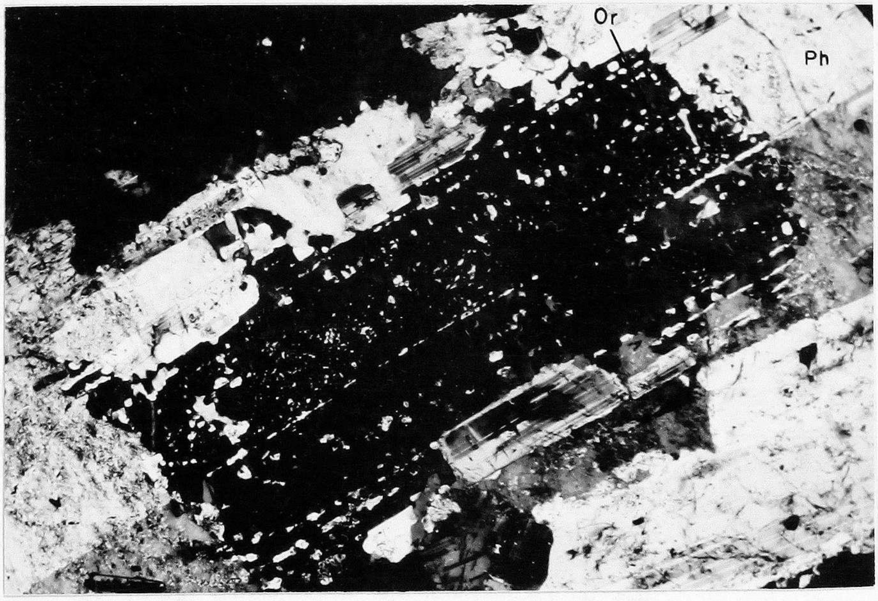
Orthoclase of the matrix occurs as randomly orientated perthitic patches, up to 2.5 mm. in diameter, that are interstitial to plagioclase. Crystals of subhedral, weakly zoned, plagioclase, that range in size from 0.3 x 0.5 mm. to 2 x 4.5 mm., generally are bent and show stress twinning. Myrmekite is common along contacts between plagioclase and orthoclase. Augite occurs as subhedral grains rimmed by green hornblende, or as small cores within large anhedral grains of hornblende.

Porphyritic Hornblende Monzonite

Porphyritic hornblende monzonite forms an irregular ring with an extension into the central core on the eastern side. This light grey rock has a distinct trachytoid texture. Pale grey orthoclase forms euhedral, tabular phenocrysts that average 2 to 3 mm. wide and 10 to

15 mm. long. Light grey plagioclase and black, euhedral hornblende of the medium-grained matrix are interstitial to the larger orthoclase crystals. Near the inner contact of this unit, the rock has a glomeroporphyritic texture formed by clusters, averaging 2 to 5 mm. in diameter, of anhedral to subhedral hornblende crystals. Orthoclase phenocrysts here have very irregular outlines and the trachytoid texture is indistinct.

In thin section, weakly perthitic, subhedral orthoclase phenocrysts have minutely irregular borders that partly enclose minerals of the matrix. Orthoclase shows weak oscillatory zoning, and the optic angles ($2V_x$) of the zones range from 60 to 70 degrees in the center of the crystals to 55 degrees in the rims. Some phenocrysts have corroded orthoclase crystals in their cores (Plate VI A). Included plagioclase laths are orientated with long dimensions parallel to the crystal boundaries of the host. Euhedral to subhedral normally zoned plagioclase of the matrix bears thin albitic mantles where in contact with orthoclase. Myrmekite is not rare. Bent plagioclase crystals, that show polysynthetic stress twinning, are most common in specimens from near the outer contact of this unit. Zoned hornblende has the following pleochroic scheme:



A. Corroded orthoclase crystal (Or) in core of an orthoclase phenocryst (Ph). (Crossed nicols X 10)

B. Plagioclase inclusions in orthoclase of the glomeroporphyritic phase of the porphyritic hornblende monzonite (Crossed nicols X 10)

	X	Y	Z
Cores	pale brown	greenish-brown	olive green
Rims	pale greenish brown	brownish-green	bluish-green

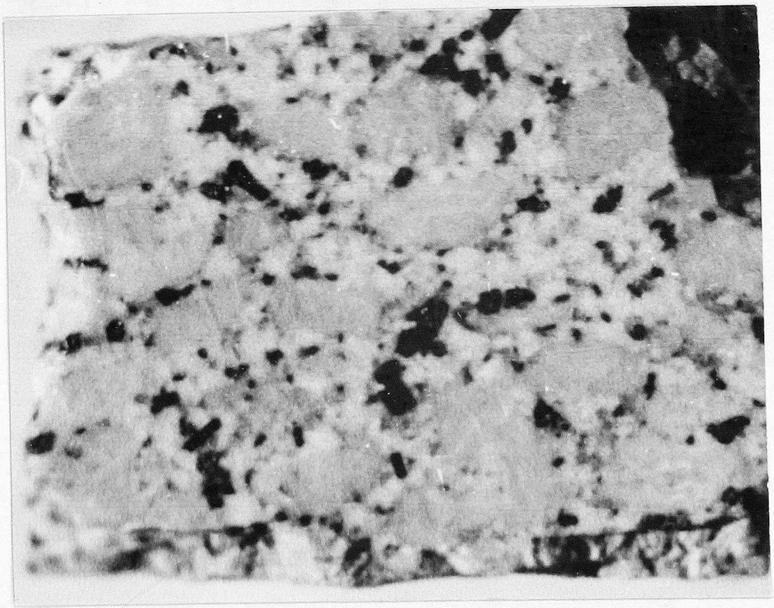
Extinction angles ($Z_{\wedge}c$) are about 26 degrees in the core and 30 degrees in the rims. Pyroxene occurs as rounded cores within hornblende or as subhedral grains with reaction rims of hornblende. Quartz, showing undulatory extinction, fills angular spaces between all of the other minerals.

In thin sections of the glomeroporphyritic phase of this unit, elongated, anhedral orthoclase grains have a "spongy" texture that is due to abundant inclusions of plagioclase (pl. VIB). Orientation of the inclusions of seems to be related to the subtrachytic texture of the rock rather than to any specific crystallographic direction in orthoclase. Subhedral plagioclase phenocrysts (An_{38-40}) have irregular, thin, albitic borders where in contact with orthoclase. Plagioclase of the matrix (An_{30}) has a similar texture, but where enclosed in orthoclase the grains are rounded and have indistinct boundaries. Hornblende has formed between the larger plagioclase crystals and has poikilitically enclosed the smaller plagioclase grains, apatite, magnetite, and clinopyroxene.

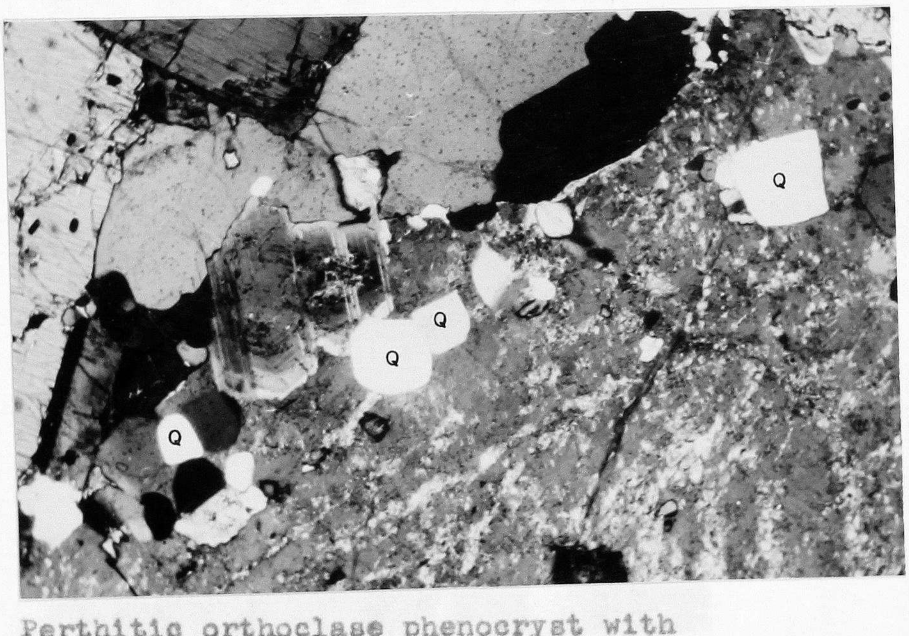
Pink Quartz Monzonite Porphyry

Pink quartz monzonite porphyry forms the core of the stock. Preferred orientation of pink, thick tabular orthoclase phenocrysts, that range from 8 to 12 mm. long and from 3 to 5 mm. wide, gives the rock an indistinct foliation. Fine- to medium-grained plagioclase, hornblende and quartz are interstitial to the orthoclase phenocrysts. Lustrous, dark green hornblende forms euhedral prisms up to 3mm. long.

In thin section, microperthitic orthoclase phenocrysts (pl. VIII) have a euhedral general habit, though their boundaries are minutely irregular. All phenocrysts display delicate but obvious oscillatory zoning. Thin outer margins of the crystals are not zoned. Optic angles ($2V_x$) of adjacent zones may vary as much as 10 degrees, and the variation of angles measured within a single crystal is from 52 degrees to 65 degrees. The lowest value ($2V_x$ 44°) was obtained in the unzoned outer margin of a crystal. Euhedral to subhedral plagioclase inclusions, generally less than 1 mm. long, are orientated most commonly with side pinacoids parallel to the (010) plane of orthoclase but are also parallel to other crystal faces (pl. IX A). Some plagioclase

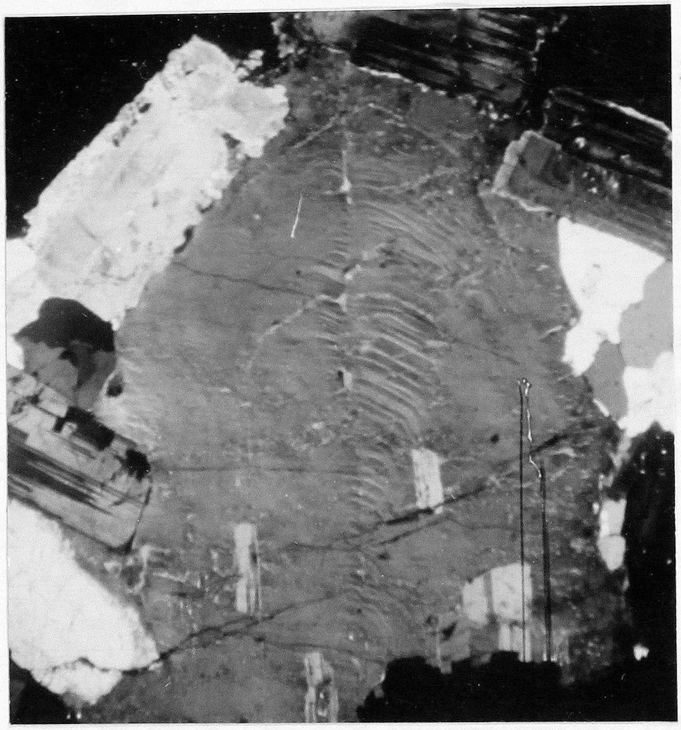


A. Pink quartz monzonite porphyry (X 1)



B. Perthitic orthoclase phenocryst with inclusions of euhedral, unstrained quartz (Q) (Crossed nicols X 10)

Plate V111

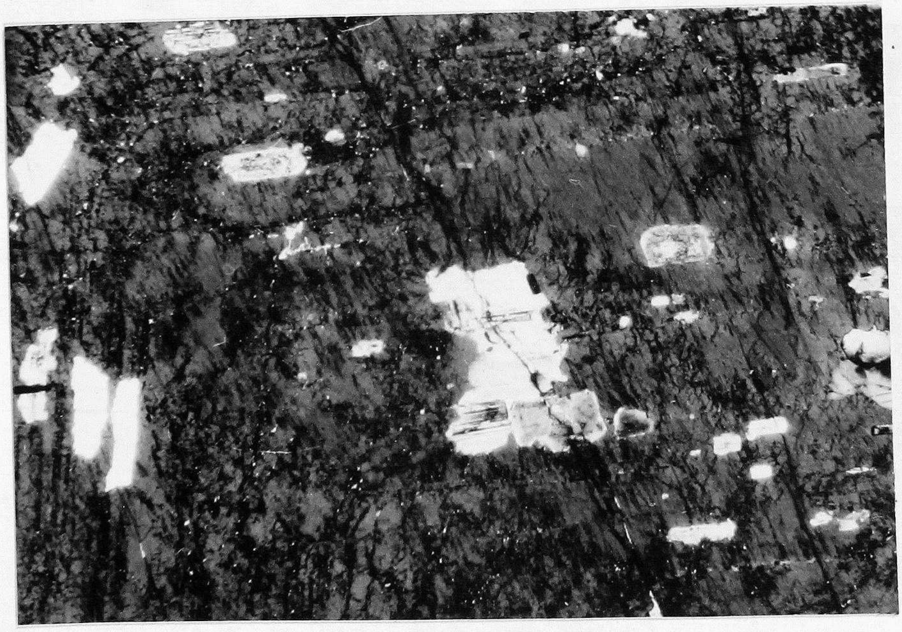


A. Zoning and alignment of plagioclase inclusions in orthoclase phenocryst of pink quartz monzonite porphyry (Crossed nicols X 5)

B. Part of phenocryst in plate A at higher magnification (Crossed nicols X 10) crystals are only partly included (pl. IX B) or are lying at the edge of the orthoclase phenocrysts as if they were attached to the crystal face of the phenocrysts (pl. IX B). Combination twinning (Ross, 1957), in included plagioclase crystals is common (pl. X A). Inclusions show weak normal zoning with compositions ranging from An_{35} in cores to An_{25} in rims.

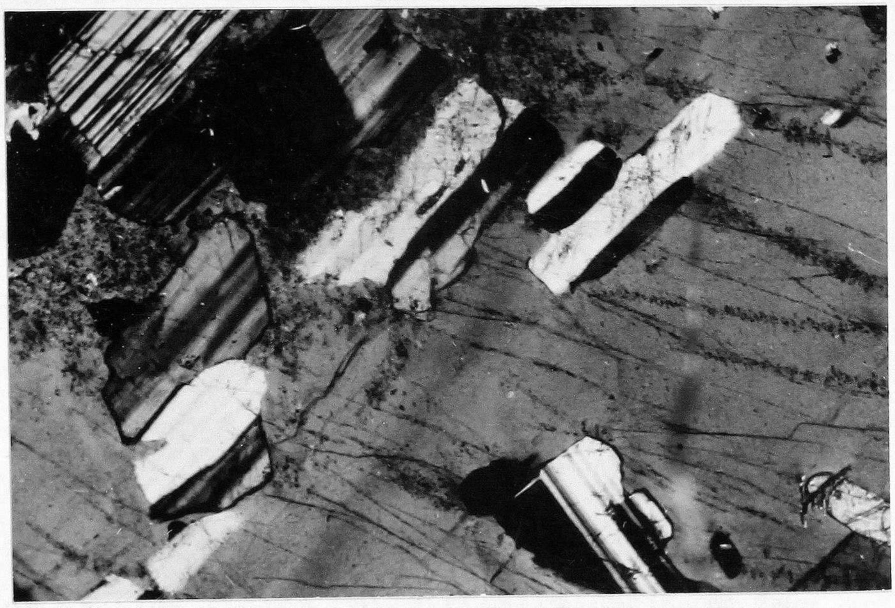
Textures of orthoclase phenocrysts suggest growth in a fluid magma. The orientation of inclusions was probably effected by a process (described by Hibbard, 1965) of continual attachment of plagioclase crystals at the sides of growing orthoclase crystals. Orthoclase formed early enough to be aligned by magmatic flow, and the growth of phenocrysts continued until the last stages of solidification of the magma. The irregular borders on the generally euhedral crystals, and the presence of late forming minerals, such as quartz and hornblende, included in the outer margins of phenocrysts, are evidence of the later stages of growth.

Plagioclase of the matrix where in contact with perthite, has a well developed rim of myrmekite (pl. X B). Complex oscillatory zoning is common with zones tending to be more albitic toward the periphery (pl. XI A).



A. Orientation of plagioclase inclusions in orthoclase phenocryst of the pink quartz monzonite porphyry (Crossed nicols X 5)

B. Plagioclase crystals within and partly included in the margin of orthoclase phenocryst (Crossed nicols X 5)

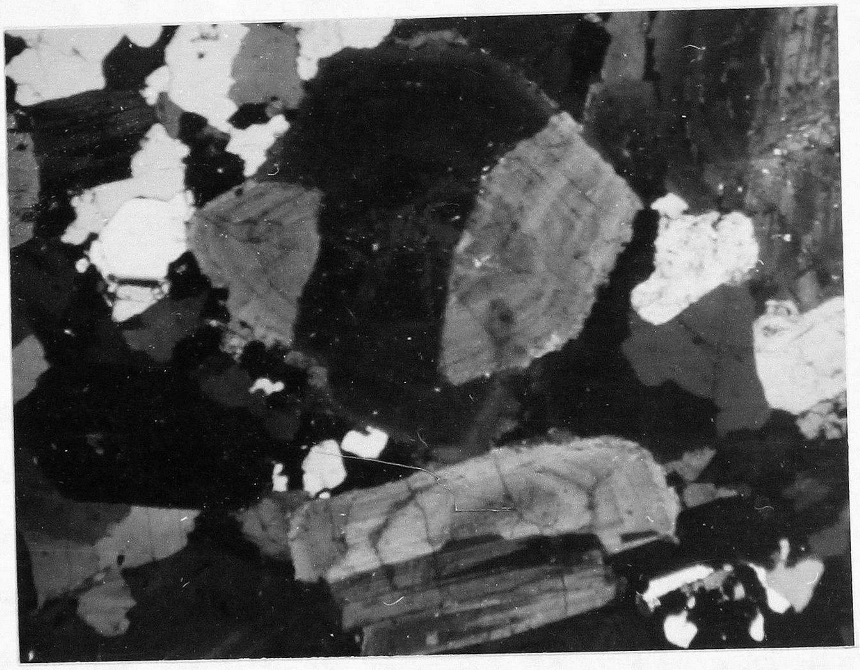


A. Combination twinned plagioclase inclusion on orthoclase phenocryst (Crossed nicols X 10)

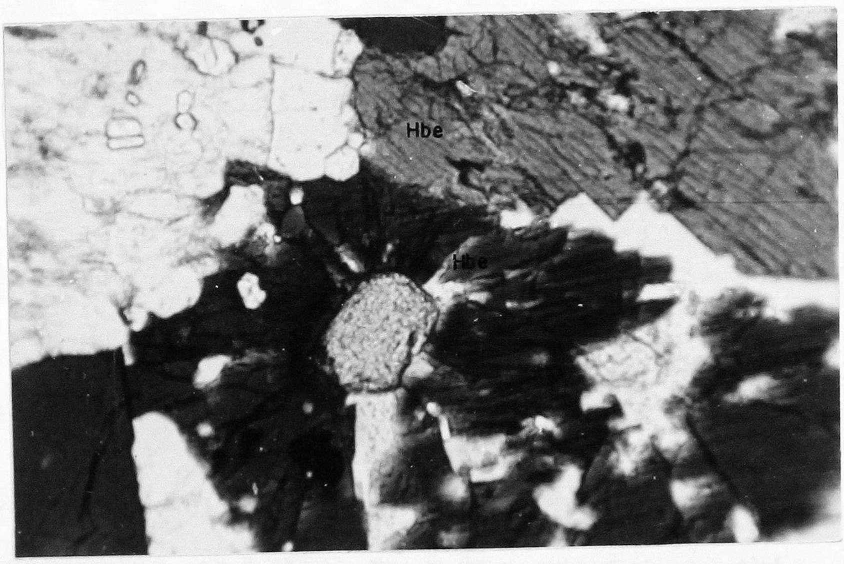
B. Myrmekite rim on plagioclase surrounded by potash feldspar (K) of the pink quartz monzonite porphyry

Composition ranges from An_{23} to An_{38}. Quartz occurs in two forms: (1) irregular, interstitial, fractured grains with undulatory extinction; and (2) euhedral, unfractured grains, with even extinction, that are included in the unzoned margins of perthite phenocrysts (pl. VII B). Zoned green hornblende that has a pleochroic scheme that is very similar to hornblende in porphyritic hornblende monzonite (see p.20), poikilitically encloses inclusions of plagioclase, augite, apatite, zircon, and magnetite. Trace amounts of augite occurs either as small grains rimmed by hornblende or as tiny grains poikilticslly enclosed in hornblende.

Allanite, sphene and zircon are very common accessory minerals in this rock. Allanite forms euhedral, prismatic crystals that are pleochroic from dark brown to light brown, some of which are twinned. An isotropic, yellow mineral, having very high relief, surrounded by a pleochroic halo and radiating fractures in hornblende, and with a narrow rim of epidote, has been tentatively identified as allanite in the metamict state (pl. XI A). Sphene has a characteristic acute rhombic habit. Zircon occurs as minute grains that produce pleochroic halos in hornblende.



A. Oscillatory zoning in plagioclase of pink quartz monzonite porphyry (Crossed nicols X 10)



B. Allanite in metamict state (?) included in hornblende (Hb). Note pleochroic halo and radiating fractures in hornblende (Plane light X 10)

Aplite

A body of aplite occupies a small area in the southcenteral part of the stock. This is a pale grey, fine-grained rock of quartz monzonite composition. In some places, the rock contains sparsely distributed potash feldspar phenocrysts and a small amount (generally less than 2%) of hornblende. In thin section, an allotriomorphic granular texture is formed by interlocking grains of plagioclase, orthoclase and quartz. Non-perthitic orthoclase is partly altered to sericite which forms minute shreds throughout the crystals.

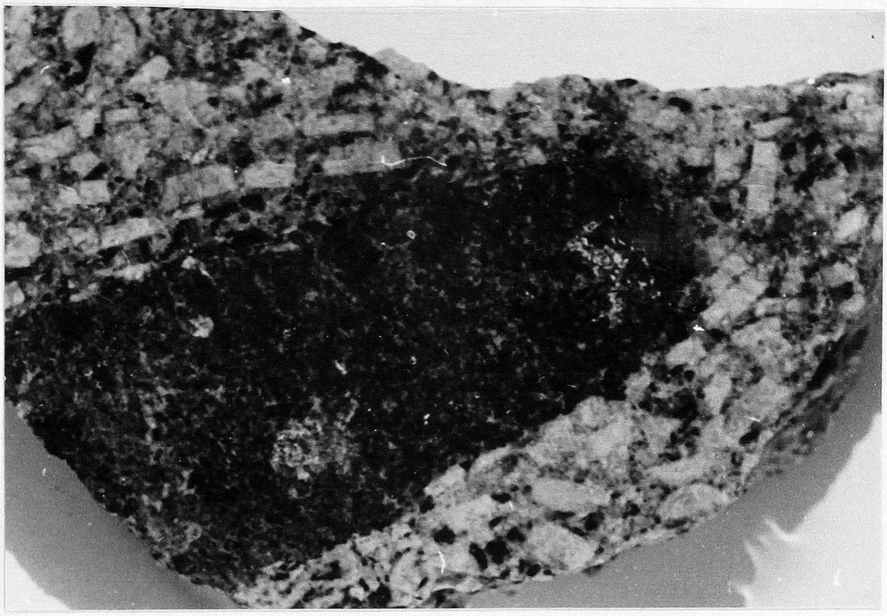
Inclusions

Inclusions are rare in this stock. Two distinct types are found: (1) plainly recognizable wall rock xenoliths and (2) dark xenoliths whose origin is not at once evident. The second type makes up the majority of inclusions in the stock.

Xenoliths of country rock are sparsely distributed in augite-biotite monzonite near the contact of this unit with hornfelsic wall rocks. The inclusions are dark-grey, hornfelsic rocks with angular to subangular, blocky and slabby forms, that range in size from a few inches to several feet. Bedding in inclusions is not commonly parallel to bedding in wall rocks, and the inclusions have obviously been rotated. Occasionally, elongate inclusions lie parallel to foliation in the enclosing granitic rocks. Contacts between inclusions and the surrounding host rock are sharp. Proximity of hornfels inclusions to similar hornfels wall rocks, the relict bedding, and forms of the inclusions leave little doubt that these inclusions are xenoliths of local wall rock.

A large inclusion of quartzite, about 3500 feet long and a maximum of 375 feet wide, lies within the southeastern margin of the stock. The outline of the southern side of the inclusion matches the outline of the adjacent quartzite wall rock. This inclusion, therefore, probably was not rotated or transported in the magma.

The dark inclusions (pl. XII) are sparsely distributed in pink quartz monzonite porphyry and in porphyritic hornblende monzonite but are not found in augite-biotite monzonite. They vary from subrounded, equant fragments to well rounded, ovoid and cigar shaped fragments that range in size from 1 or 2 inches to about 1 foot.



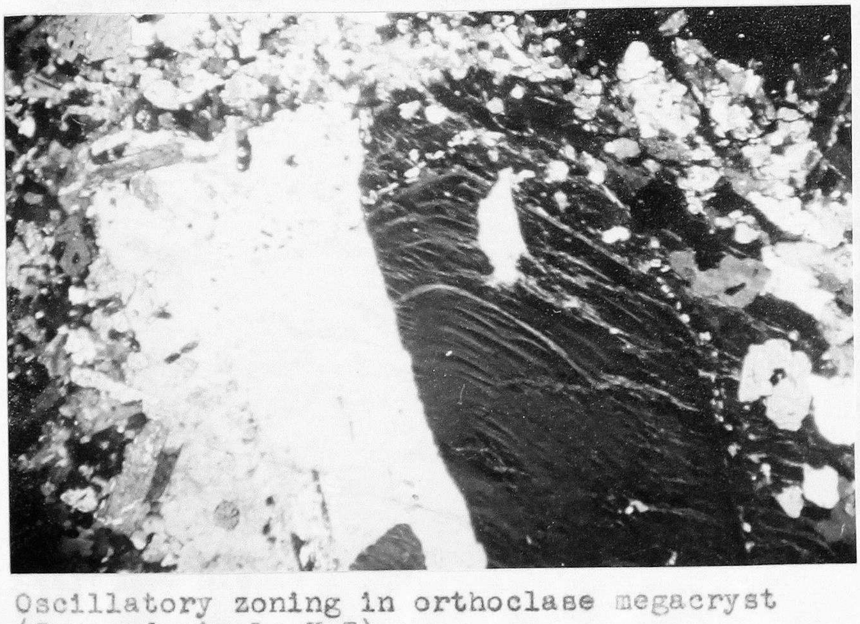
A. Inclusion in pink quartz monzonite porphyry. Potash feldspar phenocrysts 'stream' around the inclusion (X 1/3)

B. Inclusion in pink quartz monzonite porphyry. Note phenocrysts in both quartz monzonite and in the inclusion (X 1)

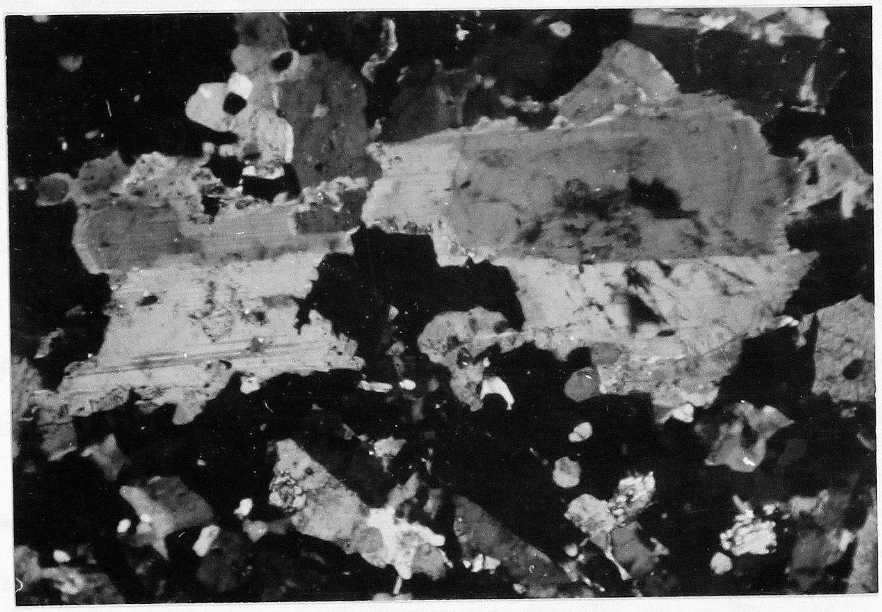
Elongated inclusions lie parallel to primary foliation in pink quartz monzonite porphyry. Boundaries are generally sharp but inclusions with diffuse boundaries were occasionally found. In some places the inclusion is enveloped by a thin rim of hornblende crystals. Texture varies from sugary to porphyroblastic. Megacrysts of subhedral to euhedral potash feldspar have random orientation in a dark-green sugary matrix.

In thin section of dark inclusions (pl. XIII), microperthitic orthoclase megacrysts, that average 4mm. by 10 mm. have euhedral cores and broad, irregular, poikiloblastic margins. Cores exhibit complex oscillatory zoning, and contain euhedral plagioclase inclusions some of which show combination twinning, that are orientated parallel to the (010) plane of orthoclase host. The broad irregular unzoned margins enclose randomly orientated minerals of the matrix but do not enclose plagioclase similar to that found in the core. Anhedral oscillatorily zoned plagioclase phenocrysts (An_{28-34}) that average 1 mm. by 3 mm., are corroded and embayed by potash feldspar of the matrix (pl. XIV). Subhedral to euhedral hornblende (pl. XIV B), that ranges up to 5 mm. in longest dimension, poikilitically enclose grains of augite, plagioclase and perthite. The matrix has a granoblastic texture made up of interlocking

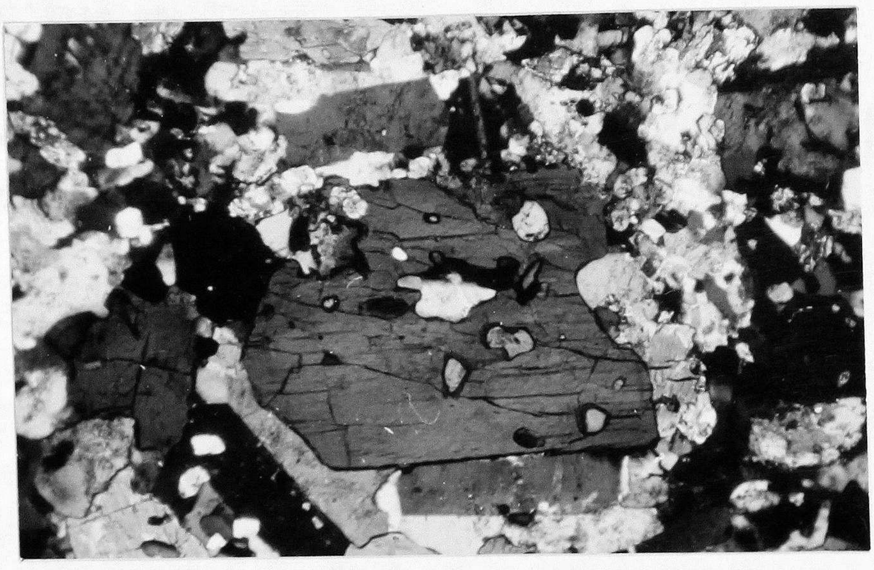
A. Porphyroblast of perthite in granoblastic matrix. Note line of tiny inclusions and irregular border (Crossed nicols X 5)



B. Oscillatory zoning in orthoclase megacryst (Crossed nicols X 5)



A. Photomicrograph showing corroded plagioclase phenocrysts in an inclusion. Black background is potash feldspar (Crossed nicols X 10)



B. Photomicrograph showing poikilitic hornblende (Crossed nicols X 10) grains that are generally less than 0.5 mm. in diameter. Pale green, weakly pleochroic diopsidic-augite forms euhedral to anhedral crystals, some of which bear reaction rims of hornblende. Corroded, lathlike crystals of plagioclase (An_{27}) are less than 0.2 mm. long. Anhedral, non-perthitic orthoclase, that encloses, corrodes, and fills the area between, almost all other minerals makes up 45 per cent of the matrix.

The origin of the dark inclusions is not readily apparent because their textures were developed after they were enclosed in the magma. Hornfelsic textures indicate recrystallization of the xenoliths. Textures of cores of megacrysts (delicate oscillatory zoning and preferred orientation of included plagioclase) are identical to textures of phenocrysts in other rock zones of the stock. These large crystals probably are phenocrysts that developed poikiloblastic margins as they continued to grow during recrystallization of the inclusion.

A magma can react with inclusions and effect changes which give them a mineral assemblage similar to that of the enclosing crystallizing magma. No liquid, saturated with a certain member of a reaction series, can melt inclusions consisting of minerals belonging to an earlier stage of the reaction series (Bowen, 1928, p. 221). Thus, augite would be out of equilibrium in a magma of quartz monzonite composition where hornblende is the stable mafic mineral phase. The presence of abundant augite in the inclusions indicates either non-equilibrium or, perhaps, that the xenolith was relatively anhydrous and impermeable.

Distribution of inclusions in the porphyritic hornblende monzonite and in the pink quartz monzonite porphyry but not in the augite biotite monzonite, the presence of abundant diopsidic-augite, and of oscillatory zoning in cores of megacrysts, suggest that the inclusions are cognate and were originally augite-biotite monzonite, which has been engulfed and recrystallized by the surrounding magma.

CHEMICAL COMPOSITION AND VARIATION

Chemical composition of the main rock zones of this stock changes systematically from the periphery of the stock to the core. This variation is illustrated by modal analyses (Table I), by calculated chemical analyses (Table II), and by variation diagrams (figs. 4, 5, and 6). Modes (Table I) were calculated by the standard point-count method averaging 1800 points per thin-section. In coarsely porphyritic rocks the ratio of phenocrysts to matrix was measured from hand specimens by tracing the respective areas on millimeter gridded transparent paper, and the matrix composition was computed from thin sections. Theoretical chemical analyses (Table II) of the rocks were calculated from the modes. Compositions of feldspars, quartz, apatite, sphene and magnetite were calculated from standard formulae. The average plagioclase compositions were estimated from the range of zoning and from the relative widths of respective zones. Compositions of hornblende, biotite, muscovite, allanite and diopsidic-augite were taken from tables of chemical analyses, given in Deer, Howie and Zussman (1962), for minerals from similar rock types and with similar optical properties to those of the Mount Brenner stock. Average values of the chemical analyses from each rock zone are used to plot the variation diagrams shown in Figures 4, 5, and 6. Differentiation indices[1], that are plotted against various oxides in Figures 8a and 8b, are superimposed on frequency diagrams which represent 5000 analyses in Washington's tables. These analyses include the compostitions of all igneous rocks.

Composition of the main rock zones varies systematically from the periphery of the stock to the core in the following manner.

1. Total mafic minerals, and consequently oxides iron and magnesium, decrease (fig. 3 and 4).
2. Anorthite content of plagioclase generally decreases (fig. 3).
3. Amount of quartz and alkalies increases (fig. 3, 4, 5)
4. Differentiation indices increase (fig. 5).

Figures 8 and 9 clearly illustrate the degree of difference between rocks of the Mount Brenner stock and most rocks,

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[1]Differentiation index is defined by Thornton and Tuttle (1960) as the sum of the weight percentages of normative quartz + orthoclase + albite + nepheline + leucite + kalsilite.

TABLE II

CALCULATED CHEMICAL COMPOSITION OF ROCKS

Mt. Brenner Stock

	1*	2	3	4	5	Average 2 to 5	6	7	8	9	Average 7 to 9	10	11	12	13	Average 10 to 13	14	15
SiO_2	62.87	57.30	53.76	53.43	53.96	54.61	59.42	60.77	59.39	61.53	61.25	65.88	64.91	62.15	66.22	64.79	72.38	43.05
TiO_2	.92	.73	.75	.64	.47	.51	.15	.15	.38	.12	.14	.10	.16	.42	.14	.20	---	1.51
Al_2O_3	17.11	17.61	18.00	19.02	18.83	18.36	18.57	19.92	16.15	17.53	18.72	17.94	16.83	19.73	17.99	18.12	16.03	7.69
Fe_2O_3	1.29	1.62	1.74	1.56	1.64	1.64	.75	1.33	1.75	.72	1.02	.84	.73	.43	.32	.56	.27	6.81
FeO	4.45	4.64	5.32	5.35	4.92	5.05	2.47	2.45	2.71	1.77	2.11	1.42	1.31	1.06	.55	1.08	.36	13.69
MnO	---	.04	---	.05	1.06	.28	1.10	---	.03	.03	.01	.02	.02	.01	---	.01	---	.15
MgO	2.50	2.77	3.27	2.76	3.05	2.96	1.37	1.58	1.63	1.28	1.43	.89	.95	.75	.57	.79	.13	8.14
CaO	4.18	5.83	7.92	7.46	8.21	7.35	4.76	5.62	4.15	3.88	4.75	3.01	3.59	6.38	2.97	3.98	2.32	13.20
Na_2O	2.75	2.35	3.49	2.65	3.33	2.95	4.24	4.86	3.10	4.23	4.54	3.69	4.25	2.16	4.03	3.53	3.96	.68
K_2O	3.02	6.16	3.22	4.71	3.85	4.48	5.80	4.60	7.91	6.04	5.32	7.18	4.90	5.91	6.61	6.15	4.27	3.03
P_2O_5	.08	.08	.43	.31	.35	.29	---	.16	.08	.38	.25	.12	.08	.04	.19	.11	.08	.78

* Chemical compositions are calculated from modes, and numbers refer to specimens in Table I and in Figures 3 and 4.

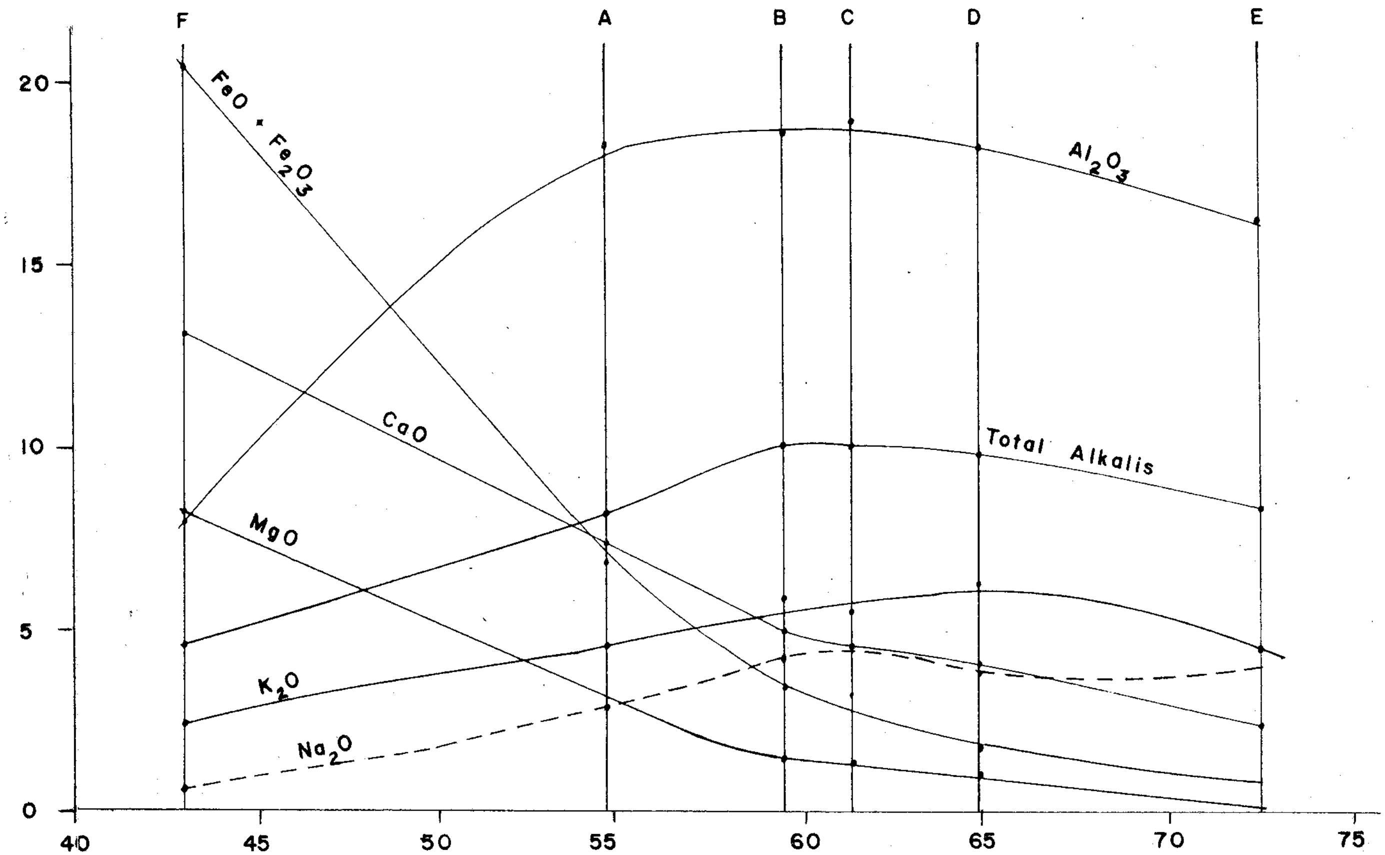

Figure 4. Variation diagram for rock zones of the Mount Brenner stock. The average weight per cent of oxides of each rock zone are plotted against total silica: A = augite-biotite monzonite; B = monzonite porphyry; C = porphyritic hornblende monzonite; D = pink quartz monzonite porphyry; E = aplite; and F = hornblende-biotite pyroxenite.

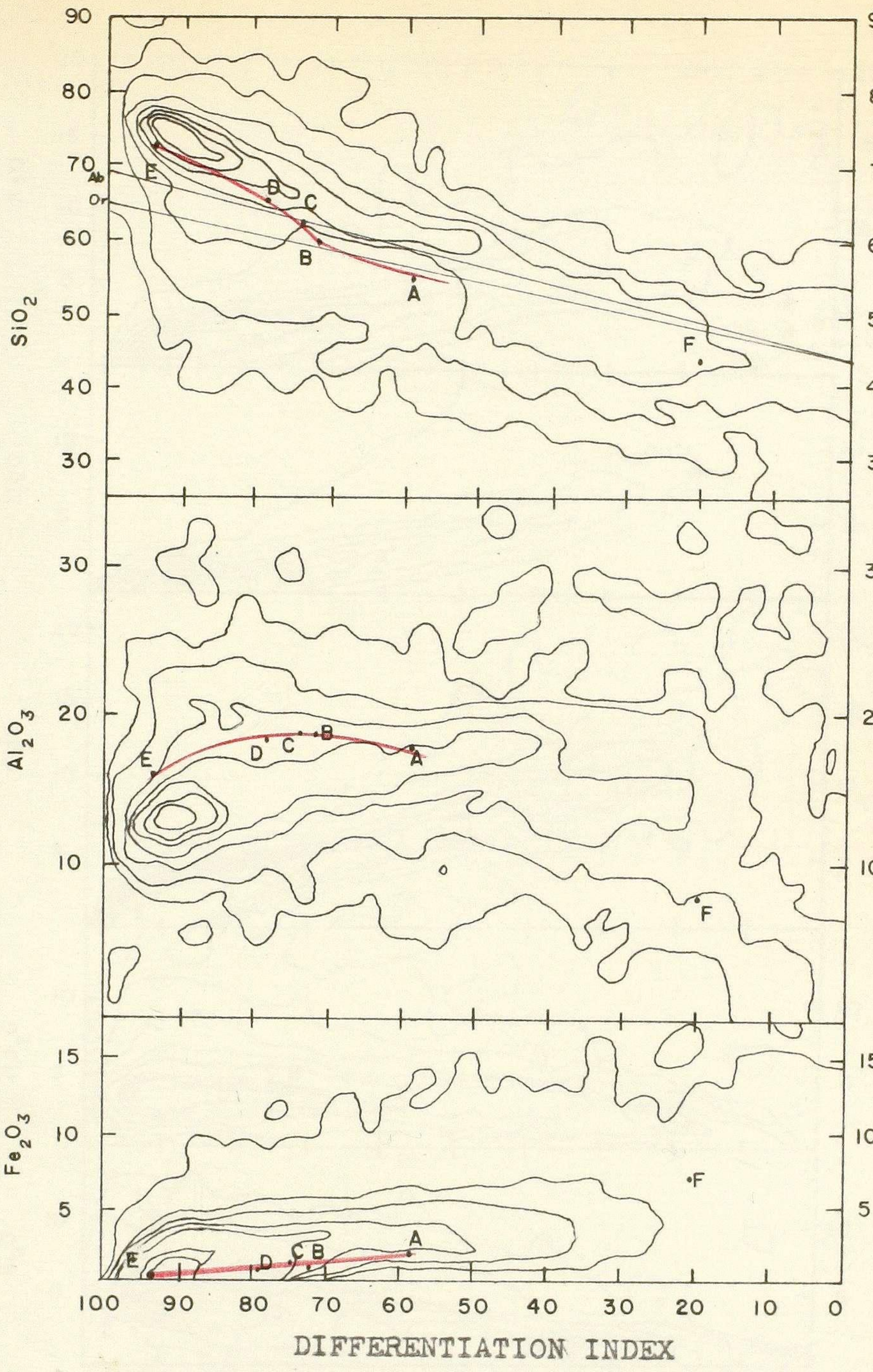

Figure 5a

Figure 5. Contoured diagrams of oxides vs. differentiation index on which analyses of rocks from the Mount Brenner stock have been superimposed. Contour diagrams, which represent 5000 analyses in Washington's Tables, are modified after Thornton and Tuttle, 1960, p. 674-679. A = augite-biotite monzonite, B = monzonite porphyry, C = porphyritic hornblende monzonite, D = pink quartz monzonite porphyry, E = aplite, and F = hornblende-biotite pyroxenite.

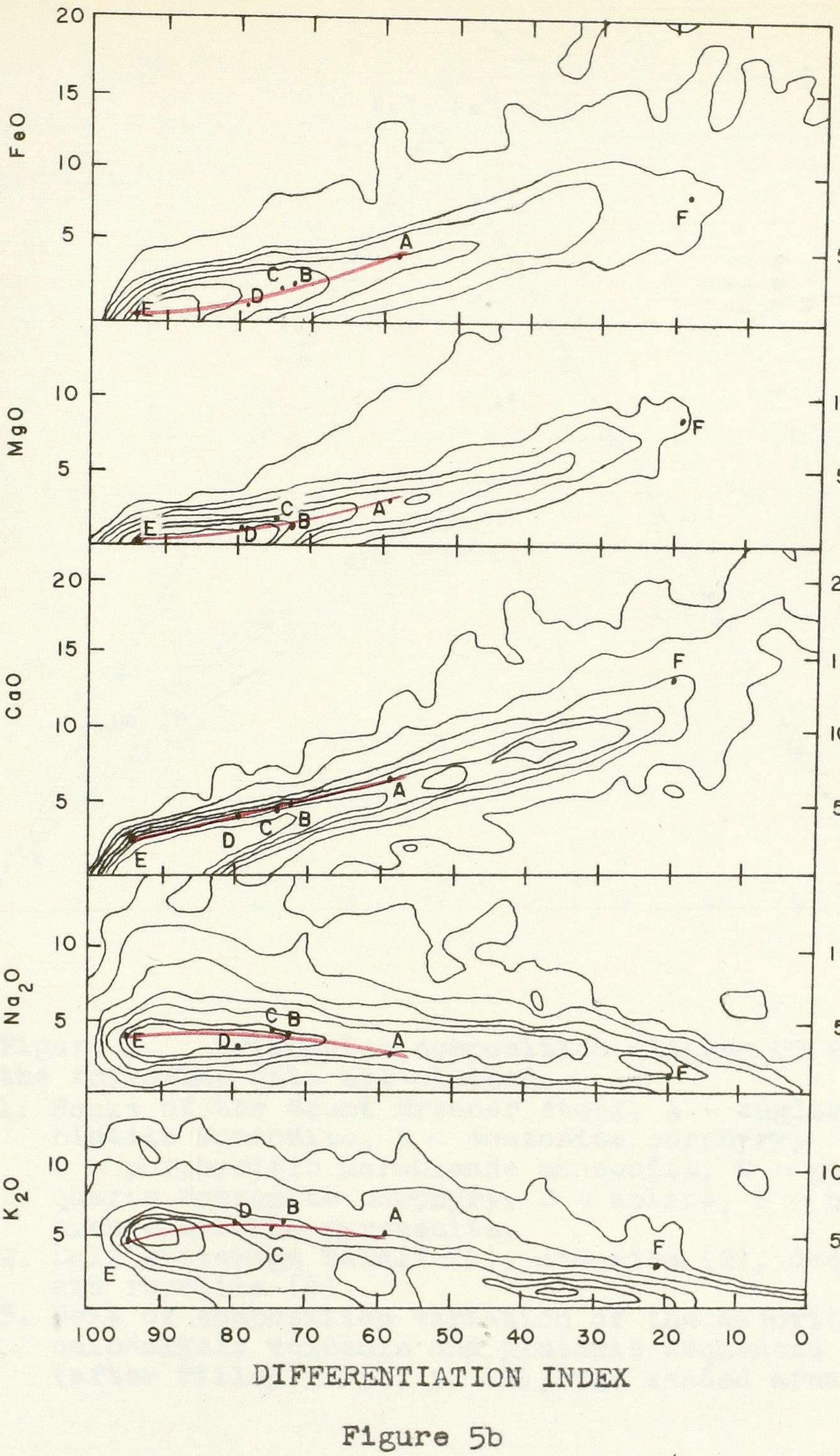
FeO
MgO
CaO
Na_2O
K_2O
A
B
C
D
E
F
20
15
10
5
100
90
80
70
60
50
40
30
20
10
0
DIFFERENTIATION INDEX

Figure 5b

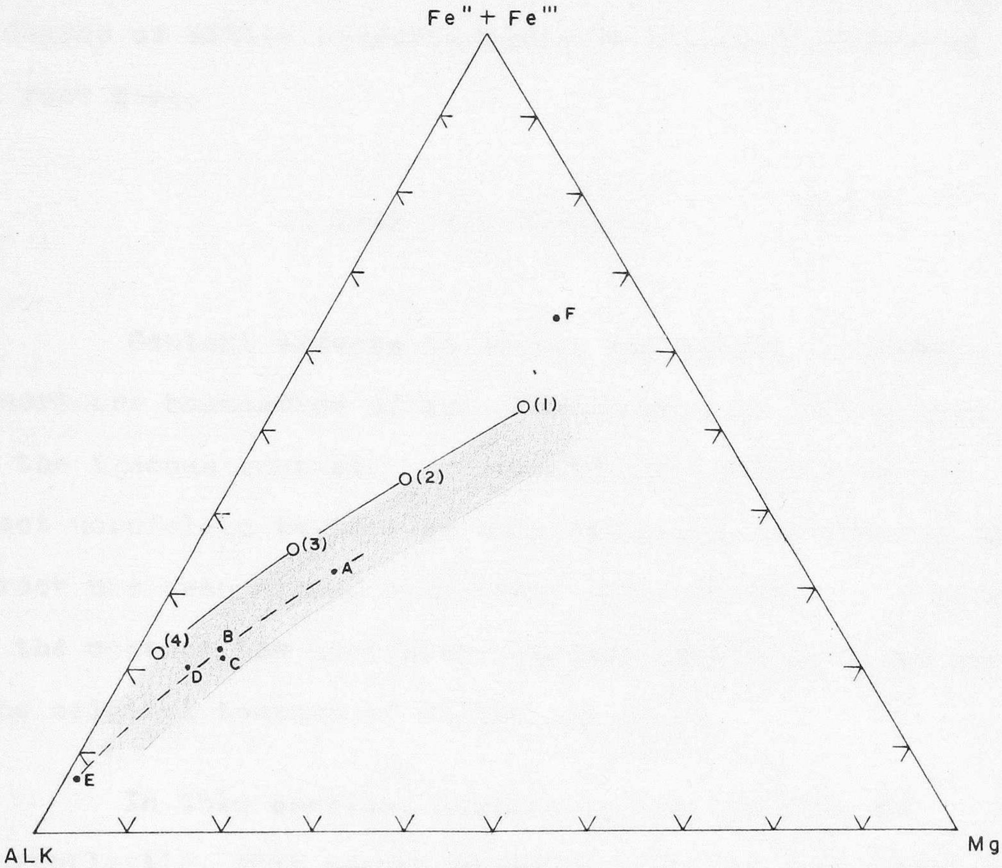

Figure 6. Triangular composition diagram on which the following data are plotted:

1. Rocks of the Mount Brenner stock; A = augite-biotite monzonite, B = monzonite porphyry, C = porphyritic hornblende monzonite, D = pink quartz monzonite porphyry, E = aplite, F = hornblende-biotite pyroxenite.
2. Daly's average basalt (1), andesite (2), dacite (3) and rhyolite (4).
3. Belt of composition variation of the majority of calc-alkali volcanic and plutonic sequences (after Tilley, 1950, p. 48); the shaded area.

the smooth trend towards "Petrogeny's residua system"[2], and the degree of silica oversaturation or undersaturation of each rock zone.

CONTACT METAMORPHISM

Contact effects in slates and shales on western and northern boundaries of the stock extend up to 200 feet from the igneous contact. Immediately adjacent to the contact hornfelsic texture is well developed and bedding in the rock has been almost completely obliterated. Farther from the contact the hornfelsic texture gradually gives way to the original texture of shales and slate.

In thin section, texture of the hornfels is porphyroblastic, with spongy porphyroblasts of cordierite in a granoblastic matrix. Pleochroic, red-brown biotite occurs along bedding planes or as tiny veinlets filling fractures in hornfels. The typical mineral assemblage is quartz, plagioclase, cordierite, sericite, biotite, and

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[2] Experimental studies by Bowen (1937), and by Thornton and Tuttle (1950), demonstrate that the system SiO_2- $NaAlSiO_4$ - $KAlSiO_4$ is the goal toward which all magmatic liquids move on fractional crystallization. Bowen (1937) has named this system "Petrogeny's residua system".

minor amounts of pyrite and ziron. The amount of plagioclase and sericite in the hornfels increases toward the igneous contact.

Contact effects in quartzites are recognizable for not more than 150 feet from the igneous contact. Metamorphism has had a "bleaching" effect: quartzite immediately adjacent the contact is pale grey to white, whereas quartzite farther from the contact is medium to dark bluish-grey. Within the bleached zone, biotite is concentrated along bedding planes and finely dispersed throughout the rock. Fine-grained pyrite is disseminated throughout the aureole and was noted beyond the zone of bleaching.

STRUCTURE

Internal Structures

Foliation and Lineation.- Foliation, here considered to be planar flow structure, is marked by the preferred orientation of (010) faces of tabular feldspars. Its attitude is almost everywhere vertical but local variations of dip to 75 or 80 degrees are common (fig. 8). The structure is present in all rock zones of the stock and it is

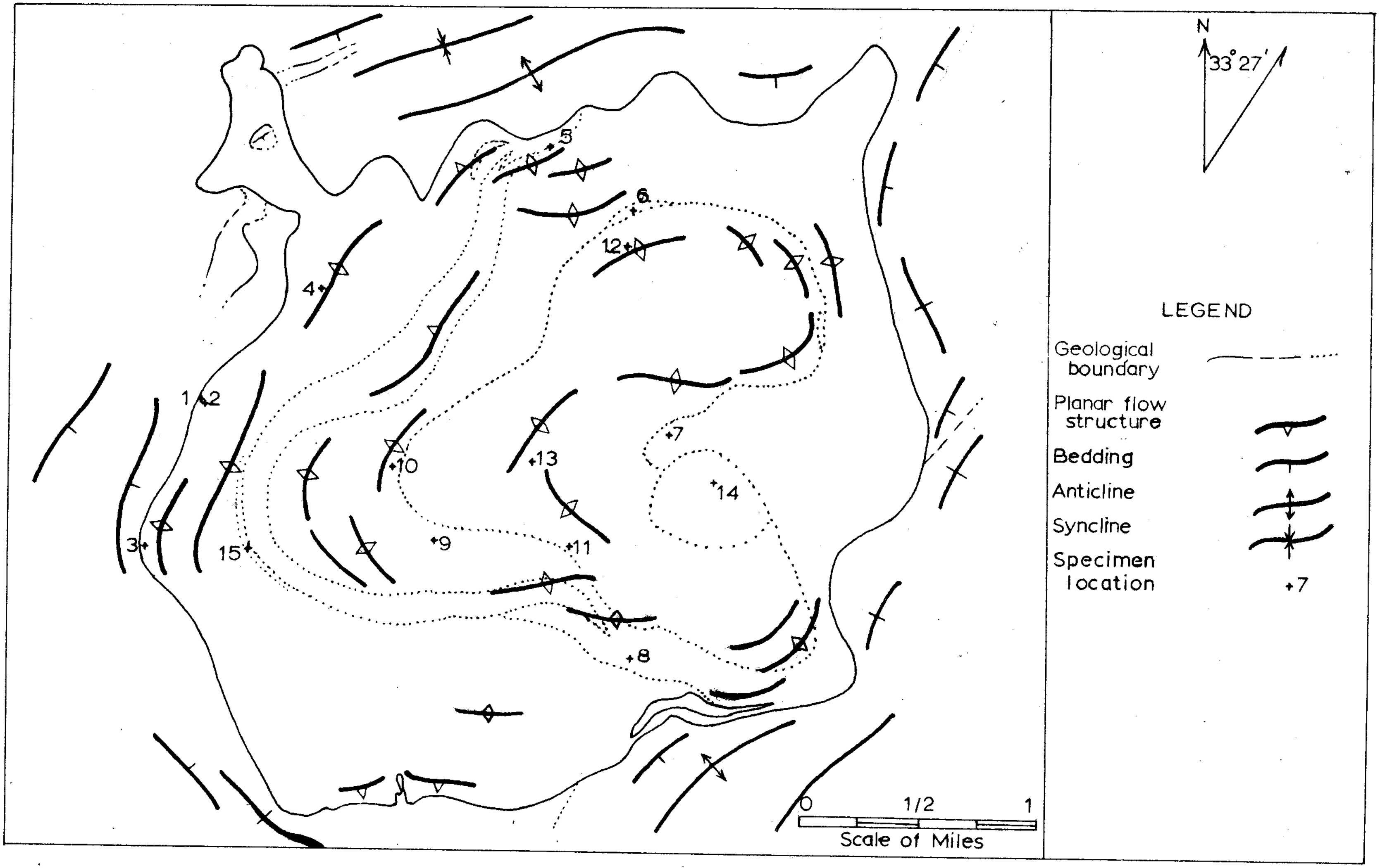

Figure 7. Structural Trend Map of
Mt. Brenner Stock
Yukon Territory

generally most distinct in the outer and intermediate zones. The overall continuity and concentric pattern of the structure are illustrated in Figure 7.

Foliation in augite-biotite monzonite and in porphyritic hornblende monzonite is everywhere parallel to the intrusive contact. In fine-grained, augite-biotite monzonite the generally indistinct foliation is accentuated by subparallel biotite plates. In some areas of the monzonite porphyry, the matrix has segregations of dark and light minerals within the plane of foliation, giving the rock a gneissic structure. Foliation is parallel to the contact of this cresent shaped band except in the northern and southern tips where it cuts across the gradational contact and follows the trend in the adjacent porphyritic hornblende monzonite. Foliation in the pink quartz monzonite porphyry is well developed near the periphery of the unit but is indistinct or absent in the core. It generally conforms to the outer contact of this zone.

Linear structures are rare. In monzonite porphyry streaks and elongated clots of hornblende in the matrix give a linear element to the rock. Individual hornblende prisms within the streaks and clots commonly show a random orientation. Where elongated inclusions are present, they lie within the plane of foliation with their longest dimensions pitching at very steep angles.

Jointing.- Two prominent sets of steeply dipping joints are well developed throughout the stock: one set is parallel or subparallel to planar structure; the other set is normal to the planar structure or cuts across it at large angles. Along the western margin of the stock, joints that are normal to foliation cut across the igneous contact and continue into the country rocks. Joints that are parallel to foliation occur in all rock zones, but they are most well developed in the monzonite porphyry. Poles to joints are plotted on a lower hemisphere Schmidt net projection in Figure 9. They form two main concentrations: the concentration in the southeastern quadrant corresponds to joints that are parallel to planar structure; concentrations in northeastern and southwestern quadrants correspond to joints that cut planar structures at large angles. The joints are all very closely spaced, and each attitude on the map represents 8 to 10 joints of the same attitude. Generally, the joints are smooth, remarkably even and persistent. None shows slickensides. A few joints in pink quartz monzonite porphyry are filled with aplite and pink quartz monzonite

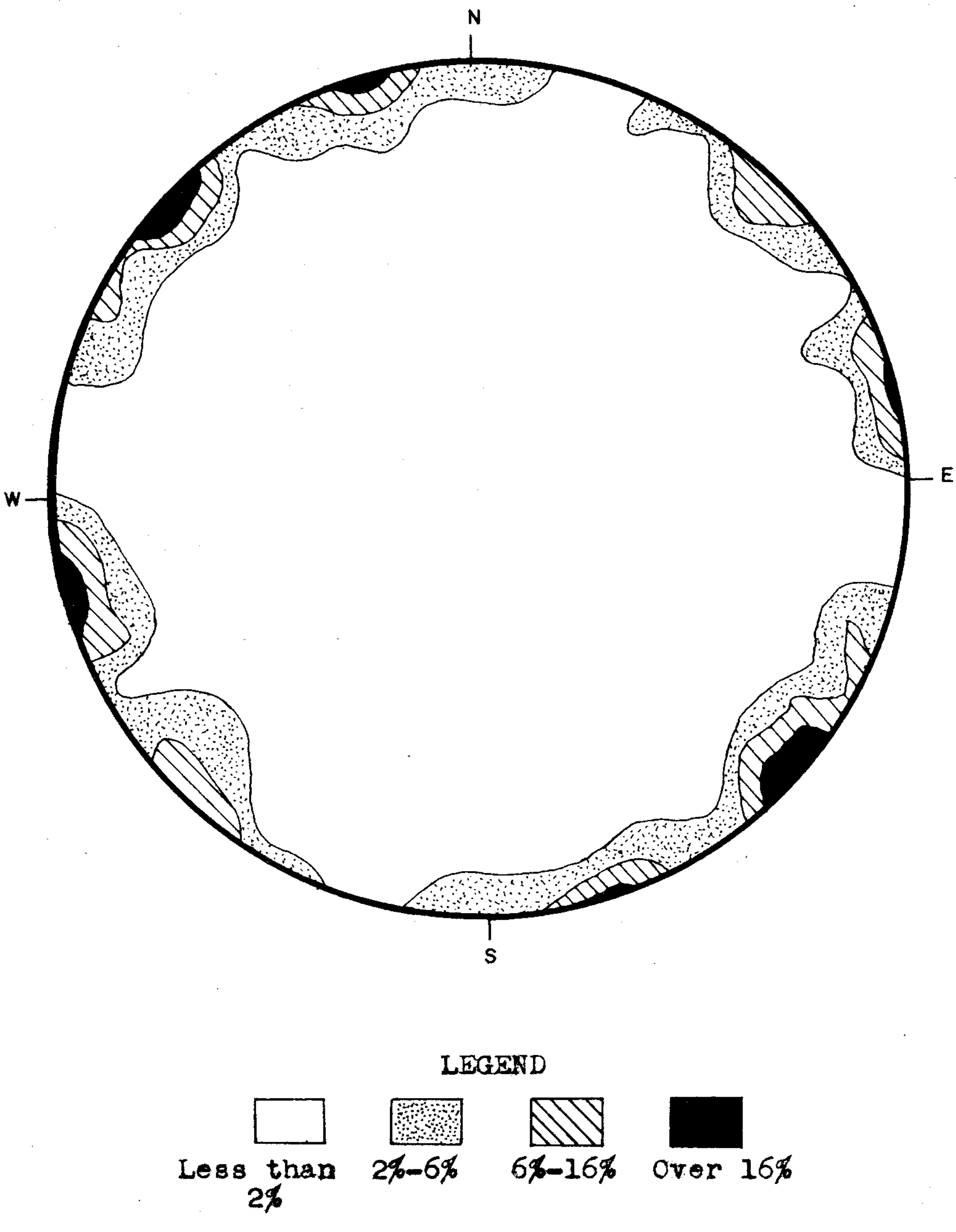

Figure 8. 172 poles to foliation plotted on a Schmidt net and contoured. Contours 2, 6, 16, and over 16% per 1% area.

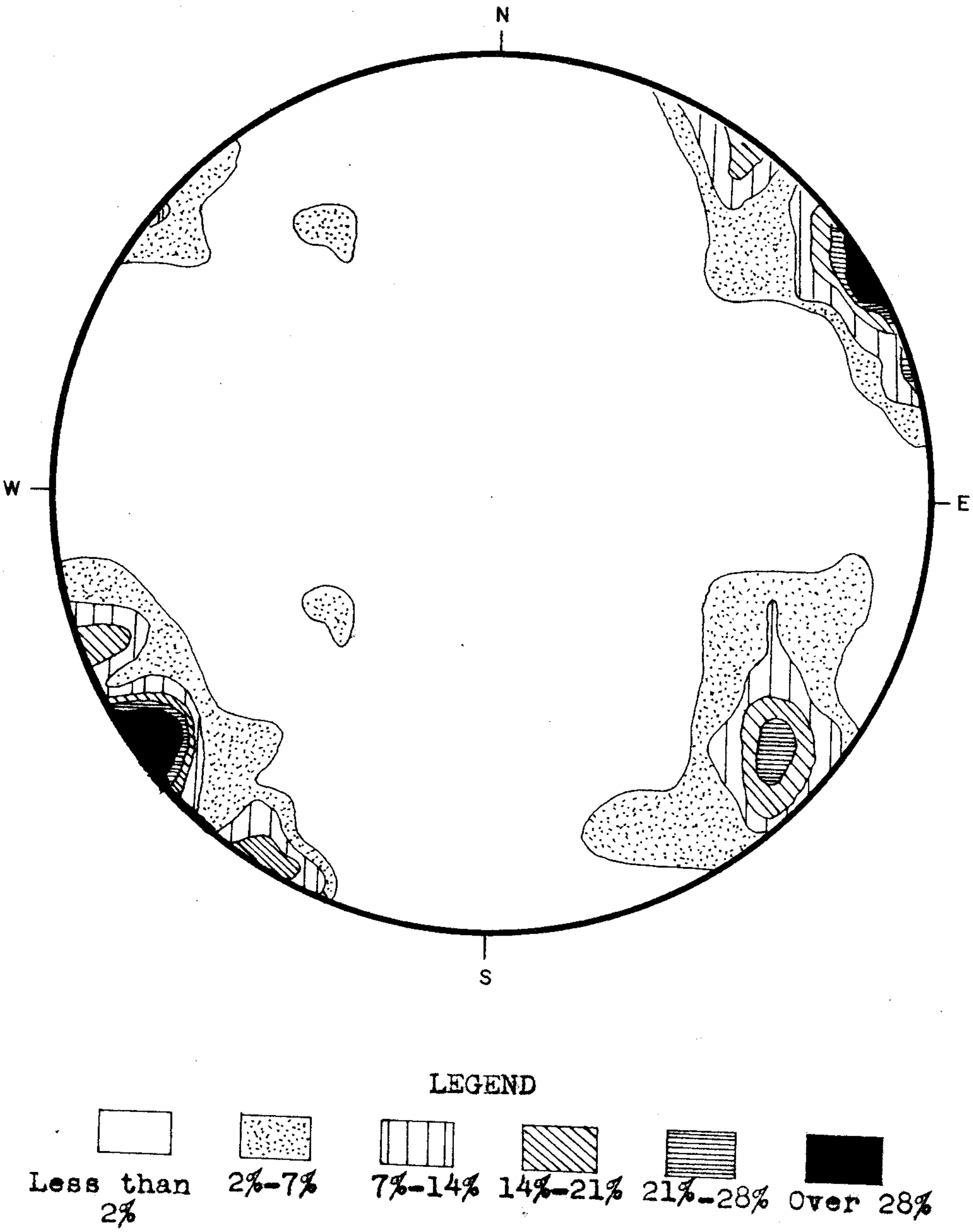

Figure 9. 231 poles to joints plotted on a Schmidt net and contoured. Contours 2, 7, 14, 21, 28, and over 28% per 1% area.

porphyry dykes. Minor fracture surfaces in many areas have been "healed" by dark green hornblende. This feature is seen in all rock phases, even those that are hornblende poor.

Shallow dipping joints were observed in only three localities. In one area, in the lower parts of the walls of a U-shaped glacial valley, joints dipping about 35 degrees are subparallel or parallel to the rock surfaces, giving a sheeted effect. In another area, closely spaced joints are nearly horizontal. Rocks in the vicinity of these joints are deeply weathered, and viewed from a distance the structure has the appearance of sedimentary bedding. Shallow dipping joints are not apparent in areas of the stock where the steeply dipping joints are well developed.

Very tight curved fractures that branch and join to form a network of lenticular prisms that range in thickness from 1/2 to 3 inches occur at the western and southern borders of the stock. These fractures occur within 5 feet of the intrusive contact and also are well developed for a few feet in the adjacent hornfels country rock. The fractures either parallel primary foliation or cut across it at low angles. Intersection of the curved fracture surfaces forms a lineation that plunges steeply in the direction of dip of the intrusive contact. Fracture surfaces are coated with reddish-brown limonite. This type of fracturing has been given the term "slip-cleavage" by Compton (1955).

Internal Contacts.- Almost all contacts between igneous rock zones are gradational and thus are somewhat approximate (See map in pocket). Their steeply dipping attitudes are shown by their lack of deflection in crossing ridges and valleys. The boundary between augite-biotite monzonite and the monzonite porphyry, which can be defined within distances ranging from 5 to 20 feet, is the least gradational of all the internal contacts. A sharp contact between these two rock types occurs at one locality near the northern end of the monzonite porphyry band. The boundary between augite-biotite monzonite and porphyritic hornblende monzonite is accurate to within 150 feet. Contact between monzonite porphyry and porphyritic hornblende monzonite is gradational over a distance of about 100 feet. Glomerophyritic hornblende monzonite forms a transition zone between porphyritic hornblende monzonite and the pink quartz monzonite porphyry. This boundary is very difficult to locate more accurately than within 200 feet.

Contact between aplite and the surrounding rock zones was not observed.

External Structures

In plan the Mount Brenner stock is roughly elliptical with its long axis trending northeastward. The northeast regional trend of the country rock structures is generally concordant with the outline of the stock (fig. 4). Along the southwestern and northeastern margins of the stock, the bedding makes an abrupt swing to conform with the flanks of the intrusion. Along the southern boundary of the stock, shale beds that dip northeastward to eastward, about 1000 feet from the igneous contact, dip steeply southward immediately adjacent to the contact. The quartzite shows thin platy cleavage in a zone 500 to 800 feet wide along the southeastern boundary of the stock. Beyond this distance the quartzite is massive. Discordant relationships occur in the northwestern corner of the map-area, where the intrusion cuts across the limestone and chert units and in the eastern part of the map area, where the stock cuts across the contact between quartzite, and shale and phyllite. Contact with the country rocks is invariably sharp. No intense brecciation or mylonitization is found in contact zones.

HISTORY OF THE PLUTON

Interpretation of Structures and Mechanics of Emplacement

Foliation can be produced by three different mechanisms: (1) dimensional orientation of phenocrysts by laminar flow in an uprising magma [1] (primary flow structure): (2) tectonic orientation of phenocrysts during regional metamorphism; and (3) mimetic orientation of phenocrysts by growth around minerals that already have a preferred orientation (Gellatly, 1964). The non-layered nature of the rock, and the lack of ubiquitus cataclasm in phenocrysts and in the matrix, suggest that the foliation is not the result of tectonic oreintation. Mimetic orientation should be characterized by phenocrysts having cores of earlier formed plagioclase crystals whose orientation

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[1] Mechanisms of dimensional orientation of crystals in a fluid are discussed by Balk (1937), Martin (1951), Hutchinson (1956), and Hills (1963).

reflects the alignment of plagioclase in the matrix. These features are not common in the Mount Brenner rocks. The overall conformity of foliation with rock zone boundaries and the presence of elongated inclusions orientated parallel to foliation suggests that the foliation is a primary flow structure. The steep outward dipping attitudes of flow structures throughout the stock indicate that vertical movement has been prominent and that the stock is not domed at the present level of erosion.

Most of the joints were measured in the central and northwestern parts of the stock. The perpendicular relationship between the two sets of steeply dipping joints shown in Figure 9, therefore, is statistically valid only for this region and not for the entire stock. The presents of aplite and pink quartz monzonite porphyry dykes filling some of the steeply dipping joints and the occurrence of hornblende and quartz along the fractures, strongly suggests that the joints are primary. Fractures normal to planar structure are interpreted as tension joints related to a slight arching of the rigid upper parts of the stock due to upward pressure from the magma below. Kuznetsov (1951) suggests that as cooling proceeds from above, a succession of the tension-joints can be formed progressively at depth. The joints are analogous to the cross-joints described by Balk (1937) and to the B-C joints described by Martin (1951)[1]. Joints parallel to foliation are possibly due to contraction during cooling: the fractures tend to develop along planes of relative mechanical weakness. Structural relations suggest that the stock was emplaced after the country rocks were folded and faulted. The joints, therefore, probably are not related to regional compressive stress in the enclosing rocks.

The shallow dipping joints probably are not of primary origin. Their broadly undulatory nature and their subparallelism to the topography indicate exfoliation phenomena. Jahns (1943) attributes such large-scale exfoliation structures to relief through removal of superincumbent load.

Slip cleavages and the lineation formed by their intersection "indicate circumferential stretching of the

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1 Balk (1937) defines cross-joints as those joints that are normal to flow lines. Martin (1951) describes B-C joints that are normal to the planar structure of a granitic diapir that has no linear structures.

batholithic walls, combined with compression and flattening normal to the walls." (Hills, 1963, p. 357).

That the stock was emplaced in a fluid or partly fluid state is suggested by the primary flow structures, the presence of rotated wall rock inclusions without disruption of their internal structure, the lack of mylonitization or brecciation along the outer contact, and the presence of a hornfels contact aureole around the stock. Structural data indicate that at the level now exposed by erosion the stock was emplaced by forceful injection. The main lines of evidence are: (1) near vertical planar and linear flow structures; (2) overall continuity and concentric pattern of primary flow structures; (3) slip cleavages and platy cleavages in the outer contact zone; (4) warping of country rock structures around the stock; and (5) bedding in shales upturned to conform with the contact of the stock.

The foregoing structural evidence seems to indicate that the stock was emplaced in the following manner. A rising fluid magma made room for itself mainly by shouldering aside the regionally folded sedimentary and metasedimentary rocks. In response to the upward and outward pressure exerted by the upsurging magma, bedding in the country rocks deflected upwards and outwards to conform with the intrusive contact, and the flanking rocks fractured to form slip cleavages and platy cleavages. The magma engulfed a large segment of quartzite just within the southeastern margin of the stock, and it also engulfed and rotated a few much smaller blocks of country rock along the outer margin. After partial consolidation of the upper and outer portions of the magma, to form the fine-grained augite-biotite monzonite, the magma continued to surge upward and it intruded this outer "shell". That the upward movement of the fluid core continued until the last stages of consolidation is suggested by the vertical flow structures in almost all parts of the pink quartz monzonite porphyry. Fracturing took place before the lower part of the stock was completely consolidated, and joints formed to accommodate stresses due to magmatic pressure from below and to cooling and contraction of the rock.

Assimilation

Contamination of the magma has occurred along the eastern margin of the stock, where augite-biotite monzonite is in contact with pelitic hornfels. The result of contamination is to change the augite-biotite monzonite into a garnetiferous quartz diorite, in a zone which is less than one foot wide. No evidence for contamination occurs where granitic rocks are in contact with quartzite. If assimilation had taken place in significant amounts the following evidence would be expected: (1) numerous inclusions of country rock in all stages of resorption; (2) the number of inclusions should increase toward the periphery; (3) heterogeneity of outer zones showing various degrees of conversion to the present rock types; and (4) the outer zones should become increasingly more siliceous toward the contact since highly siliceous country rocks would be assimilated. Such evidence is virtually absent in this stock. At the present level of erosion, therefore, contamination of the magma by assimilation of country rock has not been a factor in causing compositional variation of the stock.

Differentiation

The systematic compositional variation within the stock (See p.30 and the following figures) is compatible with the concept of differentiation of a magma as it crystallized inward from the margin. The augite-biotite monzonite is considered to represent the composition of the parent fluid because it was the first rock zone to be emplaced and because it has a composition from which all other rock types can be formed by relatively simple processes of differentiation.

That the main rock types of the stock pass from undersaturated, through saturated to oversaturated types (fig. 5a) seems to suggest that the thermal barrier of the system SiO_2 - $NaAlSiO_4$ - $KAlSiO_4$ (Bowen 1937) has been crossed. Tilley (1957) suggests, however, that the thermal barrier which prevents the transition from syenite to granite in the experimental melts may be "inoperative in a natural melt where its composition is modified by the presence of mafic components, and further, notable disparity in volatile content". The trend from undersaturated to oversaturated magma can be accomplished by various processes of silication of undersaturated magmas. During crystallization of the magma, the residual liquid can be enriched in silica by reaction or lack of reaction of the liquid with minerals that have characteristics of incongruent melting. Tilley (1957) suggests that "precipitation of magnetite in the place of aegerine would throw excess silica into the liquid if this oxide phase failed to resorb". The formation of hornblende by reaction of liquid with pyroxene will also result in setting free of quartz, and thus the possible quantity of a quartzose differentiate would be augmented (Bowen, 1928, p. 90). The change of the SiO_2 curve (fig. 5a) from the undersaturated into the saturated areas of the diagram corresponds with the appearance of hornblende as the major mafic mineral. The SiO_2 content increases toward the oversaturated area with increasing amount of hornblende (compare points B and C with the corresponding modes in Table I). Thus, the formation of hornblende may have played a significant role in silication of the residual liquid. The foregoing processes will affect the compostion of the final residual liquids and the corresponding rocks, but can only cause differentiation if relative movement between crystals and residual liquid is brought about by processes such as gravity separation or "filter pressing".

Certain oxides of the hornblende-biotite pyroxenite show significant departures from the smooth variation curves (figs. 4 and 6). This sort of departure is attributed by Bowen (1928) to crystal accumulation. If the porphyritic hornblende monzonite is to be formed from the augite-biotite monzonite by the separation of components of biotite-hornblende pyroxenite alone, the ratio of volumes of the pyroxenite to components of the monzonite should be approximately 1 to 3 (calculated from fig. 4).

Migration of water and alkalis can also contribute to differentiation of a magma. Water will diffuse and distribute itself in a magma so that the chemical potential of the water is the same throughout the magma chamber. Alkalis and certain metals will co-ordinate with the water and will be concentrated in the regions of lowest pressure and temperature (Kennedy, 1955).

A hypothetical sequence of events that is proposed to explain the development of rock zones, is illustrated diagramatically in Figure 10. The processes of volatile and alkali diffusion and of fractional crystallization, which effected differentiation of the parent magma, were interrupted by intrusion.

During the first stage of intrusion (fig. 10a) the upper and outer parts of the magma which formed a cupola of a larger magma chamber, cooled very rapidly to form the fine-grained augite-biotite monzonite. Effects of the hot magma on the relatively cool country rocks were to produce a zone of cordierite hornfels in pelitic rocks, garnetiferous quartz diorite at the contact with pelitic rocks, and a "bleached" zone in quartzite. With the

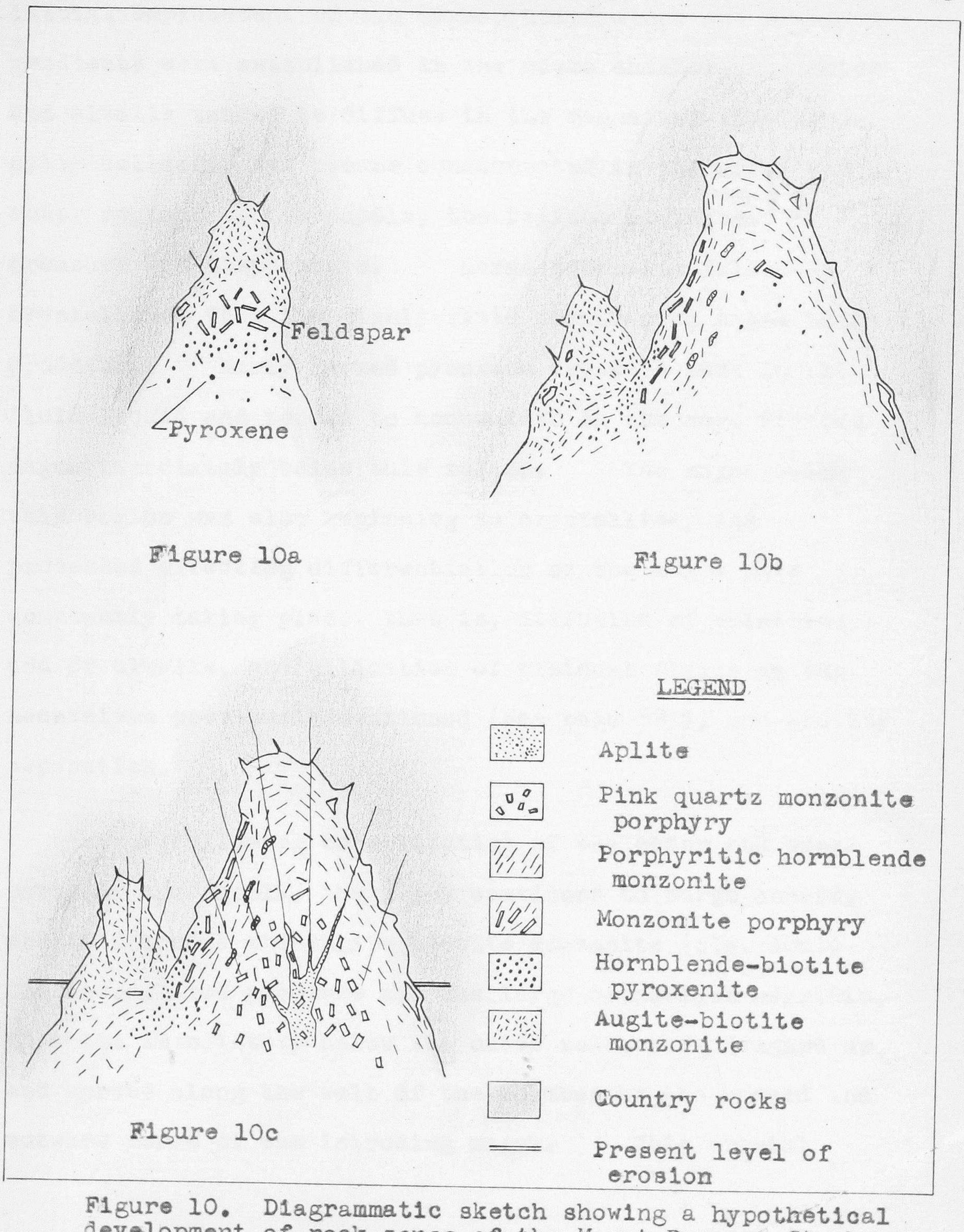

Figure 10. Diagrammatic sketch showing a hypothetical development of rock zones of the Mount Brenner Stock.

initial emplacement of the magma, temperature and pressure gradients were established in the magma chamber. Water and alkalis tended to diffuse in the magma and they gradually collected and became concentrated in the upper and outer regions of the cupola, the regions of lowest pressure and temperature. Large potassium feldspars crystallized from the highly fluid alkali-rich magma thus produced. Early formed pyroxene crystals sank in the fluid liquid and tended to accumulate on the more viscous magma immediately below this region. The magma below this region was also beginning to crystallize, and processes effecting differentiation of the magma were constantly taking place, that is, diffusion of volatiles and of alkalis, and silication of residual fluids by the mechanisms previously mentioned (See page 52), and gravity separation.

Following consolidation of the outer and upper parts of the cupola, the magma continued to surge upward, and it intruded the augite-biotite monzonite (fig. 10b). The accumulated pryoxene and the large orthoclase crystals, that lie immediately below the outer zone, were dragged up and spread along the wall of the chamber by the upward and outward force of the intruding magma. This crystal mush later cooled to form the hornblende-biotite pyroxenite and the monzonite porphyry. The newly intruded magma continued to crystallize inward in a zone which is now the porphyritic hornblende monzonite (the intermediate zone). The medium- to coarse-grained texture of this zone suggests that the magma cooled more slowly than did the augite-biotite monzonite, possibly because the country rocks were preheated by the earlier stage of intrusion.

The mobile core continued to surge upward. Crystals suspended in the fluid were aligned by magmatic flow. The magma reacted with the partially consolidated inner margin of the intermediate zone to form the transition zone of glomeroporphyritic hornblende monzonite. The lenses of monzonite porphyry, which occur in some places at the contact between the core and the porphyritic hornblende monzonite, may have formed by processes similar to those which formed the main band of monzonite porphyry. The core cooled slowly to produce the coarse-grained pink quartz monzonite porphyry (fig. 10c).

Fracturing occurred before the core was completely consolidated. It effected a sudden release of pressure, and a sudden escape of volatiles from the remaining liquid. These changes would bring about a significant rise of the temperature of crystallization of the remaining liquid, and possibly would case a "sweeping-out" action of interstitial fluids. Consequently, the partially fluid core crystallized rapidly to form the zone of fine-grained leuco-quartz monzonite, and the fluids which filled fractures cooled rapidly to form aplite dykes (fig. 10c). Some of the crystal mush of the core was swept into fractures, where it consolidated to form pink quartz monzonite porphyry dykes.

Summary of Emplacement, Crystallization and Differentiation

The Mount Brenner stock has intruded folded rocks of Silurian to Lower Cretaceous age. The regional structural trend is modified in the vicinity of the stock so that beds are generally conformable with the intrusive contact. That the stock was emplaced by forceful injection of a fluid magma is indicated by (1) near vertical planar and linear primary flow structures that have an overall continuity and concentric pattern; (2) structures in the country rock that warp around the stock; (3) bedding in shales that turns upward to conform with the contact of the stock; and (4) slip cleavages and platy cleavages that occur along the outer contact zone. Piecemeal stoping was of only minor importance during emplacement of the stock.

Chemical and mineralogical variations of the rock zones have a systematic trend toward "petrogeny's residua system", from the periphery of the stock to the core. This variation is consistent with the concept of differentiation of an augite-biotite monzonite parent magma as it crystallized from the walls of the magma chamber inward. The following hypothetical sequence of events is proposed to explain the development of the rock zones. A rising fluid magma, possibly guided by the regional structure, made room for itself mainly by shouldering aside the country rocks. The upper and outer portions of the magma chilled to form a "shell" of fine-grained augite-biotite monzonite. Differentiation of the magma was controlled by gravity separation of mafic minerals and by diffusion of volatiles and alkalies. The magma continued to surge upward, and intruded the partially consolidated outer "shell". Inclusions of the "shell" were engulfed and carried along with the rising magma. Pyroxene crystals and large orthoclase crystals that lie in the magma just below the augite-biotite monzonite, were dragged up and spread against the side of the chamber by the upward and outward force of the intruding magma. The crystal mush later cooled to form the hornblende-biotite pyroxenite and the monzonite porphyry. The magma proceded to crystallize inward in the intermediate zone. The mobile core continued to surge upward. The magma reacted with the partially consolidated intermediate zone and formed the glomero-porphyritic hornblende monzonite. The core cooled slowly to produce pink quartz monzonite porphyry. Fracturing took place before the lower part of the stock was completely consolidated. Joints formed to accommodate stresses due to magmatic pressure form below and to cooling and contraction of the rock. The fracturing effected a sudden release of pressure and of volatiles from the remaining liquid. As a result of these changes, the partially fluid core crystallized rapidly to form the zone of fine-grained leuco quartz monzonite, and the fluids that filled fractures cooled rapidly to form aplite dykes. The effects of wall rock contamination are insignificant compared to the overall evolution of rock zones by the processes of magmatic differentiation.

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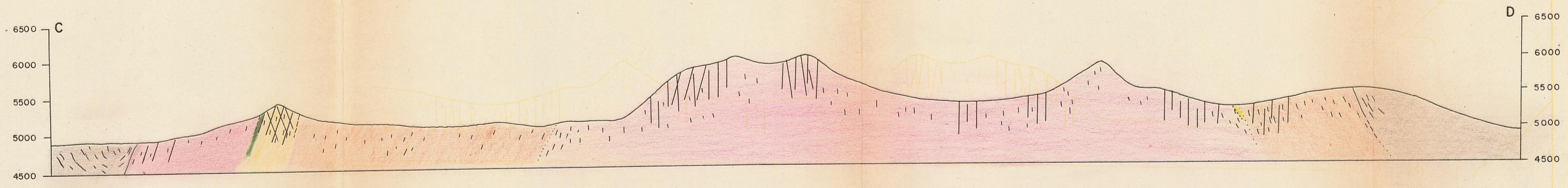
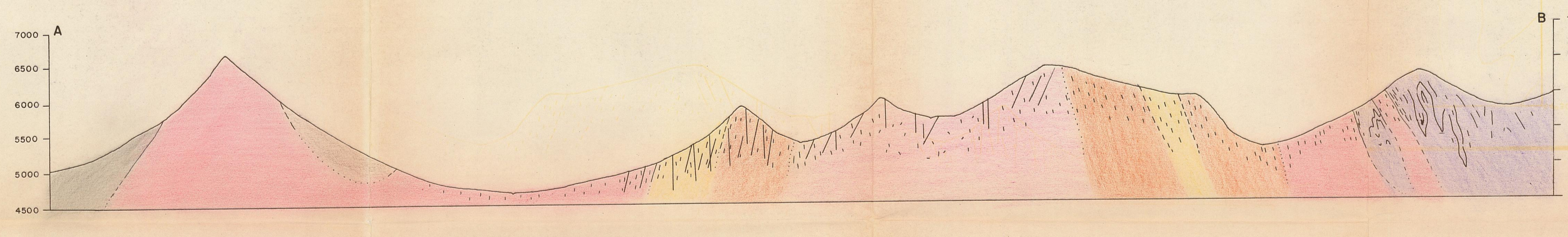




LEGEND

MIDDLE CRETACEOUS (?)

MOUNT BRENNER STOCK

- Aplite, fine grained leuco quartz monzonite
- Pink quartz monzonite porphyry
- Porphyritic hornblende monzonite
- Monzonite porphyry
- Hornblende biotite pyroxenite
- Augite biotite monzonite

LOWER CRETACEOUS

- Dark blue grey to grey quartzite with minor slate and phyllite

JURASSIC

- Dark grey argillite, shale, slate, phyllite; minor limestone

MIDDLE PERMIAN

- Light to dark grey phosphatic fossiliferous limestone

SILURIAN

- Interbedded black chert and argillite; minor chert pebble conglomerate

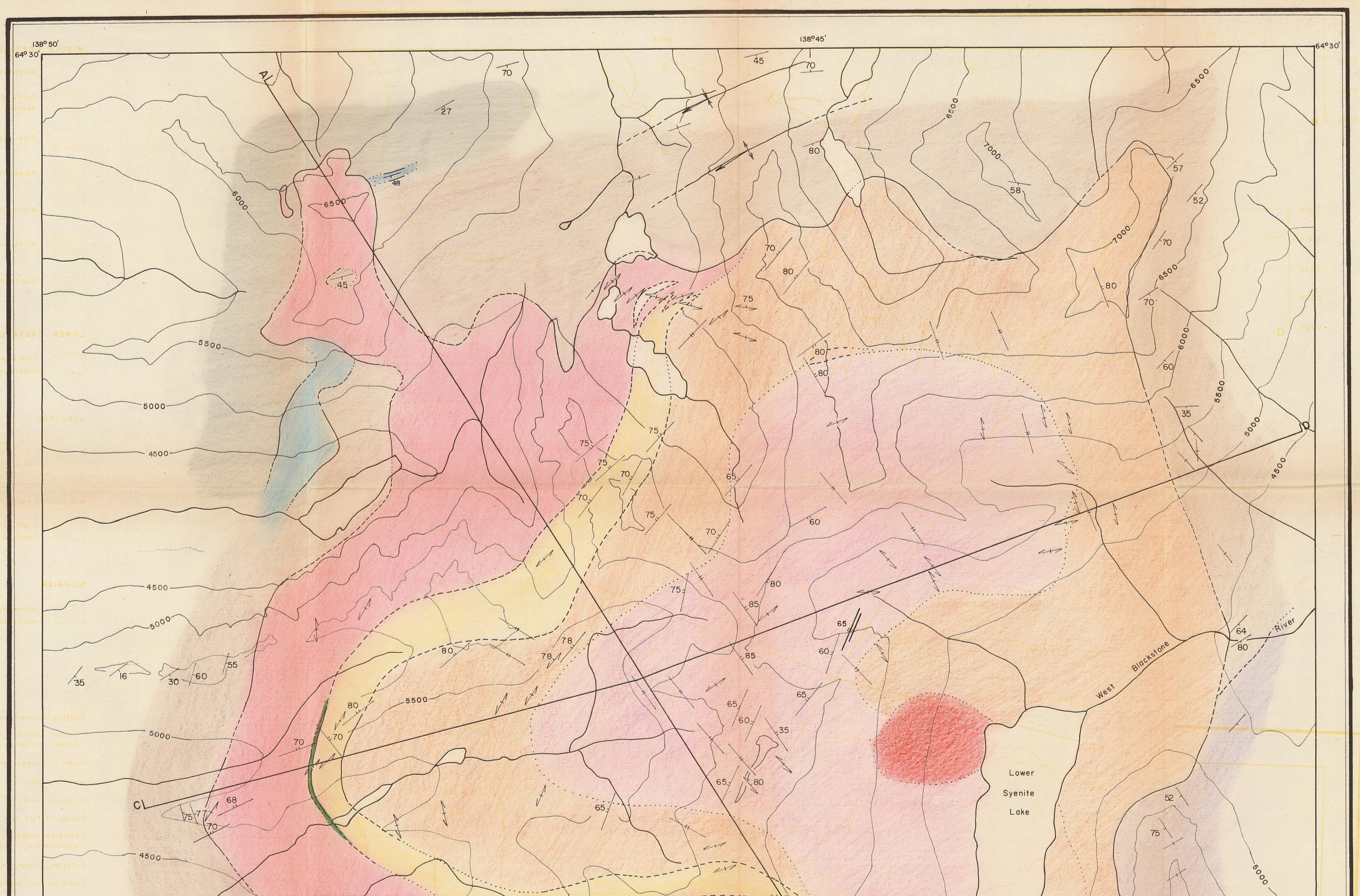
Bedding (inclined, vertical)
Foliation (primary in granitic rocks, inclined, vertical)
Joints (inclined, vertical)
Anticlinal axis
Synclinal axis
Plunge of fold axis
Geological boundry (defined, approximate, assumed)
Foliation, primary (in cross sections)
Joints (in cross section)

Geology by M. B. Lambert, 1964

Topography modified after advanced print of 116 B/7, Department of Mines and Technical Surveys, 1963.

Approximate magnetic declination 33° 27' East.

Drawn by M. B. Lambert



GEOLOGICAL MAP OF MOUNT BRENNER STOCK

YUKON TERRITORY

Scale: 1 inch = 1000 feet

0 1000 2000 3000