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A PETROGRAPHIC DESCRIPTION OF A PLUTONIC MASS ON GAMBIER ISLAND, HOWE SOUND, BRITISH COLUMBIA

by

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ABSTRACT

A granodiorite pluton near the southwest boundary of the Coast Range of British Columbia was examined by field and petrographic methods, with the object of determining the origin of the pluton.

Field and petrographic characteristics are presented and descriptions of 42 of 65 thin sections studied are included.

There are no field structures which can be explained solely by magmatic processes. Several field characteristics which should be associated with magmatic intrusion are absent.

Petrographic examination revealed no features which can be explained only by magmatic processes. On the other hand, the replacement textures found by microscopic examination cannot be attributed to crystallization from a melt. The physical chemical system which produced the present form of the pluton was an open one. Potash was added and soda and lime were removed in the early stages of recognizable replacement. Later silica was added and potash, alumina, soda and lime were removed.

The processes which developed the granodiorite pluton are most accurately described as granitization.

ACKNOWLEDGEMENTS

The entire staff of the geology department of the University of British Columbia, particularly Madam Dolar-Mantuani, Dr. H.C. Gunning and Dr. W.H. White, assisted with instruction and advice on petrographic methods, significance of textures, arrangement of material, and with discussions of regional geology, and criticism of manuscript.

Dr. J.E. Armstrong of the Geological Survey of Canada, supervised my field mapping and willingly gave me descriptions of the other geological formations in the Vancouver district.

My wife assisted considerably in preparation of plates and in typing.

To all the above, and to the Geological Survey of Canada for permission to use this topic, and for preparing thin sections, I am deeply grateful.

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A PETROGRAPHIC DESCRIPTION OF A PLUTONIC MASS ON GAMBIER ISLAND, HOWE SOUND, BRITISH COLUMBIA

INTRODUCTION

General Statement

Gambier Island is located between latitudes 49 degrees 26 minutes, and 49 degrees 32 minutes, north, and between longitudes 123 degrees 18 minutes, and 123 degrees 28 minutes, west, in Howe Sound, a fiord-like inlet near the south end of the British Columbia Coast Range. The city of Vancouver lies about 12 miles southeast. The island is accessable by water taxis from Horseshoe Bay and by aircraft from Sea Island, the year round and by Union Steamships from Vancouver, in the summer months.

Previous Work

O.E. Leroy[13] mapped the shoreline and nearby islands, from Vancouver to Jervis Inlet, in 1906. His map was published in 1908 on a scale of four miles to one inch.

In the summer of 1913, and again in 1914, E.M.J. Burwash[5] mapped parts of the Coast Range, between Vancouver and the Garibaldi area, north of Howe Sound. The scale on which Burwash's map was published is seven miles to one inch.

T.C. Phemister[16] made a detailed field and petrographic study of the Coast Range near Vancouver. His paper includes descriptions of the structure and formations of Bowen Island, as well as descriptions of the formations and

1 figures in brackets refer to bibliography page 64

structure of the Coast Range north of Vancouver.

H.C.B. Leitch[12] studied various localities on Bowen Island, particularly in the region of Wharf and Lodge Coves, in 1947.

Recently, in 1948, 1949, and 1950, J.E. Armstrong of the Geological Survey of Canada, mapped much of the Vancouver area, on a scale of one half mile to one inch. His report has not been published at the time of writing of this report.

Field Investigation

During the 1950 field season, I was employed by the Geological Survey of Canada, in the task of mapping the Howe Sound area between latitudes 49 degrees 20 minutes, and 49 degrees 30 minutes, north, and between longitudes 123 degrees 17 minutes, and 123 degrees 30 minutes, west, at a scale of one mile to one inch. We made traverses at approximately quarter mile intervals, except where apparent lack of structure rendered half mile intervals adequate. Dense shrubbery and a covering of drift obscured structure to such an extent that interpretation of detail was almost impossible between high tide line and summits of the hills. Accordingly, except where we found particularly favourable exposures, we determined the location of the contacts inland, and the detailed relationships on shore line exposures. The traverses made are shown in Plate II.

An outcrop map has not been prepared for a number of reasons. The major reason is that on a map of this scale

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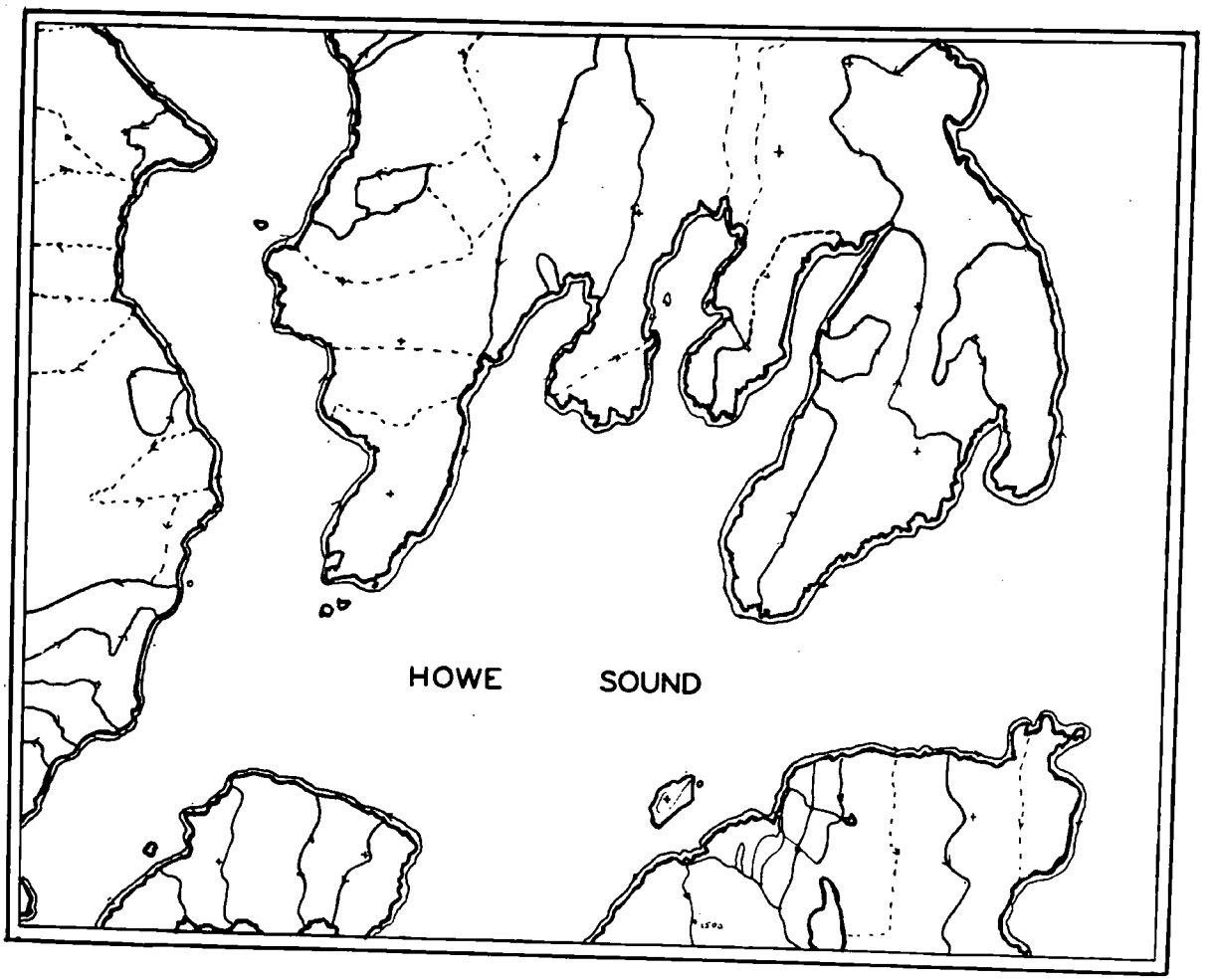

PLATE II

SCALE

TRAVERSE BY G. WILSON.....

TRAVERSE SUPERVISED BY G. WILSON.....

one does not see absolutely all rock outcrops and can correctly map only those he sees. A map which shows the presence of some outcrops infers that there is drift where outcrop is not shown. However, certain areas where outcrop should not be expected are indicated on Plate I.

Laboratory Investigation

Laboratory examination consisted entirely of petrographic analyses by means of standard and universal stage. I had hoped to make a number of silica analyses from contact zones, in order to determine the increase in silica as contacts were approached from outside the pluton. Unfortunately time has not permitted me to make such analyses. Determinations by the Fedorov method provided accurate information on the composition of feldspars. In several of those few thin sections in which amphibole or pyroxene were found, the Fedorov method was also used to determine optic characteristics.

In general, only centered or very nearly centered interference figures were used to identify feldspars. A notation in the appendix indicates where off-center figures were used. The composition, even where determined by universal stage methods, is not to be considered absolutely representative. A true impression of the range of plagioclase in a rock can be gained only by identifying many grains and considering the most calcic and least calcic plagioclase to represent the range in composition for the thin section.

COAST RANGE OF BRITISH COLUMBIA

General Statement

The Coast Range of British Columbia is a topographic and geologic unit which extends northwest 1,000 miles from the northern part of Washington to the Yukon. The width of the Coast Range averages about 50 miles, but locally exceeds 125 miles. The peaks vary in height from 7,000 to 11,000 feet.

Stratigraphy and History

A detailed description of the stratigraphy and history of the Coast Range is not properly part of this report. Various Geological Survey of Canada reports listed in the bibliography contain known information on the Coast Range. T.C. Phemister[16] included a very complete summary of both stratigraphic and tectonic history in his paper on the Coast Range batholith near Vancouver, British Columbia. Only a few brief comments are included here.

Paleozoic strata, older than Carboniferous, are rare within the Coast Range or adjoining areas. For this reason the Coast Range is generally assumed to have been a land mass exposed to erosion until late Paleozoic. From Carboniferous until Late Triassic, sedimentation and volcanic activity in the Western Cordillera appear to have been coincident with gradual subsidence of the geosyncline. No unconformity has been mapped between Paleozoic and Mezozoic formations, though paleontologic evidence indicates that a

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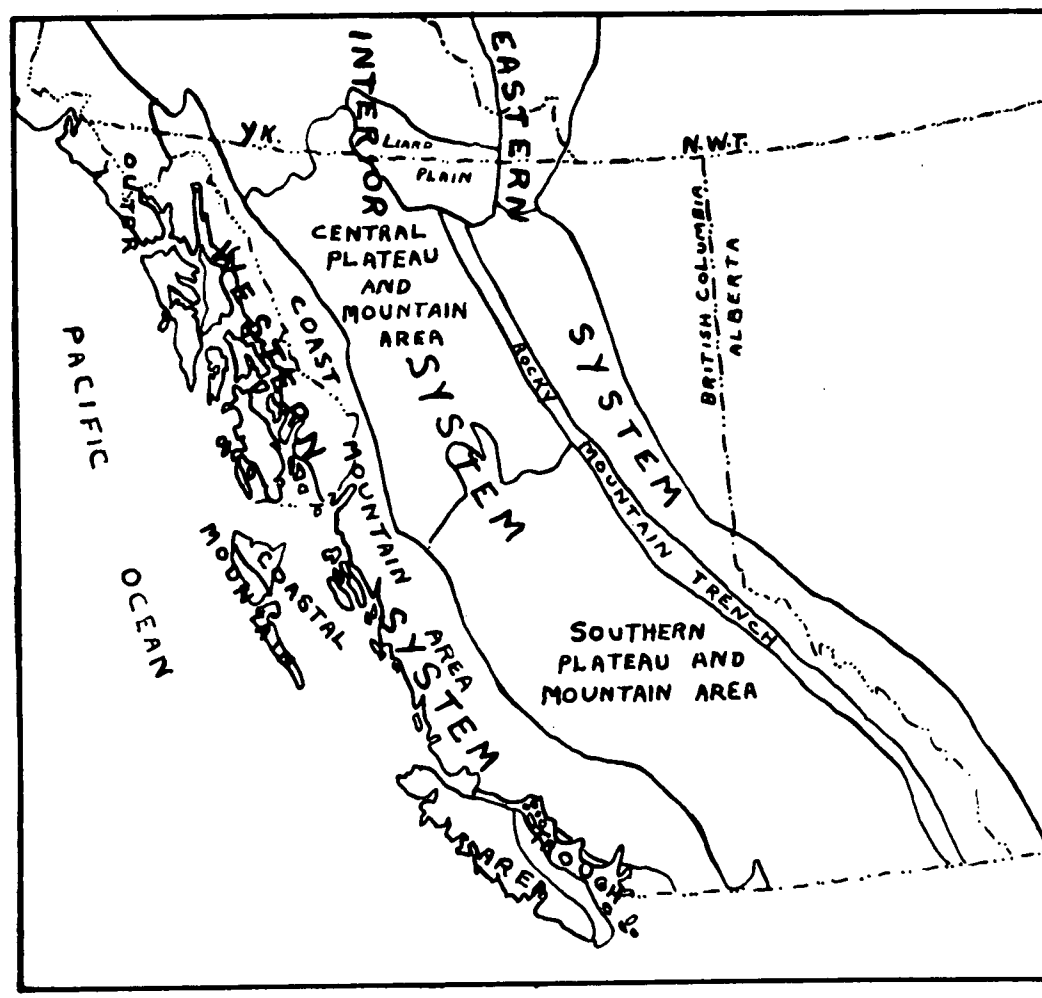

PLATE III

PHYSIOGRAPHY OF BRITISH COLUMBIA

ADAPTED FROM H.S. BOSTOCK

hiatus exists.

Development of the geosyncline reached a maximum in the Mezozoic Era. Considerable thicknesses of both Triassic and Jurassic sedimentary and volcanic strata probably extended across the Western Cordillera, but have been eroded away. The greatest development of the geosyncline is coincident with extensive igneous intrusion.

Toward the end of the Jurassic period forces from the west folded pre-existing rocks in a north-west direction. This folding was accompanied by igneous intrusion and possibly by granitization on a vast scale. Uplift, at least above base level of erosion, must have followed sedimentation, folding, and intrusion. Debris from Jurassic intrusives occurs in Cretaceous conglomerates at several localities. (Mathews,W.H.[15]; Rice,H.M.A.[19]; Crickmay, et al.[21])

Cretaceous volcanic activity and sedimentation differ from the same processes of the Triassic period in that Cretaceous sediments are of continental origin to a very considerable extent. Marine waters never again invaded the region of the Western Cordillera in large scale.

Renewed folding, faulting and igneous intrusion followed Cretaceous volcanism and sedimentation. Then agents of erosion once again commenced to reduce topography, but did not entirely eliminate relief before Tertiary volcanic and sedimentary rocks started to accumulate in inland depressions. Along the coast, Tertiary strata are recognized as being of both continental and marine origin. The earliest strata are

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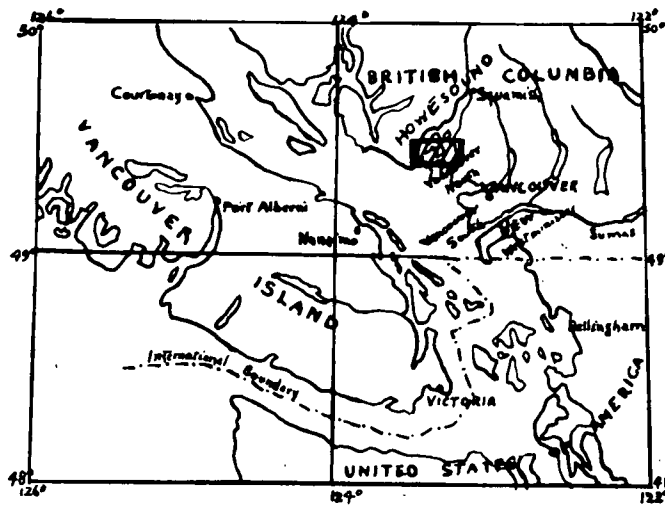

PLATE IV

LOCATION MAP

OF

HOWE SOUND AREA

unconformable over pre-existing rocks, but are themselves gently folded. Later Tertiary strata are nearly horizontal.

From mid Upper Cretaceous time until the present, erosion and uplift with minor periods of depression combined to give the Coast Range its present form.

Structure of the Coast Range

As noted in the preceeding section, the Coast Range is an uplifted mass of plutonic and metamorphosed rock. Immediately east of the Coast Range, the strata are closely folded and in places overturned toward the north-east. The contact is abrupt at some places, but transitional and indistinct at others.

In general, the Coast Range trends parallel with regional folding, but in detail, intrusive contacts transect structure along dip as well as along strike. The known western limit of the Coast Range swings toward the east a few miles northwest of Vancouver. This eastward trend of the Coast Range in the Vancouver district, may account for the east-west trend of many pre-batholithic rocks about Howe Sound.

GAMBIER ISLAND AREA

Topography

The mountains around Howe Sound rise abruptly from sea level to elevations of 4,500 to over 5,800 feet. Nearly all of the higher peaks have sharp ragged profiles. The islands within Howe Sound are much lower. The highest elevations on both Gambier Island and Bowen Island to the south, are 2,800 to 2,900 feet. The summits are more rounded than those of the mainland, and slopes too precipitous to climb are rare on Gambier and absent on the islands south of Gambier. The lower hills and ridges are somewhat the shape of very large rock drumlins or "roches moutonnees", with the steepest slopes facing northward. This is particularly true of Bowyer Island and Mt. Artaban on Gambier Island. The drumlin-shaped ridges, with the exception of Bowyer Island, trend in a direction of about 200 degrees sub-parallel with glacial striae. Bowyer Island trends nearly north-south. Glacial debris and gravels were found at all elevations and it is assumed, therefore, that the group of islands was entirely covered by ice, during Pleistocene glaciation.

Some of the streams, for example those north of Centre and West Bays, on Gambier Island, follow structural trends. This is particularly noticeable in the course of a stream which follows a supposed fault in a southwesterly direction in west Gambier Island. The entire area has a dry climate in summer. Moreover, the heights on the islands are not

great enough to gather any large proportion of moisture available in westerly winds. For this reason many of the streams are small in the summer.

Table of Formations

MESOZOIC	CRETACEOUS	8. Acid Lavas.	Massive and fragmental. Northeast part of area mapped, on Gambier Is.
		7. Pyroclastic Rocks	Lower part is conglomerate with pebbles from (6a). Separated from (6a) and (6b) by an unconformity. Occurs south of (8) and north of (6a &b).
		Unconformity	
	JURASSIC	6a. Coast Intrusives.	Gambier granodiorite. South part of Gambier Island; medium grained pink or gray: quartz, characteristically 25-35% subhedral: numerous inclusions, some of which are tuffs, younger than (6b), but relationship to (6c) is unknown. (6a) also occurs as pebbles in (7).
		Intrusive contact.	
			b. Artaban granodiorite. Occurs as two separated masses north of Gambier granodiorite (6a), red brown weathering, medium grained rock, composed of 60% feldspar and 40% mafic minerals. Older than (6a). Age relative to (6c) is unknown.
		Not in contact.	
			c. Crystalline rocks of Bowen and Keats Islands. All have the following characteristics; transitional contacts, foliation and inclusions parallel with contacts and regional structural trend. Age relative to (6a) and (6b) unknown.

MESOZOIC OR OLDER	PROBABLY TRIASSIC		Intrusive contact.
		5.	Argillaceous sedimentary formation. East-west trend ; dip is steep. Age relative to (1) unknown. Occurs as an isolated mass on west central Gambier Island.
			Not in contact.
		4. Acid Lavas.	Mostly inclusions in (6a) and (6b). One large 75 foot mass separates (6a) and (6b) at north end of West Bay. A second mass outcrops immediately north of (6b) on West Bay. Age relative to (3) or (1) unknown.
			Not in contact.
		3. Lavas.	Melanocratic altered lavas north (3a) and south (3b) of Gambier granodiorite.
			Not in contact.
		2. Tuffs.	One inch laminations of dense dark and light gray or brown material: sparse interbedded lavas: age of (2) relative to (1) is unknown. Occur on Bowen and Keats Island as west trending belts one quarter to one half mile wide.
		1. Lavas.	Occur on Bowen and Keats Islands, basic to medium basic: interbedded with tuffs; age relative to (2), (3), and (4) is unknown.

General Geology

Bowen and Keats Islands are underlain by lavas (1) and tuffs (2). (See Table of Formations). Granitic rocks are conformably intruded into, or more probably, developed from these rocks. Bedding in the tuffs, contact zones between lavas and granitic rocks, and inclusions and foliation in the granitic rocks, all trend at 80 degrees to 110 degrees.

Most of the mapped part of Gambier Island is underlain by crystalline rocks, Gambier granodiorite (6a) and Artaban granodiorite (6b). The older of the two plutonic rocks (6b), occurs as two isolated masses. The larger mass trends in an east-west direction across Mt. Artaban. It is a rusty or pink weathering, medium grained rock. The fresh surface is mottled pink and dark green. Mineral proportions are, approximately, feldspar 60 to 70 per cent, and mafic minerals 30 to 40 per cent. The Artaban granodiorite is bounded on the north by an unconformity and on the south by a transitional zone with Gambier granodiorite.

The other, smaller mass of Artaban granodiorite occurs at the northwest corner of West Bay. The north contact with pyroclastics (7) was not found. On the south 75 feet of acid volcanics separate Artaban granodiorite from Gambier granodiorite. There is no Artaban granodiorite between pyroclastics (7) and Gambier granodiorite on the south slope of Mt. Gambier.

Gambier granodiorite, the largest crystalline mass

mapped, underlies most of south Gambier Island. The north contact extends along a faulted, somewhat irregular, line from the north end of Halkett Bay to the north west corner of Gambier Island. An unconformity marks the north contact of the Gambier granodiorite, except where Gambier granodiorite is in contact with Artaban granodiorite or pre-batholith volcanic rocks (3b). The south contact of the Gambier granodiorite crosses the southwest point of Gambier Island. The trend of the contact is about 105 degrees and is parallel with the structure defined for Keats Island to the south. A zone of metamorphosed tuffs occurs on Bowen Island, southwest of Hood Point, on strike with the contact on southwest Gambier Island. The zone contains quartz porphyroblasts typical of some inclusions in Gambier granodiorite.

Gambier granodiorite is a medium grained aggregate of quartz up to 15 millimetres long, potash feldspar up to 3 millimetres long, plagioclase up to 3 millimetres, and chlorite and amphibole. Quartz comprises 25 -35 per cent of the rock in the form of subhedral grains. The remaining part is microcline - 10 per cent, plagioclase - 35 -55 per cent and mafic minerals - 10-20 per cent.

Both (6a) and (6b) contain dark xenoliths. The xenoliths are zones of rock somewhat finer grained and more mafic than their surroundings. The xenoliths invariably trend parallel to one another and to foliation wherever a distinct long dimension or foliation is recognizable.

The only pre-batholith volcanic and sedimentary rocks

on Gambier Island occur at the following localities:

1. Southwest Gambier Island, south of and in contact with Gambier granodiorite.

2. North of Gambier granodiorite on the west side of Port Graves.

3. Within Artaban granodiorite and Gambier granodiorite.

Melanocratic lavas, division (3b) of the table of formations, outcrop across the southwest end of Gambier Island. The other outcrop of dark colored lavas (3a) is north of Gambier granodiorite on the west side of Port Graves. Alteration of (3a) is more extensive than alteration of (3b) south of Gambier granodiorite.

Acid lavas lie north of, and within Artaban granodiorite. The only outcrop of acid lavas (4) north of granodiorite is at the north end of West Bay. On the south slope of Mt. Gambier, conglomerate (7) and Gambier granodiorite are in mutual contact. Conglomerate and Artaban granodiorite are in contact on the south slope of Mt. Artaban.

Another mass of acid volcanic separates Artaban granodiorite from Gambier granodiorite (6a) at the northwest corner of West Bay. Numerous other inclusions of acid volcanics occur in both crystalline rocks, but are clearly recognizable as volcanics only in the Artaban granodiorite.

A large mass of pre-batholith argillaceous sedimentary rocks (5) occurs on west central Gambier Island. This sedimentary unit is bounded on the north, east, and south by crystalline rock. On the east, it is limited by a fault: on the west by Thornborough Channel. Strike of bedding is

east-west and dip is steep or vertical. This rock does not extend across Thornborough Channel to the west shore of Howe Sound, within the area mapped.

Pyroclastic rocks (7) and lavas (8) with an east-west strike and steep dip, occur throughout all of the mapped part of Gambier Island, north of the Gambier and Artaban granodiorites.

The basal unit of pyroclastics (7) is a conglomerate composed of small granitic and volcanic pebbles in a matrix of quartz, feldspar and other fragments. The position of the unconformity was definitely located at the following points: the 1,400 foot level on the south slope of Mt. Gambier; the northeast corner of West Bay; both sides of Centre Bay; the east side of Port Graves; the crest of Mt. Artaban; the south east slope of Mt. Artaban; and the north east corner of Halkett Bay. On Mt. Gambier and on West and Centre Bays the conglomerate is an indefinite zone which contains 30 to 50 per cent granitic debris. The Port Graves and Mt. Artaban exposures consist of rocks which contain much more volcanic than granitic debris. The Halkett Bay outcrop consists of a stratigraphic thickness of 300 feet of rusty colored conglomerate with rounded siliceous or tuff pebbles, one to two inches in diameter. The conglomerate on Halkett Bay is interbedded with acid lavas. This outcrop was viewed along a narrow band, across strike, at water level. A conglomerate of this type was not seen elsewhere.

Dykes

Post-batholith Tertiary dykes occur throughout the area. They are not usually noted except near sea level, where exposures are good. They have a variety of strikes, but the directions most favoured on Gambier Island are 000, 010, 030, 065, and 110 degrees. One brown weathering dyke, on a point southwest of Centre Bay on Gambier Island, follows two joint directions 085 and 175 degrees. All dykes dip steeply.

The weathered surfaces are shades of brown, green, gray; some are porphyritic and some are not. All of the dykes are apparently unmetamorphosed and have no foliation. This universal characteristic, coupled with the fact that all have similar attitudes within certain limits, suggests that the dykes reached their present position after the metamorphism and tilting of the rocks about Howe Sound.

Structure

The topographic effect on the contacts as they cross ridges, shows that contacts are steep or vertical. The north contact of the Artaban granodiorite appears to dip steeply south. The effect of numerous small faults was not determined, but it is presumably small.

The irregularity of the unconformity could be due to flat lying strata deposited on a very uneven erosion surface, and not subsequently steeply tilted, or strata deposited on an uneven surface and subsequently moderately or steeply tilted. A large number of structural attitudes were noted

on the east shore of Gambier Island. Most of them are of small value individually. When considered collectively they have some significance. All the doubtful measurements indicate within a few degrees, a common westward strike. Some are most suggestive of a steep dip. The accuracy of this information is borne out by a single good strike determination on the east shore of Gambier Island, about one half mile south of the map boundary. At that point, layers of spherulites in a rhyolitic volcanic, strike at 125 degrees and dip steeply or vertically. (Plate VI, B).

If the volcanics north of the unconformity strike westward and dip steeply, then the unconformity itself, which originally must have been nearly horizontal, has also been tilted on edge so that it dips steeply. It follows, then, that the exposed section across the Artaban and Gambier granodiorites, now nearly horizontal, was at one time nearly vertical.

Age and Correlation

Fossils were not found and so definite information on relative ages of the formations is lacking. The highly altered zone of tuffs near Hood Point may be a zone of contact with the granodiorite. If this is so, lavas, and banded tuffs are in contact with, and older than, Gambier granodiorite. A strong indication that the rocks of Bowen and Keats Islands are older, is that both the granodiorite plutons of Gambier Island include fragments, some of them of considerable size, of tuffaceous rock. Finally, the lavas and tuffs

of Bowen and Keats Islands are intruded by plutonic rocks, somewhat resembling the Gambier plutons in appearance, but differing in foliation. The plutons may be contemporaneous. The oldest volcanic rocks of Gambier Island are probably similar in age to the volcanic rocks of Bowen and Keats Islands.

The relative ages of the plutonic bodies of Gambier Island are not perfectly known. The best evidence with respect to relative ages was found by thin section analyses. The Artaban granodiorite appears to have more quartz near its contact with granodiorite. This may be interpreted as evidence that the Artaban granodiorite is the older rock, and was altered by Gambier granodiorite

The pyroclastic rocks of north Gambier Island must be younger than the crystalline rocks, because they contain fragments of crystalline rocks.

Correlation between formations of the area under discussions and other coastal regions, without good stratigraphical or paleontological evidence, cannot be definite. However, it seems feasable to correlate the pyroclastics (7) with similar Lower Cretaceous rocks in the Princeton, Nicola or Harrison Lake areas, or with Upper Cretaceous formations in the Garibaldi area. The granitic rocks would then be Jurassic. The volcanic rocks are considered to be Triassic.

With regard to correlations and age determinations using granite bearing conglomerate, W.H. Mathews (15) (p.75),

says:

> "... Similar granitic debris is abundant in known Lower Cretaceous rocks and locally in Upper or Mid Jurassic rocks of the southern Coast Mountains and adjacent areas whereas in still older rocks it is uncommon if present at all. "

INVESTIGATION OF PLUTONIC ROCK

Artaban Granodiorite

Field Relations

The Artaban granodiorite located north of the Gambier granodiorite and south of volcanic rocks, is a medium grained, red brown weathering rock, composed of about 60 to 70 per cent feldspar and 30 to 40 per cent mafic minerals. Fresh surfaces of this rock are mottled pink and gray with mafic minerals of various orientations. (Plate VIII,A).

Large xenoliths of volcanic material occur sparsely throughout the Artaban granodiorite, but are more numerous along the north boundary. Many xenoliths appear to have a volcanic origin; some may have been tuffs. Almost all xenoliths are fine grained, and closely jointed, so that one or two inch cubes weather out and leave a ragged surface. Strike of xenoliths was determined with precision at only one point, southwest of the crest of Mt. Artaban. At that point two parallel light colored xenoliths of volcanic origin[1], (W-212), trend at 105 degrees. Both xenoliths are 35 feet long, and three to five feet wide.

The Artaban granodiorite is massive apart from the xenoliths and there is no evidence of flow lines or turbulence about any of the xenoliths.

[1] All numbers, such as W-212, W-64, Z-77, etc. refer to thin sections described in the appendix.

Petrography and Laboratory Investigation

Matrix of Artaban Granodiorite

Four specimens were examined petrographically and only one of them (W-64), the least altered, was examined by means of the Fedorov method.

Quartz

Unstrained grains of quartz with a poorly developed peripheral zone of micrographite are present in amount from 10 to 20 per cent. Some of the quartz of specimen W-209, has the form of rounded vermicular areas. The intergrowths for any given mass are oriented similarly so that when the stage is rotated with polarized light, one gets the impression that one mineral is superimposed on top of the others, in such a way that the superimposed mineral covers parts of several grains. Another form of quartz is irregular masses with distinct micrographic rims. The micrographic quartz is separated from clear quartz by a cuspate line which is convex away from the clear quartz. The core of this type of quartz has a tendency toward euhedrism. (Plate XVIII, B). The third type of quartz consists of subhedral masses without micrographic borders. If coarse micrographic rims are present they are separated from the clear body of the grain by an area which is almost transitional between the two parts. The outerppart of the transition zone, in places, is micrographic granite with triangular or hexagonal quartz rods. The quartz of the central part of the transition zone is coarser than in the outer part and many of the rods are

sub-hexagonal or rounded, instead of triangular. The inner part of the zone may be fancied as micrographic quartz in which the quartz rods enlarged until in contact with one another, so that only a thin film of extraneous material now remains between them. The material between the rods now forms a dendritic network across certain zones in the quartz.

Quartz of the Artaban granodiorite is much less strained than quartz of the Gambier granodiorite. An attempt to account for this will be made later.

Microcline

Microcline was positively identified only in W-64. Feldspar, entirely similar to the microcline of W-64, has been regarded as microcline in all other thin sections, in which it was encountered. It is a dusty, irregular mineral which clearly replaces plagioclase as in Plate XII,A. Normally, it is finely twinned in only one direction. In appropriate positions on a universal stage and with high magnification, the twin individuals appear as short, very narrow lenticular lamellae. One of its more noteworthy characteristics is a tendency toward euhedrism (See appendix, p. iv, W-64, Grain 3).

Plagioclase

Zoned subhedral or anhedral plagioclase in various stages of alteration constitutes up to 60 per cent of the groundmass of the Artaban granodiorite. A plagioclase grain in W-64 partly replaced by microcline, has a core An46 and a rim An28. The replaced part of the grain is about An30 or

less calcic (plagioclase grain 1, W-64). The plagioclase in W-209 is albite, and in W-210 is An55-30. Specimen W-209 was collected within 20 feet of known Gambier granodiorite.

The feldspars of all thin sections are much altered to secondary white mica, chlorite and epidote.

Mafic Minerals

Augite, the only primary mafic mineral of the four thin sections examined, occurs in W-64. The optic and physical features of the augite are given on page iv of the Appendix.

The augite is considerably altered to a pale green amphibole, which is probably actinolite, and to epidote and chlorite.

In all of the other thin sections primary mafic minerals are entirely altered to epidote and chlorite.

Accessory Minerals

Magnetite, present in amounts of one or two per cent, appears to form a larger proportion of the Artaban granodiorite than it does of the Gambier granodiorite. The other accessory mineral, apatite, is present in such small quantity that it is difficult to make a comparison based on apatite content.

Paragenesis

Both pyroxene and plagioclase are roughly subhedral. Their relative ages cannot be suggested with any real degree of accuracy. Microcline clearly replaces plagioclase and so

must be later.

The position of quartz in the system can be determined with nearly as much certainty as that of microcline. The possible origins for micrographic borders are:

1. Simultaneous crystallization from a melt.
2. Ex-solution from a single phase, stable at high temperature.
3. Replacement of quartz by microcline or microcline by quartz.

The first possibility would require that a number of separated quartz crystals develop around a liquid filled space with the same orientation regardless of the orientation of the intergrown feldspar grains. It would seem extremely fortuitous and unlikely that numerous tiny unconnected nucleii would all adopt the same orientation. Hence it seems reasonable to abandon the idea that the two components of quartz feldspar intergrowths are a product of simultaneous crystallization from a melt.

Suppose a melt with appropriate constituents to form feldspar and quartz had filled the last spaces remaining in a solidifying magma. Suppose also, that it cooled from a temperature at which it was homogeneous. A melt of such small size, measurable only in millimetres, would be homogeneous across the space. It would still contain enough of the last phase to crystallize, that it would not react with the other phases in its environment. As it cooled, the feldspar phase would separate out, evenly distributed across

the space. This is not the case, as micrographic structures exist only in border zones of grains. Therefore the second suggestion must be abandoned.

The only possibility left is that quartz replaced microcline or else microcline replaced quartz. Elsewhere in the area quartz replaces microcline. The same age relationships are assumed to be the case here.

Xenoliths in Artaban Granodiorite

Both xenoliths examined petrographically, are trachytes. Specimen W-62 was taken from a closely jointed gray to brown weathering xenolith on the south slope of Mt. Artaban at an elevation of 1,000 feet. The plagioclase laths are albite An0. The other xenolith examined petrographically is W-211. It is located 1,300 feet above sea level, one half mile west from the xenolith from which W-62 was taken. In W-211, sodic oligoclase laths An14, are sub-parallel with one another and with interstitial quartz. In both rocks no primary mafic minerals remain. However, epidote, chlorite, and iron oxides attest to their former presence.

Specimen W-282 was collected from a band of acid volcanic rock, 75 feet wide, between the Gambier granodiorite and Artaban granodiorite, at the northwest end of West Bay, Gambier Island. The contact relationships between the volcanic and the plutonic rocks north and south of it, are not known. Rightfully it is not a xenolith in either the Artaban granodiorite or Gambier granodiorite, but it closely

resembles other xenoliths within the Artaban granodiorite. It is a light colored, dense volcanic with very small spherules, visible only in thin section. Feldspar is sodic.

Gambier Granodiorite

Field Relations

The Gambier granodiorite pluton occupies most of Gambier Island. The south contact, across the southwest point of Gambier Island, is parallel to the regional trend as determined on Bowen and Keats Islands. Similarly, the north contact, in spite of being in part an eroded surface, nearly parallels the regional trend, provided that post-batholith faulting is taken into account.

Foliation within the Gambier granodiorite is quite markedly different from the regional trend, a few degrees south of east. Throughout most of the plutonic mass, particularly in the southeast area, north of Hope Point, there is a strong foliation at 050 degrees 10± degrees. This foliation is recognizable in the light colored granodiorite matrix by a parallelism of quartz grains and aggregates of quartz grains. Small specimens as those of Plate IX, AB, do not show this foliation clearly. A directional trend is also shown in the attitude of certain inequidimensional xenoliths and by bedding in those xenoliths where it is present. East of Hope Point there is a very crude foliation near 80 degrees, as well as the normal for the granodiorite direction of 050 degrees. A light gray phase on the west

shore of Gambier Island at latitude 48 degrees 27 minutes, North, has a distinct east-west foliation. At the north end of West Bay, foliation strikes at 70 degrees.

The Gambier granodiorite is a medium to coarse grained holocrystalline rock, composed of approximately 25 to 35 per cent quartz; 35 to 50 per cent plagioclase; 10 per cent microcline; and 10 to 20 per cent mafic minerals.

There are a few textural variations which do not appear to bear any definite relationship to either xenoliths, extent of xenoliths, or to the limits of the pluton.

Much of the rock is pinkish gray on the weathered surface and a slightly darker color on the fresh surface.

Quartz occurs mostly as oblong grains, but it may consist of irregular small grains or streaks of grains. Where the quartz is in large oblong grains it is frequently subhexagonal in outline. Close inspection in such cases usually reveals that although the quartz appears to be subhedral, in reality it has a number of feeler-like structures extending out between adjacent feldspar grains. All of the quartz appears to be fractured to a sugary mass in the hand specimen. Many of the feldspars, either pink or gray in color, appear to have inclusions of dark mineral. Only very rarely are mafic minerals recognizable in hand specimens. Occasionally mica or amphibole may be identified by means of a hand lens, but most often the dark mineral is a shapeless mass of chlorite or epidote.

The light gray colored phases found on the east shore of

West Bay and on the west shore of Gambier Island differ mainly from the pink-gray phase in color and quartz. The quartz of the gray phase may be either large grains or dispersed smaller grains. It occurs most frequently as small grains. The quartz of the pink phase occurs in blocky subhedral grains. Otherwise the two phases are very similar. The proportions of light and dark minerals are not recognizably different, except on the west shore of Gambier Island, where the quartz comprises only about ten per cent of the rock.

Petrography and Laboratory Investigation

Matrix of Gambier Granodiorite

Quartz

The proportion of quartz in thin sections varies from 10 to 60 per cent. This great variation is probably more apparent than real, because a thin section might just miss a large quartz grain, or might include a large quartz grain or aggregate of grains, and miss an area devoid of quartz. It is considered that more accurate figures concerning quartz variation would give a range of 25 to 35 per cent.

In parallel light it is always clear, with ribbons of dusty material along fractures. Strain effects are present in every thin section. Rarely, there is only undulating extinction. More often distinct lamellae and mortar structure divide grains that were formerly intact, into an aggregate of smaller grains with sutured borders. The

aggregates are usually surrounded or partly surrounded by mortar structure.

Further evidence of dynamic metamorphism is indicated by the almost universal presence of two mutually sub-perpendicular planes of fracture. These planes cross quartz and occasionally other minerals, as two sets of straight parallel lines, highly reminiscent of cleavage in feldspars.

Much of the quartz contains fragments of other minerals. In fact, half of some quartz consists of included plagioclase. Normally, less than ten per cent of a quartz grain is foreign material. This material may have a number of forms. It may be shard or crescent shaped with marked re-entrant angles, rectangular, long and slender, or nearly round. Potash feldspar tends to be shard, crescent or rod shaped; plagioclase tends to be round or rectangular. Where the margins of two quartz grains approach, a triangular remnant of feldspar with re-entrant angles may remain, as evidence of possible replacement.

The quartz grains which contain a high proportion of included material are a more blocky shape than those which contain little or no foreign minerals. Quartz which contains very few isolated inclusions often is very irregular in shape and parts of a grain may project between other minerals for some distance. Other minerals may even divide a quartz grain, in the plane of the thin section, into a number of separate parts (Plate XIII A).

The borders of quartz grains are irregular except where deformation has produced mortar structure. Contacts are bulbous and curved. This feature is not always obvious until examination is done in detail. A large number of quartz boundaries are characterized by projections of feldspars into quartz, or of quartz into feldspars. Small feldspar islands are isolated from other grains of similar or identical orientation. This latter characteristic is most noticeable in the case of quartz-microcline boundaries. Quartz-plagioclase boundaries tend to be straighter than quartz-microcline boundaries. The relationship of quartz to other minerals is often difficult to interpret, and in many of the specimens the quartz-feldspar relationships cannot be directly determined. However, they can be indirectly inferred with a reasonable degree of certainty.

In specimens which have been both fractured and altered, quartz commonly contains veins of fine quartz, epidote, sericite or carbonate. In at least one case quartz in a fracture, adopted an orientation identical with the quartz surrounding it.

Microcline

Potash feldspar is not present in all phases of the granodiorite. One specimen W-261, contains no recognizable potash feldspar. In other specimens, the amount of potash feldspar varies from two per cent or less (W-232) to about 30 per cent (W-287). The grains are highly variable in both size and shape. The shape of microcline grains is nearly

equidimensional where there is little potash feldspar in a rock and either equidimensional or extremely irregular in specimens with 15 to 30 per cent potash feldspar.

Grid twinning may or may not occur throughout a grain of microcline. In fact microcline may appear wholly untwinned even in a thin section in which other grains are entirely or partly twinned. Re-orienting microcline on the universal stage has sometimes shown that grid twinning is really present but invisible in the plane of the thin section.

Much of the microcline is perthitic. The perthite lamellae take the form of tiny branching or wavy quartz-like objects. They may have a marked "en echelon" habit. Where this habit is noticeable, the line of "en echelon" lamellae are parallel with a fracture. One group of lamellae in thin section W-252 is interrupted by a twinned plagioclase grain which projects into perthitic microcline: a disturbed zone extends across the plagioclase continuous at both ends with a line of perthite lamellae. The indices of the wavy bodies are well above those of the potash feldspar and their relief relative to feldspar corresponds to that of quartz.

The larger irregular grains of microcline contain a good deal of included material, mostly in the form of rectangular, rounded, or irregular feldspar (Plate XVI, A & B). Rarely, amphibole is included along with feldspar as in Z-77. Plagioclase included in microcline may be either similarly or diversely oriented across the microcline.

In general, borders of microcline are of two distinct

types: some are straight and some are extremely erratic (Plate XVI,A & B; Plate XVII,A & B). The erratic type of boundary is most common where a microcline grain is in contact with a number of plagioclase grains, which have a variety of orientations. In these, the mutual boundaries follow the rectangular shapes of plagioclase. The smooth type of boundary tends to be more normal where microcline is in contact with a single plagioclase grain. This broad generality, however, does not hold when contacts are examined carefully. Many, apparently straight, contacts turn out to be minutely sinuous. Detailed examination with a medium or high power objective exposes veinlets of microcline which have worked their way along cleavages and fractures (Plate XVI, B). Plate XV, A shows what appeared to be a subhedral plagioclase grain surrounded by microcline. In reality it is a portion of a larger zoned plagioclase grain which has been replaced by microcline. The lobe of plagioclase is connected to a much larger grain by a narrow neck. Replacement, though it has left the plagioclase broadly euhedral, has not been complete. Remnants of plagioclase still remain around the edges of the partly replaced lobe. Though isolated, they are optically continuous with the subhedral plagioclase lobe.

Microcline is altered to kaolin-like material, chlorite, sericite, and epidote. Fractures in microcline are frequently filled with epidote. Microcline appears to have resisted alteration to a much greater degree than has plagioclase.

Plagioclase

Estimated plagioclase content is as low as 20 per cent in specimen W-253 and as high as 50 per cent in a number of other specimens (W-98, 168, 170, 191.). Most of the Gambier granodiorite, however, contains 35 to 45 per cent plagioclase.

The size and form of the plagioclase is somewhat variable. The smallest grains usually occur as inclusions within quartz and microcline. Plagioclase not included in quartz or microcline, varies from one half millimetre to five millimetres or larger. Size variation is seriate. There appear to be two distinct types of plagioclase boundaries. Mutual anhedrism is the normal condition between adjacent plagioclase grains, whereas subhedrism of plagioclase is normal in plagioclase-microcline or plagioclase-quartz associations.

The details of the boundaries between plagioclase and microcline or quartz were previously discussed.[28,29] The tendency toward euhedrism is shown by Plate XV,A and Plate XVII,B. Occasionally, replaced plagioclase has a six sided form, strongly reminiscent of crystals which developed in a melt. Most frequently the form is rectangular with the long dimension parallel with the (010) direction as in Plate XV,A, Plate XVI,A & B, and Plate XVII,B. Two cleavages are prominent in the plagioclase lobe in Plate XV,A. The cleavage parallel to the long dimension is (010). The other cleavage trace, at an angle to (010) is $(1\bar{1}0)$. It is note-

worthy that at least two of the physical boundaries of the replaced grain are roughly parallel to cleavage planes.

The composition of plagioclase ranges from An_{47} to An0. The most calcic plagioclase identified was in a comparatively unzoned grain in specimen W-59. Grain 5 of that thin section with composition An_{47}, is intergrown with grain 5B andesine An_{34}. Neither grain is noticeably zoned. In the same thin section other grains are zoned or unzoned. Grain 3 is zoned through a minimum range of An26-14. If the average value between An26 and 35 is taken for the core, then the zoning is through a range of at least An30-18. The least calcic plagioclase identified is in thin sections W-261 and W-191. Grain 1 of W-261 is albite An7, grains 2 and 3 are both albite, less calcic than An5. Specimen W-287, three quarters of a mile north of W-261, contains oligoclase An27-24. Specimen Z-77, a similar distance to the west, is approximately An_{24}, as determined with a standard stage. Plagioclase in Z-77 is only slightly zoned. Zoning is generally of a normal type, most calcic at the core and least calcic at the rim. Both gradational and abrupt zoning are usually present. Frequently as in specimen W-96, zoning is oscillatory through very narrow ranges. In that thin section one elongate grain, about three millimetres long, has about 38 zones. (Plate XIV,B). Fortunately this grain is so oriented that it gives a very near centered bisectrix figure. The core of the grain is An28, several intermediate zones are An15-20, the rim is An23.

Oscillatory zoning of this type through a narrow range

is common though not always as well developed as in W-54. One feature this grain has in common with a great many zoned grains is the slightly orbicular shape and the unsymmetrical character of the zones. This may be due partly to solution and partly to normal tendency to form oblong grains.[2] However the shape of the zones indicate that the crystal developed in a medium where growth was restricted. Many other grains also show unconformities between certain zones, especially in parts where zones are numerous and broad.

Three thin sections W-191, W-232, W-285, contain plagioclase with reversed zoning. One grain in thin section W-191 was determined by means of the universal stage and Nikitin's diagrams. The core proved to have composition of An2 and the rim a composition of An13. There is a possibility that the reversed zoning merely represents oscillatory zoned grains that were fortuitously cut by the plane of the thin section so that a zone, somewhere away from the core of the original crystal, now is at the least calcic phase of the grain measured. Whether the figures derived are representative or not, they do prove that reversals in zoning through a mod moderately great range are quite possible.

Almost all plagioclase is slightly less clear than microcline. The usual alteration products of plagioclase are secondary white mica, colorless epidote and grass green or pale green pleochroic chlorite. The most intense alteration is invariably near the core of a grain, whatever its

2 See page 59

composition may be. Plate XV,A, shows a remnant lobe of unreplaced plagioclase in microcline. The core of this lobe is 20 to 25 per cent altered to secondary white mica in small plates parallel with cleavages, especially the cleavage at an angle to the long dimension of the figure ($1\bar{1}0$). The less calcic rim of the lobe is quite unaltered. The main part of the plagioclase grain to the left of the figure is similar in that the rim is relatively unaltered. The peculiarity is that the unaltered rim of the main grain is more calcic than the altered core of the lobe.

Epidote alteration produces a somewhat similar effect though much less pronounced. Some grains have a core of epidote surrounded by a rim of plagioclase and secondary white mica which in turn is surrounded by a rim of relatively unaltered plagioclase. Epidote formed as an alteration product within plagioclase is generally, but not always, a colorless non pleochroic, or a pale yellow weakly pleochroic variety.

Fractures which cross plagioclase are usually filled with sericite or chlorite, and less frequently with epidote. A few fractures are filled with a combination of epidote and sericite.

Mafic Minerals

Primary mafic minerals, hornblende and, or biotite, sufficiently unaltered to be recognizable, occur in only eleven out of 20 thin sections of Gambier granodiorite. The term primary is used rather loosely in this case, for the

relationships of mafic minerals are difficult to interpret with any real certainty. In the other nine thin sections, the previous presence of amphibole may be indicated by aggregates of diversely oriented pleochroic pale yellowish green epidote grains. Specimen W-59 contains an aggregate of carbonate with plates of chlorite intersecting at angles appropriate for amphibole cleavage. It is considered to be a pseudomorph after amphibole. (Plate XIX,B). The former presence of biotite may be indicated by laminar pseudomorphs of chlorite alone, or of chlorite, yellowish green epidote, and quartz. Most specimens contain both types of pseudomorphs. One specimen (W-285), contains hornblende alone and others (W-59,W-70, W-167), contain biotite alone. A fourth thin section (W-261), contains both biotite sufficiently unaltered to be recognizable, and aggregates of epidote possibly pseudomorphing after hornblende.

Optic characteristics of hornblende were determined in most cases on a standard petrographic microscope. Optic angles were estimated by means of curvature of the isogyre in optic axis figures. Extinction angles were measured on grains with parallel cleavage traces and highest birefringence for any one thin section. Such extinction angles are noted as follows: $Z' \wedge c = 20$. Grains so oriented that they would give optic normal figures, and hence a true $Z \wedge c$ value, were not found. Pleochroic formulae were derived by reading the color of Y on optic axis or bisectrix figures. Colors of X' and Z' were taken from grains with either maximum birefringence

in the zone parallel to c or from grains which gave bisectrix figures.

By the above method optic characteristics appear to be $Z\wedge c = 15^{\circ} - 24^{\circ}$ (average of 7-21): $-2V = 65^{\circ}-75^{\circ}$.

X' = yellow or brownish yellow: Y' = green or brownish green: Z' = green with blue green borders, or blue green.

Subsequent determinations by the Fedorov method on amphibole of thin section Z-77, indicated that estimates of optic angle and pleochroism, were reasonably accurate, but that extinction angles as read by standard methods may be up to ten degrees too large.

Optic characteristics determined on a univeral stage are:

$Z \wedge c = 7^{\circ} - 20^{\circ}$ (5 determinations).

$-V = 22^{\circ} - 32^{\circ}$ (4 determinations).

$110 \wedge 1\bar{1}0 = 51^{\circ} - 57^{\circ}$ (5 determinations).

If these figures are weighted according to the accuracy factors given for thin section Z-77 in the appendix (p.xxv), and then averaged as follows:

Extinction Angle -		
	3 x 12°	= 36°
	1 x 7°	= 7°
	3 x 18°	= 54°
	2 x 20°	= 40°
	1 x 8°	= 8°
10		145

The average $Z \wedge c$ is $\frac{145}{10} = 15^{\circ}$.

Optic Angle /2

3 x 32°	= 96°
1 x 25°	= 25°
2 x 22°	= 44°
2 x 35°	= 70°
8	235°

Then average V = $-\frac{235°}{8}$ = -29°

Then -2V = 58°

If grain 4 is disregarded; average -V = $-\frac{191°}{6}$ = 32°

Then -2V = 64°.

X = brown yellow

Y = green

Z = blue green

The age relationships between hornblende and other minerals are not always distinct. One of the cases in which there is little doubt that hornblende is older, is in specimen Z-77 (Plate XVI, A). In that thin section amphibole is distinctly euhedral to microcline. Similarly in some other specimens, amphibole is euhedral to quartz and microcline, which surrounded it in places. In the same thin section and in others, there is a tendency for hornblende to be intergrown with plagioclase. This characteristic is well shown in W-98 in which a plagioclase grain is almost divided by hornblende. It would be difficult to prove whether the intergrowth is replacement or interference during crystal growth. Broadly speaking one can only note that amphibole is there and is intergrown to some degree with plagioclase. One could scarcely postulate mineral sequence.

Biotite mica was not studied with the universal stage. The characteristics as observed with a standard stage, are a

small negative optic angle and X nearly parallel c.

Pleochroic formula:

X = straw yellow or honey yellow

Y = Z = brownish green or green

Absorption formula:

$X \ll Y = Z$ or $X < Y < Z$

Dark red brown mica does not occur. Biotite was probably present in nearly all specimens in amounts varying from 10 - 15 per cent but little, other than chlorite pseudomorphs, now remains. Commonly biotite has two forms, either grains one and one half millimetres by one millimetre, or aggregates of much smaller grains.

The relationships between biotite and other minerals are as obscure as those of hornblende. Some biotite occurs interstitial to quartz, other small biotite grains occur in fractures in hornblende as in W-98. Still other individual hornblende grains are intergrown with mica.

Accessory Minerals

Very few accessory minerals were found. Apatite and either magnetite or pyrite or both occur in all specimens. The quantity is invariably small and does not exceed one per cent.

Secondary Minerals

Secondary white mica, colorless epidote, pale green chlorite, dusty kaolin-like material, and zoisite are the most common secondary minerals, in the feldspars. Clear pleochroic chlorite, greenish yellow pleochroic epidote, and

sphene are the usual secondary minerals in amphibole and mica. Fine quartz, as well as epidote and chlorite, occurs in mica in some thin sections.

Fractures in feldspar are generally filled with almost colorless epidote or chlorite. Fractures in mafic minerals are generally filled with pleochroic green chlorite or yellow epidote.

Paragenesis

In summary, relative ages of mafics with each other and with plagioclase, could not be interpreted. Evidence on the relative ages of microcline and plagioclase almost overwhelmingly indicates that microcline replaces plagioclase.

The position of quartz is less definite. Many examples appear to show that quartz replaces microcline. If that is true, then quartz is the youngest mineral. A large number of associations cannot be interpreted, either because the boundaries naturally do not lend themselves to simple interpretation, or because mortar structure has obscured detail. Plate XVIII,A, illustrates a quartz grain which has replaced both plagioclase and microcline.

Xenoliths in Gambier Granodiorite

Field Characteristics

Dark colored finer grained phases of the Gambier granodiorite are to be referred to as xenoliths.

The field relationships of the xenoliths in Gambier granodiorite are similar to the field relationships of xenoliths in Artaban granodiorite. Foliation is quite pronounced in Gambier granodiorite at 050 degrees ±10 degrees.

but absent in xenoliths. Long dimension and trend of xenoliths were measured at only one place. North of Hope Point, trend of xenolith W-188 is parallel with foliation. There is no evidence of turbulence in foliation or bending of foliation around any xenoliths. Foliation simply ends at the margins of xenoliths.

There is considerable variety in the structure, color and texture, of the xenoliths. Some xenoliths are large and blocky, measurable in tens of feet, and may comprise up 30 or 40 per cent of the rock. Others are small lenticular, measurable in inches, and amount to as little as one per cent or less, of the whole rock. Some xenoliths (there are two or three north of Hope Point), have a distinct laminated character. Recognizable bedding in xenoliths is parallel with both the long dimension of the xenolith and the foliation in the matrix. One large inclusion 20 to 25 feet wide and 50 to 60 feet long, has a completely recrystallized core in which bedding is obliterated, (Specimens W-88 and 90), and a very much less recrystallized margin with obvious bedding (W-87). (Plate XII,B).

At another locality, just north of Hope Point, two adjacent dark xenoliths are identical except that one of them has a lenticular core of dense white material 18 inches long and six inches wide. This core resembles the laminated sedimentary xenoliths so closely that it is difficult or impossible to believe that it can be anything but a sedimentary remnant. Yet the rim of this xenolith is

identical with other dark fine grained dioritic xenoliths. The contact zone between the lenticular core and the rim, is granitic and one inch wide. (See appendix p.xxxv, W-186, 187, and 188.).

A second type of xenolith might be related to the Artaban granodiorite, north of the Gambier granodiorite. This type occurs near or in the north contact zone. Its weathered surface is reminiscent of the Artaban granodiorite, but close inspection of the fresh surface reveals that the xenoliths more closely resemble others within the Gambier granodiorite, and far from the Gambier granodiorite-Artaban granodiorite contact, than it does the fresh Artaban granodiorite.

The dark colored, fine grained xenoliths show a variety of shapes, colors and textures, even in adjacent xenoliths. However, variations are through a narrow range and cannot be related to the composition of the original rock from which the xenolith was formed. In fact, even in a single xenolith ten feet in diameter, variations in texture and composition may be as great as between widely separated xenoliths. Plate VII,B, a photograph of a xenolith or group of xenoliths on Hope Point, illustrates a number of variations in color and texture. The color is controlled in part by grain size and in part by proportion of dark material. The darkest blobs have the finest grain and the largest proportion, about 50 per cent, of dark mineral. The lightest colored xenoliths have the coarsest grain, still somewhat finer than the Gambier granodiorite, and the smallest proportion, about

30 to 40 percent, of dark mineral. This amount is somewhat greater than that of Gambier granodiorite matrix. It can be seen from the photograph that some of the margins are sharp and some are not. The margins of dark fine grained xenoliths are not usually gradational. Normal Gambier granodiorite extends right up to the contact, which is sharp but jagged in detail. Beyond the contact, xenoliths are usually homogeneous. Locally, alteration or granitization is noticeable along zones which may have been joints or fractures. The light colored xenoliths frequently are megascopically discernable from the matrix only by a reduction in grain size. There may be little change in mineral proportions or composition as observed in the hand specimen.

Some variations in mineral proportions and textures may be seen in Plates VIII,B; X,A & B; XI,A & B; XII,B;and XIII, A & B. Plate XIII,B, is a nearly even grained aggregate of amphibole and feldspar in proportions of 40 per cent feldspar and about 60 per cent amphibole. Specimen W-78,(Plate XIII,B) has a fine grained groundmass of about equally divided plagioclase and amphibole with porphyroblasts of quartz and [illegible] plagioclase. The photograph clearly shows a border zone about quartz, rich in hornblende, possibly expelled by the growing quartz grain. The quartz porphyroblasts are seriate in size. The smaller quartz porphyroblasts have a much less distinct rim of hornblende.

The borders of many xenoliths are crossed by quartz or feldspar grains, common to both xenolith and matrix.

Petrographic characteristics

The mineral assemblage of most xenoliths in Gambier granodiorite is quartz 2-25 per cent, plagioclase 35-50 per cent, hornblende 40-50 per cent, biotite 0-5 per cent, and minor apatite, pyrrhotite or magnetite. Specimen W-87 contains no quartz and specimen W-188 contains no hornblende or biotite. Specimen W-252 resembles the light colored granodiorite phase more than it resembles the xenoliths. Specimen W-100 is from an extensive zone of dioritic rock with little quartz and no microcline, on the east shore of Port Graves. In grain size, mineral proportions and color, this rock resembles xenoliths more closely than it resembles Gambier granodiorite. For this reason it is described as a xenolith.

Quartz

One xenolith (W-87) contains no quartz. This xenolith is an altered tuff. (Plate XII,B). Another xenolith (W-188) probably derived from a tuff, contains as much as 50 per cent quartz. Most of the 15 thin sections examined contain five to ten per cent quartz.

The form and relationships of quartz in the xenoliths are very similar to those of quartz in the matrix, but on a smaller scale. In some specimens (W-84, W-186, W-187) quartz clearly replaces plagioclase. In thin section (W-84), quartz appears to be intergrown with hornblende. Quartz, in xenoliths with five per cent quartz or more, is irregular in detail, or else consists of isolated groups of similarly

oriented grains. In such cases the area, bounded by a line which passes through the extremeties of the irregular arms or units, is usually blocky. These structures may be considered intermediate between single small grains and inclusion filled masses of quartz. A common type of quartz in numerous xenoliths consists of eye shaped masses which in the hand specimens appear to approach a euhedral shape. (Plate XI, A). Hornblende may or may not formaa sort of rim partly embedded in, and partly outside quartz.(Plates XI,A and XIII,B). A less perfectly developed stage occurs in other xenoliths as exemplified in thin section W-99. In that thin section the concentration of small rectangular hornblende grains about the periphery of quartz, is less perfectly developed, and the center of the grain contains about ten per cent included hornblende.

Specimen W-188 with the highest proportion of quartz of all the xenoliths examined, is made up of microcline and plagioclase in a fine micrographic intergrowth, Quartz, which comprises 50 per cent of the rock, occurs as small triangular worm or rod shaped structures, less than one tenth millimetre across and about one half millimetre long. The xenolith from which W-188 was taken, has been described on page 40. Here it suffices to say that the part of the xenolith sampled, bears a very megascopic close resemblance to a sedimentary rock.

Microcline

Microcline is a constituent of only two xenoliths. In W-188, microcline forms part and perhaps all of the host feldspar in quartz feldspar intergrowths. Microcline without quartz is found in small quantity in the same specimen. The other microcline occurrence is in specimen W-252 from a zone which appeared to be granitized, in the field. The amount of microcline present is about 20 per cent. It occurs as irregular, straggling masses which replace and isolate rectangular remnants of plagioclase.

Plagioclase

Rectangular grains of plagioclase less than one millimetre long constitute 40 to 60 per cent of almost every thin section.

The form of plagioclase is variable. It may be a fine mosaic of unzoned grains with epidote or hornblende, as in W-251, or without mafic minerals as in W-87. More common forms are one half millimetre, rectangular, highly zoned andesine or calcic oligoclase, accompanied by larger two to three millimetre unzoned grains of less calcic plagioclase.

The mixed variety is fairly well typified by specimen W-78, in which both sizes of grains were determined by the Fedorov method. The finer rectangular groundmass grains are An60 at their core and An30 at the rim. Another determination indicated a range of zoning from An60 to An7 in the same thin section.

The larger two to three millimetre porphyroblasts of W-78

are unzoned. Their composition is An35. The larger plagioclase grains in some xenoliths, are only slightly zoned and in still others zoning of the porphyroblasts may range from An41 to An28, as in thin section W-79. In general, even where porphyroblasts are zoned, a visual examination confirms the fact that the porphyroblasts are less zoned than the ground mass grains.

An interesting transition is shown by three specimens (W-87,W-89,W-90) from a xenolith of sedimentary rock. (Plate XII, B). Specimen W-87 from the edge is composed of a mosaic of feldspar grains with a small proportion of feldspar laths. All grains are one tenth millimetre or less in diameter. The maximum extinction angle with 15 grains is five degrees, and the indices are slightly less than balsam. Hence the feldspar is oligoclase. The next specimen, W-89, selected about five feet closer to the center of the dyke at a point where bedding had become obscure, contains plagioclase in two distinct forms. Small grains and rods less than one half millimetre long form a matrix about the largest grains, which are for the most part, greater than one millimetre. The fine grains are zoned. Maximum extinction angles indicate that the groundmass is andesine about An40, though some grains have an extinction angle which varies from 15 degrees to zero degrees, for different parts of the grain. The porphyroblasts are An30 as determined from a fairly well centered bisectrix figure perpendicular to X. In this case the porphyroblasts are not very zoned and are lath shaped.

Specimen W-90, from the center of the xenolith is similar to W-89, but coarser. A number of grains of intermediate size are slightly zoned.

As far as the age relationships of plagioclase are concerned, one can do little but guess. The above brief description of the plagioclases in a xenolith suggests that euhedrism or subhedrism and zoning can develop in a solid medium. The general euhedral aspect of plagioclase cannot be used to indicate age.

Mafic Minerals

The mafic minerals of the xenoliths are much the same as those of the light colored matrix. The main differences lie in a finer grain size and higher proportion of mafic material, in the xenoliths. The principal mafic constituent is a hornblende. The Fedorov method was applied in thin sections W-78, W-97, W-187, in order to determine optic characteristics. The results indicate that the extinction angle $Z \wedge c$ is in the region of 15 to 20 degrees, and the negative optic angle is 55-65 degrees. The pleochroic formula is: X = yellow or yellowish brown; Y = green or brownish green; and Z = blue green or green. It will be noted that in all three thin sections the value of V on opposite sides of X may show considerable variation. This is not considered to reduce the grade of the optic angle determination since the value of 2V is independent of the accuracy of the X direction. In most cases, if the position of the X

direction were changed only a few degrees in the direction of the larger angle, the two readings for the V would be rendered equal. The discrepancies in the X∧c angle cannot be accounted for, except through inaccuracies in determining optic directions as a result of indefinite extinction or alteration. It is believed however, that the error in the weighted average value is less than five degrees.

As in the light colored Gambier granodiorite matrix, optical data determined by means of a standard stage indicate a Z∧c angle slightly higher than the angle found by universal stage methods. This can probably be accounted for in some cases by poor development of one cleavage so that the angle read was actually the extinction between Z and the trace of (110) or $(1\bar{1}0)$, and not a true Z∧c angle.

Hornblende is universally fine grained and nearly equidimensional. In detail, some aggregates or individual grains are either highly irregular, prismatic or acicular. Relationships to its surroundings are difficult to interpret. The needles and prisms which frequently occur in feldspar grains can hardly be considered replacement in view of the highly irregular character of the basal portions of some individual grains. Hornblende inclusions in feldspar are possibly irregular projections from a hornblende grain into a contemporaneous plagioclase grain. All things considered, one cannot positively state that either plagioclase replaces hornblende or vice versa. Regardless of grain size, there appears to have been a simultaneous development of both

hornblende and plagioclase.

Alteration products in amphibole consist principally of yellowish epidote, pleochroic deep green chlorite, sphene, and carbonate. Pyrite and, or magnetite appear to have been introduced into nearly all xenoliths. Generally, amphibole shows a much lower resistance to alteration than feldspar. The only xenolith in which alteration has been particularly noticeable is the one represented by W-95. Amphibole grains of that thin section are larger than normal size. They have borders, particularly basal surfaces, so ragged that the grains appear feathery. Colors are of much paler hue than in the compact hornblende of other specimens. The extinction angle is very little smaller than that of the darker colored amphibole. However, the general characteristics and the occurrence suggest that it is actinolite.

Biotite mica with small negative 2V and X nearly equal to c, occurs in specimens W-78, W-87, W-97, W-100. Its pleochroic formula is: X = straw yellow; Y = brown; Z = brown. The color of Y and Z is definitely not red brown, but is somewhater green. Many other xenoliths probably contained biotite. Its former presence is indicated by lamellar pseudomorphs of chlorite and epidote.

The position of biotite in the sequence is not clear except in thin section W-100, (plate XIX, A), in which it replaces and isolates parts of a plagioclase grain. In the same thin section, biotite isolates parts of an amphibole grain.

The alteration products of biotite are epidote and chlorite and some sphene. Pseudomorphing of chlorite and epidote after biotite, is indicated by the presence of chlorite and, or epidote between some biotite flakes. Associations of that type are considered to be arrested stages in the alteration of biotite to lamellar masses of epidote and chlorite.

Accessory Minerals

Apatite, magnetite, pyrite or possibly pyrrhotite are present as minute grains, in small amounts, in all xenoliths.

Secondary Minerals

The alteration products of xenoliths, are secondary white mica (plagioclase), colorless epidote (plagioclase), yellowish epidote (mafic minerals), green or pale green chlorite (plagioclase and mafic minerals), sphene (mafic minerals), and occasionally traces of hydrated iron oxides. In general, xenoliths are much less altered than the Gambier granodiorite matrix.

Paragenesis

The paragenesis of the components of the xenoliths in Gambier granodiorite, is somewhat more interpretable than the paragenesis of the Gambier granodiorite matrix. The finest grained xenolith, such as W-253, consists of a mosaic of contemporaneous feldspar, epidote, and some hornblende. The coarser xenoliths consist of more or less intergrown plagioclase and blue green hornblende. Euhedrism of plagioclase in some xenoliths is not taken to indicate early formation, because

the plagioclase of W-90, a recrystallized tuffaceous rock, is somewhat euhedral particularly in the more advanced stages of recrystallization.

The larger sized porphyroblastic plagioclase crystals, less calcic than the finer matrix, are highly suggestive of development under metamorphic, rather than magmatic conditions.

Microcline replaces plagioclase and so is younger than plagioclase in W-252, the only xenolith in which microcline occurs.

Quartz is the last mineral to form in all xenoliths where it occurs. It displaces hornblende grains as in W-78 and W-99. It replaces microcline which replaces plagioclase in W-252 and so must be younger than plagioclase and microcline.

NOTEWORTHY FEATURES

Artaban Granodiorite

1. The megascopic and microscopic features of the xenoliths show that they are remnants of pre-diorite volcanic rocks.

2. The attitude of the xenoliths in space is similar to that of the regional trend.

3. There is no evidence of high temperature contact metasomatic effects of either xenoliths in Artaban granodiorite, or contact zones adjacent to Artaban granodiorite. The only metamorphic effect on the xenoliths that is apparent in the field, is cubic jointing, so close that xenoliths weathers into one inch blocks and pits. Albitization may or may not have taken place.

4. There is no evidence of turbulence about xenoliths.

5. There is microscopic evidence of replacement of plagioclase by microcline and of microcline by quartz.

6. The plagioclase of the Artaban granodiorite is quite highly zoned.

Gambier Granodiorite

1. Foliation in the Gambier granodiorite is quite different from the regional trend.

2. The long dimension and bedding of xenoliths, if present, is parallel with foliation.

3. There is no evidence of turbulence in foliation about xenoliths, nor is there any tendency for foliation to

to be wrapped around the xenoliths.

4. The southern part of the Gambier granodiorite was originally at a deep level, probably near the bottom of the pluton. (Evidence regarding the original attitude, of the presently exposed section, relative to the pluton is given on page 14.) None the less there has been no accumulation of xenoliths or basic minerals near the south contact of Gambier granodiorite with pre-batholith lavas.

5. In regions, notably north of Hope Point, where quartzz tends to form subhedral grains in the matrix, it has the same tendency to form subhedral grains in xenoliths but to a smaller degree.

6. Almost all xenoliths in Gambier granodiorite have lost their identity. One of those which has not lost its identity contains a core 18 inches long and six inches wide, of dense white microcline. This core is surrounded by a one inch granitic zone which in turn is surrounded by an outer zone several feet wide. The outer zone is indistinguishable from other xenoliths.

7. The first effect on one laminated xenolith, was recrystallization with the formation of oligoclase feldspars. In a more advanced stage, at the centre of the xenolith, bedding is less distinct, zoning of feldspars is more distinct, and plagioclase is more calcic. At this stage the rock contains porphyroblasts, less calcic than the matrix. In the most advanced stage, grain size has increased, though porphyroblastic texture remains; zoning is less evident and

calcium content of feldspars is less than in the intermediate stage. (W-87,89,90). This is considered to be proof that subhedral zoned plagioclase is not necessarily a product of magmatic crystallization. It is suggestive that the first effect is recrystallization without destruction of primary structures such as bedding. This is followed by an increase in grains size and in calcium content of plagioclase. Further metamorphism is attended by a decrease in total calcium and a decrease in calcium content of feldspars.

8. Quartz porphyroblasts in many xenoliths are enveloped by a zone characterized by a high proportion of hornblende.

9. The xenoliths tend to develop two varieties of plagioclase. The more calcic type forms a subhedral groundmass, which is highly zoned. The less calcic type forms much less zoned porphyroblasts.

10. Oscillatory zoning with a small net change in anorthite content is common in plagioclase in Gambier granodiorite.

11. Plagioclase and mafic minerals are intergrown in such a way that age sequence cannot be worked out in either xenoliths or matrix. Mosaic texture between plagioclase and amphibole is common in xenoliths.

12. Replacement of plagioclase by microcline, or microcline and plagioclase by quartz, tended to produce euhedral or subhedral remnants in replaced minerals.

13. Quartz without inclusions tends to be irregular, quartz with inclusions tends to be blocky.

ORIGIN OF XENOLITHS

In the field, all xenoliths in Artaban granodiorite have the appearance of lavas or tuffs. The xenoliths are fine grained and some are laminated. Petrographic examination of specimens W-62, 211, 282, (appendix, part B), disclosed that at least three xenoliths in Artaban granodiorite have a trachytic texture. One specimen W-282, contains small spherules. Feldspar microlites are one half millimetre long in W-62 and W-211, and one millimetre long in W-282.

The few xenoliths in Gambier granodiorite with undoubted origin with regard to field appearance, are tuffs. One xenolith (W-188), with a dense white tuffaceous core has a border zone indistinguishable from adjacent xenoliths of unknown origin. Xenoliths without distinguishing features must be identified by inference. According to F.F. Grout[3], (9) an unknown xenolith is likely to be sedimentary if associated with sedimentary xenoliths. Grout[4] (9) states also that sedimentary structures may prove sediments but their absence proves nothing.

Grout[5] (9) discussed the significance of textures as follows:

> "True igneous textures" are often noted as evidence of igneous origin(...), but these textures are not easily distinguished from some recrystallized sediments. There may be in slate, for example, a development like igneous, porphyritic, poikilitic and even granitoid textures, so that the criterion is of little value.

Nor has the zone trend of the plagioclase with decrease in anorthite content from core to rim any significance as a

3 Loc cit pp 1553
4 Loc cit pp 1569
5 Loc cit pp 1553

criterion of origin. Accoring to Grout[6] a medium or basic feldspar in a xenolith may be zoned with a higher percentage of albite outside, regardless of the origin of the xenolith.

Thus there is good field and petrographic evidence that the xenoliths in Artaban granodiorite are remnants of pre-granodiorite country rock.

Less complete evidence indicates that xenoliths in Gambier granodiorite are pre-granodiorite country rock. There is no evidence to support a suggestion that the xenoliths are part of an early chilled phase of an intrusive magma.

6 pp 15-41

ORIGIN OF THE GAMBIER GRANODIORITE

Several features of the Gambier granodiorite should be discussed before any theories of origin can be presented. These features are:

1. absence of turbulence in the vicinity of xenoliths.
2. origin of foliation and time at which foliation was impressed on the rock.
3. oscillatory zoning of feldspars.
4. extensive replacement textures.
5. normal zoning and subhedrism of plagioclase.

These five features will be discussed in the order named.

If the xenoliths had settled or risen through a partly crystallized magma, they should have left some evidence of movement. Flow lines should occur on one side of the xenoliths. Effects of turbulence should occur opposite to flow lines. The evidence of movement between xenoliths and magma might be partly obliterated by subsequent metamorphism. None the less, some indication that the xenoliths had moved relative to magma should remain, unless later metamorphism was particularly severe. There is evidence of neither movement of xenoliths nor subsequent severe metamorphism.

In the absence of proof of movement of xenoliths, it is reasonable to assume they have not moved relative to the magma.

The foliation in Gambier granodiorite could be either primary, due to flowage or secondary, due to dynamic metamorphism. Primary foliation, due to flow of a partly solidified magma, should be parallel to the walls of the

magma chamber. Foliation in Gambier granodiorite is at an angle of 40 to 60 degrees with the margins of the pluton. Another factor which detracts from an hypothesis of primary origin of the foliation, is the character of the foliation itself. Foliation is recognizable because quartz, one of the most susceptible minerals to dynamic metamorphism has a tendency to occur as parallel subhedral grains or streaks of grains (Plate IX,A & B). No other minerals are noticeably parallel. Flowage which could produce foliation in the last mineral to form, should also have produced foliation in other minerals.

The extensively fractured character of quartz is plain, both megascopically and microscopically. Quartz in a fluid medium could not have been strained to the extent one sees in Gambier granodiorite.

The dynamic forces which strained quartz and foliated the Gambier granodiorite must have been post consolidation, or in any case post quartz. In fact the foliation in Gambier granodiorite is probably related to orogenic forces which tilted the rocks of Gambier Island to their present position.

Foliation is absent in Artaban granodiorite because the Artaban granodiorite did not contain sufficient quartz to record stress. Apparently stress was taken up entirely by feldspar without producing parallelism or directional trend. The same theory is probably applicable to the xenoliths in Gambier granodiorite. Stress was sufficient to strain quartz but insufficient to noticeably recrystallize plagioclase or

to obliterate textures.

Number ten of the noteworthy features of Gambier granodiorite refers to oscillatory zoning, of plagioclase, in which there is a small net change in anorthite content. Plate XIV,B illustrates a zoned plagioclase grain from thin section W-96. The core of the grain is An28 and the rim is An23. At least two intermediate zones one third and two thirds out from the core, are An15. In addition, there are a number of unconformities due to solution of parts of some zones. Each reversal in zoning and each unconformity indicates a change in chemical environment. Some writers attribute the effects illustrated in Plate XIV,B, to movement of a growing crystal relative to a magma. If the net change in anorthite content is small , one must assume that conditions at the point where the crystal finally ceased movement, were similar to conditions where the crystal started movement.

Close examination of Plate XIV,B reveals that growth perpendicular to the long dimension of the crystal (010) has been restricted more than growth parallel to (010). The zones parallel to (010) diverge at the left end of the grain. An extinct zone marks the location of a solution surface which truncates many zones near the left end of the crystal. The solution surface does not extend symmetrically around the crystal but curves out to the rim of the crystal in the same region where growth was restricted. Obviously the agent which restricted growth also protected the grain from solution, at least during the latter part of the period of growth. The

crystal in Plate XIV,B, must have retained its physical environment. Similarly, many other plagioclase crystals retained their physical environment throughout much of their growth. It is questionable whether groups of attached plagioclase crystals would circulate within a magma as units. The problem of oscillatory zoning can be simplified by considering that the feldspar grains remained in one place while the intergranular solutions changed. Each minor change in composition of circulating solutions would be reflected in precipitation of a new zone or solution of an old one.

Nearly all thin sections contain extensive replacement effects. Quartz has replaced microcline: quartz and microcline have replaced plagioclase. Locally, three quarters of the quartz and all of the microcline have replaced older minerals, usually plagioclase. This means that throughout a large part of the Gambier granodiorite, thirty, and perhaps forty, per cent of the rock originated by replacement processes. This is a conservative estimate. Replacement in many specimens may have been so complete that no record of the pre-existing minerals remains.

It is difficult to relate such extensive replacement to late magmatic alteration. Deuteric processes probably could not have produced textures such as the ones illustrated in Plates XV,A; XVI,A & B; XVII,A & B; XVIII,A &B. Space now occupied by quartz and microcline, the two minerals whose replacement origin is certain, was formerly occupied by a replaced mineral, probably plagioclase.

The minimum amount of mineral (quartz and microcline) of

replacement origin has been conservatively estimated at 30 per cent. The average quartz and microcline content of Gambier granodiorite is 35 and 10 per cent respectively; a total of 45 per cent. This means that not more than 15 per cent of the rock could have been solution filled space before quartz and microcline started. If late alteration had occurred within a magma in a closed system, solutions contained in 15 per cent of the rock could not have provided enough material to form 45 per cent of the rock. In fact, solutions contained in 15 per cent of the rock could scarcely fill the spaces without introduction of material from outside the system.

Another difficulty in considering the system closed, is in accounting for replaced material. Lime released from replaced plagioclase could have reacted with plagioclase to form clinozoisite. Sericitic alteration of plagioclase could account for a small amount of the potash taken into solution where quartz replaced microcline. However, there is no trace of the soda, most of the potash, and the alumina, which must have gone into solution during the replacement processes. Moreover, amounts of epidote and sericite in specimens examined, bear no relationship to the extent of replacement of plagioclase or microcline.

Materials must have been removed from, as well as added to, the system.

Two characteristics of plagioclase, normal zoning and euhedrism, are sometimes used as criteria for crystallization from a magma. The value of zonal trend from most calcic at

the core to least calcic at the rim, has been discussed on page 55. Euhedrism and subhedrism are no more valid than zone trends as a basis for the postulation of magmatic crystallization. Plates XII,A; XV,A; XVI,A & B; and XVII,B, illustrate a strong tendency for replacement to produce subhedral or rectangular shapes in a replaced mineral.

Microcline replaced plagioclase along cleavages and produced rectangular subhedral grains. Replacement of zoned minerals probably has a similar effect. Once a zone is partly replaced along a cleavage or fracture, replacement should proceed most easily around the zone. If one zone is more easily replaced than others, replacement could continue within the easily replaced zone, and leave those zones, which are replaced with more difficulty, as remnants. Any projection beyond the general margin of the replaced mineral would present greater surface per unit mass, and would be more easily replaced than a flat margin. Irregularities would be reduced so that the end result would be a subhedral or euhedral grain.

CONCLUSIONS

Passive stoping does not account for the xenoliths in either Artaban granodiorite or Gambier granodiorite.

Intrusion and magma flow do not account for foliation in Gambier granodiorite: dynamic metamorphism later than Gambier granodiorite, does account for foliation.

Textures and structures cannot be attributed to crystallization from a magma. The processes which produced Gambier granodiorite must have taken place in an open system. Potash and silica were added to the system, and at other times lime, soda, potash and alumina were removed from the system. This is granitization according to a definition by F.F. Grout (11)[7] that granitization, " includes a group of processes by which a solid rock (without enough liquidity at any time to make it mobile or rheomorphic) is made more like a granite than it was before, in minerals, or in texture and structure or in both."

No attempt to define the pre-granodiorite rock has been made. However, it is strongly suggested that pre Gambier granodiorite rock consisted of lavas and tuffs now represented by xenoliths in both Gambier and Artaban granodiorites.

The source of the hydrothermal solutions responsible for granitization has not been identified, nor has the subsequent history of replaced material been discussed. However, rock, such as Artaban granodiorite, adjacent to Gambier granodiorite and xenoliths within Gambier granodiorite may have become more basic according to the principals laid down by D.L. Reynolds (18).

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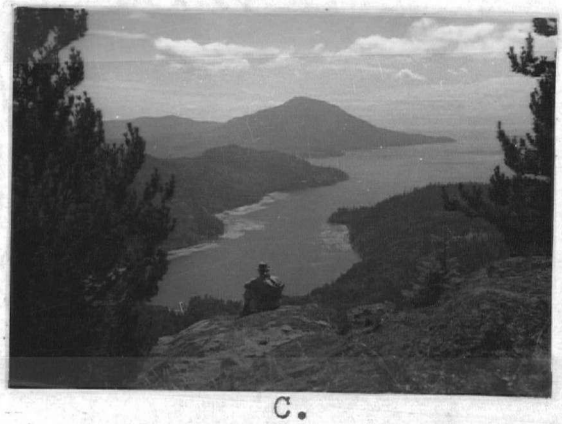
PLATES: V - XIX.

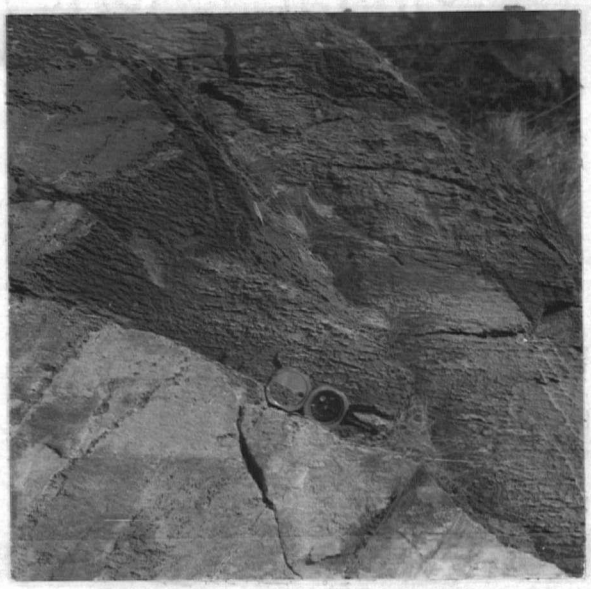
A.
Looking north from Bowen Island. Hutt Island in left middle ground; Mt. Artaban in right background; Mt. Wrottesley and mountains of west shore of Howe Sound in far background.

B.
West shore of Howe Sound, toward the northwest, from Gambier Island, at latitude 48° 29′ N.

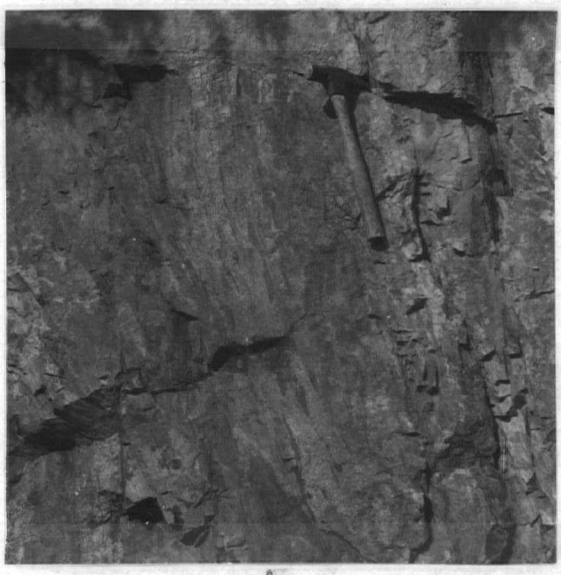


C.
View south from 1200 foot level; south slopes of Gambier Island, north of Port Graves. Bowen Island is in background; Port Graves is in foreground.

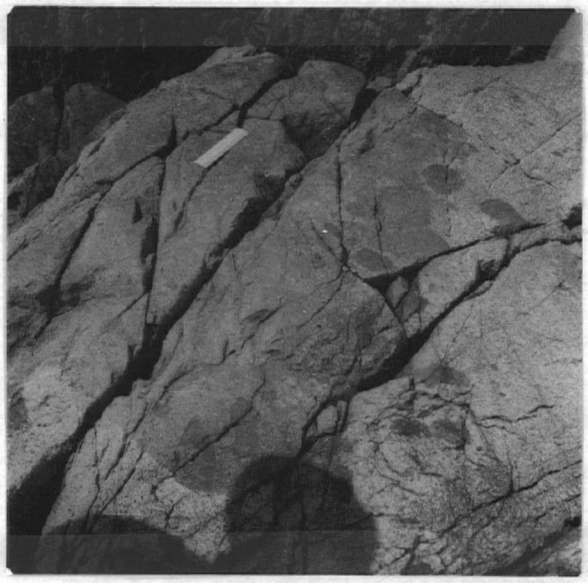
A.
View south, from 1500 foot level on west side of Gambier Island, at north boundary of Plate I.



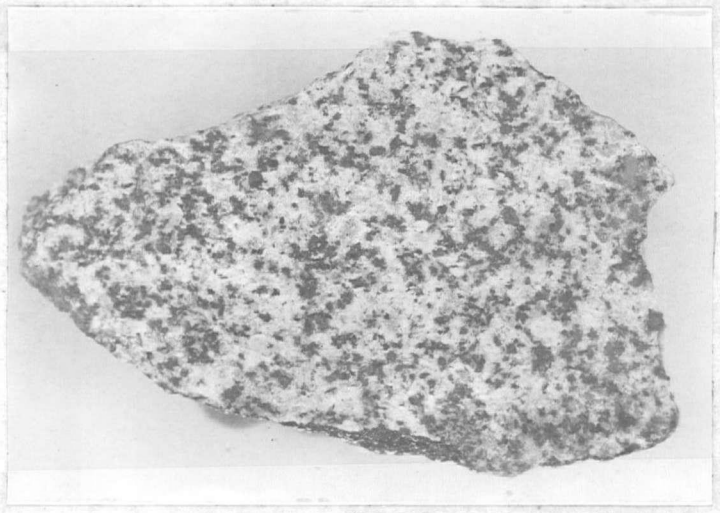
B.
Spherulites in lavas on east shore of Gambier Island, one half mile south of north margin of Plate I.



A.
Granitization of tuffs, west shore of Howe Sound, near latitude 49° 28'N. The vertical granitized area contains lenticular inclusions parallel with bedding.



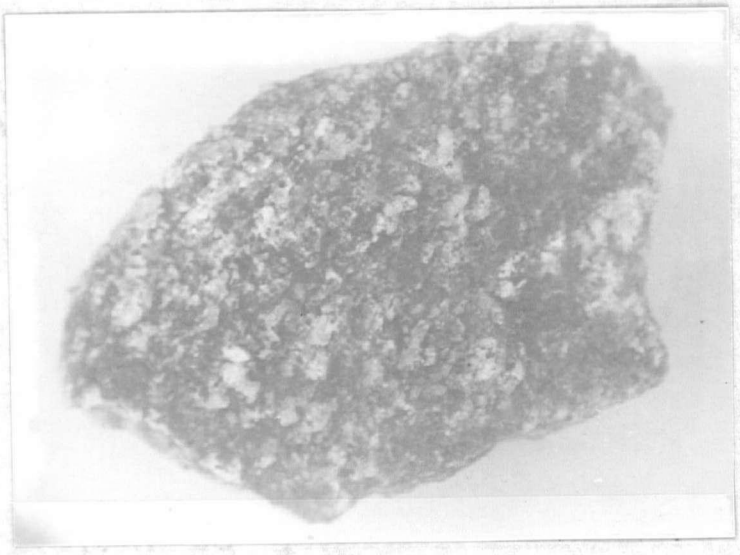
B.
Inclusions with three phases, in south tip of Gambier Island, one quarter mile east of Hope Point. Variations in color are partly due to increase in grain size and partly due to reduction in amount, of mafic constituents.



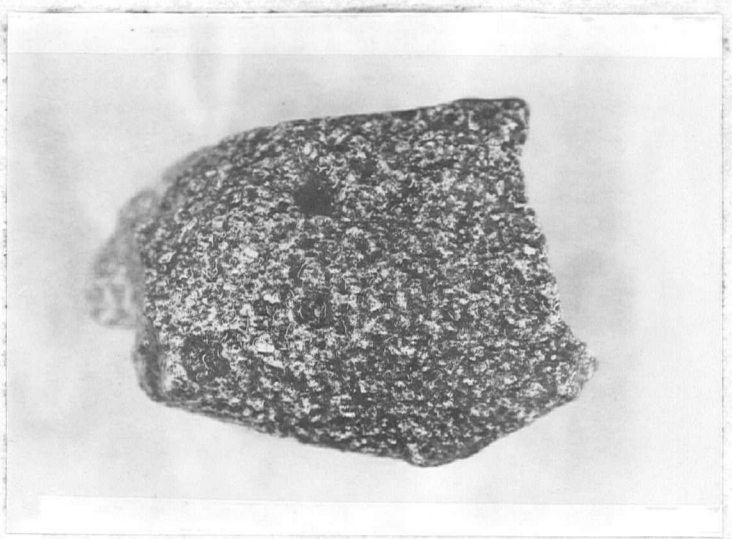
A.
Fresh surface of W-64, Artaban granodiorite, from south slope of Mt. Artaban. Natural size.

B.
Fresh surface of W-251, a hornfels like inclusion from southwest Gambier Island. Natural size.

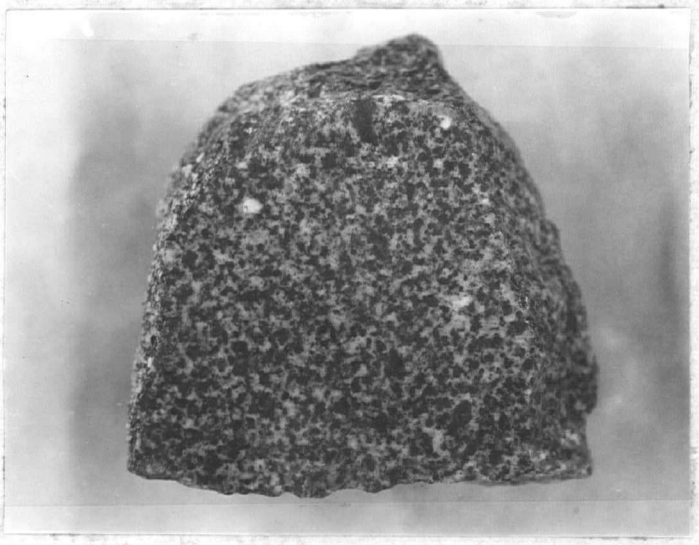
A.
Weathered surface of W-98, granodiorite located one mile north of Hope Point. The large grains of quartz which in places appear subhedral, are quite distinct. Natural size.



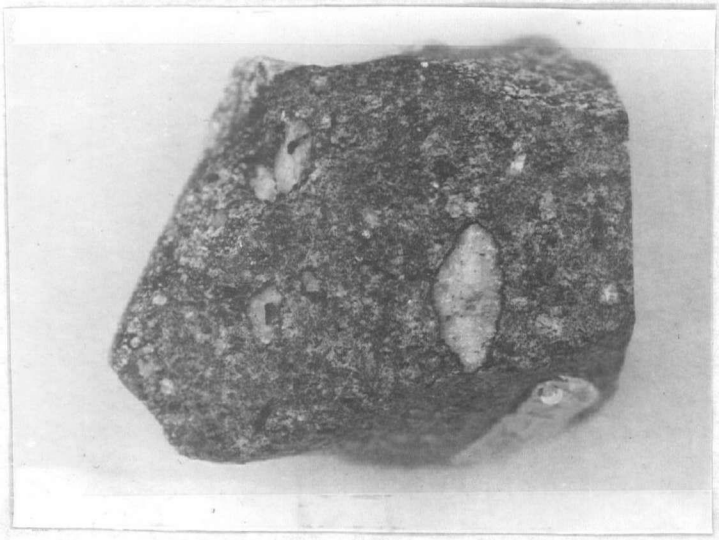
B.
Weathered surface of Z-76 granodiorite, from western Gambier. In this rock, quartz is in slender streaks rather than in single masses. Foliation trends from lower left to upper right.



A.
Weathered surface of inclusion W-84, from Hope Point. Natural size.



B.
Fresh surface of W-84 above. Natural size.

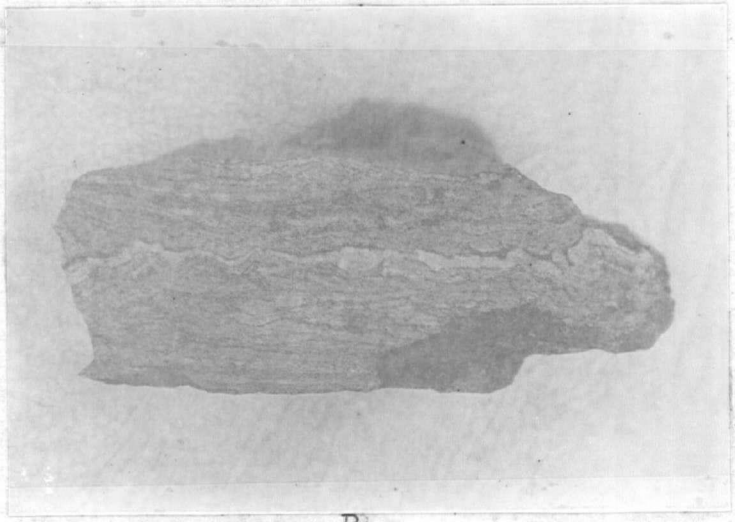


A.
Fresh surface of inclusion W-78, south Gambier Island, one half mile west of Hope Point. The dark rim about the quartz porphyroblasts of various sizes is blue-green hornblende, partly embedded in the quartz. The light patch above the large quartz grain is a plagioclase porphyroblast. Natural size.
(Compare with Plate XIII, B.)

B.
Fresh surface of inclusion W-97, one mile north of Hope Point. Natural size.

A.

Photomicrograph of W-64, Artaban granodiorite. Quartz(Q) replaces microcline(M), which replaces plagioclase(P). Grain P at core is An46, isolated remnant at X is An28. The dark patches in Q are remnants of microcline of same orientation as M. ×8.5

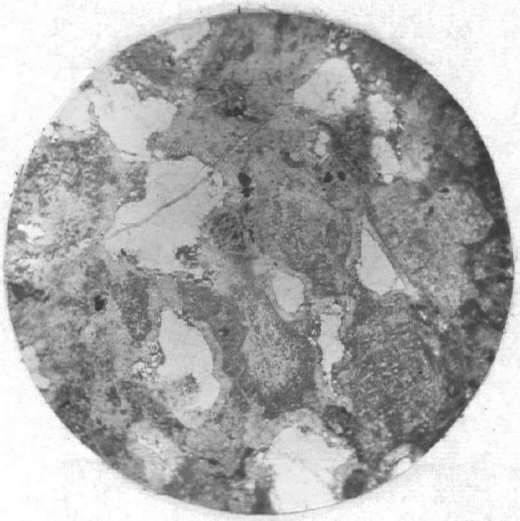


B.

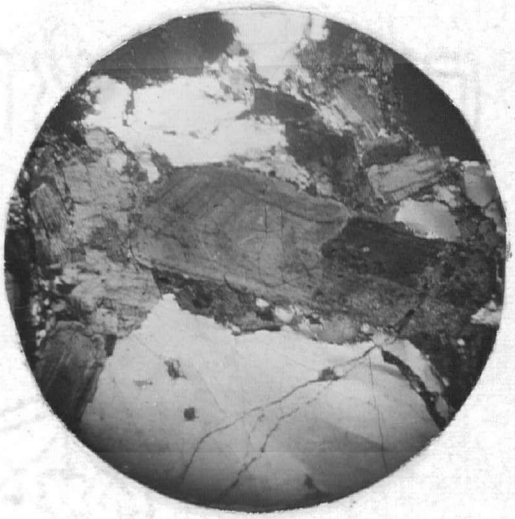
Border zone of W-87, from an inclusion 25 feet wide, near Hope Point. Bedding planes are distinct on both sides of the inclusion, but have been obliterated by recrystallization at center of the inclusion. Natural size.

A.
Isolated parts of a quartz grain in inclusion W-100. Replacement effects occur elsewhere in the same thin section. Crossed nicols. ×10

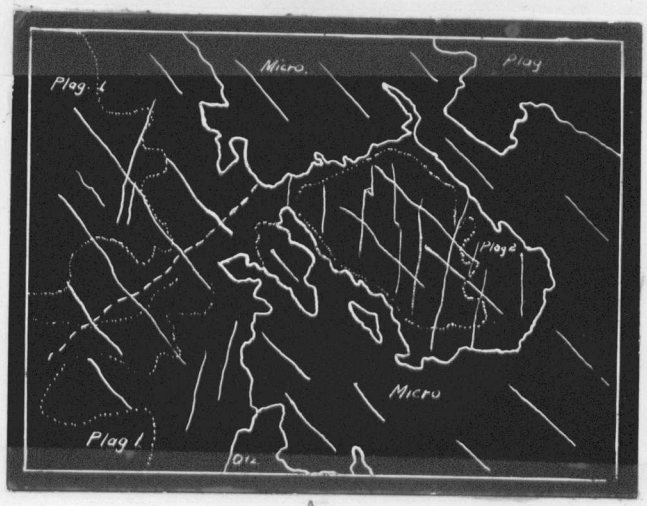
B.
Quartz porphyroblast in W-78, an inclusion east of Hope Point. The hornblende around the rim is embedded in quartz, one hornblende grain at the right end is surrounded by quartz. Crossed nicols. (Compare with Plate XI, A.) ×10



A.
Quartz in W-210, from Artaban granodiorite. Each grain has a rim of micrographic quartz. ×10

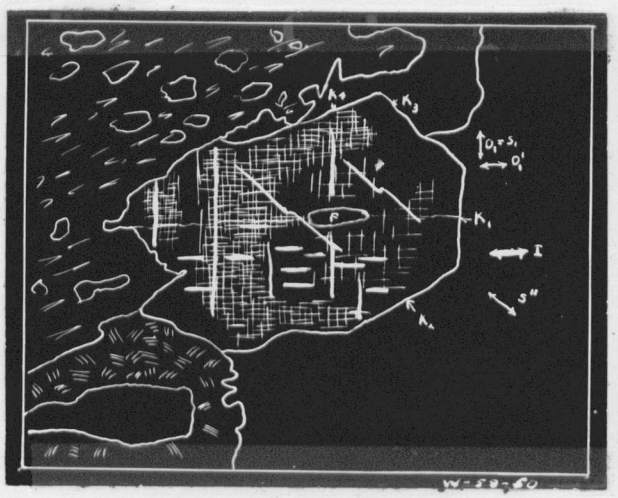


B.
Highly zoned plagioclase grain in Gambier granodiorite W-96, about one mile north of Hope Point. Growth in a lateral direction appears to have been restricted much more than growth in the longitudinal direction. ×15



A.

Specimen W-59; a single grain of microcline (Micro.) in replacing a zoned grain of plagioclase (Plag.) has left a subhedral lobe of plagioclase. Plagioclase 1 is grain 3 core, plagioclase 2 is grain 3 rim. Microcline is grain 4. Description is in Appendix. ×50

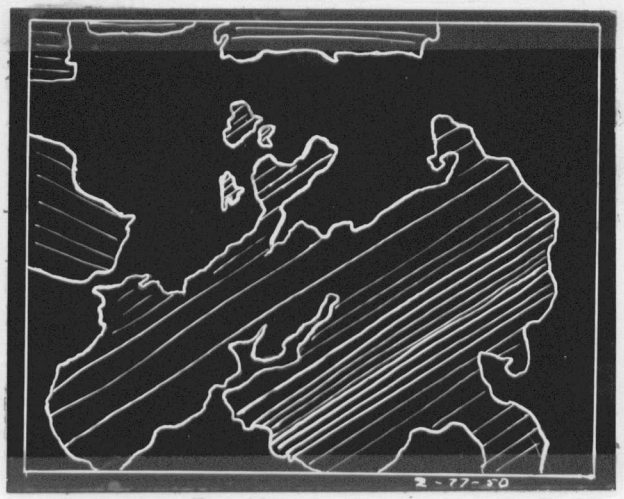


B.

Subhedral microcline in W-59. Upper left - mixed chlorite and carbonate; lower right - quartz.
K_1 = (010); K_2 = (110); K_3 = $(\bar{1}11)$; K_4 = $(1\bar{1}0)$;
D_1 = S = composition plane and cleavage = (010);
D_1' = composition plane = (001);
I, plane of inclusion = $150\bar{2}$. ×55

A.

Microcline (plain) in Z-77, replacing plagioclase (ruled). Individual microcline plagioclase margins are straight, but collective microcline boundary is irregular. Subhedral blue-green hornblende (cross hatched, except one large sub-angular grain adjacent to amphibole of lower left. ×15



B.

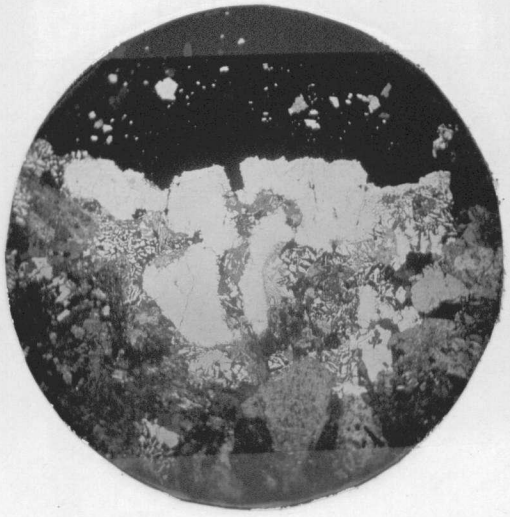
Portion enclosed in broken line of A above. The microcline plane can be seen replacing plagioclase along cleavage direction. The small isolated plagioclase grains in mid-centre, are similar in orientation to the large grain, and are assumed to be unreplaced remnants. ×50

A.
Microcline in W-170 replacing plagioclase along cleavage directions and mineral boundaries. Microcline ++, quartz +, plagioclase ✓, same orientation shown by parallel lines. ×45

B.
Microcline in W-232 replacing plagioclase in such a way that angular forms result. Legend same as in A. ×35

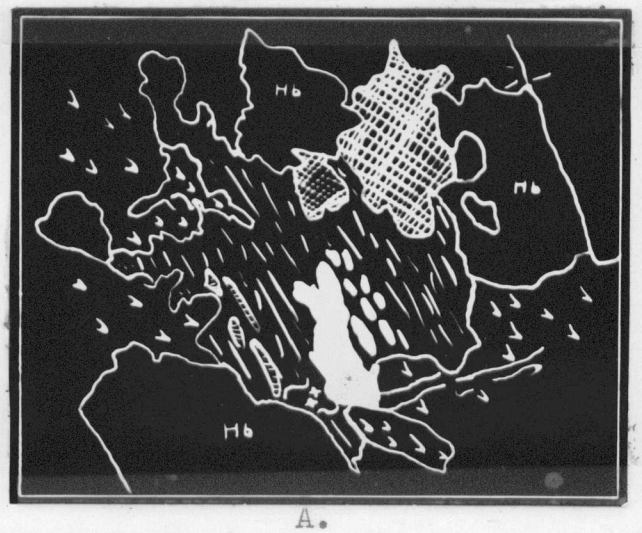
A.

Specimen W-226, Gambier granodiorite. Quartz replacing plagioclase and microcline. The two separated plagioclase areas marked A, have same orientation. Similarly, the two separated microcline masses have the same orientation. Quartz + , microcline ## , plagioclase =. ×50



B.

Specimen W-107, Artaban granodiorite. Quartz(white), is surrounded by a zone of micrographic quartz oriented the same as the main mass. The dark material is feldspar. Note the finely re-entrant margin and tendency toward euhedrism of the main quartz mass. ×10



A.

Specimen W-100, inclusion in Artaban granodiorite on east side of Port Graves. Mica (parallel lines) is intergrown with plagioclase grain(solid white). Two parts of the same hornblende grain(cross hatched) are isolated by mica. Plagioclase-Pl; hornblende- Hb. X35

B.

Specimen W-59, Gambier granodiorite, chlorite-carbonate pseudomorph after amphibole. Chlorite tends to follow two directions at about 125°. Chlorite Chl, epidote- Ep, magnetite- Mag, biotite- Bio. X25

APPENDIX

Mafic Minerals:-

Amphibole -

Z'∧c indicates that a close approximation of the true Z c angle is 20 .

Z∧c indicates that the true angle determined on a universal stage, is 20 .

2V = $5\overline{4}$ optic angle read on one optic axis.

2V = $\underline{54}$ optic angle read on two optic axes.

Mica -

X≐c indicates that X is almost equal to c.

S.W.M. - is an abbreviation for secondary white mica, probably sericite.

General:-

Mineral percentage estimates are entirely visual. Very high and very low amounts are less accurately estimated than intermediate amounts.

The expression "replacement boundaries" is intended to signify that mineral contacts are not the straight line type normally found when minerals crystallize from a melt in an orderly sequence. "Replacement boundaries" here, means that margins are curved and characterized by embayments, but that relative ages are not known with certainty. Where ages are decipherable, the replaced mineral is noted under the heading of the replacing mineral e.g. Microcline .....; replaces plagioclase: or vice versa Plagioclase .....; replaced by microcline.

The following criteria were used individually and in combinations as indicators of replacement.

1. Curved or re-entrant margins which could not be explained by orderly crystallization from a melt.

2. Island-like remnants of the host mineral within the metasome. This criterion was not used unless the structure was accompanied by similarity in orientation.

3. Numerous similarly oriented inclusions of the host mineral within the metasome. The inclusions may or may not be oriented the same as adjacent host mineral outside the metasome. This criterion was not used where crystal irregularities could account for inclusions of one mineral in another. Normally, however, the inclusions themselves have irregular replacement type boundaries.

4. Replacement of host along cleavages.

Explanation of Symbols used in Appendix.

Quartz:-

Stress effects on quartz are indicated as follows:

Grade 0 - homogeneous extinction.
Grade 1 - undulating extinction, but with little or no fracturing.
Grade 2 - undulating extinction and minor fracturing.
Grade 3 - undulating extinction and considerable fracturing.
Grade 4 - undulating extinction, considerable fracturing and slight to moderate mortar structure.
Grade 5 - undulating extinction, extensive fracturing and extensive mortar structure.

Feldspars:-

Identification of feldspars was made on the basis of centered interference figures, except where an off center figure is noted.

Precise studies by the Fedorov method were made on some feldspar grains. The data are presented as angles between the poles of crystallographic planes and the Z, Y, and X vibration directions.

Microcline -
D = composition plane.
I = plane of regular dusty inclusions.
K = an outline plane.
L = twin lamellae.
perthite indicates that microcline perthite is present in the thin section, but that not all the microcline is perthitic.

Plagioclase -
An25-15:- the first number indicates composition of the core; the second number indicates the composition of the rim.
An25 5 :- the composition of the feldspar is known only within the limits of the second number.
C = cleavage.
L = twin lamellae.
S.W.M.- signifies secondary white mica, probably sericite.

PART A

MATRIX OF ARTABAN GRANODIORITE

Thin Section	Page
W-64	iv
W-107	v
W-209	vi
W-210	vi

ARTABAN GRANODIORITE (MATRIX).

W - 64 - 50

Quartz:- 15%; clear; 1 mm. grains; grade 1; replaces potash feldspars.

Feldspars:-

Microcline - dusty; 1-1.5 mm. grains which surround and replace plagioclase.

		Z.	Y.	X.	Error
Grain 2.	⊥(010)L	17°	78°	78°	7° S.W.
Grain 3.	⊥(001)S	88°	20°	70°	15° N.W. (indistinct).
	⊥(010)L	7°	88°	85°	20° S.E.
	⊥Face(101)	88°	30°	60°	10° S.
	⊥Face(021)	39°	52°	83°	3° N.W.

	Observed Angle	True Angle	Error
(001)∧(010)	88°	90°	-2°
(001)∧($\bar{1}$01)	10°	14°	-4
(001)∧(021)	53°	50°	+3
(010)∧($\bar{1}$01)	88°	88°	0
(010)∧(021)	38°	46°	-8
($\bar{1}$01)∧(021)	54°	62°	-8

$-2V = 83°$

Plagioclase - 40%; cloudy; 2 mm; subhedral; highly altered to epidote and S.W.M.

		Z.	Y.	X.		Error
Grain 1						
Core	⊥(010)L	26°	65°	84°	An46	2% S.W.
	⊥(110)C	50°	80°	42°	An40	15% N.W.
	⊥(010)	Composition plane and quite sharp				
	⊥(110)	Is irregular and indistinct.				
Isolated island of plagioclase, formerly the rim of Grain 1.						
	⊥(010)L	9°	85°	83°	An28	8% N.
	⊥(110)c	63°	64°	39°	An30	15% S.W.

(110) is a poorly defined cleavage and measurable only in the core of the grain.

Mafic Minerals:

Pyroxene - 15%; scattered large grains; considerably altered to pale green, feathery, amphibole.

Twinned pyroxene grain (universal stage method).

	Z∧c	+2V	110∧1$\bar{1}$0	Composition Plane	Optic Plane
Sub. 1	42	54	94	100	010
Sub. 2	47	49	92		
Average	45	50	93	100	010

Accessory Minerals:-
Apatite
Magnetite - 1-2%

Secondary Minerals:-
S.W.M. and epidote in plagioclase; about one third of plagioclase is altered.
Amphibole - Z∧c 12 , pale green to colorless. Feathery clusters of grains after pyroxene.
Chlorite - 10% of thin section. Present in both pyroxene and feldspar.
Hydrated iron oxides.

W - 107' - 50

Quartz:- 20%; clear; 2-3 mm; many quartz grains are surrounded by a zone of micrographic quartz and feldspar. Some micrographic quartz retains its orientation across feldspar boundaries.
(The feldspar of the micrographic structures has a very low index. Similar feldspar was identified as microcline in W-64.)

The main body of quartz is separated from micrographic intergrowths of quartz and feldspar by a surface which is composed of numerous connected short arcs convex away from quartz. This is well shown in sections in which the micrographic quartz appears as triangular bodies in a zone around quartz. Some micrographic quartz rods appear to have enlarged so that a number nearly coalesce. The result is an angular mass of quartz transected by a fine network of feldspar.

Feldspars:- 60%. Microcline as well as plagioclase, may have been present. All feldspar is highly altered to S.W.M., chlorite, epidote, kaolin.

Mafic Minerals:- 20%. Entirely altered to chlorite and epidote, sphene, and oxides; both amphibole or pyroxene and mica may have been in rock.

W - 209 - 50

Quartz:- 5%; clear; less than .5 mm; interstitial to other minerals; some rounded micrographic areas are up to 1 or 2 mm.in diameter. They transect grain boundaries, isolate parts of grains and without appearing to have exact borders they change birefringence of the feldspar grains in which they occur.

Feldspars:- 60%.
Feldspar similar to that identified as microcline in W-64 is present.

Plagioclase - cloudy; 1-2 mm; unzoned; slightly off center figure ⊥X; Z∧c1(001) = 13 ;
Z∧ lamellae and c1(010) = 72 , indices below balsam, so composition is An20.
Highly altered to S.W.M., epidote, and chlorite.

Mafic Minerals:- 25%.
Entirely altered to chlorite and epidote, sphene, hydrated iron oxides.

Accessory Minerals:
Apatite
Magnetite, titaniferous - 1%.

Secondary Minerals:-
S.W.M., epidote (colorless, and pleochroic yellow), chlorite, sphene, hydrous iron oxides.
Some feldspar grains contain minute rods of blood red, almost opaque material with square cross section and extremely high birefringence. These rods are tentatively identified as rutile.

W - 210 - 50

Quartz:- 15 - 20%; clear; 1-2 mm; grade 2; aggregates and single grains, of fairly regular shape. The central part of each grain is solid quartz; beyond this is a zone of micrographic quartz and feldspar. The orientation of micrographic quartz is constant, regardless of the orientation of the associated feldspar.

Feldspars:-50-60%.
Microcline - 20%(?); dusty; 2 mm; irregular; replaces plagioclase. This feldspar was not proved to be microcline. However, its characteristics- index well below balsam; lower birefringence than the plagioclase; indistinct, very fine, parallel, lensiform twinning,and its similarity to microcline of W-64, suggest that it is microcline.

Plagioclase - 30-40%; dusty to very cloudy; 2 mm; subhedral to anhedral; $\perp XZ$(core)$\wedge 010 = 62$; Z(rim)$\wedge 010 = 78$; indices vary from well above to just below balsam, so plagioclase is An55-30. Considerably altered to S.W.M., epidote, chlorite.

Mafic Minerals:- 20%.

Entirely altered to epidote, chlorite, sphene, and minor hydrated oxides.
The chlorite is mostly a deep green pleochroic variety with a blue interference color.

Accessory Minerals:-

Apatite - very small quantity.
Magnetite - 1-2 %.

PART B

XENOLITHS IN ARTABAN GRANODIORITE

Thin Section		Page
W-62	.....	ix
W-211	.....	ix
W-282	.....	x

XENOLITHS IN ARTABAN GRANODIORITE

W - 62 - 50

Quartz:- 15%; clear; .2 mm; grade 0.

Feldspars:- 60%; dusty; less than .5 mm. long. Maximum extinction angle = 12° (10 grains); indices below balsam. Albite, An10.

Mafic Minerals:
Epidote - some epidote is interstitial to feldspars.

Kaolinite -

Some fractures are filled with epidote, others with quartz, and the former cut the latter.

Texture:- trachytic; many feldspar microlites are separated by quartz grains.

W - 211 - 50

Quartz:- 15%; clear; 2 mm. grains; grade 0. Flow texture about quartz indicates that quartz is primary.

Feldspars:-Clear; sub parallel, twinned microlites up to 0.2 mm. long; maximum extinction angle = 10°; indices are just below balsam so microlites are An14.

Accessory Minerals:-
Apatite - tiny needles in quartz.

Secondary Minerals:-
Sphene - 3%; tiny flakes of high relief and high birefringence.
Epidote- yellowish green.
Pyrite - small cubes up to .2 mm. across.

Texture:- trachytic but not well developed.

W - 282 - 50

Quartz:- 15%; clear; grade 0; fine radiating needles with feldspar in spherulites and as 1 mm. grains which may have replaced plagioclase.

Feldspar:-75%; dusty; altered to S.W.M; occurs as rectangular 1 mm. phenocrysts and with quartz in 0.2 mm. spherulites.

Mafic Minerals:

Amphibole - 5%. $Z \wedge c = 5^{\circ}$ or less.
X' = colorless; Z' = blue.
Very fine needles between and projecting into spherulites.

Opaque Oxides - 1%.

Secondary Minerals:-

S.W.M. - in feldspars.
Chlorite - pale green, in feldspars.

Texture:- spherulitic.

PART C

MATRIX OF GAMBIER GRANODIORITE

Thin Section		Page
W-59	.....	xii
W-79	.....	xiii
W-85	.....	xiv
W-96	.....	xv
W-98	.....	xvi
W-101	.....	xvii
W-103	.....	xvii
W-166	.....	xviii
W-167	.....	xviii
W-169	.....	xix
W-170	.....	xix
W-191	.....	xx
W-226	.....	xx
W-232	.....	xxi
W-239	.....	xxii
W-253	.....	xxii
W-261	.....	xxiii
W-285	.....	xxiv
W-287	.....	xxiv
Z-77	.....	xxv

GAMBIER GRANODIORITE (MATRIX).

W - 59 - 50

Quartz:- 30%; irregular; grade 2; sutured borders; interstitial to feldspar and replaces plagioclase and microcline.

Feldspars:-

Microcline:- 10%; up to 2 mm. long; irregular in shape; dusty patches; replaces plagioclase (Plate XV, A.).

	Z.	Y.	X.	Pole	Error	2V.
Grain 4	85°	7½°	84°	⊥(001)	6½° W.	-2V = 79½°
Grain 2						
D = S	13°	84°	79°	⊥(010)	5° S.E.	
I'	79°	83°	13°	⊥(1$\bar{5}$02)	5½° W.N.W.	
L"	83°	8½°	88½°	⊥(001)	6° S.W.	
S"	75°	76°	20°	⊥(1$\bar{1}$0)	3½° N.E.	
K,	13°	83°	80°	⊥(010)	5½° S.	
K₂	40½°	82°	50°	⊥(110)	2½° E.	
K₃	59°	65°	40½°	⊥(1$\bar{1}$1)	14° N.E.	
K₄	46°	82°	44½°	⊥(110)	5° N.N.W.	

Forms	Observed	True
K, (010)∧K₂ (1$\bar{1}$0)	52°	59½°
K, (010)∧K₃ (1$\bar{1}$1)	54°	63°
K, (0$\bar{1}$0)∧K₄ (1$\bar{1}$0)	56°	59°
K₄ (1$\bar{1}$0)∧K₃ (1$\bar{1}$1)	76½°	60°
K₂ (110)∧K₃ (1$\bar{1}$1)	89°	71°
D (010)∧K₃ (1$\bar{1}$1)	59°	63°

K₄ is rather poorly developed - See Plate XV, B.

Plagioclase:- 45%; dusty; subhedral to anhedral; size is seriate from 1 mm. to 5 mm.

	Z.	Z.	Y.	X.		
Grain 3						
Core	(⊥(010)C	14½°	76°	88°	An35	
	(⊥(1$\bar{1}$0)C	67°	69°	31°	An26	5% N.W.
Rim	(⊥(010)C	-2°	89°	89°	An19½ or An23	1% S.W.
	(⊥(1$\bar{1}$0)C	-62°	75°	33°	An20	1% N.W.

Those based on (010) are probably more accurate than those based on (1$\bar{1}$0).

		Z.	Y.	X.		
Grain 5a.	⊥(001)C	70°	20°	90°	An47	2% S.E.
Grain 5b.	⊥(001)C	80°	12°	83½°	An34	2% N.E.

5a and 5b are intergrown; neither is noticeably zoned.

Grain 6.	⊥(010)C	19°	70°	88°	An39	2% S.W.
	⊥(001)C	67°	23½°	85°	An37	2% S.E.

Grain 7.	⊥(010)C	15°	76°	85°	An34	2% N.E.
Grain 7	⊥(010)C	11°	79°	87°	An31	2% N.

Slightly cloudy, not noticeably zoned until rotated; faint zoning then shows.
Grain 6 and Grain 7 are sub-individuals of a carlsbad twin.

Mafic Minerals:-

CaFe Silicates:-15-20%; almost entirely altered to pale yellow pleochroic epidote ($Z' \wedge c = 27°$); brown or green pleochroic chlorite (small 2V); quartz, sphene, carbonate.

Possible former presence of mica shown by lamellar bands of quartz, chlorite, epidote.

Amphibole grains represented by carbonate with intervening chlorite plates, along former cleavage lines.

One small remnant of green biotite.

W - 79 - 50

Quartz:- 35%; irregular; grade 3; sutured borders; minor flaser structure about edges; replaces feldspars; 5-10% included material, mostly feldspar. One grain has a marked tendency toward euhedrism.

Feldspars:-

Microcline - 10%; clear; straggling; perthitic in places; replaces plagioclase.

Plagioclase - 50%; slightly dusty; subhedral to anhedral; seriate from 1 mm. to 5 mm.
Grain 1:- comparatively unzoned An35.
Grain 2:- An35-18. -2V core = 89 ; -2V rim = 86°.
some fracturing of grains; obstructed growth; much of zoning is elliptical. Alteration to S.W.M., epidote, chlorite, not extensive.

	Z°	Y°	X°			2V.
Grain 1.						
Sub. 1-⊥(010)LC	16°	75°	89°	An35	½% S.S.W.	-87°
⊥(001)C	77°	14°	85°	An31	1% N.W.	
Sub. 2-⊥(010)LC	17°	77°	85°	An36	5% N.N.E.	
⊥(001)C	80°	13°	85°	An34	2% N.E.: An26-2%N.E.	
Grain 2.						
Sub. 1-⊥(010)L	17°	75°	83°	An32	6% N.N.E.	-87°
(Core) ⊥(001)C	72°	18°	88°	An32	1% S.E.	
Sub. 1-⊥(010)L	8°	87°	83°	An17	6% N.N.E.	-86°
(Rim) ⊥(001)C	89°	7°	83°	An16	1% N.W.	
Sub. 2-⊥(010)L (Core)	14°	76°	87°	An35	1% N.E.	
Sub. 2-⊥(010)L (Rim)	2°	89°	90°	An19 or An23	1% S.W.	

Mafic Minerals:-
Mica- -2V small. X ≐ c
X = yellow, nearly colorless
Y = Z = brownish green.
10%; occurs as 1.5 mm. plates and .5 mm. aggregates. Alters to zoisite, chlorite, S.W.M. in plates.

Accessory Minerals:-
Apatite - Tiny .1 mm. needles.
Pyrrhotite (?)

W-85-50

Quartz:- 25%; irregular; grade 4; many grains have sutured borders; replaces plagioclase; 3-5% included material. One fracture which crosses the thin section is filled with strained quartz.

Feldspars:-
Microcline-5%; clear to cloudy; perthite; grid twinning is not distinct; relationship to plagioclase is not distinct.
Plagioclase- 45%; dusty; cloudy; 3-5 mm; fractured; margins irregular; each grain is shot with small epidote grains and kaolin; fractures filled with epidote; minor alteration to chlorite.

Mafic Minerals:-15%; entirely altered to chlorite (possibly peninite), yellowish green epidote, titanite.

Accessory Minerals:- None.

Remarks:- Fractures filled with colorless epidote where they cross feldspar; quartz where they cross quartz.

W - 96 - 50

Quartz:- 40%; irregular or blocky; grade 4; 5% included plagioclase, hornblende, epidote; included plagioclase grains are clear. Replacement borders with feldspars; replaces amphibole inclusion.

Feldspars:-

Microcline - 5%; clear; grains 1.5 to 2 mm; perthitic; wavy lamellae; not distinctly twinned.

Plagioclase - 35%; cloudy and clear; 1-5 mm; obstructed zoning (Plate XIV, B). Some evidence of grain deformation; slight epidote and kaolin alteration; fractures filled with epidote. Plagioclase intergrown with, and may be replacing, mica. Highly zoned grain very near center bisectrix figure;

1Z	$X\wedge(010)$ core	= 0	An28
	$X\wedge(010)$ 1/3 & 2/3 out from center	= 15	An15
	$X\wedge(010)$ rim	= 4	An23

Both indices of rim are distinctly below quartz so zone trend is assumed to be normal. Extinction angle retains the same sign, so least calcic phase is An15.

Mafic Minerals:-

Hornblende - 10%. $-2V = 65 \pm 10$, maximum $Z'\wedge c = 21$
X = yellow green, Y = green, Z = bluish green
Slender grains up to 1.5 mm; replaced by quartz and altered to brownish green chlorite.

Biotite - 10%. $-2V = 5$ $X \doteq c$
X = pale yellow, Y = Z = brownish green.
In $\frac{1}{2}$ mm. grains and groups of much finer diversely oriented plates; altered to epidote and chlorite.

Accessory Minerals:-

Apatite - .1 mm. and smaller; needles.

Magnetite (?) - very small proportion.

W - 98 - 50

Quartz:- 20%; irregular; grains 4-5 mm; strained; grade 4; most borders are crushed; age relationships are obscure.

Feldspars:-

Microcline - 5%; sub-equidimensional .5 mm; grid twinning; perthite; some wavy quartz-like intergrowths.

Plagioclase - 50%; composition An30 = 20; clear; subhedral to anhedral; grains to 6 mm; zoned; partly restricted; some distortion; very slight alteration to small grains of epidote and S.W.M. Fractured zones contain an aggregate of S.W.M; epidote and quartz.

Mafic Minerals:-

Hornblende - 15%. $Z' \wedge c = 25$ $-2V = 70$
X' = yellow, Y' = green, Z' = blue green.
Slender grains to 1.5 mm; intergrown with at least one plagioclase grain; alters to chlorite.
Brownish green biotite occurs in a fracture in hornblende, as tiny diversely oriented plates.

Biotite - 15%. -2V small;
X' = yellow, Y' = greenish brown, Z' = brownish green
Occurs as grains up to 1 mm. and aggregates of small grains; some biotite occurs in fractures in hornblende. One mica grain is intergrown with a quartz grain which it may be replacing, but precise interpretation is difficult. Much of biotite is deformed into wavy shapes. It is altered to epidote, chlorite, quartz.

Accessory Minerals:-

Apatite
Opaque minerals - very little
Magnetite (?)

Secondary Minerals:-

S.W.M. - in feldspar.
Epidote - in feldspar and mica.
Chlorite - in amphibole and mica.
Quartz - in biotite.

W - 101 - 50

Quartz:- 45 - 50%; irregular; grade 4-5; very little included material; relationships obscured by flaser structure but general shapes are highly suggestive of replacement. Poorly developed tendency toward euhedrism.

Feldspars:-

Microcline - 10%; perthitic; 2 mm; clear grains with inclusions of hornblende; wavy lamellae; some wavy lamellae are sub-parallel with fractures in quartz. There is a tendency toward sub-parallelism of lamellae from grain to grain, and in at least one grain, lamellae do not follow cleavages.

Plagioclase - 35-40%; An34-29; clear; 1.5 mm; subhedral to irregular; alters to epidote and S.W.M.

Mafic Minerals:-

Hornblende - 10%. $Z \wedge c = 20$
X = yellow, Y = yellowish green, Z = blue green. Irregular to subhedral grains to 1.5 mm; very slight alteration to chlorite.

Mica - small -2V; X = yellow, Y = brownish green, Z = brown
A second type X = yellow, Y = green Z = green
Type 2 is considerably altered to chlorite. Both types alter to epidote.

Accessory Minerals:-

Apatite - rare

Magnetite - very little.

W - 103 - 50

Quartz:- 15-20%; irregular; and in aggregates of grains up to 1 cm. long; grade 3; contains 3-5% included material; clearly replaces plagioclase.

Feldspars:-

Microcline - 10%; irregular; 1 mm; twinned and untwinned; clear perthite; replaces plagioclase.

Plagioclase - 40%; An31; dusty; 4-5 mm; blocky; not extensively zoned; considerably altered to S.W.M, epidote.

Mafic Minerals:- 20%; entirely altered to yellowish epidote, green pleochroic chlorite, titanite, and opaque oxides. Both mica and hornblende may have been present.

W - 166 - 50

Quartz:- 35-40%; large blocky grains with slightly irregular boundaries; grade 3; included material 10-15% (plagioclase and orthoclase) in the form of small angular and shard shaped masses. One microcline inclusion lies along what may be a fracture in quartz. Quartz borders are of a bulbous replacement type. At one point, quartz definitely replaces microcline. Secondary white mica fills some fractures.

Feldspars:-

Microcline - 25%; clear; .5-2 mm; sub-equal dimensions with perthite; much included plagioclase; replaces plagioclase.

Plagioclase - 35%; dusty; two sizes- about 1 mm. and 5-6 mm; not highly zoned.

Mafic Minerals:- 15%; entirely altered to yellowish green pleochroic epidote, nearly colorless chlorite, and hydrated iron oxides.

Accessory Minerals:-

Apatite

Pyrite (?)- small grains enclosed in chlorite.

W - 167 - 50

Quartz:- 30%; irregular grains and aggregates of grains up to 7 mm. long; grade 3-4; 5% included material in form of crescent and rounded plagioclase and microcline grains; replaces microcline; less definite information suggests replacement of plagioclase.

Feldspars:-

Microcline - 10%; clear; 2 mm; includes plagioclase; ±perthite; replaces plagioclase.

Plagioclase - 30%; An18; subhedral; cloudy; 5 mm; zoned; some distortion; considerably altered to S.W.M; veined by chlorite.

Mafic Minerals:- 15-20%; almost entirely altered to chlorite, epidote, hydrated iron oxides, and S.W.M. A few distorted flakes of greenish brown biotite are only partly altered.

Accessory Minerals:-

Apatite - Rare.

General subhedrism in plagioclase. None in other minerals.

W - 169 - 50

Quartz:- 40%; irregular grains; grade 3; included material 5-10%; some of it is smaller grains of quartz with a different orientation; fractures are filled with secondary white mica, titanite and iron oxides. These fractures parallel one set of fractures in the quartz grains. Relationships are not definite, but islands of feldspar, probably microcline, are isolated from other grains of identical orientation. Replacement is most likely.

Feldspars:- 50%.

Microcline and Plagioclase - Formerly present, but now almost entirely altered to masses of very fine S.W.M., some kaolin, but almost no epidote or zoisite.

Mafic Minerals:- Entirely altered to pale chlorite, sphene, epidote.

W - 170 - 50

Quartz:- 5%; irregular; grade 2; 3% included material in form of angular and curved feldspars. Replaces microcline and plagioclase.

Feldspars:-

Microcline - 15%; clear; 2-3 mm; ± perthite; replaces plagioclase; up to 20% included plagioclase.

Plagioclase - 50%; An36-25; dusty; 3-5 mm; zoning partly abrupt, partly gradational; tendency toward euhedrism; some grains considerably replaced by S.W.M. and epidote.

Mafic Minerals:-

Biotite - 10-15%; almost entirely altered to green pleochroic chlorite and epidote and oxides. Original mica appears to have been a brown or brownish green biotite.

Accessory Minerals:-

Apatite - 1%. Very small hexagonal needles.

Secondary Minerals:-

S.W.M. - in plagioclase.
Epidote - in plagioclase and mica.
Chlorite, green pleochroic - occurs in mica.
Hydrated iron oxides - in mica.

W - 191 - 50.

Quartz:- 25%; irregular; grade 2; 30-50% included feldspars in irregular shapes; replaces both feldspars.

Feldspars:-

Microcline - 15%; clear; .5 -1 mm; ± perthite, and some perthite lamellae definitely quartz-like; replacement of plagioclase along fractures.

Plagioclase -45 - 50%; clear or cloudy; 2-4 mm; subhedral; zoning partly gradational, partly abrupt; altered to S.W.M., chlorite, epidote; some grains much more highly altered than others.

	Z.	Y.	X.		
Grain 1. (Core).					
⊥(010)CL	15°	76°	87°	An2	3% N.E.
⊥(1$\bar{1}$0)C	55	87	36	An0	5% E.
(Rim).					
1(010)CL	8	82	89	An13	1% S.
1(1$\bar{1}$0)C	60	79	33	An18	2% E.

(0$\bar{1}$0) is a distinct cleavage and more reliable than (110)
(1$\bar{1}$0) is marked by strings of dusty inclusions.
Composition is An2 -13.

Mafic Minerals:- 10%

Hornblende - -2V = 70± Z∧c = 25
X = pale yellow, Y = green, Z = blue green.
Intergrown with feldspars; appears to be younger, but relationships are obscure.

Biotite - 5%. small 2V.
X = yellowish, Y = brownish green.
Altered to epidote, chlorite.

Accessory Minerals:

Apatite - less than 1%.
Magnetite - less than 1%.

W - 226 - 50

Quartz:- 40 - 50%; large irregular grains and aggregates to 15 mm. long; grade 2; 20% included feldspars, plagioclase, and microcline; some small isolated inclusions with re-entrant boundaries are similarly oriented. Remnants with re-entrant angles are left where different quartz grains meet. Some of the broader fractures are filled with S.W.M. and hydrated iron oxides.

Feldspars:-

Microcline - 15%; dusty; grains 1 mm; blocky to erratic with included subhedral plagioclase; replaces plagioclase.

Plagioclase - 30-40%; An20; cloudy; 5 mm; subhedral and anhedral; not extensively zoned; considerably altered to S.W.M.; much less alteration to epidote and chlorite; fractures in plagioclase are filled with chlorite, S.W.M., and iron oxides.

Mafic Minerals:- 15%. Entirely altered to diversely oriented aggregates of chlorite and pleochroic epidote or to laminated plates of green pleochroic chlorite. The two types may indicate former presence of both hornblende and mica. Some sphene and iron oxides formed.

Accessory Minerals:-

Apatite

Pyrite - small cubes in laminated type of chlorite.

W - 232 - 50

Quartz:- 10 - 15%; highly irregular grains; grade 1; little included material; replaces microcline; fills late fractures in plagioclase, but evidence is not good for replacement of plagioclase.

Feldspars:-

Microcline - 2%; clear to slightly dusty; 1-2 mm; sub-blocky grains with included material; replaces plagioclase.

Plagioclase - 70%; An0-3; dusty; 4-5 mm; almost unzoned; broadly euhedral to microcline, except in detail; plagioclase contacts anhedral; some distortion; extensive alteration to epidote in some grains, less alteration to chlorite and S.W.M.

Mafic Minerals:- 15%; entirely altered to aggregates of small grains of yellow pleochroic epidote, sphene, and chlorite. The chlorite is green pleochroic and laminated.

Accessory Minerals:-

Apatite - very few tiny prisms.

W- 239- 50

Quartz:- 35%; irregular grains and aggregates of grains in ragged strings up to 15 mm. long and 3 mm. wide; grade 3; very dusty; some smaller grains contain inclusions of unreplaced plagioclase of same orientation as adjacent plagioclase grains. One grain of quartz is entirely of replacement origin, plagioclase being the replaced mineral. Quartz also replaces microcline perthite; 10-30% included subhedral plagioclase grains.

Feldspars:-

Microcline -10%; clear to slightly dusty; sub equidimensional 1 mm; includes and replaces plagioclase; ± perthite; fractures filled with epidote or quartz.

Plagioclase- 40%; indices just above balsam; dusty; 4-5 mm. blocky grains; broadly subhedral to quartz and microcline, but anhedral to other plagioclase; moderate alteration to epidote and S.W.M. in about equal parts; chlorite fills fractures. Very little zoning.

Mafic Minerals:- 15%. Entirely altered; now represented by aggregates of yellow epidote and chlorite or laminated chlorite.

Accessory Minerals:-

Apatite-

W- 253- 50

Quartz:- 30%; irregular 6 mm. aggregates of smaller ragged grains with sutured borders; grade 4; little included material; bulbous margins toward microcline. Isolated parts of microcline grains are probably remnants of replaced microcline; small peninsulas of plagioclase protrude into quartz.

Feldspars:-

Microcline - 20%; clear; 2 mm. perthite and lamellae are sub parallel fractures; includes and replaces plagioclase. Perthite lamellae of one microcline grain are connected across a disturbed zone of a partly included twinned plagioclase grain.

Plagioclase - 20%; slightly dusty; 2-4 mm; zoned gradationally; subhedral to quartz and microcline; anhedral to other plagioclase; some fracturing; replaced by quartz and microcline; some alteration to S.W.M.

Mafic Minerals:-

Amphibole - 20%; prisms up to 1½ mm. $Z' \wedge c = 15^\circ$.
X' = brownish yellow; Y' = green; Z' = green.
Altered to hydrated iron oxides.

Biotite - 10%; brown; considerably altered to laminated green pleochroic chlorite and epidote.

Accessory Minerals:-

Apatite-
Magnetite-

Secondary Minerals:-

S.W.M, Chlorite, Epidote.

W - 261 - 50

Quartz:- 45%; 6 mm. aggregates of sutured grains; grade 4; fractures are filled with carbonates. Deformation has made interpretation of quartz feldspar boundaries difficult but re-entrant boundaries convex toward feldspar cannot be result of simultaneous crystallization.

Feldspars:-

Microcline - absent.

Plagioclase - 40%; An8 or less; cloudy; 3-4 mm; considerably deformed; mosaic type of boundaries; altered to epidote, chlorite, S.W.M., carbonate; fractures filled with chlorite.

		Z.	Y.	X.		
Grain 1.	⊥(010)LC	14°	75°	88°	An6	1% N.W.
	⊥(001)LC	81°	23°	69°	An6	4% N.W.
Grain 3.	⊥(010)CL	18°	71°	88°	An0	1% W.
	⊥(001)C	75°	27°	68°	An0	1% N.E.
Grain 4.	⊥(010)CL	12°	79°	83°	An12	10% N.
	⊥(001)C	80°	28°	64°	An2	10% N.W.

Mafic Minerals:- 15%; possible amphibole replaced by aggregates of yellowish green epidote and green chlorite, similar to that in mica, S.W.M., sphene, carbonate. Mica replaced by chlorite.
-2V less than 5° X ≏ c.
X=pale yellow, Z=bluish green; interference color ultra blue.
(- peninite?, ripidolite?, or aphrosiderite?).
Other alterations- yellowish green epidote, sphene, quartz.

Secondary Minerals:

Epidote, Chlorite, S.W.M., Sphene, quartz

W - 285 - 50

Quartz:- 25-30%; irregular grains; grade 5; dusty; relations obscured by fracturing.

Feldspars:-

Microcline - 15%; somewhat dusty; 2 mm; microcline-like, but not proved to be microcline.

Plagioclase- 30% An15-28; cloudy; 1-3 mm; blocky anhedral; distorted; considerably altered to S.W.M, chlorite and epidote; some fractures filled with epidote and S.W.M.

Mafic Minerals:-

Hornblende- X' = yellow Z' = clear green. Z' ∧ c = 24°.
Acicular forms 1½ mm. long. About half altered to green chlorite similar to that in W- 261, and to yellowish green epidote, sphene, hydrated iron oxides.

Accessory Minerals:-

Apatite-
Magnetite-

Secondary Minerals:-

S.W.M.; Chlorite; Epidote; Hydrated iron oxides.

W - 287 - 50

Quartz:- 30%; 7 mm. aggregates of smaller grains; grade 5; bulbous; penetration of both plagioclase and microcline grains; greatest irregularity toward microcline.

Feldspars:-

Microcline- 20-30%; clear; 2-3 mm; sub blocky; 50% included; rounded to subhedral plagioclase; replaces plagioclase.

Plagioclase- 20-30%; An27-24; clear to slightly dusty; 2-3 mm; rectangular to blocky; subhedral to anhedral; altered to S.W.M.

Mafic Minerals:- 10%.

Hornblende- Z' ∧ c = 24° X = yellowish green; Z' = green. -2V = 70° considerably altered to chlorite, as in W - 261.

Biotite- X' = pale yellow, Y' = Z' = brown. Altered to chlorite, epidote, sphene.

Accessory Minerals:- Apatite, Magnetite - bpth in small quantities.

Secondary Minerals:- S.W.M., Chlorite, Sphene.

Z - 77 - 50

Quartz:- 25%; irregular grains; grade 2; very little included matter; fills interstices against flat plagioclase forms, but some isolated particles do exist adjacent to other grains.

Feldspars:-

Microcline - 10-15%; clear; 3 mm. grains; highly irregular shape; 60-80% included subhedral plagioclase; replaces plagioclase.

Plagioclase - 40%; An24; clear; 2-4 mm; zoned through narrow range; rectangular distortion and fracturing; moderate alteration to S.W.M.

Mafic Minerals:- 20%

Hornblende - Almost unaltered subhedral to euhedral shapes; up to 1½ mm. diameter.

	Z∧c	Accuracy Factor	−2V	Accuracy Factor	110∧1̄10
Grain 1.	12°	3	64°	3	57° = 123°
Grain 2.	7°	1			52° = 128°
Grain 3.	18°	3	50°	1	56° = 124°
Grain 4.	20°	2	44°	2	51° = 129°
Grain 5.	8°	1	70°	2	52° = 128°

X = Brown yellow, Y = Green, Z = Blue Green.

Biotite - X' = yellow, Y' = Z' = brown.
Absorption X<<Y = Z;
Partly altered to green pleochroic chlorite.

Accessory Minerals:-
Apatite
Magnetite

Secondary Minerals:- S.W.M., Chlorite.

PART D

XENOLITHS IN GAMBIER GRANODIORITE

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XENOLITHS IN GAMBIER GRANODIORITE

W - 60 - 50

Quartz:- 5-10%; small - ½ mm. and less; grade 0-1; interstitial to feldspars etc.; arcuate margins.

Feldspars:-

Microcline - None.

Plagioclase - 45%; An38-42 ($\perp ZX \wedge Cl = 8^\circ, 12^\circ$); indices similar to quartz. Zoning is slight and gradational; clear; 1 mm.; subhedral; possible alteration to another feldspar around edges; altered to S.W.M., epidote, chlorite (pale green), kaolin.

Mafic Minerals:- 50%

Amphibole - Maximum $Z \wedge c = 22^\circ$, X = nearly colorless; Y = pale brownish green, Z = pale blue green; Occurs as aggregates and ragged growth intermixed with fibrous material of very low birefringence, ($Z \wedge c = 12^\circ$); fine prisms and needles project into plagioclase. The darker variety is probably hornblende, the paler variety - actinolite.

Accessory Minerals:-

Apatite - less than 1%.

Secondary Minerals:-

Epidote - 10%. 2V near 90°; length fast; mildly or non pleochroic; it is an alteration product which occurs mostly in amphibole.

Sphene - 10% - in femic minerals.

Carbonates - 5%

Chlorite - 5%. Palegreen, in feldspar and femic minerals.

S.W.M. - occurs in feldspar.

Pyrite - less than 1%.

W - 78 - 50

Quartz:- 25%; clear; .1 - 2 mm. grains; grade 1-2; isolated similarly oriented groups, or as large porphyroblasts with a rim of hornblende (Plate XIII,B). The hornblende of the rim is still partly embedded in quartz. Some quartz contains zoned rectangular inclusions of plagioclase. The borders of the inclusions, though fairly straight, cross crystal directions at small angles.

Feldspars:-

Microcline - None.

Plagioclase - 35%; clear; two distinct sizes; the smaller grains are less than 1 mm. in length; subhedral; highly zoned and twinned. Composition ranges from An59 to An31. The larger grains are about 2 mm. or more in diameter; comparatively unzoned and not extensively twinned; composition An 35±2. The porphyroblasts contain fine prismatic grains of amphibole, some of which are oriented similarly to one another; these may have replaced feldspar. Alteration to S.W.M. is noticeable in both types but is most prominent in the fine, highly zoned laths. In some grains the core is entirely replaced by an aggregate of S.W.M.

		Z.	Y.	X.		
Grain 1(groundmass)						
Core	⊥(010)CL	33°	59°	76°	An59	8% S.W.
	⊥(001)C	57°	51°	56°	An62	8% N.W.
Rim	⊥(010)CL	12°	80°	89°	An31	1% N.
	⊥(001)C	81°	14°	81°	An31	7% N.W.

Remarks:- (010) is probably more reliable than (001).
λ_Y rim > λ_ω quartz.
λ_Z rim > λ_ϵ quartz.

Grain 2(porphyroblast)						
	⊥(001)C	72°	19°	86°	An34	1% N.W.
	⊥(1$\bar{1}$0)C	69°	55°	44°	An36	1% N.W.

(001) and (1$\bar{1}$0) are equally accurate, average value is An35.

Grain 3(groundmass)						
Core	⊥(001)C	60°	48°	56°	An60	5% W.
Rim	⊥(001)C	81°	22°	71°	An7	1% N.W.

Mafic Minerals:-

Amphibole - 30%; irregular or prism shaped; maximum size is 1 mm. Age relative to plagioclase indeterminate, appears to be pre-quartz.

Optic properties determined by Fedorov Method:

	$Z\wedge c$	$-2V$	$\frac{110}{54°}\ \frac{1\bar{1}0}{=126}$
Grain 1	14°	54°	
Grain 2	16°	66°	
Average	15°	60°	

Then $Z\wedge c = 15$ $-2V = 60$

Pleochroism:-
X = greyish green with blue tint at borders.
Y = brownish green with green borders.
Z = bluish green.

Biotite - 10%; very small -2V;
Pleochroism X' = straw yellow, Y' = brown, Z' = brown.
Absorption X<<Y = Z
Occurs as irregular grains 1 mm. or less; slightly altered to chlorite and epidote.

Pyrite - Less than 1%.

Accessory Minerals:-
Apatite - trace.
Magnetite - less than 1%.

Secondary Minerals:-
Epidote - in mica and amphibole; epidote in mica is as follows:- 2V = 89° (Fed.)

	Z	Y	X
Cleavage	2°	90°	8°

S.W.M. - in feldspars.

W - 84 - 50

Quartz:- 15%-20%; clear; .2 mm; grade 2; includes and replaces plagioclase, parallel with cleavage; intergrown with hornblende.

Feldspars:-
Microcline - None.

Plagioclase - 40%; clear; two sizes - rectangular and irregular grains less than 1 mm., and equidimensional grains nearly 2 mm. in diameter.
The smaller grains are subhedral in some cases and show crystal forms to quartz; lamellar twinning is prominent. They are altered to S.W.M., particularily at cores.
The large grains are not much zoned, and are anhedral. Cross twinning is present. Some of them have a nearly circular ring of S.W.M. near borders. Both types contain slight alteration to epidote and chlorite.

Mafic Minerals:-
Amphibole - 35%; brownish green with blue green borders; size - 1 mm. or less.
$Z' \wedge c = 18°$; X' = yellowish green; Y' = brownish green; Z' = bluish green; -2V = 65°; this amphibole resembles that of W-78 very closely.
Some ragged edges of amphibole project into feldspar; small plagioclase inclusions in amphibole; slightly altered to green pleochroic chlorite.

Biotite - Original content may have been 10%; former presence now suggested by chlorite pseudomorphs.

Accessory Minerals:-
Apatite-
Magnetite (?).

Secondary Minerals:-
S.W.M. in plagioclase - moderate.
Epidote in plagioclase - very little.
Chlorite in plagioclase - pale green. Quantity small.
Chlorite in amphibole - pleochroic green. Quantity small.
Zoisite - in mafic minerals possibly as pseudomorphs after biotite; mixed with chlorite.
Carbonates - very little.

Note:-
The next three specimens (W-87, 89, and 90) were collected from a xenolith of tuff 25 feet in width, north of Hope Point. The xenolith is bounded partly by faults. The trend of the xenolith and bedding is 007 . The margins of the contact are distinctly sedimentary, Plate XI, A. Bedding is obscure four feet from the margin and imperceptible six feet from the margin. The central part, represented by W-90, has the same color and appearance as the outer part, except that grain is coarser and bedding has been obliterated.

W - 87 - 50 One foot from margin of inclusion.

Quartz:- 5%. Contains minute rods of apatite-like mineral.

Feldspars:- 75%; cloudy; two kinds - some with index below balsam, some with index near balsam. Lath shaped grains with maximum extinction angle = 5° (15 grains), hence laths are oligoclase. Mosaic interlocking grains have an index below balsam, not accurately identified.

Alteration Products:-
Pale green chlorite, zoisite?, carbonate.

Mafic Minerals:-
Sphene) -5%
Epidote)

Secondary Minerals:-
S.W.M.)
Epidote) none extensive.
Chlorite)

W - 89 - 50 Six feet from margin of inclusion.

Quartz:- 5% or less; clear; less than 0.2 mm; grade 0; interstitial to feldspar grains.

Feldspars:-

Microcline - none.

Plagioclase - 80%; cloudy; two distinct sizes - less than ½ mm. and 1 mm. or more. The smaller size occurs as mosaic interlocking or subhedral rectangular grains; they are highly zoned; index varies from considerably above to slightly below balsam. The larger type is much less zoned; n_x just less than balsam, n_γ just greater than balsam. Feldspars closely resemble those of W-78, but with less euhedrism. Both types are altered to pale green chlorite, very little S.W.M., and considerable carbonate.
Off center figure on larger size gives composition An30 ± 5.
Maximum extinction angle (15 grains) of groundmass plagioclase = 23°, indices just above balsam. Therefore groundmass plagioclase is andesine about An40.

Mafic Minerals:- 2%. Mafic minerals are entirely altered to sphene, chlorite.

Accessory Minerals:-

Apatite.

Secondary Minerals:- Total 20%.

Sphene, Chlorite, S.W.M., Carbonate.

W - 90 - 50 Twelve feet from margin of inclusion.

Quartz:- 2% or less; clear; 0.2 mm; grade 0.

Feldspars:-

Microcline - None.

Plagioclase - 85%. Very similar to W-89, but coarser. Small grains have a maximum of ½ mm. and large grains have a maximum of 3 mm. In this section there are a number of very slightly zoned subhedral plagioclase grains of intermediate size. Indices of both sizes are slightly less than balsam, and neither type is highly zoned.

Alteration Products:- Carbonate, considerable S.W.M., and pale green chlorite.

Mafic Minerals:- One area which may have been a Ca-Fe-Mg silicate, is entirely altered to green chlorite. Elsewhere, sphene occurs in small groups of grains. Opaque oxide or sulphide - 1%. Content of mafic material is slightly above that of thin section W-89.

Accessory Minerals:-
Apatite.

Secondary Minerals:
S.W.M. in feldspar.
Epidote in mafic minerals.
Chlorite in mafic minerals and feldspar.
Sphene.
Carbonate in feldspar.

W - 95 - 50

Quartz:- 15%; clear; ½ mm. and smaller; grade 0 - 1; interstices and micrographic intergrowths.

Feldspars:-
Microcline - None.

Plagioclase - present content is small; indices very near balsam; unzoned; highly altered to epidote.

Mafic Minerals:-
Amphibole - 15%. $Z' \wedge c = 14^\circ$ (6 grains) $-2V = 70^\circ$
X'=very pale yellow; Y'= pale green; Z'= pale green. Forms slender feathery aggregates. It appears to be of secondary origin, some acicular prisms project into feldspar and quartz.

Accessory Minerals:-
Apatite -

Secondary Minerals:-
Epidote - 25%. $-2V = 85^\circ$, optic plane cleavage and parallel with parting.
$X \wedge c = 3^\circ$, $X \wedge 001 = 68^\circ$
$Z \wedge 001 = 22^\circ$
X'=colorless; Y'=pale yellow; Z'=pale yellow. It occurs throughout the thin section and appears to replace both mafic and felsic minerals.
Chlorite - pale green, not prominent.
Kaolin - dusty alteration feldspars.

W - 97 - 50

Quartz:- 5 - 10%; clear; 1 mm; grade 2; includes hornblende and plagioclase, single grains or aggregates of small grains; in places grains of similar orientation are isolated.

Feldspars:-

Microcline - None.

Plagioclase - 40%; clear; two sizes; small subhedral ½ mm. and larger 2 mm. grains; both kinds are zoned, some of the larger grains contain clear quartz inclusions with lower index. Some separated quartz and hornblende inclusions are similarly oriented. Composition of one large grain An41-28; some have indices below balsam.
Altered to epidote, S.W.M., mica (?), zoisite(?).

Mafic Minerals:

Amphibole - occurs in a variety of shapes up to 1 mm. long; relationships to other minerals are such that age relationships cannot be deciphered. It occurs as similarly oriented fine prisms in some plagioclase. Alteration very minor.

Hornblende - (Fedorov).

	$Z \wedge c$	$-2V$	$110 \wedge 1\bar{1}0$
Grain 1.	13°	50°	$\frac{}{55} = 125°$
Grain 2.	22°	60°	
Average -	17	56	

X = yellow; Y = brownish green; Z = bluish green. When Y or Z is in the plane of the thin section, the grains appear to have distinctly blue borders.

Biotite- 10%; small -2V; $X \simeq c$.
X = straw yellow; Y = brown; Z = dark brown;
Absorption $X << Y << Z$;
Occurs as irregular masses up to 1 mm. diameter intergrown with other minerals.

Accessory Minerals:-

Apatite -
Magnetite-

Secondary Minerals:-

S.W.M. - 15%; occurs in plagioclase.
Epidote - 5%; occurs in mica and plagioclase.

W - 99 -50

Quartz: - 10%; clear; two sizes, very small 0.1 mm. or less, and medium 3-4 mm.; grade 2; the smaller grains are interstitial to other minerals, the larger ones occur as eye shaped masses with included rectangular hornblende, particularly at borders.

Feldspars:-

Microcline - none.

Plagioclase - 20%; clear; 2 mm. porphyroblasts in matrix of ½ mm. subhedral grains.
Porphyroblast - An39, nearly unzoned.
The smaller grains are more highly zoned and all indices are above balsam.
Slight alteration to S.W.M. and epidote. Some of larger plagioclase grains contain prisms and irregular masses of hornblende.

Mafic Minerals:-

Amphibole - 50%; $-2V = 65° \pm$; $Z\acute{A}c = 19°$.
X' = pale yellow; Y' = green; Z' = green.
Occurs as very fine equidimensional grains, mostly less than .1 mm., of prismatic or irregular shape; intergrown with feldspars; some isolated prisms included in plagioclase. Amphibole is unaltered.

Mica - Biotite may have constituted 5-10% of the rock formerly. If so, it is now altered to laminar masses of epidote (colorless) and green chlorite.

Accessory Minerals:

Apatite and Magnetite are both present but very sparse.

Secondary Minerals:

S.W.M. - in feldspars.
Epidote chlorite - pseudomorphous after mica
Chlorite in feldspars.

W - 100 - 50

Quartz:- 20 -30%; irregular grains, parts of which may be isolated from one another; grade 2; 40 - 50% included material in the form of euhedral plagioclase. Relations difficult to interpret but quartz fills interstices between plagioclase grains and either replaces or is replaced by brownish biotite.

Feldspars:-
Microcline - Absent.

Plagioclase - 40%; zoned; An40-27, An49-34; clear; twinned subhedral grains; euhedrism best against quartz. Most are less than .5 mm. long; diverse orientation. Moderately altered to S.W.M.

Mafic Minerals:-
Hornblende - 35%. -2V = 70° ± 5°, Z' ∧ c = 19°.
X' = yellow, Y' = brownish green, Z' = green to blue. Irregular 1 mm. grains and aggregates of grains 2-3 mm. across, interlocking to smooth boundaries with plagioclase; relations difficult to decipher. Slight alteration to chlorite and epidote.

Biotite - 5%. -2V = 5 X ≐ c.
X' = yellow, Y' = Z' = greenish brown.
Ragged boundaries; intergrown with plagioclase; divides one grain of hornblende; alters to chlorite and epidote (Plate XIX, A.).

Accessory Minerals:-
Apatite
Magnetite- 1-2%.

Secondary Minerals:-
S.W.M. - in feldspars.
Chlorite) both occur in mafic minerals in small
Epidote) quantity.

Note:-
Specimens W-186, W-187, and W-188, were collected north-east of Hope Point. W-186 and W-187 are from a xenolith 10 to 15 feet wide. W-186 was collected near the center of the xenolith and W-187, near the border zone. Alteration of the minerals of W-186 precludes accurate comparison of composition. However, the border zone does appear to have more quartz and less mafic material.

W-188 was taken from a dense white lenticular mass within a xenolith adjacent to the above xenolith. This lenticular mass eighteen inches by six inches is separated from the outer part of the inclusion by a one inch granitic zone. Some quartz crystals cross the margin between the granitic zone and the dense white lenticular core. The same is true of the boundary between the granitic zone and the outer part of the xenolith.

The outer region of the xenolith is megascopically indistinguishable from the adjacent xenolith (W-186,187).

The strike of the dense white core is 060°.

W - 186 - 50

Quartz:- 15%; clear; 1½ mm; grade 1-2; inclusions of subhedral to rectangular plagioclase and hornblende; replaces plagioclase. Grains are irregular in detail.

Feldspars:-

Microcline - None.

Plagioclase - 35%; highly altered and not determined; indices vary from slightly above n_ϵ quartz to slightly above n_ω quartz. Hence plagioclase is probably calcic oligoclase or sodic andesine. Altered to S.W.M., epidote, chlorite.

Mafic Minerals:-

Amphibole - 40% originally; $-2V = 60°-70°$; $Z \wedge c = 26°$.
X = pale yellow; Y = brown; Z = brownish green.
X = pale yellow; Y = brown; Z = blue - green.
Occurs as ragged, highly altered masses 1-2 mm. in diameter. Alteration products are carbonate, epidote and pleochroic green chlorite.

Biotite - may have been one of the original constituents as indicated by chlorite, epidote, pseudomorphs.

Accessory Minerals:-

Apatite, and magnetite - combined amount about 2% of rock, though apatite is in very small quantity.

Secondary Minerals:-

S.W.M. - much of feldspars.
Carbonate - considerable amount in mafic minerals.
Chlorite - green pleochroic, deep blue interference color; occurs in mafic minerals.
Epidote - pale yellow.
Sphene - associated with mafic minerals.

W - 187 - 50

Quartz:- 25%; clear; .5 - 3mm; irregular; includes and replaces plagioclase.

Feldspars:-

Microcline - None.

Plagioclase - 45%; much altered to S.W.M. Occurs as zoned grains generally less than 1 mm; some grains are cloudy, some are clear.

		Z.	Y.	X.		Error
Grain 1.	groundmass					
Core	⊥(010)L	13	79	83	An33	6% N.E.
	⊥(001)C	75	15	88	An32	1% N.W.
Rim	⊥(010)L	7	90	83	An20	7% N.
	⊥(001)C	86	6	87	An22	2% S.W.
Grain 2.	groundmass					
	⊥(001)L	69	24	87	An38	
	⊥(010)L	10	77	87	An32	
	(010) is less accurate than (001)					
Grain 3.	groundmass					
Core	⊥(001)C	69	23	79	An38	2% N.W.
Rim	⊥(001)C	80	11	84	An25	1% N.E.
Grain 4.	enclosed in quartz - unzoned.					
	⊥(010)C	9	83	87	An28	3% N.E.
	⊥(001)C	76	15	84	An28	2% N.E.

The most calcic plagioclase is An38 and the least calcic is An20. The unzoned grain included in quartz is An28.

Mafic Minerals:- 30%.

Amphibole - grains and masses of grains up to 2 mm.; ragged to linear margins; altered to epidote, chlorite.

	Z∧c	-2V	110∧1$\bar{1}$0
Grain 1	28		
Grain 2	18	64	48 = 132
Grain 3	12	64	

Weighted average Z∧c = (1 x 28) (2 x 18) (1 x 12) /4 = 19 .
average -2V = 64.
Both 2V determinations are considered to be of equal value.
X = yellowish brown; Y = brownish green;
Z = green with blue green borders.

Mica - only pseudomorphs of chlorite and epidote remain as indicators of the possible former presence of mica.

Accessory Minerals:

Apatite and Magnetite - total content very small.

Secondary Minerals:

S.W.M. - in feldspars, some grains of which are much altered.
Epidote- singly and in masses in feldspars and amphibole.
Chlorite
Sphene.

W - 188 - 50

Quartz:- 50%; clear; 2 mm.; grade 2; occurs partly as solitary masses but mostly as fine worm-like growths in microcline, and plagioclase. The myrmekitic quartz grains are sub parallel in one dimension; but are triangular in cross section.

Feldspars:- 45%. Some of the feldspars in the intergrowth are definitely microcline. All feldspar has an index less than quartz. A few grains of microcline up to 2 cm. across, are not micrographic.

Mafic Minerals:-
Epidote - as isolated grains and as masses of pleochroic grains (X' = colorless; Z' = very pale green.). Maximum size-2 cm. long. Total content about 5% or less.

Remarks:- 75% of this thin section is a fine micrographic intergrowth of quartz and potash or sodic feldspar.

W - 251 - 50

Quartz:- 10%; clear; 0.1 mm; grade 0; mosaic intergrowths with feldspar and epidote.

Feldspars:-
Microcline - not recognized.

Plagioclase - 40%. Fine grained mosaic of calcic feldspar 0.05 mm. and less. Maximum extinction angle of 10 grains = 33°. Index well above balsam so plagioclase is An57±3.

Mafic Minerals:-
Hornblende - 5%; 0.05 to 0.1 mm; X' = yellowish; Y' = green; Z' = blue green. Occurs as fine needles which project into feldspar and as masses of small grains.
Epidote - 40%; 0.1 mm. grains, equidimensional, mosaic. ±2V = 85°; Z'∧ cleavage = 44°.
Magnetite - 5%; small - 0.1 mm.
Sphene - 0.1 mm. aggregates of very fine grains.

A poorly developed banded effect is produced by alternating epidote rich and plagioclase rich zones.

W - 252 - 50

This specimen was taken from a shadowy zone, slightly darker than the granodiorite matrix. It appeared to be a remnant of a very highly altered or granitized xenolith.

Quartz:- 30%; clear; up to 1 mm; grade 2; wavy, slightly bulging or irregular boundaries; age relative to feldspars obscure.

Feldspars:-

Microcline - 20%; clear; 2 mm; irregular; replaces plagioclase and leaves rectangular remnants.

Plagioclase - 20-25%; slightly dusty; 1.5 mm; highly zoned; subhedral; replaced by microcline. Centered figure gives composition of one grain as; core An19; intermediate part An35; rim An19. n_γ rim is less than n_ϵ quartz.

Mafic Minerals:-

Amphibole - 40%. $Z' \wedge c = 25$; $-2V = 65$
X' = pale yellow; Y' = brownish green; Z' = green to bluish green; small equidimensional grains .1 - .5 mm. in diameter form mosaic pattern with feldspars and quartz. Minor alteration to epidote, particularly along fractures.

Accessory Minerals:-

Apatite - many grains are quite small but at least one is about 1 mm. long.
Sphene - grains up to 1 mm.

Secondary Minerals:-

Epidote - occurs as aggregates which show no indication that they are alteration products from other minerals, and as alteration products of feldspars or fracture filling. Epidote which fills fractures in hornblende is more yellow and more distinctly pleochroic than epidote which fills fractures in feldspar.