PETROGRAPHY AND PETROLOGY OF THE ROCKS IN THE FISH LAKE AREA, SOUTHEASTERN WALLOWA MOUNTAINS, OREGON

by

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CONTENTS

ILLUSTRATIONS

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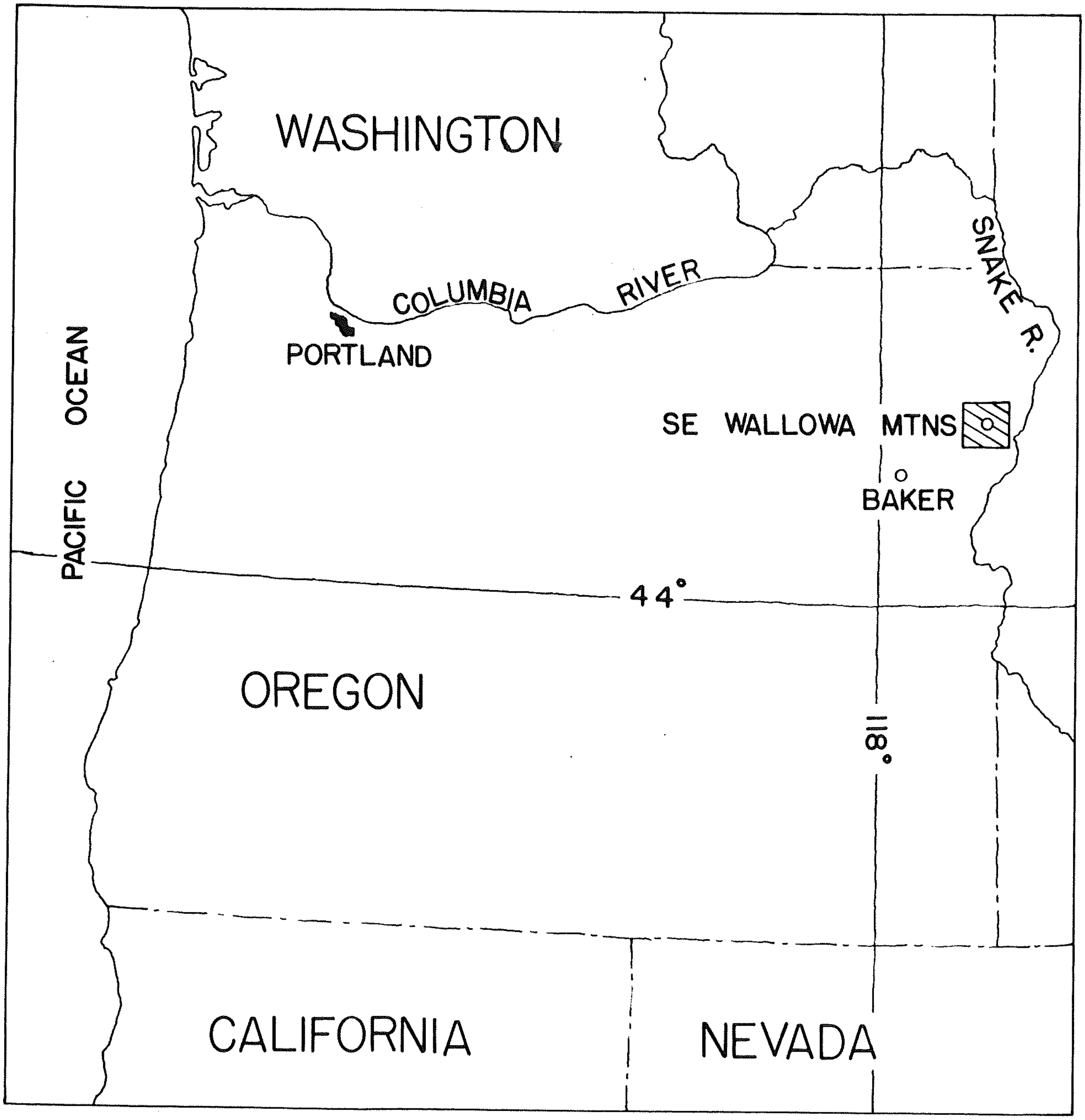

Fig. 1. Index map showing the location of the southeastern Wallowa Mountains, Oregon.

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INTRODUCTION

SCOPE OF THE THESIS

As shown in Fig. 1, the area covered by this thesis lies in the southeastern part of the Wallowa Mountains in Baker County in northeastern Oregon. This area was first seen by the writer in the summer of 1950 while on a side trip during the second half of the University of Washington Summer Geology Field-Course at Cornucopia, Oregon, conducted by Professor G.E. Goodspeed with assistance by Harry Smedes. The small area was chosen so that the petrography and petrology could be done in some detail. Field study and mapping of the stock was done during the summer of 1951. Pre-Tertiary rocks only were studied.

PREVIOUS WORK IN THE AREA

C.P. Ross made a preliminary or reconnaissance study of the southeastern Wallowa Mountains in 1921 which included most of the area covered by this thesis; hereafter, for ease of reference, to be called the "Fish Lake area."

THE GEOLOGIC MAP

The only topographic map available for this area was the reconnaissance topographic map of the U.S. Forest Service, with 500-foot contour interval. Because this was not sufficiently accurate, 3X enlargments of 1 : 20,000 U. S. Forest Service aerial photographs were used as a base for mapping.

An adjusted map was prepared directly from the enlarged aerial photographs by photogrammetric methods; this was reduced ⅓X to produce the final geologic map. Because a base line was not established in the area during the course of the field work it was impossible to correctly orient the final map; therefore, the line connecting the N-S collimation points on Aerial Photo CSN 28-49 was arbitrarily chosen as true north. The scale of the map was computed from the scale of the aerial photos and is thus only approximate. However, the photogrammetry was done with some care and the location of features on the map with respect to each other is considered to be reasonably accurate.

ACCESSIBILITY AND TOPOGRAPHY OF THE AREA

The Fish Lake area is easily accessible by a Forest Service road which leads to Fish Lake from Halfway, Oregon, approximately 60 miles, by excellent paved highway, northeast of Baker. Good camping space, fresh spring water, and good fishing are found at Fish Lake. The road is generally closed by snow until the first of July and one may occasionally have to pack in the last half mile or so until the middle of July. It is usually not adviseable to attempt the road beyond Fish Lake before the last week in July unless one is equipped with tire chains, a good shovel, and the desire to use both.

This area has undergone glaciation and many outcrops are smoothly rounded roches moutonnees from a few feet to a hundred feet high; the intervening areas have been plucked out and more or less filled with till. Most important contacts have also been plucked out and covered with till. Many of the low spots are occupied by marshy meadows or small lakes and others are covered with evergreens. The smooth massive rock is difficult to sample properly. Fig. 2 shows some of the higher country.

The area has nearly 2,000 feet of relief, from about 5,500 where Clear Creek leaves the West Stock to 7,450 atop Sugarloaf Mountain on the ridge between Clear Creek and the Imnaha River, to the north.

PETROGRAPHIC METHODS

147 thin sections were examined in the petrographic microscope. 73 of these were duplicates of other rock-types and were not studied in detail. The remaining 74 were examined with some care. They are not described individually in the body of the paper, however. The description

Fig. 2. Characteristic topography of the Fish Lake area.

of one thin section of lamprophyre is made to suffice for the 10 sections studied because, although each one represents a different dike, they are all very similar. On the other hand, selected specimens of some of the gabbros and lime-silicate rocks are described individually to provide a more detailed picture of the rocks.

Three specimens of gabbro and peridotite were chosen from the stocks, crushed, and studied in index oils to determine the indices of refraction and thus approximate composition of olivine and hypersthene. Six specimens of the lime-silicate rocks were crushed and studied in index oils to determine the indices of refraction and thus approximate composition of garnet, diopside, enstatite, epidote, and untwinned plagioclase; the indices of vesuvianite were noted in two samples. Crushed samples of three specimens of the fine-grained contact facies of massive greenstone, two extra-dense lamprophyre dikes and one xenolith of sheared greenstone were studied in index oils to determine the composition of their plagioclase.

The mineral composition of some of the gabbros and skarn rocks was determined by counting intercepts on a cross-hair calibrated in 100 divisions, employing from eight to twenty-five traverses depending on the grain size of the rock. As each traverse was 1.5 mm in length, the total length of traversing varied from 12 mm to 38 mm. The volume per cent of each mineral present was calculated from these figures and rounded off to the nearest five per cent.

where the values were sufficiently large, and to the nearest one per cent otherwise. Volume per cent was not changed to weight per cent. Using these values and the graphs of weight per cent oxide composition of isomorphous minerals (Appendix A), the chemical composition of the rocks was computed. These figures were rounded off the same way as were the mineral percentage values; it is realized that these figures are not accurate, but it is felt that the proportions are probably reasonably accurate and that the figures are thus of value for illustrative purposes.

GENERAL GEOLOGY AND STRUCTURE

SUMMARY NOTE

The oldest rocks in the area are tuffaceous arkoses of Pennsylvanian(?) age which underlie the Permian Clover Creek greenstone. One outcrop was observed a quarter of a mile east of Fish Lake which contained interbedded greenstone and tuffaceous arkose, indicating that the contact may be conformable.

The Clover Creek greenstone appears to be mostly undeformed in the Fish Lake area; although much variation is found from outcrop to outcrop, one exposure of pillow lava found appeared to be undeformed. The tuffaceous arkoses are deformed in open folds; the greenstone may be similarly folded. A prominent band of sheared greenstone cuts across the area in one place and is associated with marble lenses.

Four small diorite-gabbro stocks intrude the greenstone and seem to be partly controlled in location by the zone of shearing or lenses of marble.

AGES OF OROGENY

With respect to ages of orogeny in this area, the following statements by previous workers are pertinent.

According to Ross (1):

> At the close of the Paleozoic, there was great orogenic movement . . . probably most of the metamorphism of the Paleozoic rocks occured at this time . . .
>
> The greatest orogenic movements of which a clear record remains took place in late Mesozoic, probably Cretaceous time. The batholithic masses of granodiorite (to the west and northwest) . . . were intruded. The older rocks were violently compressed and thrown into great folds, metamorphosed, sheared and probably faulted.

Also Ross (p. 45) says, "As the (diorite-gabbro) . . . cuts rocks at least as young as Permian the intrusion can hardly be older than Mesozoic."

No evidence was discovered in the Fish Lake area to substantiate an orogeny at the close of the Paleozoic.

Gilluly (2) says:

> . . . the more or less metamorphosed plutonic rocks are . . . classed . . . as post-Carboniferous (?), while the biotite-quartz diorite is considered doubtfully post-Jurassic. It is entirely possible, however, that some of the so-called post-Carboniferous (?) rocks are really Permian.

With regard to two ages of orogeny, one at the end of the Paleozoic and another in late Mesozoic, Gilluly is in general agreement with Ross.

Fitzsimmons (3) found evidence of Jurassic orogeny in the rocks of the Pine Quadrangle to the south.

WORK IN THE FISH LAKE AREA

Age of Marble

An immediate problem is the age of the marble with respect to the greenstone. Three possibilities must be considered.

1. The marble is older than the greenstone and was carried to its present position, bordering the stocks, from below by rising magma.

2. The marble was an interbedded lens in the greenstone and has been partly broken-up and shouldered aside by the magma.

3. The marble is younger than the greenstone and was carried to its present position, bordering the stock, from below a thrust plane by rising magma.

If point (1) were to be valid, it would be necessary that the rocks underlying the greenstone contain marble. No marble was noted in the tuffaceous arkoses adjacent to the stock, which appear to dip beneath the greenstones. Ross also mentions no limestones in these rocks. In general, limestone is not found intercalated with arkose; their environments of formation are too different.

However, Pennsylvanian(?) rocks (which underlie the Clover Creek greenstone) in the Elkhorn Ridge sixty miles to the southwest are described by Gilluly (4) as follows:

> Limestone is present as a very subordinate but highly interesting constituent of the Elkhorn Ridge argillite. It occurs as lenses or pod-

> like bodies, some with rectilinear boundaries, clearly resultant from stretching and breaking-up of a once continuous bed or beds . . . The limestone is commonly bluish gray, highly jointed, and locally altered to marble.

It is not impossible that rocks similar to this could be present farther down in the section, but it is unlikely.

If point (2) were to be valid, it would be necessary that lenses of limestone be commonly present in the Clover Creek greenstone.

Gilluly (p. 19 this paper) is quoted as saying that the Clover Creek greenstone contains subordinate limestone. Ross(5) states that the Clover Creek of the Wallowa Mountains contains subordinate marble. Fitzsimmons(6) mentions minor amounts of limestone associated with tightly folded greenstone forty miles to the SW. As mentioned on page 16, the writer found a little purple marble as a matrix in pillow lava. Thus point (2) seems possible.

If point (3) were to be valid it would be necessary to show that the greenstones are a plate thrust over upper Triassic Martinbridge limestone, the only younger limestone in the region.

Livingston (7) describes a thrust which runs along the Snake River valley about 20 miles east of Fish Lake. As the attitude of the thrust is N40E to N50E, 20 to 60 NW, the thrust plane probably extends beneath the Fish Lake area. Its age is known only as "post-Jurassic and pre-Miocene."

An interesting point is the similarity between the stretched dikes noted in one of the xenoliths and stretched dikes noted in the Triassic limestone to the north (p. 34).

A more compelling point remains to be considered. It will be shown in the petrographic descriptions that the lime-silicate rocks are present as lenses in the sheared amphibolitic greenstone; although no marble was found in the sheared greenstone, it will be shown that all degrees of intermixture between marble and lime-silicate granulite exist and that they are certainly contemporaneous. The fact that lime-silicate is present as lenses in the sheared greenstone precludes the possibility that it was carried into position by rising magma. One cannot ignore the possibility that the lime-silicate granulite was moved upward in the shear zone during the time of deformation. However, this would imply movement of large magnitude, probably enough to expose the older rocks.

Therefore, in view of the foregoing evidence, it seems most likely that the marble and associated lime-silicate granulite are of the same age, that both were originally present as rather large, somewhat siliceous dolomitic limestone lenses in the Permian Clover Creek greenstone.

Age of Sheared Greenstone

A problem which arises in dating the rocks of the Fish

Lake area is as follows: In which of the two supposed orogenies was the sheared greenstone made?

The sheared greenstone might have been made in either of two orogenies. Because intense deformation of late Mesozoic age is present nearby both to the north and south, it is felt that deformation of the greenstone must be referred to the Mesozoic. No evidence of more than one period of deformation was found in the sheared greenstone, the only strongly deformed element present.

Age of Diorite-Gabbro Complex

Another problem which arises is as follows: After which supposed orogeny was the diorite-gabbro emplaced? In agreement with Ross, it is seen that the diorite-gabbro must be post-Mesozoic-orogeny in age; if it were pre-orogenic it would show signs of deformation. In the petrographic descriptions, it is shown that the diorite-gabbro is undeformed.

One feature common to all the rocks in the area may shed some further light on the age of the intrusives. In the petrographic descriptions, the same kind of feldspar alteration is noted in describing every rock type; an exceedingly fine-grained (sub-microscopic) brownish aggregate of clinozoisite(?), believed to be clinozoisite because of its high relief and occasional display of anomalous colors characteristic of clinozoisite. The presence of this ubiquitous alteration product suggests that all the rocks in the area have been subjected to the same process, a late low temperature phase of regional alteration.

One may postulate as follows: A dying surge of movement accompanied by low-temperature hydrothermal solutions developed a strong joint system and partly altered the feldspar in all the rocks. This was probably simultaneous with late mineralization at Cornucopia to the west, described by Goodspeed(8).

The sheared peridotite xenoliths to be described may have been formed from pre-orogenic basic intrusives. In the discussion of petrology, it will be shown that the sheared peridotites were probably synkinematic intrusives (i.e. intruded simultaneously with deformational movement.)

HISTORY OF THE AREA

On the basis of the foregoing evidence, a partial history including the rocks of the Fish Lake area is as follows. The Permian greenstones were deformed in a late Mesozoic orogeny. Because of their massive character they were deformed only along certain zones of weakness, where epizonal greenschists were formed. Synkinematic ultrabasics were intruded and sheared while still hot, maintaining their mineralogic content.

In immediately post-orogenic time, the diorite-gabbro complex was emplaced and formed its various contact metamorphic phases.

A dying surge of movement was unable to further deform the rocks; the principal effects were formation of strong jointing and alteration of feldspar.

PETROGRAPHY

PRE-INTRUSIVE ROCKS

Summary Note

The oldest rocks in the area are tuffaceous arkoses of Pennsylvanian(?) age which appear to underlie the Permian Clover Creek greenstone. Small basic stocks cut the greenstone and have formed contact metamorphic aureoles in the greenstone. Within the stocks are various inclusions of peridotite, gabbro, and lime-silicate granulites. Later dikes transect the stocks and neighboring rocks.

Tuffaceous Arkose

The presence of tuffaceous arkose is noted; it is not considered part of this thesis and will not be discussed at any length.

Clover Creek Greenstone

The Clover Creek greenstone is described by Ross(9) as follows:

> The old lavas that form the principal part

> of the formation . . . were originally andesites and dacites. They have all been altered, partially recrystallized, and in a few places, are schistose. Ferromagnesian minerals do not appear to have been abundant and they have now been altered mainly to epidote and chlorite. The feldspars not completely clouded by alteration products appear to be oligoclase and oligoclase-andesine . . . A few of the rocks are nearly black . . . These dark rocks are thought to have had the composition of basic andesites.

The greenstones surrounding the stocks are massive, structureless, generally green rocks which convey the general impression of not having been deformed. However there is considerable variation from roche moutonnee to roche moutonnee so that few easily mappable units appear to be present. Two units were noted which, if mapped in detail, might lend a clue to any structure. The first of these is a porphyritic rock with large (1 in.) feldspar phenocrysts which was noted about 3/4 mile west of Fish Lake. The other is a lens (?) of tuff-breccia with a purple marble matrix about 3/4 mile northwest of the Melhorn reservoir. Near this rock was noted one exposure of pillow lava with a matrix of purple marble. It appears to be completely undeformed. See Fig. 3.

Several specimens of greenstone were collected at different distances from the stocks so that the contact metamorphic aureole could be studied. Those specimens collected farthest from the stocks are most nearly representative of unaltered greenstone.

A specimen collected about 3300 feet north of the West Stock resembles other greenstones in hand specimen;

its description will suffice for the other slides studied. In thin section the following features are seen.

Euhedral relict labradorite (An_{60}) is present in grains averaging 0.5 mm in length. It is strongly altered, partly to sericite and partly to dense brownish masses of very fine-grained clinozoisite with abnormal colors occasionally visible. Little stringers of clinochlore have formed along inter-grain cracks and along albite twinning planes. Green hornblende is pleochroic as follows: Z-darker bluish green, Y-yellowish green, X-light brown. It forms thin rims on augite grains or occurs as discrete xenoblastic grains. It alters to clinochlore (occasionally to penninnite). Relict augite encloses laths of feldspar, exhibiting blasto-ophitic texture. Clinochlore is very fine-grained, the average length of the tiny interlocking fibers being 0.008 mm. It occurs in irregular masses (av. dia. 1 mm) which enclose small relic plates of augite and tiny fibers of green hornblende. Magnetite is present as irregular grains partly wrapped around corroded plagioclase laths. See Fig. 4.

The estimated mineral composition is as follows:

Augite	40%
Labradorite	50%
Green hornblende	7%
Clinochlore	3%
Magnetite	2%

The rock is a slightly altered diabase.

The minor green hornblende in this rock may have been formed in either of two ways: (1) It may have been formed by deuteric alteration of pyroxene late in the cooling his-

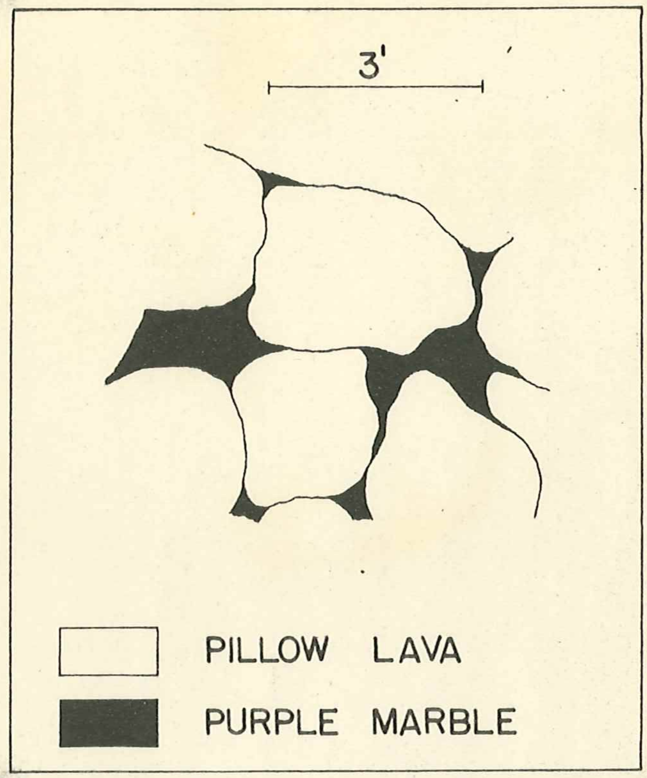

Fig. 3. Pillow lavas which occur in the greenstones north of the West Stock. A vertical exposure.

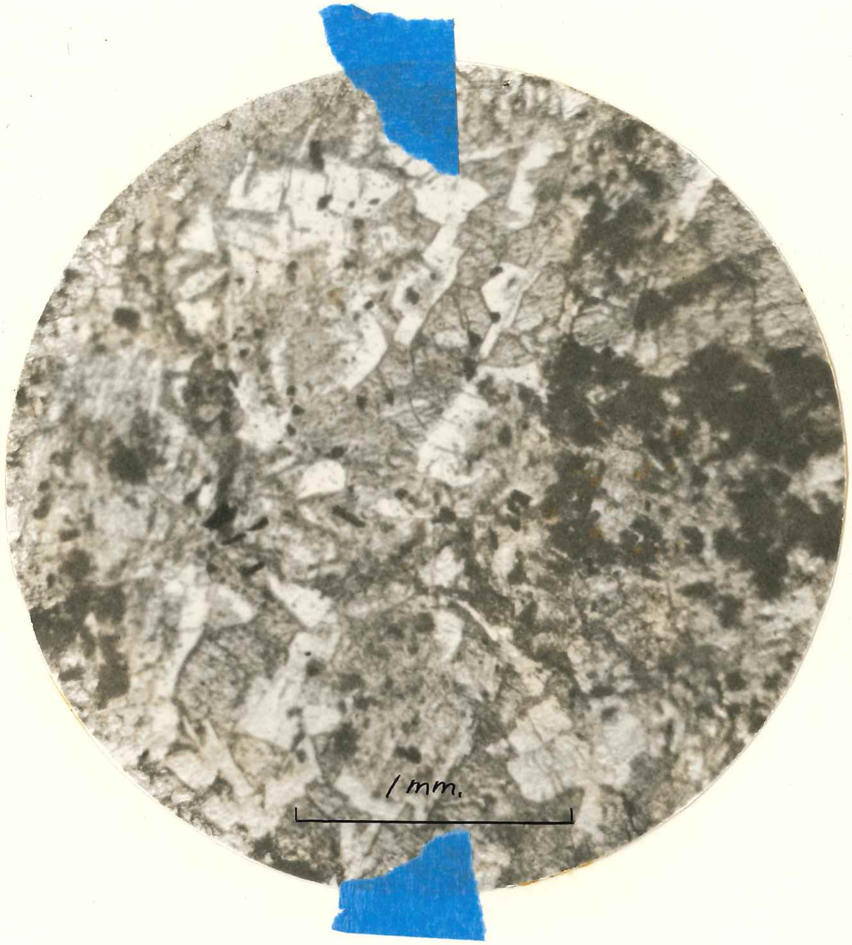

Fig. 4. A slightly altered diabase exhibiting blasto-ophitic texture. Augite is rimmed with green hornblende. The fuzzy black-appearing material is characteristic of feldspar alteration in all the rocks of the area. It is commonly so dense that it is nearly opaque. Plane light.

tory of the rock or (2) it may have been formed by contact metamorphism. If the first is true then the rock is completely unaltered by contact metamorphism and lies beyond the outer boundary of the contact metamorphic aureole. If the second is true, the rock then nearly represents the outer limits of hornblende-making and thus the outer boundary of the aureole.

The only way to choose between these two possibilities is to study more thin sections; however, sufficient specimens were not collected. Two considerations favor the second point: (1) Ross mentions no green hornblende in the Clover Creek greenstone elsewhere. (2) Green hornblende becomes more plentiful in the rocks nearer the intrusives.

This rock and others observed are more basic than the rocks described by Ross; even rather strongly metamorphosed former greenstone near the stocks commonly exhibits relict labradorite phenocrysts. Therefore it appears that in the Fish Lake area, and probably in the near vicinity, the Clover Creek greenstone consists mostly of only slightly altered basaltic rocks.

The greenstones of this area are certainly more basic than rocks described by Gilluly(10) sixty miles to the southwest, even though they have undergone later alteration:

> The rocks comprising the Clover Creek greenstone include quartz keratophyre, keratophyre, spilite, albite diabase, keratophyre and quartz

keratophyre tuff and breccia . . . and limestone.

The greenstones of the Fish Lake area are less altered than those described elsewhere. It is not at all rare to see relict ophitic textures and relict labradorite. This suggests that the greenstone did not react uniformly to the agents of metamorphism, even within the area of the Wallowa Mountains.

Contact Metamorphic Clover Creek Greenstone

Rocks nearer the intrusive, within the contact metamorphic aureole, contain progressively larger amounts of green hornblende.

A specimen collected 1500 feet from the stock may represent approximately the vanishing point of metamorphic green hornblende in the rock. In hand specimen it is a dark greenish-black porphyritic-appearing rock. In thin section it is seen to contain mostly strongly altered euhedral plagioclase phenocrysts (av. length 2.5 mm) and smaller groundmass laths (av. length 0.15 mm). The principal alteration product is very fine-grained brownish clinozoisite. The composition lies between An_{22}-An_{27}. Xenoblastic green hornblende (av. dia. 0.05 mm) and epidote (av. dia. 0.05 mm) comprise the dark minerals. Minor magnetite is present.

The estimated mineral composition is as follows:

Oligoclase(?) Phenocrysts	40%
Oligoclase laths	40%
Green hornblende	10%
Epidote	10%
Magnetite	m

This rock is still mostly unaltered, but the green hornblende appears to have been formed by contact metamorphism and to be contemporaneous with epidote.

A specimen collected near the center of the greenstone xenolith or roof pendant in the Northeast Stock (about 150 feet from the contact) is similar to the rocks previously described, but without phenocrysts. In thin section the following features can be seen.

Relict euhedral stongly altered grains of plagioclase average 0.1 mm in length. Fresh grains (av. dia. 0.05 mm) are bytownite (An_{75}). Their composition was established by determining their indices of refraction. The bytownite is partly altered to exceedingly fine-grained aggregates of brownish clinozoisite which are partly coarse-grained enough to show the characteristic anomalous colors of clinozoisite. Xenoblastic green hornblende is strongly poikiloblastic, including magnetite and both fresh and altered plagioclase. It is pleochroic as follows: Z-dark greenish brown, Y-yellowish green, X-light brown. Minor later quartz is present; biotite forms at the expense of green hornblende near quartz grains.

The estimated mineral composition is as follows:

Bytownite	50%
Green hornblende	50%
Quartz	m
Biotite	m
Magnetite	m

The rock is thermally altered basalt. The preservation of fresh bytownite in the rock indicates that this xenolith was subjected to considerably higher temperatures than any of the greenstones outside the stock.

A specimen collected three feet from the contact at the north end of the Central Stock is a dense black rock in hand specimen with plentiful small phenocrysts of feldspar. In thin section the following features can be seen.

Relict euhedral phenocrysts of labradorite-bytownite (An_{70}) exhibit normal zoning and are partly altered to sericite and exceedingly fine-grained brownish clinozoisite. Some grains have been broken to groups of fragments and the resulting cracks have been invaded by green hornblende. Small fresh xenoblastic grains of labradorite (An_{59}) exhibit faint normal zoning, are only slightly altered to sericite, and are intergrown with green hornblende. Two varieties of green hornblende are present. The first (earliest) is mostly xenoblastic (av. dia. 0.3 mm) and pleochroic as follows: Z-dark greenish brown, Y-greenish brown, X-pale brown. The second forms rims on the first and forms also as small idioblastic grains associated with quartz. It is pleochroic as follows: Z-dark bluish green, Y-yellowish green, X-pale brown. Both varieties include magnetite. A second generation of metamorphic plagioclase (composition between An_{35}-An_{50}) is associated with the quartz and blue-green hornblende. It is untwinned, perfectly fresh, and partly forms rims on relic phenocrysts; it exhibits strong normal zoning.

The estimated mineral composition is as follows:

Relict labradorite------25%
Labradorite------------15%
Hornblende (1)---------20%
Hornblende (2)---------15%
Andesine---------------10%
Quartz------------------5%
Magnetite---------------m

The original rock was a somewhat altered basalt or diabase porphyry (greenstone) which was still more altered by thermal metamorphism. Thermal alteration appears to have been active in two main phases: (1) The making of brownish hornblende and labradorite and (2) the making of andesine and blue-green hornblende, accompanying the introduction of quartz. The making of the second phase probably corresponds to late deuteric action within the stock - late deuteric fluids carrying silica in solution penetrated the adjacent greenstone.

A specimen collected ten feet from the contact at the same locality is similar to the previously described rock in hand specimen, but differs in that the relict phenocrysts are larger and that patchy areas of the rock contain notable fine-grained garnet. In thin section the following features are seen.

Relict euhedral andesine (at least An_{40}) exhibits normal zoning, flow alignment, and is strongly altered to clinozoisite. The average length of the phenocrysts is 1.5 mm; smaller euhedral laths in the groundmass average 0.15 mm in length. Xenoblastic green hornblende (av. dia. 0.03 mm) forms a solid mat around the relict plagioclase grains and includes a minor amount of magnetite. It is pleochroic as follows: Z-dark bluish green, Y-yellowish green, X-pale brown.

The estimated composition of this part of the rock is as follows:

Relict andesine	50%
Green hornblende	50%
Magnetite	m

The other part of the rock (in irregular patchy interconnected areas) has relict plagioclase which is so strongly altered to clinozoisite that it is not possible to get even an estimate of its composition. The groundmass surrounding the clinozoisite masses is composed of xenoblastic garnet of variable grain size, xenoblastic calcite, xenoblastic untwinned plagioclase with strong normal zoning (more calcic than An_{12}), and xenoblastic diopsidic augite (av. dia. 0.02 mm).

The estimated composition of this part of the rock is as follows:

Altered plagioclase	50%
Garnet	4%
Diopsidic augite	45%
Calcite	1%
Oligoclase(?)	m

This rock contains two different assemblages of minerals in close juxtaposition. The first seems clearly to have been originally igneous rock. The second has the composition of a lime-silicate. It is possible that this rock is an intermixture of originally molten rock with impure dolomitic sediments, perhaps similar on a small scale to the pillow lavas with marble matrix observed to the northwest.

A sample of dense greenstone was collected five feet from the north end of the West Stock at the one place the contact is exposed. As seen in Fig. 18 this contact is complicated by the presence of an intrusive hornblende pegmatite. In a thin section of the greenstone the following features are seen.

Xenoblastic plagioclase has an average diameter of 0.01 mm and exhibits only a little poor albite twinning. It is dusty with very fine-grained alteration products and includes some magnetite. In index oils it composition is found to be An_{17} (oligoclase). Xenoblastic green hornblende grains coalesce in amoeba-like fashion and become larger; they are poikiloblastic, enclosing tiny rounded grains of plagioclase and some magnetite. Most smaller grains form rims on xenoblastic diopsidic augite (av. dia. 0.02 mm) which is scattered through the rock.

The estimated mineral composition is as follows:

Oligoclase	60%
Green hornblende	15%
Magnetite	10%
Diopsidic augite	15%

The sodic plagioclase and hornblende rims on diopsidic augite may represent retrogression from an original higher temperature assemblage; the hornblende pegmatite may have been at a lower temperature than the original intrusive rock and thus been responsible for the formation of a lower temperature assemblage of minerals.

Clover Creek Greenstone, Sheared

Sheared amphibolitic greenstone is present only in a band along the northeast side of the West Stock, except for a few small xenoliths of it found in the stock within a quarter of a mile of the contact. The shearing dies out gradually, within a few feet, into massive greenstone.

In outcrop and in hand specimen the sheared greenstone is a dark fine-grained rudely schistose rock with large lenticular feldspar grains present in some places.

The sheared amphibolitic greenstone shows a considerable degree of intermixture with lime-silicate granulite at the one place they are in contact - the two having the appearance of being sheared at the same time so that lenses of lime-silicate granulite may be found in sheared greenstone and lenses of sheared greenstone in lime-silicate granulite. See Fig. 5. Lenses of sheared greenstone showing very poor mineral alignment may be observed in otherwise massive lime-silicate xenoliths a sixth of a mile in the stock from the contact.

A specimen collected near the lime-silicate-sheared greenstone contact to show the intermixture is a black fine-grained rudely schistose rock with irregular feldspar-bearing stringers running through it and containing lenses of reddish and gray-green lime-silicate rock. In thin section the following features can be seen.

Fine-grained xenoblastic quartz, xenoblastic biotite and green hornblende, magnetite with shells of penninite, epidote (av. length 0.1 mm and well-aligned), very fine-

Fig. 5. Lime-silicate granulite lenses in sheared greenstone near the end of the band of sheared greenstone on the geologic map.

grained sericite, and elongate fibers of penninite (av. length 0.1 mm and well-aligned) are present in varying proportions in different bands. Certain lenses contain irregular masses of exceedingly fine-grained clinozoisite (after plagioclase(?), xenoblastic epidote (av. dia. 0.05 mm), and green hornblende which partly includes epidote. Scattered through the other bands of the schist are xenoblastic porphyroblastic grains of green hornblende which are strongly poikiloblastic, including quartz, sericite, magnetite, and epidote; green hornblende formed at the expense of penninite. These grains have no alignment, very irregular almost amoeba-like form, and tend to push the other minerals of the schist aside. See Fig. 6.

The mineral assemblage indicates that this schist was formed under epizonal conditions. The green hornblende grew during static heating, probably by the intrusive. The preservation of this low-grade rock within a hundred feet of the stock presents a problem: Why was it preserved when rocks father out were made into amphibolite? The rock may be called an amphibolitic greenschist.

Two specimens were collected to show "typical sheared greenstone"- one where the band of sheared greenstone crosses the ridge and one near the south end of the same band. These show such similar features in thin section that the description of one will suffice for both.

Relict phenocrysts of labradorite (An_{56}) are much cracked and broken, and more or less drawn out into lenticles and small stringers by shearing. Alteration to both sericite and exceedingly fine-grained brownish clinozoisite has occurred. The average grain size is 1.2 mm. In some bands euhedral andesine laths (An_{46}) show a preferred orientation parallel to the schistosity. These average 0.15 mm in length. They also exhibit prominent reverse zoning, rims having the composition An_{59}. In other bands, the plagioclase is anhedral, mostly untwinned, but still shows zoning and may have the same composition as the euhedral andesine. Some larger grains have notable inclusions of green hornblende. Two kinds of green hornblende are found in the rock. The first is in xenoblastic fairly well-aligned grains averaging 0.05 mm in diameter. Grains are dotted with inclusions of magnetite and are pleochroic as follows: Z-bluish green, Y-light greenish brown, X-light brown. The second is in larger grains (av. dia. 0.2 mm), xenoblastic also, but present only in spotty areas and exhibits no preferred alignment. These grains are occasionally altered to biotite. Minor xenoblastic quartz appears to have been the last mineral to form.

The estimated mineral composition of the rock is as follows:

Relict labradorite	10%
Andesine	35%
Green hornblende (1)	30%
Green hornblende (2)	10%
Magnetite	5%
Biotite	m
Quartz	m

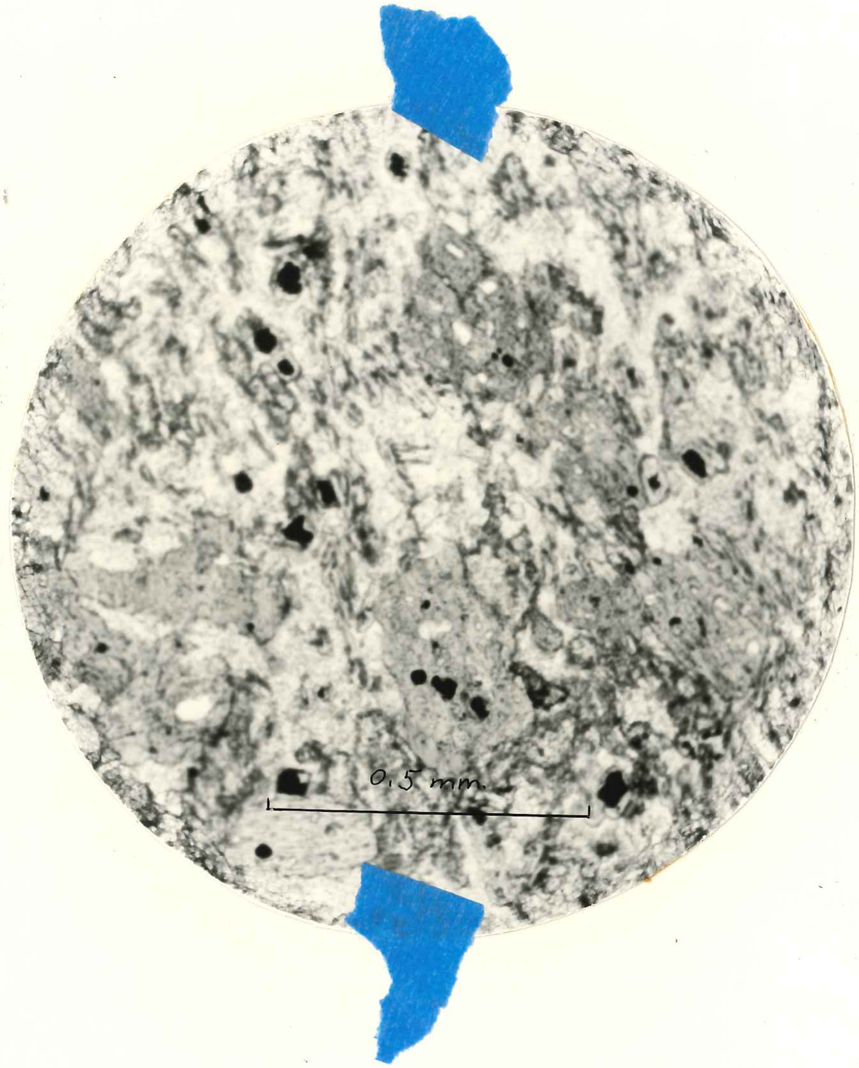

Fig. 6. The light groundmass of this greenschist contains partly sericite and partly pale green fairly well-aligned penninite (which also partly forms as rims on magnetite grains). Post-shearing green hornblende porphyroblasts are directionless.

The original rock was probably a basalt porphyry. Shearing was not too intense, so that relict phenocrysts could be preserved. This schist was surely made from the epizonal schist described above. The alignment of the green hornblende is mimetic, following the original schistosity. The overall alignment in the most schistose bands is not too good; in some bands the green hornblende has begun to grow larger and to free itself from the mechanically dead schistosity. This rock may be called a schistose amphibolite.

A dense black spotted rock forms somewhat schistose lenses in the northern-most lime-silicate xenolith mapped in the West Stock. A similar rock forms long stringers in the small skarn xenolith just west of the south end of the band of sheared greenstone. These rocks are so closely similar that the description of one will suffice for both.

Xenoblastic green hornblende (av. dia. 0.05 mm) shows exceedingly poor alignment. Occasional large grains (av. 0.5 mm) partly surround altered plagioclase. All grains include small magnetite grains and are pleochroic as follows: Z- dark green, Y-yellowish green, X-pale brown. Xenoblastic plagioclase (av. dia. 0.04 mm) is mostly unaltered. Occasional tiny grains of sericite are noted and a few scattered spots of exceedingly fine-grained brownish clinozoisite(?). It includes some magnetite and is partly intergrown with hornblende. It is mostly untwinned; most grains exhibit moderate normal zoning. It has a composition of An_{38}, determined in index oils and is thus andesine.

The estimated mineral composition is as follows:

Green hornblende	60%
Andesine	40%
Magnetite	m

This rock was originally a greenschist formed by shearing of the greenstones in the area and is now a slightly schistose amphibole hornfels formed by thermal alteration. The prolonged heating and recrystallization of the xenoliths in the stock was sufficient to almost completely destroy the alignment of the minerals in the original greenschist. Such alignment as remains is wholly mimetic after the original schistosity. See Fig. 7.

It is worthy of note that none of the sheared greenstone xenoliths within the stock retain relict phenocrysts of plagioclase. The phenocrysts were largely able to maintain themselves in the bordering rocks, but once within the stock were completely recrystallized.

<u>Marble</u>

The marble is found as either round masses or as rather elongate bands in the contact between the intrusives and the older rocks. The marble at Twin Lakes undoubtedly extends over a larger area than shown but is covered with morainal materials. Occasional xenoliths of marble are found within the stock but are mostly too small to show on the geologic map.

Wherever found, the marble exhibits strong jointing and

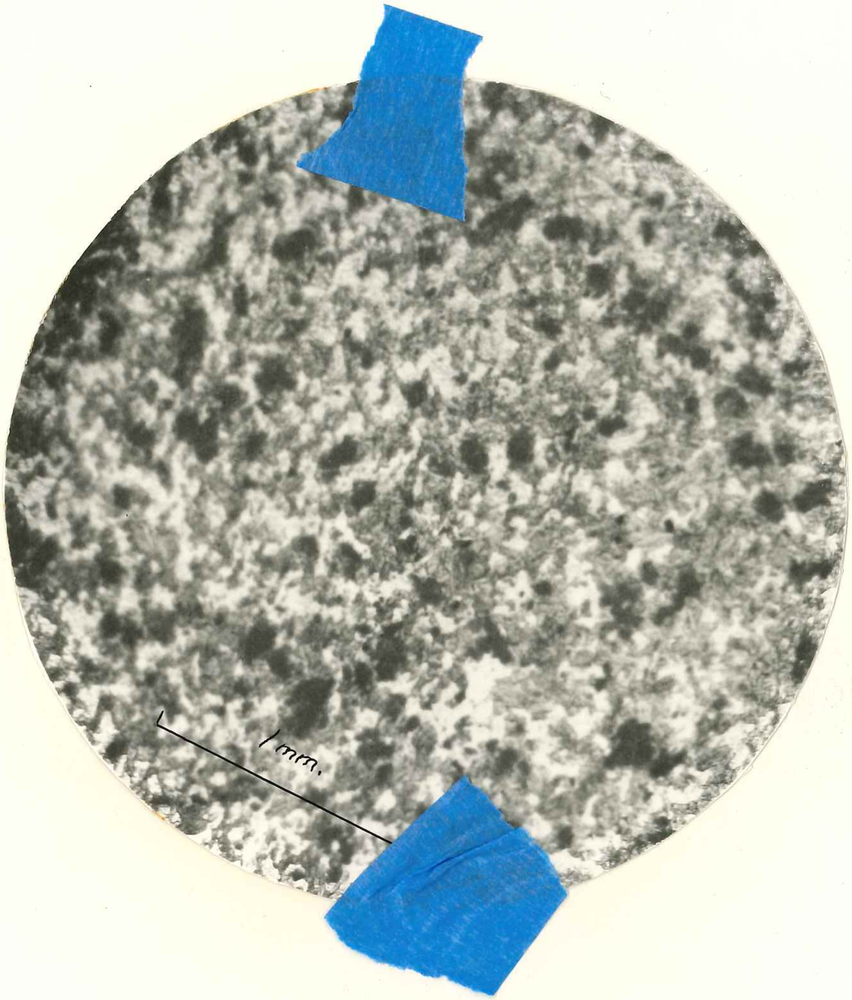

Fig. 7. A slightly schistose amphibole hornfels. Schistosity is visible faintly in hand specimen; in thin section, it may be imagined that it is seen. Note the dark fuzzy alteration product of the feldspar. Plane light.

and isoclinal folding. The trend of the isoclinal folding parallels the contact and the foliation in the sheared greenstone. In many places the marble is slightly impure, containing small bands of garnet or diopside granulite. The mass of marble in the SE corner of the West Stock is more impure than most and grades into the mass of lime-silicate granulite adjacent to it.

An unusual feature in the large marble xenolith at the north end of the West Stock is the presence of stretched dikes. See Fig. 8. In hand specimen these dikes have the appearance of lamprophyre, a dense dark rock. These dikes were not observed in any of the other xenoliths. Similar features were described by Smith (11) in the upper Triassic Martin Bridge limestone in the Northern Wallowa Mountains. His description follows:

> Within the Martin Bridge formation are found dikes which . . . have been broken and pulled apart by the movements that folded and distorted the limestone . . .The flow banding in the crystalline limestone follows evenly around the isolated more or less angular fragments and blocks of fine-grained igneous rock . . . Just west of Ice Lake a 1¼ inch dikelet originally 10 feet long has been broken in some 25 parts which were pulled apart so that they are now traceable along a distance of 55 feet . . . (The dikes are) a fine-grained allotriomorphic rock with plagioclase, diopside, tremolite, and remnants of leached biotite . . . probably a lamprophyre, possibly approaching spessartite.

In those more pure xenoliths of marble the only effect of being immersed in the dioritic magma was recrystallization

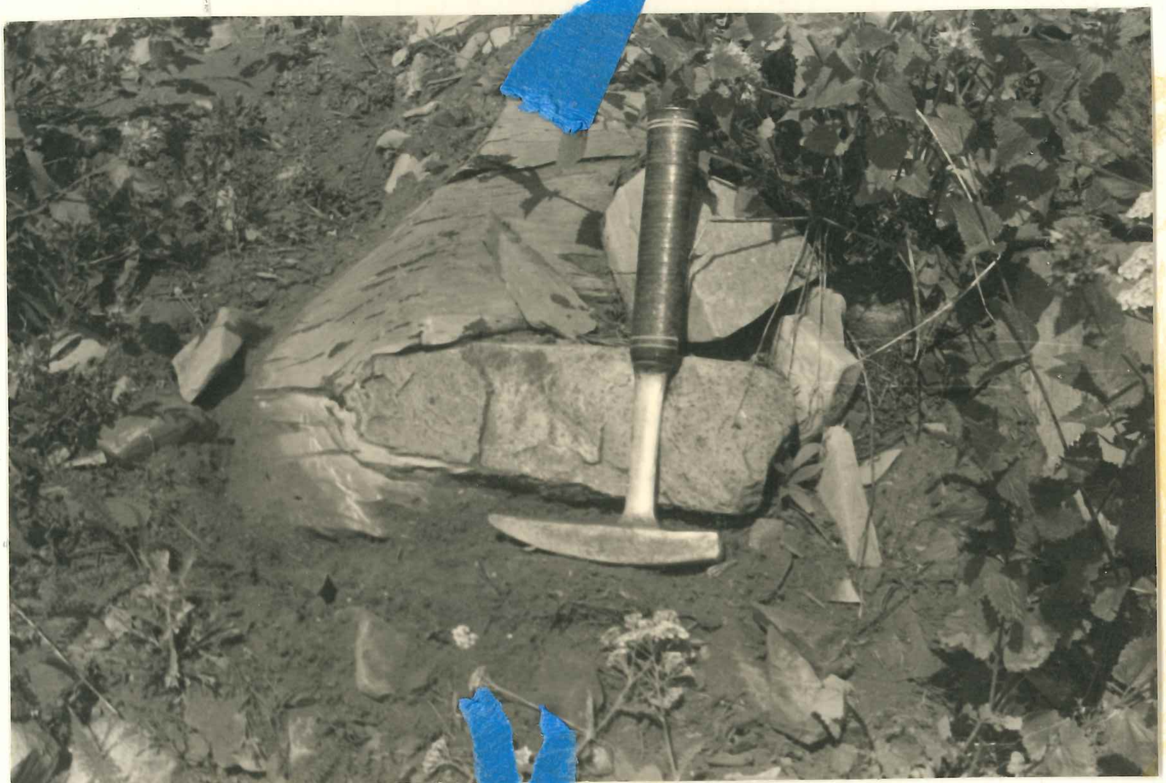

Fig. 8. A portion of a stretched dike in the northernmost xenolith of marble in the West Stock.

to coarser grain size. The marble near Twin Lakes is dolomitic, according to Ross(12) who states:

> In Sec. 3, T. 6 S., R. 46 E., there is a small outcrop of white marble, whose relations to the other rocks are concealed by glacial deposits. An analysis by J.G. Fairchild, U.S. Geological Survey, shows that the marble contains 32.84 per cent lime, 20.52 per cent magnesia, 46.60 per cent carbon dioxide with traces of iron oxides and water, a total of 99.96 per cent.

This location is within the belt of marble SW of Twin Lakes.

The presence of dolomite is further borne out by the appearance of plentiful diopside in some of the lime-silicate rocks.

Lime-silicate Granulite

The lime-silicate granulites occur only in the SE part of the West Stock, partly as xenoliths, partly as masses in contact with the sheared amphibolitic greenstone wall of the stock, and partly as lenses in the sheared greenstone.

In outcrop the lime-silicate granulite is complexly intermixed with marble in all proportions. Near its contact with sheared amphibolitic greenstone the lime-silicate granulite is strongly sheared and trends parallel to the greenstone; lime-silicate xenoliths away from the walls are directionless. The following description of the lime-silicate granulite is taken from field notes:

> Skarn includes several complexly intermixed rock types: (a) massive crystalline garnet, (b) massive hornblendite, (c) a dense gray-green rock which may consist chiefly of diopside, (d) all gradations between hornblendite and diopside rock, (e) epidote, (f) irregular wavy dikes of dioritic-appearing rock, and (g) minor patches of marble. In other places the rock may be very coarse-grained feldspar-garnet-hornblende skarn.

Because of the complex intermixture, numerous specimens were collected at random to represent the occurrences as closely as possible.

In thin section, as would be expected, the lime-silicate rocks show rather wide mineralogic variation.

A specimen collected to show "epidote in skarn" megascopically appears to consist largely of pistachio-green epidote with scattered gray-green diopside. In thin section the following features are seen.

Xenoblastic greenish-colored diopside (av. dia. 0.4 mm) occurs as inclusions in epidote. Its indices of refraction indicate that it contains approximately 10% of hedenbergite molecule. Idioblastic sphene (av. length 1.5 mm) also occurs as inclusions in epidote. Xenoblastic epidote (av. dia. 2.5 mm) is poikiloblastic, including diopside and sphene. Its indices of refraction indicate that it contains approximately 18% of $HCa_2Fe_3Si_3O_{13}$ molecule. Scattered large idioblastic grains of clinozoisite are intergrown with epidote and include occasional large grains of apatite (av. dia. 1 mm). See Fig. 9.

The mineral composition of the rock is as follows:

Epidote	70%
Diopside	20%
Clinozoisite	5%
Sphene	5%
Apatite	2%

The calculated chemical composition of the rock is as follows:

SiO_2	40%
Al_2O_3	20%
CaO	25%
Fe_2O_3	5%
FeO	1%
MgO	3%
P_2O_5	1%
TiO_2	2%
H_2O	1%

This rock was derived from an impure dolomite and is now a diopside-bearing epidote granulite. On the basis of evidence seen in other thin sections, it appears likely that the epidote in this rock is a retrogressive alteration product of andradite-containing grossularite; the diopside inclusions were inherited from the garnet.

A specimen collected to show "lime-silicate minerals in marble" megascopically appears to contain medium-grained calcite, very fine-grained greenish-gray diopside, and large (½" dia.) greenish brown crystals tentatively identified as garnet. In thin section the following things are seen.

Xenoblastic calcite (av. dia. 1 mm) forms irregular patchy areas between diopside grains in part of the rock. Idioblastic to xenoblastic diopside varies in grain size from 0.05 mm to 2 mm in diameter and is cloudy, perhaps with incipient alteration. Its indices of refraction indicate that it contains approximately 10% of hedenbergite molecule. Idioblastic enstatite (av. length 0.5 mm) is contemporaneous with diopside; its indices of refraction indicate that it contains not more than 2% of $FeSiO_3$ molecule. It is noticeably pleochroic (Z-green, Y-pale green, X-pale reddish brown), especially in thick sections, and has an abnormally small axial angle, probably less than 10°. Large xenoblastic grains of vesuvianite (av. dia. 5 mm) are poikiloblastic including calcite, diopside, and enstatite. Vesuvianite has indices of refraction lower than average values given by Winchell, N_o and N_e both being between 1.65-1.66. Larger grains appear to have formed as pseudomorphs after garnet whereas smaller grains appear idioblastic.

The mineral composition is as follows:

Diopside	55%
Calcite	25%
Vesuvianite	15%
Enstatite	10%

The calculated chemical composition is as follows:

SiO_2	40%
Al_2O_3	2%
CaO	35%
FeO	3%
MgO	10%
CO_2	10%

This rock was derived from a siliceous, dolomitic limestone and is now a calcite-bearing diopside-enstatite-vesuvianite granulite. The presence of enstatite indicates that temperature attained the high-grade zone of thermal contact metamorphism. Enstatite is seen in only a few of the specimens.

A coarse-grained specimen collected to show "epidote-actinolite(?) skarn" megascopically appears to consist partly of pistachio-green epidote and partly of a fibrous grayish-green mineral tentatively identified as actinolite. In thin section the following features can be observed.

Xenoblastic green (actinolitic) hornblende (av. dia. 0.6 mm) exhibits, in different grains, transitions to nearly pure actinolite. It has a fibrous habit with many small inclusions of calcite and quartz intercalated between the fibers. It is pleochroic as follows: Z-bluish green, Y-yellowish green, X-pale yellowish green. Minor sphene appears to be contemporaneous with hornblende. Xenoblastic epidote (av. dia. 1.5 mm) is poikiloblastic, including calcite, quartz, hornblende, and sphene. Its indices of refraction indicate that it contains approximately 18% of $HCa_2Fe_3Si_3O_{13}$.

The mineral composition of the rock is as follows:

Epidote	65%
Green hornblende	25%
Calcite	3%
Quartz	3%
Sphene	3%

The calculated chemical composition of the rock is as follows:

SiO_2	40%
Al_2O_3	20%
CaO	20%
Fe_2O_3	10%
FeO	5%
MgO	2%
TiO_2	1%
CO_2	1%
H_2O	1%

This rock is probably retrogressive from garnet granulite. The presence of calcite and quartz together is of interest because these two minerals generally react to form wollastonite in the high-grade zone.

A specimen collected to show greenish "lime-silicate rock" megascopically appears to contain two very fine-grained minerals, one yellowish green and the other dark greenish black, both unidentified. In thin section, the following features are observed.

Xenoblastic enstatite (av. dia. 0.3 mm) is poikiloblastic, including very small diopside grains. Its indices of refraction indicate that it contains approximately 5% of $FeSiO_3$ molecule; its axial angle is abnormally small, probably less than 10^o. Xenoblastic green diopside averages 0.05 mm in diameter in part of the rock and 0.6 mm in the rest of the rock; areas of different grain size are in irregular patchy distribution. Its indices of refraction indicate that it contains approximately 38% of hedenbergite molecule. Scattered irregular grains of penninite (av. dia. 0.5 mm) are mostly associated with smaller grains of pleonaste (av. dia. 0.3 mm). Pyrite forms a minor accessory, replacing the other minerals.

The mineral composition of the rock is as follows:

Diopside	80%
Enstatite	15%
Pleonaste	2%
Penninite	3%

The calculated chemical composition is as follows:

SiO_2	50%
Al_2O_3	3%
CaO	20%
FeO	10%
MgO	15%
H_2O	1%

This rock was derived from a siliceous, dolomitic limestone and is now an enstatite-bearing diopside granulite. The presence of enstatite again testifies that temperature attained the high-grade zone of static metamorphism.

A specimen collected to show "the occurrence of garnet and epidote in skarn" megascopically appears to consist largely of garnet which is partly altered to epidote. In thin section the following features are observed.

Xenoblastic grains of calcite (av. dia. 10 mm) are scattered through the rock. Grains present as inclusions in garnet are smaller (av. dia. 2 mm). Quartz is present in grains averaging 0.1 mm dia. and is the same age as the calcite. Xenoblastic, partly idioblastic diopside (av. dia. 0.3 mm) contains approximately 6% of hedenbergite molecule, according to its indices of refraction, and is not noticeably colored. Occasional grains exhibit skeletal form, and include calcite. Xenoblastic porphyroblastic garnet has a composition of 35% grossularite and 65% andradite molecule, according to its specific gravity and index of refraction. It is distinctly zoned, with alternating brown and less brown rings. It is strongly poikiloblastic, including calcite, quartz, diopside, and actinolite; it appears to be intergrown with sphene and alters to epidote. Green (actinolitic) hornblende, forming at the expense of diopside, forms small (0.3 mm) needles in calcite. It is pleochroic as follows: Z-dark bluish green, Y-yellowish green, X-light brownish green. Minor pyrite replaces the other minerals.

The mineral composition is as follows:

Andradite	50%
Calcite	20%
Diopside	10%
Quartz	10%
Epidote	5%
Sphene	m
Pyrite	m

The calculated chemical composition is as follows:

SiO_2	35%
Al_2O_3	5%
CaO	35%
Fe_2O_3	10%
CO_2	10%

The original rock was probably an impure dolomitic limestone. It was subjected to high-grade temperatures, although quartz and calcite did not react to form wollastonite, and is now a calcite-bearing andradite-diopside skarn. See Fig. 10.

A specimen collected to show the occurrence of "garnet in a coarse-grained lime-silicate rock" megascopically appears to consist of large brown garnets in a base of coarse-grained white feldspar, quartz, and a very fine-grained greenish-gray mineral tentatively identified as diopside. In thin-section the following features are observed.

Xenoblastic colorless diopside (av. dia. 0.5 mm) is partly cloudy with incipient change; according to its index

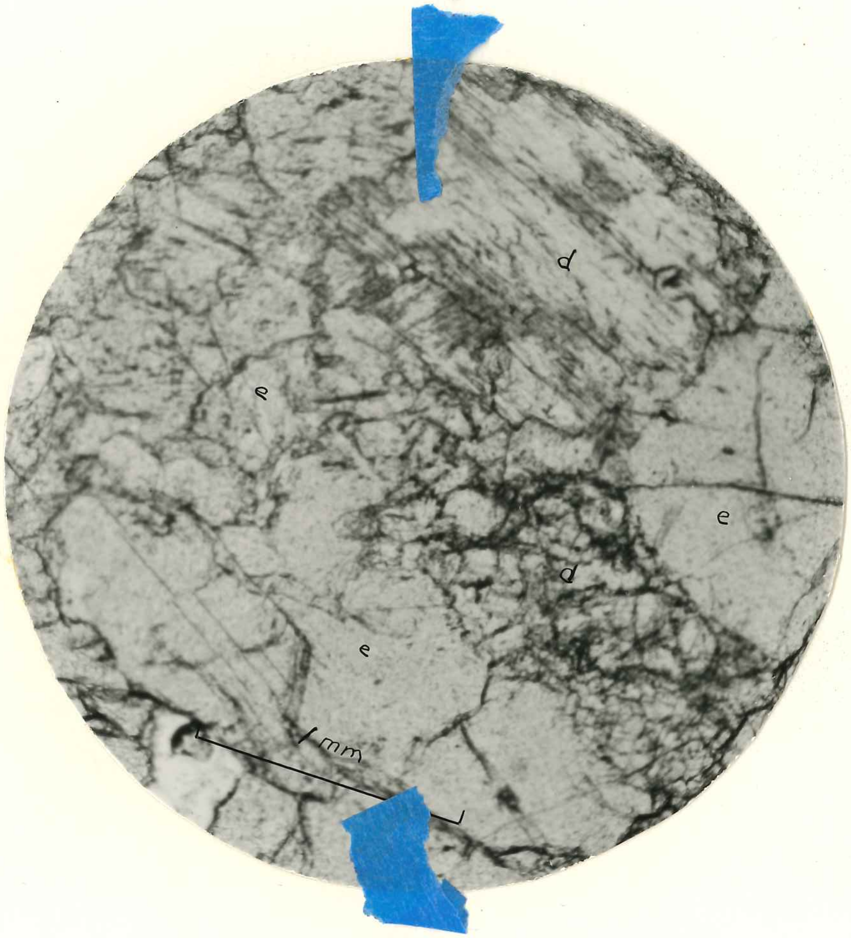

Fig. 9. Diopside included in poikiloblastic epidote. (d - diopside, e - epidote.) Plane light.

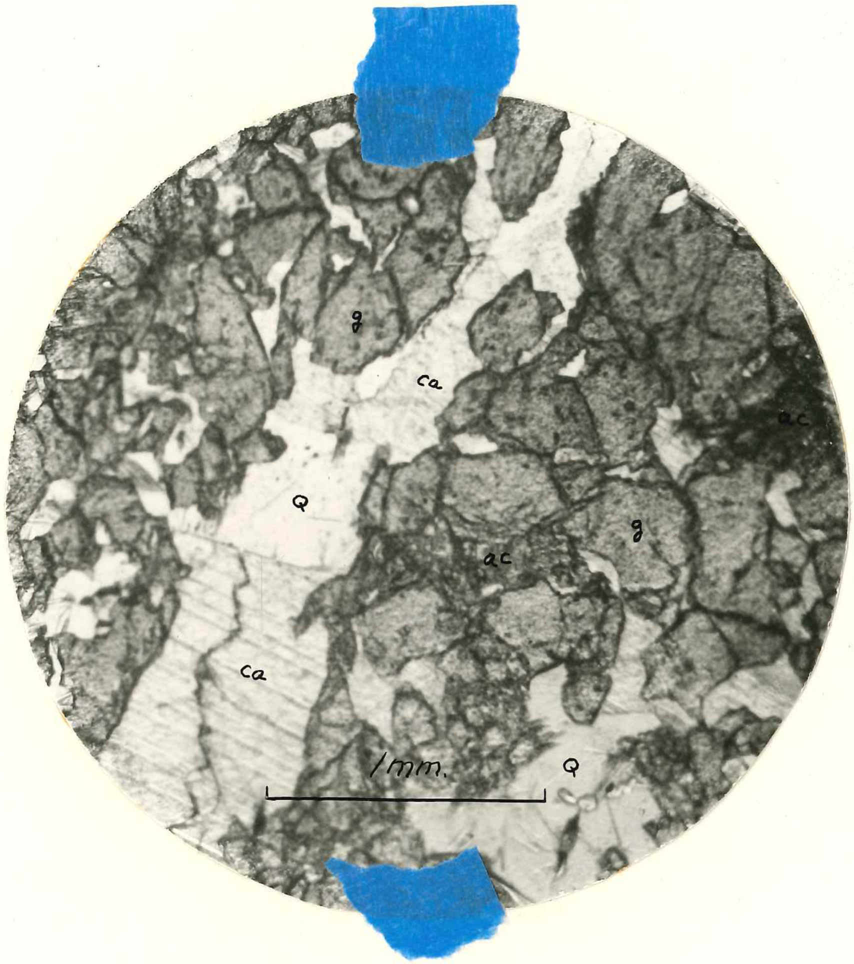

Fig. 10. Calcite and quartz included in poikiloblastic andradite. Some actinolitic green hornblende is present as inclusions also. (ac - actinolitic hornblende, g - andradite, ca - calcite, Q - quartz.) Plane light.

of refraction it contains approximately 6% of hedenbergite molecule. Xenoblastic plagioclase (An_{37}) (av. dia. 1 mm) occasionally includes small grains of diopside. It is partly altered to clinozoisite and strongly altered to prehnite. Grossularite is strongly poikiloblastic, including small grains of plagioclase and diopside. According to its index of refraction it contains approximately 18% of andradite molecule; the presence of inclusions prevented the determination of specific gravity as a check. It alters to clinozoisite. Occasional grains of vesuvianite are intergrown with the grossularite and are also partly altered to clinozoisite which contains, according to its indices of refraction, about 5% of $HCa_2Fe_3Si_3O_{13}$ molecule. A small amount of relict quartz is present in the rock; sphene and apatite are the accessory minerals.

The mineral composition of the rock is as follows:

Andesine	30%
Diopside	25%
Grossularite	25%
Prehnite	10%
Vesuvianite	10%
Clinozoisite	m
Quartz	m
Sphene	m
Apatite	m

The calculated chemical composition of the rock is as follows:

SiO_2	50%
Al_2O_3	15%
CaO	25%
Na_2O	2%
Fe_2O_3	1%
FeO	1%
MgO	5%
TiO_2	1%
H_2O	1%

The rock was derived from a more impure dolomitic limestone and is now a diopside-grossularite-andesine skarn. Andesine probably represents originally more calcic plagioclase which was decalcified by the formation of prehnite (retrogressive).

INTRUSIVE ROCKS (DIORITE-GABBRO COMPLEX)

The diorite-gabbro occurs in four small stocks which intrude the Clover Creek greenstone. For ease in reference they will be referred to individually as the Northeast Stock, the Central Stock, the Little Stock, and the West Stock; each stock can be readily distinguished by a glance at the geologic map (Plate 1).

Ross(13) mapped this area as one stock during his reconnaissance of the southeastern Wallowa Mountains in 1921. His description of the rocks follows:

> The rock varies in appearance as well as composition. Most of it contains so much pyroxene as to be almost black and is finer than the average granitoid rock farther west. There are some small patches composed almost exclusively of ferromagnesian minerals. In many localities, however, the rock is coarser and contains a smaller proportion of dark minerals than the average . . .
>
> The rock is so variable in texture and composition that it is difficult to select specimens that can be considered at all representative of the whole. Much of the mass consists essentially of titaniferous augite, hypersthene, hornblende, dark green biotite, and bytownite and has marked flow structure. There is a very little interstitial quartz. The rock is fresh with very little development of secondary minerals.
>
> More silicic portions of the intrusive mass

consist essentially of quartz, sericitized oligoclase, chlorite, epidote, and sub-ordinate muscovite. The chlorite and epidote are alteration products of pyroxene. No residual pyroxene was found, but its crystal form is preserved in some of the chlorite-epidote aggregates. The rock is thus a somewhat altered quartz-pyroxene diorite.

Northeast Stock

Gabbro

The Northeast Stock is composed entirely of gabbro. Its contacts with the greenstone and marble were not observed; they are everywhere etched out by glacial abrasion and covered with till, but must dip steeply.

In outcrop and in hand specimen the gabbro is a medium-grained massive dark-gray rock which exhibits the following features in thin section.

Anhedral olivine (0.4 to 2 mm in dia.) has undergone subsequent reaction and replacement by later minerals. According to its indices of refraction, it contains approximately 24% of Fe_2SiO_4 molecule. Euhedral to subhedral hypersthene occurs partly as rims on olivine grains and partly as plates (av. dia. 0.3 mm) embedded in augite. According to its indices of refraction the hypersthene contains approximately 20% of $FeSiO_3$ molecule. Labradorite (An_{65}) is present as euhedral to subhedral laths averaging 0.6 mm in length and partly altered to exceedingly fine-grained brownish aggregates of clinozoisite. Large anhedral frequently twinned grains of augite (av. dia. 2.0 mm) include, in addition to hypersthene, tiny rounded plates of labradorite in their margins. Minor uralitic hornblende is present as rims on augite grains.

The mineral composition of the rock is as follows:

Augite	50%
Labradorite	35%
Olivine	10%
Hypersthene	5%
Uralitic hornblende	m

The calculated chemical composition of the rock is as follows:

SiO_2	50%
Al_2O_3	15%
CaO	15%
Na_2O	2%
Fe_2O_3	3%
FeO	5%
MgO	10%

The rock is thus an olivine-hypersthene-bearing gabbro.

Cognate Inclusions

Scattered haphazardly through the gabbro of the Northeast Stock are black coarse-grained irregular inclusions. See Fig. 11.

The irregular drawn-out form of these inclusions suggests that they were softened by the magma and somewhat drawn out by differential flow.

In thin section the following features can be seen. Anhedral olivine (av. dia. 0.7 mm) is partly altered to antigorite and partly to bowlingite or iddingsite and is mostly crowded into narrow spaces between augite grains. Euhedral to subhedral hypersthene (av. dia. 0.1 mm) is partly poikilitic, enclosing small grains of olivine and

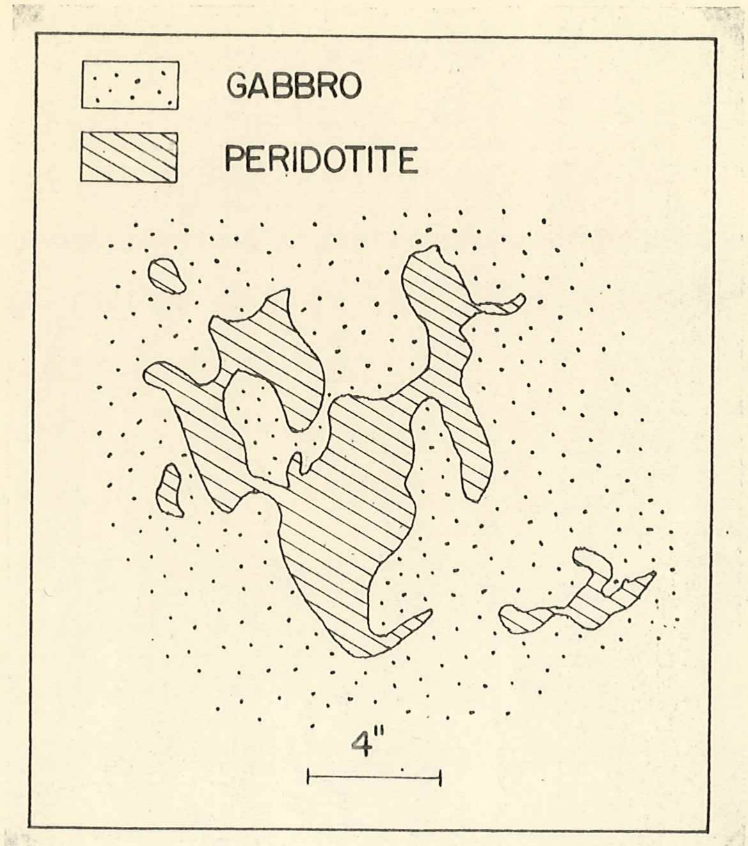

Fig. 11. A vertical rock face on the ridge in the Northeast Stock, showing the irregualr form of many of the cognate inclusions. Other exposures indicate that they are equally irregular in all three dimensions.

early magnetite. Anhedral augite (av. dia. 2 mm) is poikilitic, including olivine and hypersthene, and partly altered to uralitic hornblende which is pleochroic as follows: Z-dark reddish brown, Y-lighter reddish brown, X-light brown, or Z-dark brownish green, Y-yellowish green, X-pale green.

The estimated mineral composition is as follows:

Augite	55%
Olivine	40%
Hypersthene	5%
Uralitic hornblende	m
Antigorite, bowlingite, iddingsite	m
Magnetite	m

The rock is a hypersthene-bearing peridotite.

The following description is of an irregular-shaped inclusion mostly less than an inch in thickness. As a general rule the smaller inclusions are more strongly altered than the larger ones. In thin section the following features can be seen.

Subhedral labradorite (An_{64}) (av. length 1.5 mm) is partly sericitized and partly altered to exceedingly fine-grained brownish clinozoisite. Euhedral hypersthene (0.4 to 1.5 mm) is faintly pleochroic: Z-very faint greenish gray, Y-very faint pinkish gray, X-faint pink, and is partly altered to talc. Subhedral to anhedral uralitic hornblende (av. dia. 6 mm) is poikilitic, including plates of labradorite, hypersthene, and relict grains of augite (1.5 mm av. dia.) from which it formed.

The estimated mineral composition is as follows:

Uralitic hornblende	75%
Labradorite	10%
Hypersthene	10%
Augite	5%
Talc	m

The rock is an altered hypersthene-bearing pyroxenite. The principal effect of the gabbroic magma on this inclusion was to alter it to uralitic hornblende.

Other Inclusions

A large mass of rudely foliated black coarse-grained rock crops out in the central part of the Northeast Stock. In the outcrop it is reddish brown in color. In thin-section the following features can be observed.

Anhedral augite (av. dia. 3.5 mm) grains are strongly cut by shear planes, but twinning lamellae and inter-augite-grain contacts are not offset by shearing except in occasional grains. Antigorite is present as irregular grains (av. dia. 1 mm) and as stringers in the shears through augite grains. Magnetite forms stringers of tiny grains in the antigorite; more magnetite is included in antigorite in the shears traversing augite than in the larger grains of antigorite. Uralitic hornblende forms at the expense of augite.

The estimated mineral composition is as follows:

Augite	50%
Antigorite	50%
Magnetite	m
Uralitic hornblende	m

The rock is a partly serpentinized sheared peridotite.

The presence of the shearing indicates that this rock is much older than the gabbro surrounding it; also it is older than any of the cognate inclusions, which are simply earlier differentiated phases of the gabbro. The sheared peridotite was intruded prior to orogenic movement; the gabbro in which it is included post-dates the orogenic movement and the rocks may be considerably different in age.

Lighter schistose dikes cut the sheared peridotite. In thin section, the following features can be seen.

Anhedral olivine (av. dia. 2.5 mm) is present with talc, which may have formed from original hypersthene; the olivine alters to antigorite. Anhedral labradorite (An_{65}) averages 0.8 mm in diameter, encloses olivine, is partly altered to exceedingly fine-grained brownish clinozoisite, and exhibits undulatory extinction in many grains. Anhedral augite (av. dia. 4 mm) is poikilitic, including olivine and rounded grains of feldspar. The grains of augite are not so strongly sheared in this rock as in the enclosing peridotite. Uralitic hornblende forms at the expense of augite and is pleochroic as follows: Z-brown, Y-light brown, X-pale brown.

The estimated mineral composition of the rock is as follows:

Augite	85%
Olivine	10%
Labradorite	5%
Uralitic hornblende	m
Talc	m
Antigorite	m

The rock is a slightly sheared pyroxenite. It is noteworthy that the plagioclase in this rock exhibits undulous extinction. This implies that temperature did not become high enough to cause recrystallization of the plagioclase.

About 100 yards west of the large xenolith of sheared peridotite a xenolith of translucent yellowish rock about 150 feet in diameter crops out. In thin section the following features can be observed.

Limonite is present in tiny clusters of very small round grains; it lends its color to the rock. Round grains of antigorite (0.2 mm av. dia.) make up the bulk of the rock. Extremely small grains of either diaspore or alunite are present; a few tiny relict grains of augite are seen.

The estimated mineral composition is as follows:

Antigorite	90%
Limonite	m
Diaspore (or Alunite)	10%
Augite	m

The rock is a completely serpentinized dunite. This rock is believed not to be a cognate inclusion because all the cognate inclusions found are either pyroxenite or peridotite.

Central Stock

The east part of the Central Stock is made of gabbro; the west prong, however, has quartz diorite in its central part and is probably ringed by gabbro.

Gabbro

The gabbro in the Central Stock is a medium-grained dark gray massive rock both in outcrop and in hand specimen. In the microscope the following features can be observed.

The principal texture is sub-ophitic. Euhedral to subhedral labradorite (An_{60}, av. length 0.3 mm) is free of inclusions and according to its indices of refraction, contains approximately 20% of $FeSiO_3$ molecule. Augite is subhedral to anhedral and 1.0 mm in average diameter. Larger grains occasionally enclose hypersthene; most grains enclose small laths of labradorite. Late magnetite is the only accessory mineral present; penninite has formed only along joint cracks. See Fig. 12.

The mineral composition is as follows:

Labradorite	60%
Hypersthene	15%
Augite	25%
Magnetite	m
Penninite	m

The calculated composition of the rock is as follows:

SiO_2	50%
Al_2O_3	20%
CaO	10%
Na_2O	3%
Fe_2O_3	2%
FeO	5%
MgO	10%

Another specimen was collected from the middle part of the Central Stock. It exhibits the following features in thin section. Subhedral labradorite (An_{64}) is in grains averaging 2 mm in length and partly altered to exceedingly fine-grained brownish masses of clinozoisite. A certain alignment of grains appears to be present. Subhedral augite, partly altered to uralitic hornblende, is present in medium-sized grains. Euhedral hypersthene (0.3 to 0.7 mm in length) is partly altered to talc-clinochlore aggregates. Magnetite is the principal accessory.

The estimated mineral composition of the rock is as follows:

Labradorite--------------50%
Augite-------------------25%
Hypersthene--------------15%
Talc-clinochlore---------10%
Magnetite----------------m

A specimen was collected at the south end of the Central Stock on the crest of the ridge southeast of Fish Lake. In hand specimen and in outcrop the rock is a dark gray rather fine-grained massive rock. In thin section the following features can be observed.

Labradorite (An_{57}) is in subhedral to anhedral grains averaging 0.5 mm in diameter and partly altered to sericite and to spotty areas of exceedingly fine-grained brownish clinozoisite. Green hornblende appears to have formed as pseudomorphs after augite. It is in anhedral grains and is pleochroic as follows: Z-bluish green, Y-yellowish green, X-pale green and partly altered to clinochlore.

The estimated mineral composition is as follows:

Labradorite--------------30%
Green hornblende---------70%

The rock is a strongly altered gabbro. Being near the

Fig. 12. Typical gabbro. Plane light.

contact it was altered by late deuteric solutions working outward from farther within the stock.

An intrusive breccia is present in the center of the west prong of the Central Stock at the contact between the gabbro and the quartz diorite. The matrix is a light gray medium-grained massive rock. Inclusions of altered gabbro exactly similar to the last-described rock occur as cognate inclusions in the diorite.

Quartz Diorite

Thin sections of the diorite show the following features.

Euhedral to subhedral andesine (An_{38}) is present in grains averaging 0.4 mm in length. Occasional micrographic intergrowths of quartz and andesine are noted. Some grains exhibit normal zoning and have cores strongly altered partly to sericite and partly to exceedingly fine-grained brownish masses of clinozoisite. Euhedral to subhedral green hornblende (av. length 1.2 mm) partly includes grains of andesine. It is pleochroic as follows: Z-dark green, Y-yellowish green, X-light brown. Some grains are large xenoblastic, complexly intergrown aggregates and presumably were formed from earlier pyroxene. Anhedral quartz (av. dia. 0.5 mm) is interstitial. Scattered grains of euhedral magnetite form the principal accessory mineral.

The estimated mineral composition is as follows:

Andesine	30%
Green hornblende	50%
Quartz	20%
Magnetite	m

The rock is thus a quartz-hornblende diorite.

Cognate Inclusions

As previously mentioned, the gabbro inclusions in quartz diorite breccia are cognate inclusions. They will not be described here because the rock-type was adequately described under gabbro. Cognate inclusions in the gabbro are similar to those in the Northeast Stock but in general more strongly altered.

A specimen of a cognate inclusion collected near the south end of the Central Stock on the crest of the ridge SW of Fish Lake exhibits the following features in thin section. Large anhedral and small euhedral green hornblende grains (0.4 to 4.0 mm in length) are pleochroic as follows: Z-dark green, Y-green, X-light brown or Z-bluish green, Y-yellowish green, X-pale green. Hornblende is partly altered to clinochlore. Relict plagioclase is entirely altered to exceedingly fine-grained brownish masses of clinozoisite. Minor sphene and fresh secondary quartz form accessory minerals.

The estimated mineral composition is as follows:

Green hornblende	85%
Altered plagioclase	10%
Clinochlore	5%
Quartz	m
Sphene	m

The rock is probably a strongly altered pyroxenite.

Other Inclusions

Xenoliths of schistose black rock as large as several feet in diameter are scattered sparsely through the east part of the Central Stock. A specimen collected from one of these is jet black and very fine-grained; it could be mistaken for basalt if only examined superficially. It exhibits its weakly schistose character only on weathered surfaces which are reddish brown in color. In thin section the following features can be observed.

Antigorite makes up the bulk of the rock; grains are more or less aligned along shear planes. Tiny grains of magnetite lie mostly in the shear planes.

The estimated mineral composition of the rock is as follows:

Antigorite--------------90%
Magnetite---------------10%

The disseminated magnetite lends its color to the rock which is a completely altered sheared dunite - now somewhat schistose serpentine. As with the sheared inclusions of peridotite in the Northeast Stock, this sheared dunite is much older than the gabbro in which it is enclosed.

Another xenolith noted weathers to a dark brown color. It is coarse-grained, black, and obviously schistose, even on fresh surfaces. In thin section it exhibits the following features.

Anhedral olivine (av. dia. 0.4 mm) is partly included by large augite grains and is partly crowded into the spaces between augite grains. The grains are traversed but only little offset by shears which are partly filled with later magnetite. Olivine alters to antigorite, grains of which all contain centers of magnetite. Large anhedral grains of augite (av. dia. 1.5 mm) are traversed and somewhat offset by shearing, the shears again occupied by later magnetite. They alter to uralitic hornblende which is present as rims on augite grains or as irregular blebs within them and is pleochroic as follows: Z-olive green, Y-light grey green, X-lighter greenish brown. See Fig. 13.

The estimated mineral composition is as follows:

Augite	80%
Olivine	15%
Antigorite	5%
Magnetite	5%
Uralitic hornblende	m

The rock is a sheared partly serpentinized pyroxenite, considerably older than the enclosing gabbro.

Chilled Contact Phase

The contact of the stock with the greenstone was observed on only one roche moutonnee, north of Fish Lake, about 150 yards west of the Twin Lakes road. A 12-inch layer of ultra-basic rock is present adjacent to the greenstone and probably represents differentiation of gabbroic magma at the chilled contact. In thin section the following features can be observed.

Subhedral to anhedral augite (av. dia. 0.5 mm) is dusty with tiny magnetite inclusions. Iron-stained talc includes

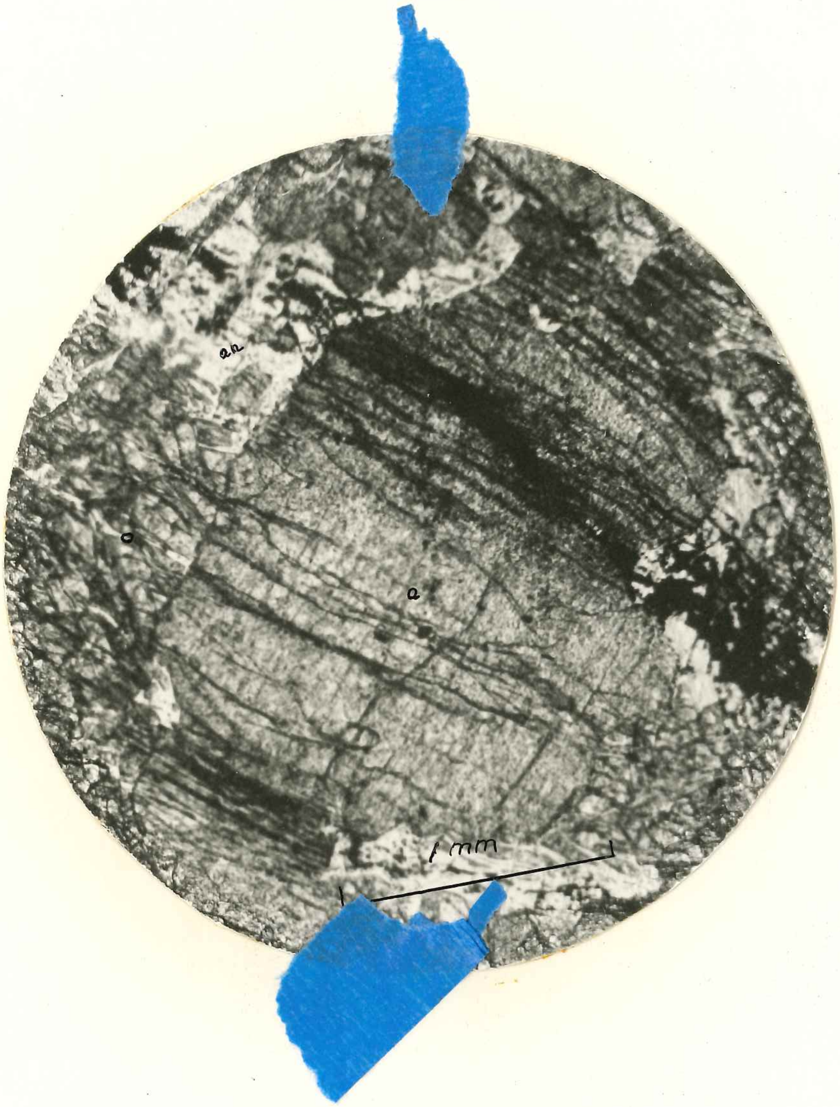

Fig. 13. Sheared partly serpentinized pyroxenite. Note that the shears, although prominently developed, have not offset the grain boundaries. (a - augite, an - antigorite, o - olivine.) Plane light.

antigorite and magnetite; these minerals indicate the former presence of olivine and hypersthene. Uralitic hornblende forms at the expense of augite and includes talc-magnetite aggregates. It is pleochroic as follows: grain centers, Z-dark greenish brown, Y-greenish brown, X-light brown and rims, Z-dark bluish green, Y-light yellowish green, X-pale green. Clinochlore forms at the expense of green hornblende. Apatite and calcite (associated with clinochlore) are accessory minerals.

The estimated mineral composition is as follows:

Augite	35%
Talc	10%
Uralitic hornblende	35%
Clinochlore	5%
Magnetite	5%
Antigorite	m
Apatite	m
Calcite	m

This rock has undergone thermal metamorphism and is now a partly altered peridotite.

The Little Stock

Gabbro

Gabbro of the Little Stock is best seen just east of the Melhorn reservoir. In outcrop and in hand specimen the gabbro is a medium-grained dark gray massive rock; the stock is liberally sprinkled with black coarse-grained mafic inclusions. In thin section the following features can be seen.

The rock is fresh and the principal texture is intersertal. Euhedral hypersthene (av. dia. 0.3 mm) is faintly pleochroic. Unaltered labradorite (An_{54}) is present in grains averaging 0.5 mm in length and is dusty with magnetite inclusions. Euhedral to subhedral augite (av. length 0.8 mm) is fresh and free of inclusions. Magnetite forms a minor accessory.

The estimated composition of the rock is as follows:

Labradorite	60%
Hypersthene	20%
Augite	20%
Magnetite	m

Another specimen from the Little Stock is almost exactly similar in mineral composition to the above described rock; it differs only in that the augite is in larger grains, poikilitic, including plates of hypersthene and laths of labradorite, and partly altered to uralitic hornblende.

Cognate Inclusions

Cognate inclusions here, as in the other stocks, are black coarse-grained irregular inclusions. In thin section the following features can be seen. Anhedral augite (av. dia. 2.5 mm) includes hypersthene and labradorite; it makes up the bulk of the rock and is partly altered to uralitic hornblende. Anhedral olivine (av. dia. 0.4 mm) is crowded into the spaces between augite grains; according to its indices of refraction olivine contains approximately 26% of Fe_2SiO_4 molecule. Euhedral to subhedral hypersthene (av. dia. 0.2 mm) is with olivine in the inter-augite spaces and is partly altered to talc; according to its indices of refraction the hypersthene contains about 20% of $FeSiO_3$. Anhedral labradorite (An_{60}) averages 0.2 mm in diameter and is present mostly as inclusions in augite. Apatite and magnetite are the accessory minerals.

The mineral composition of the rock is as follows:

Augite	60%
Olivine	15%
Hypersthene	10%
Uralitic hornblende	10%
Labradorite	3%
Apatite	1%
Magnetite	[illegible]

The calculated chemical composition of the rock is as follows:

SiO_2	45%
Al_2O_3	5%
CaO	15%
FeO	10%
Fe_2O_3	5%
MgO	20%

The rock is a peridotite. In thin section it can be further seen that the gabbro reacted upon the inclusions. See Fig. 14.

The West Stock

The intrusive rocks in the West Stock are principally gabbro, quartz gabbro, and quartz diorite. Most of the inclusions observed were skarn, marble, and amphibolitic sheared greenstone.

Gabbro

The outer ½ mile of the stock near the Melhorn Reservoir

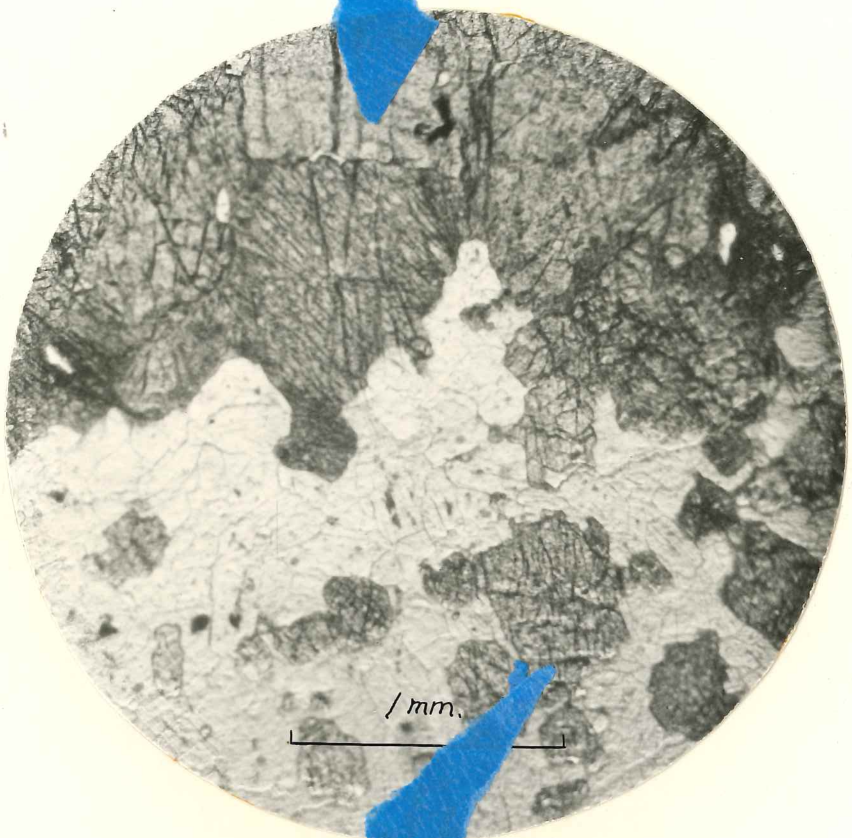

Fig. 14. Cognate inclusion in gabbro. Note embayments formed by gabbro (light) in resorbing part of the pyroxene-rich cognate inclusion. Plane light.

is gabbro, which extends approximately to the large skarn xenolith on the ridge to the SE, parallel to the contact. See Fig. 15

In hand specimen the gabbro is a medium-grained dark-colored rock; in outcrop, it is weathered to a lighter gray. In thin section the following features are seen. The principal texture of the gabbro is sub-ophitic, with augite partly surrounding labradorite (An_{64}). The labradorite, averaging 0.4 mm in length, is euhedral to subhedral and is strongly altered to exceedingly fine-grained brown aggregates of clinozoisite and partly to sericite. Augite is subhedral and is in grains averaging 1.2 mm in diameter; it is partly altered to uralitic hornblende, present mostly as rims on augite. Accessory magnetite and apatite are present.

The mineral composition is as follows:

Labradorite	45%
Augite	25%
Hornblende	25%
Magnetite	3%
Apatite	m

The calculated chemical composition is as follows:

SiO_2	45%
Al_2O_3	20%
CaO	10%
Na_2O	3%
Fe_2O_3	7%
FeO	10%
MgO	5%

Quartz Gabbro

The southeast corner of the stock is made of quartz gabbro. In hand specimen this rock is indistinguishable from the quartz diorite previously described; it is probably an earlier slightly more basic phase of the quartz diorite. In thin section the following features can be seen.

Euhedral to subhedral labradorite (An_{55}) forms grains averaging 1.5 mm in length. It is strongly altered, partly to sericite, partly to very fine-grained prehnite(?), and partly to exceedingly fine-grained cloudy brownish clinozoisite(?). In places labradorite is molded around euhedral to subhedral green hornblende (av. length 1.5 mm) which is pleochroic as follows: Z-dark green, Y-yellowish green, X-light brown. Cores of larger grains are altered to epidote (former pyroxene (?)), some grains are partly altered to clinochlore. Other grains have been altered to aggregates of fine-grained clinochlore, penninite, and epidote. Anhedral interstitial quartz has a poikilitic tendency, single grains extending over two mm and including small grains of all other minerals.

The estimated mineral composition is as follows:

Labradorite	50%
Hornblende	25%
Quartz	25%

Alteration products included in the above figures.

The rock is a somewhat altered quartz-hornblende gabbro.

Quartz Diorite

The inner portion of the West Stock is composed of

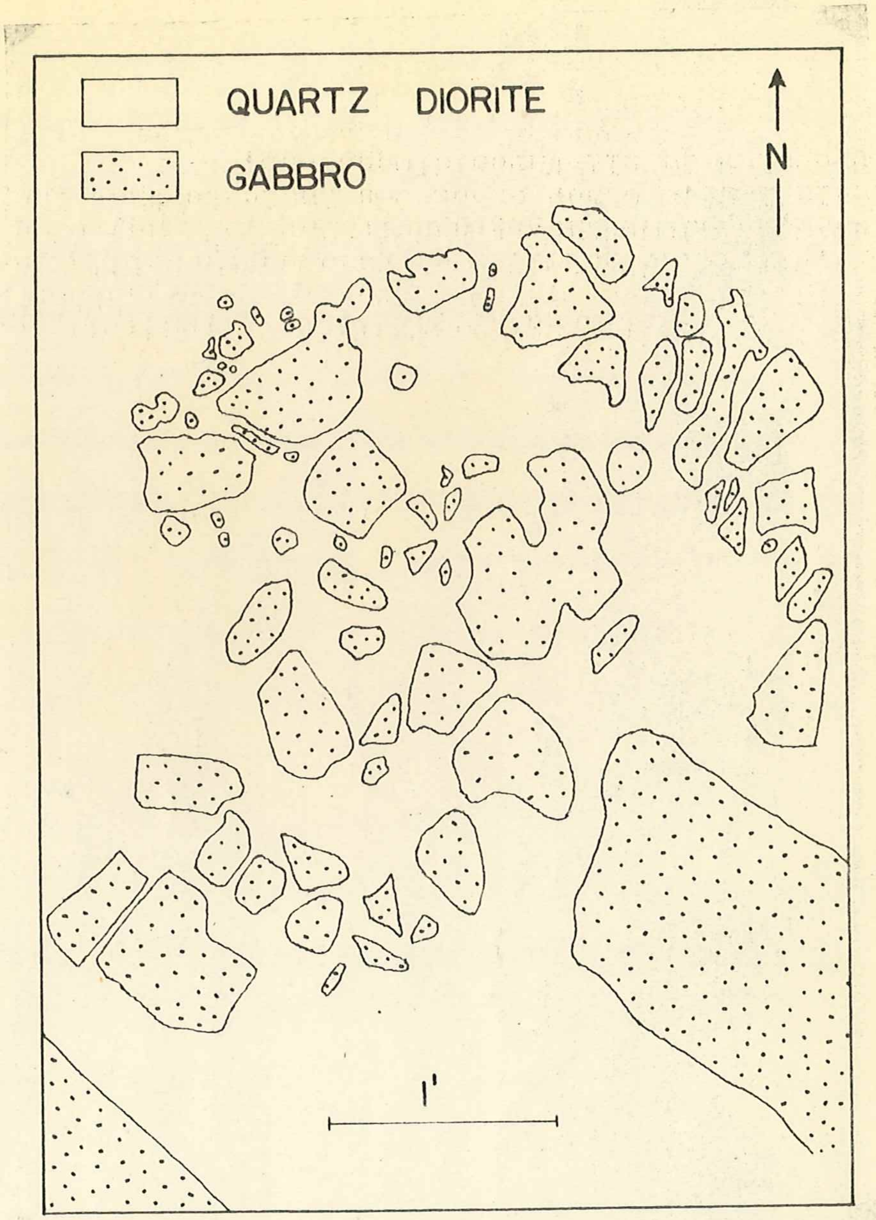

Fig. 15. An outcrop showing intrusive breccia at the quartz diorite-gabbro contact about ¼ mile SW of Melhorn Reservoir.

quartz diorite which is uniformly gray in outcrop and has none of the ultrabasic inclusions that characterize the gabbro. In hand specimen it is a uniform medium-grained gray rock.

The principal texture of the rock is hypidiomorphic granular. Euhedral to subhedral andesine (An_{44}) grains average 1 mm in length and are partly altered to sericite and partly to exceedingly fine-grained brown aggregates of clinozoisite. Anhedral green hornblende (av. dia. 1 mm) has a poikilitic tendency; partly enclosing andesine. It is pleochroic as follows: Z-bluish green, Y-yellowish green, X-light brownish green. It is partly altered to biotite and partly to chlorite. Dark brown anhedral biotite (av. dia. 1.5 mm) forms at the expense of green hornblende; tiny grains of epidote form little stringers along the biotite cleavage planes. Penninite forms from biotite and clinochlore from hornblende. Anhedral quartz is present in grains averaging 0.3 mm in diameter. Apatite and magnetite are accessory minerals.

The mineral composition is as follows:

Andesine	45%
Hornblende	15%
Biotite	20%
Quartz	15%
Penninite	5%
Apatite	m
Clinochlore	m
Epidote	m
Magnetite	m

The calculated chemical composition is as follows:

SiO_2	55%
Al_2O_3	20%
CaO	5%
Na_2O	3%
K_2O	2%
Fe_2O_3	5%
FeO	6%
MgO	3%
H_2O	1%

Intrusive Breccias

About two hundred yards west of the end of the "finger" of sheared greenstone which protrudes into the stock, and at the base of the hill is a prominent outcrop of "breccia". See Fig. 16.

The inclusions are well-aligned, strike parallel to the contact, and dip steeply, probably paralleling the contact vertically. Their elongation may be explained as follows: They were somewhat softened by the magma, and, in this softened condition, they were drawn out by differential flow.

The matrix of this rock is quartz gabbro, which makes up most of this corner of the stock. The dark inclusions are fine-grained varieties of the quartz gabbro; the hornblende is less altered, the plagioclase is altered beyond recognition, and the quartz is minor. These inclusions are probably cognate; their well rounded form suggests that they have been carried upward by the magma for a considerable distance.

Occasional large dikes of intrusive breccia are found in the marginal gabbro of the West Stock, near its contact

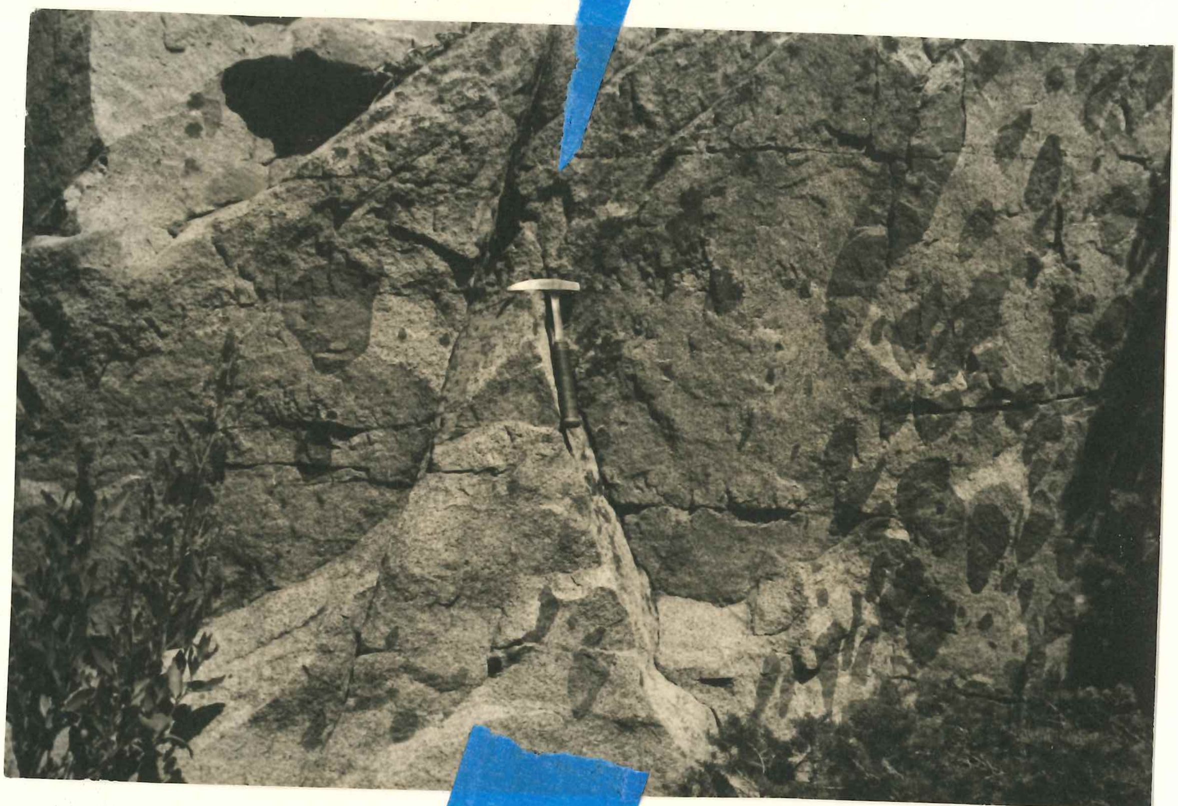

Fig. 16. Aligned elongate cognate inclusions of hornblende gabbro in quartz-hornblende gabbro in the SE part of the West Stock, near the sheared amphibolitic greenstone.

with the quartz diorite. See Fig. 17. These breccias contain a wide variety of inclusions; those noted were several kinds of pyroxenite and gabbro, diopside skarn, hornblendite, dark quartz diorite, sheared greenstone, and massive greenstone, all in a matrix of lighter quartz diorite. The glacially smoothed outcrop was difficult to sample; the one specimen obtained was a reconstituted schistose amphibolitic greenstone exactly like those described on page 31. The matrix is a basic quartz diorite containing euhedral to subhedral andesine (An_{47}), anhedral green hornblende, minor quartz, and magnetite.

Dark-colored breccia dikes in the skarn seem to represent the early basic phase of intrusive activity, corresponding to the chilled contact phase and cognate inclusions observed in the other stocks.

In hand specimen the breccia dike-rock consists of black fine-grained angular inclusions in a matrix of medium-grained dioritic-appearing rock. In thin section the matrix is seen to contain olivine (av. dia. 0.15 mm) which is partly altered to antigorite grains surrounded by rims of magnetite. Anhedral poikilitic augite (av. dia. 0.5 mm) includes the olivine and partly includes altered plagioclase. The plagioclase is completely altered to brownish exceedingly fine-grained clinozoisite which partly grades into epidote. Uralitic hornblende forms at the expense of augite; it is pleochroic as follows: Z-dark bluish green, Y-yellowish green, X-pale greenish brown or Z-dark brown, Y-yellowish brown, X-light brown.

Fig. 17. Intrusive breccia in marginal gabbro of the West Stock, containing fragments of greenstone, sheared greenstone, peridotite, gabbro, and quartz diorite. The matrix is quartz diorite.

The estimated mineral composition is as follows:

Augite	45%
Clinozoisite	40%
Uralitic hornblende	15%
Olivine	m
Antigorite	m
Magnetite	m

The rock is thus an altered gabbro. The dark inclusions have almost exactly the same minerals as the rock just described, but in different proportions.

The estimated mineral composition of one of the dark inclusions is as follows:

Olivine	10%
Augite	10%
Uralitic hornblende	70%
Clinozoisite	10%
Magnetite	m

The rock is an altered olivine pyroxenite; an earlier basic phase of the gabbro. It may have been carried into the dike as a cognate inclusion by the intruding gabbro; it may also have been an earlier basic dike which was shattered and re-intruded by gabbro.

Contact Phase

The contact of the West Stock with the greenstone was observed at one place at its northernmost end. The contact relations are somewhat obscured by a hornblende pegmatite which is intrusive in the contact. See Fig. 18. Some hornblende crystals attain a foot in length; the pegmatite sample chosen was finer-grained. In thin section the following features can be seen.

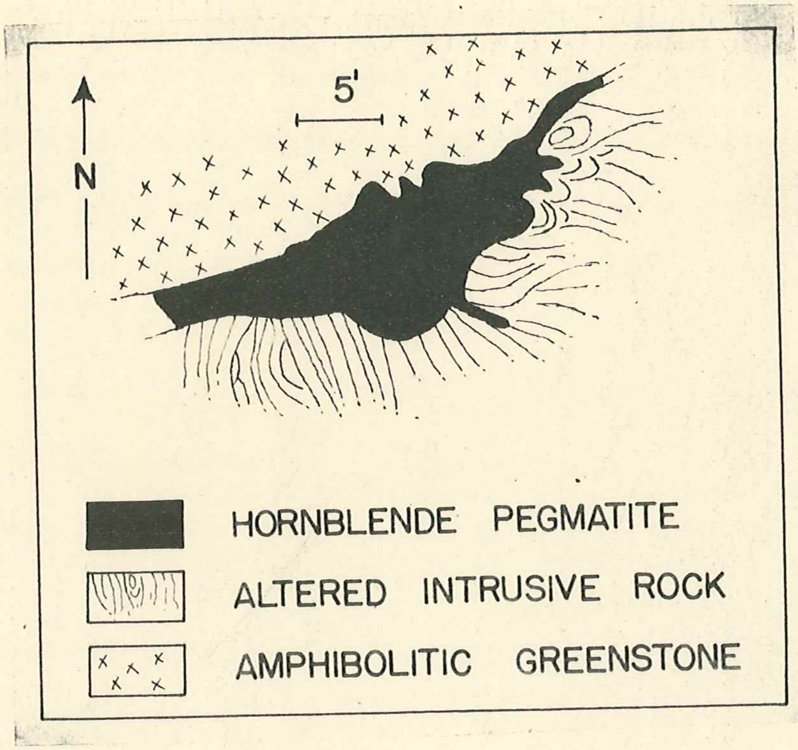

Fig. 18. Intrusive hornblende pegmatite in the contact between the West Stock and the greenstone. Note the unusual foliation in the altered intrusive rock. It is caused by the hornblende pegmatite. The manner of formation is not known.

Euhedral green hornblende (av. length 5 mm) is pleochroic as follows: Z-dark brownish green, Y-brownish green, X-pale brown. It includes quartz and feldspar and is partly altered to epidote and clinochlore. Euhedral to subhedral andesine (composition lies between An_{35}-An_{38}) exhibits occasional strong oscillatory normal zoning as well as occasional micrographic intergrowths with quartz. It is strongly altered to sericite and exceedingly fine-grained brownish masses of clinozoisite. Quartz is partly interstitial. Euhedral sphene is a prominent accessory.

The diorite near the contact has an unusual foliated structure normal to the contact with the hornblende pegmatite. As shown in the figure above, the foliation swirls out smoothly and disappears into massive diorite. The apparent foliation is caused by the concentration of mafics in certain layers. It is seemingly related in some way to the hornblende pegmatite because the swirls follow irregularities of it. In hand specimen the foliation is less apparent than in the outcrop; in detail it is hardly foliation, only a very irregular concentration of magics in certain zones and feldspar in others. In thin section the following features are seen.

Irregular grains of antigorite are generally surrounded by a rather thin rim of tremolite; surrounding both minerals are large anhedral grains of hornblende which are strongly poikilitic, including much altered plagioclase. Hornblende is partly altered to clinochlore and is variously pleochroic in either bluish-green or brownish-green. Euhedral plagioclase is completely altered to exceedingly fine-grained brownish masses of clinozoisite(?) which, is in places, recrystallized to larger grains of recognizable clinozoisite. Later interstitial feldspar is almost completely altered to sericite; one grain of feldspar is almost completely altered to sericite; one relatively fresh grain of feldspar has a composition of at least An_{87}. On the scale of a thin section, the foliation is barely visible, and only as a variable aligned concentration of green hornblende and clinochlore.

The rock was originally part of the early basic differentiated phase of the intrusion and has been somewhat altered by late deuteric action. The formation of the foliation normal to the contact is probably associated with the cooling of the hornblende pegmatite.

Quartz Diorite Dikes

Quartz diorite dikes from four to twenty feet wide occur sporadically throughout the area. A particularly dense swarm occurs in the north third of the West Stock and in the greenstone just to the north. They are older than lamprophyre dikes also present in the area. See Fig. 19.

A specimen collected from such a dike in the greenstone a quarter of a mile east of the Central Stock is in

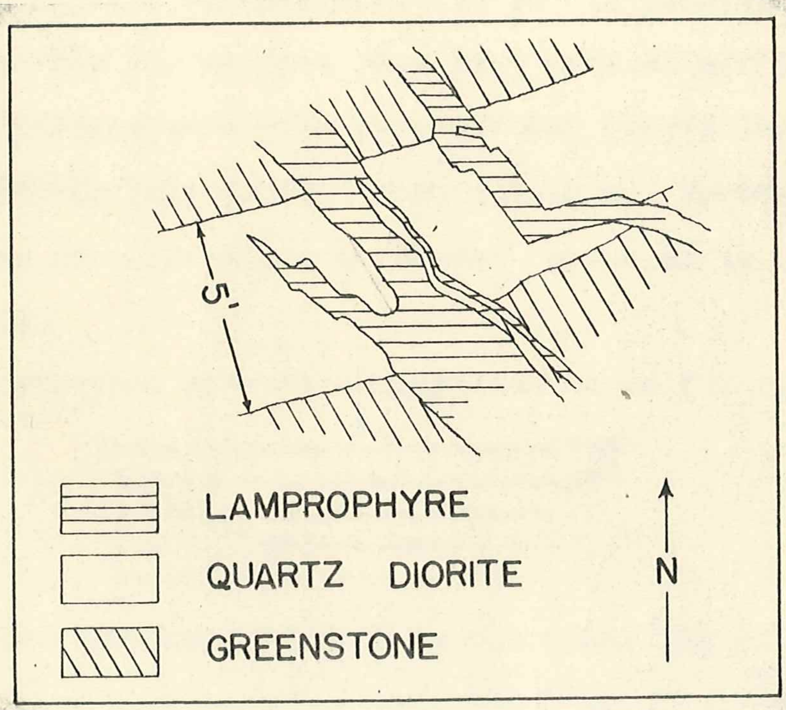

Fig. 19. Lamprophyre dikes cutting a quartz diorite dike.

hand specimen a medium-grained light greenish rock containing quartz, feldspar, and chlorite. In thin section the following features are seen.

Andesine (An_{35}) has an euhedral temdency although most grains are subhedral (av. dia. 0.5 mm). It is mostly untwinned; only a few grains show albite twinning. It is partly altered to sericite and to exceedingly fine-grained brownish masses of clinozoisite (?) and to xenoblastic epidote. Iron for the epidote came from altered mafic minerals. Quartz is present partly as interstitial grains and partly as micrographic intergrowths with andesine. Scattered irregular grains of clinochlore represent former mafic minerals. See Fig. 20.

The estimated mineral composition is as follows:

Andesine	75%
Quartz	15%
Epidote	5%
Clinochlore	5%
Sericite	m

Another specimen of one of these dikes was collected in the greenstone just north of the West Stock. In hand specimen it is a dense medium-colored rock with phenocrysts of quartz, feldspar, and hornblende. In thin section the following features can be seen.

Large (to 8 mm dia.) euhedral phenocrysts of andesine (composition lies between An_{30}-An_{38}) are untwinned and show strong normal zoning. Some large grains are fresh and exhibit tiny growth cilia extending a short distance into the groundmass. These grains are traversed by cracks and zones

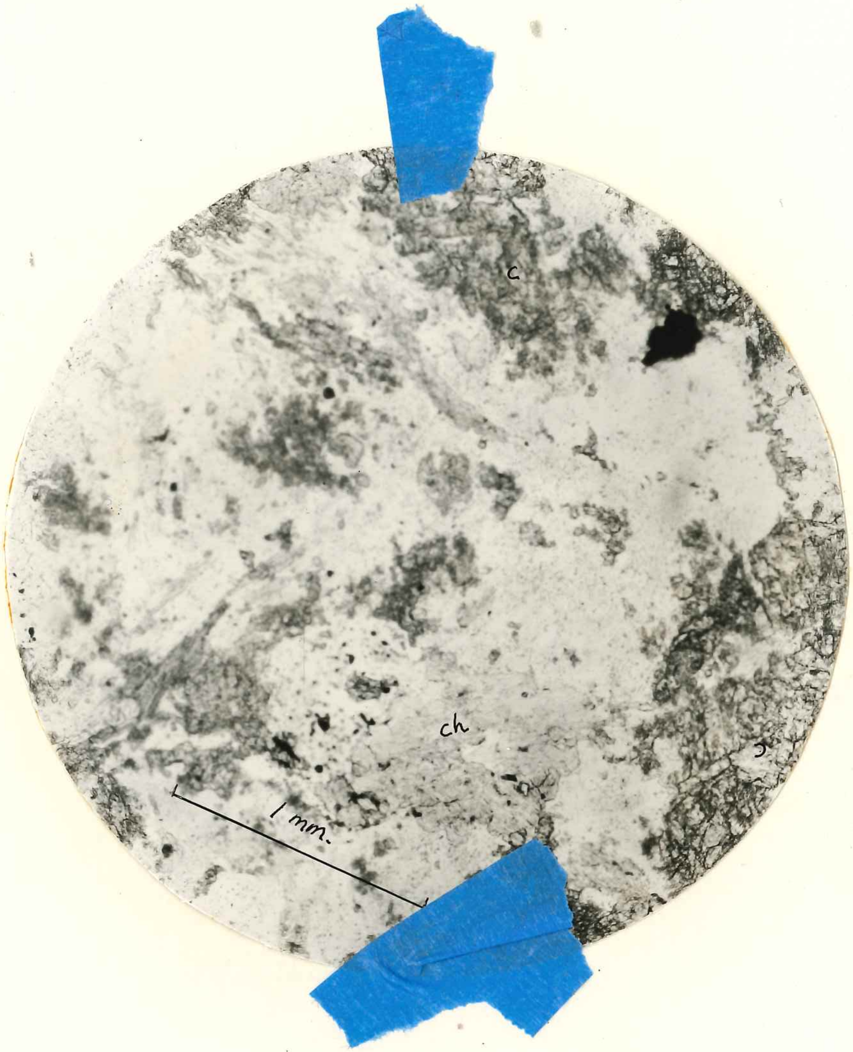

Fig. 20. Quartz diorite in plane light. Epidote has formed at the expense of former mafics and andesine. Some pale green chlorite is present. (c - epidote, ch - chlorite.) Plane light.

of incipient microbrecciation; some wider cracks contain very fine-grained groundmass material. Other equally large grains are strongly altered to sericite and fine-grained clinozoisite. Euhedral hornblende (av. 0.5 mm length) is pleochroic as follows: Z-bluish green, Y-yellowish green, X-pale brown, and partly altered to clinochlore and epidote along cleavage planes. The groundmass contains tiny anhedral grains of biotite and hornblende (av. length 0.04 mm). Quartz and oligoclase(?) have an average diameter of 0.02 mm. The oligoclase(?) is untwinned and has positive relief.

The estimated mineral composition is as follows:

Phenocrysts

Andesine	45%
Quartz	10%
Hornblende	5%
Biotite	5%

Groundmass

Oligoclase(?)	15%
Quartz	10%
Hornblende	5%
Biotite	5%

The rock is a quartz diorite porphyry.

Lamprophyres

Numerous dense black dikes of nearly identical composition are found in all the intrusive rocks and adjacent greenstones and arkoses. They occasionally intersect one another; as many as three ages of dikes could be discerned in places. A specimen of one collected from the Central

Stock exhibits features common to all-thus the following description will suffice for all the lamprophyre dikes and the lamprophyre stock at the south end of the Central Stock. Fig. 21 shows the often-seen form of these dikes in quartz diorite.

Euhedral to subhedral green hornblende occasionally contains inclusions of relict augite. Two varieties of hornblende are present. Larger grains (av. dia. 0.8 mm) are euhedral and pleochroic as follows: Z-dark greenish brown, Y-greenish brown, X-light brown. Occasional phenocrysts are altered to ragged masses of blue-green hornblende. Smaller subhedral grains (av. dia. 0.15 mm) and rims of larger grains are pleochroic as follows: Z-dark bluish green, Y-yellowish green, X-pale brown. Hornblende occasionally has inclusions of feldspar in the outer edges of grains. Plagioclase exhibits strong normal zoning; centers of crystals are labradorite and rims of crystals are oligoclase (An_{22}). It is altered partly to sericite and partly to exceeding fine-grained brownish masses of clinozoisite. It is mostly subhedral except against quartz, which is interstitial. See Fig. 22.

The estimated mineral composition is as follows:

Green hornblende---------75%
Labradorite--------------15%
Quartz-------------------10%
Augite-------------------m

The rock may be called lamprophyre. All of these dikes are fine-grained and most of them, if not all, exhibit

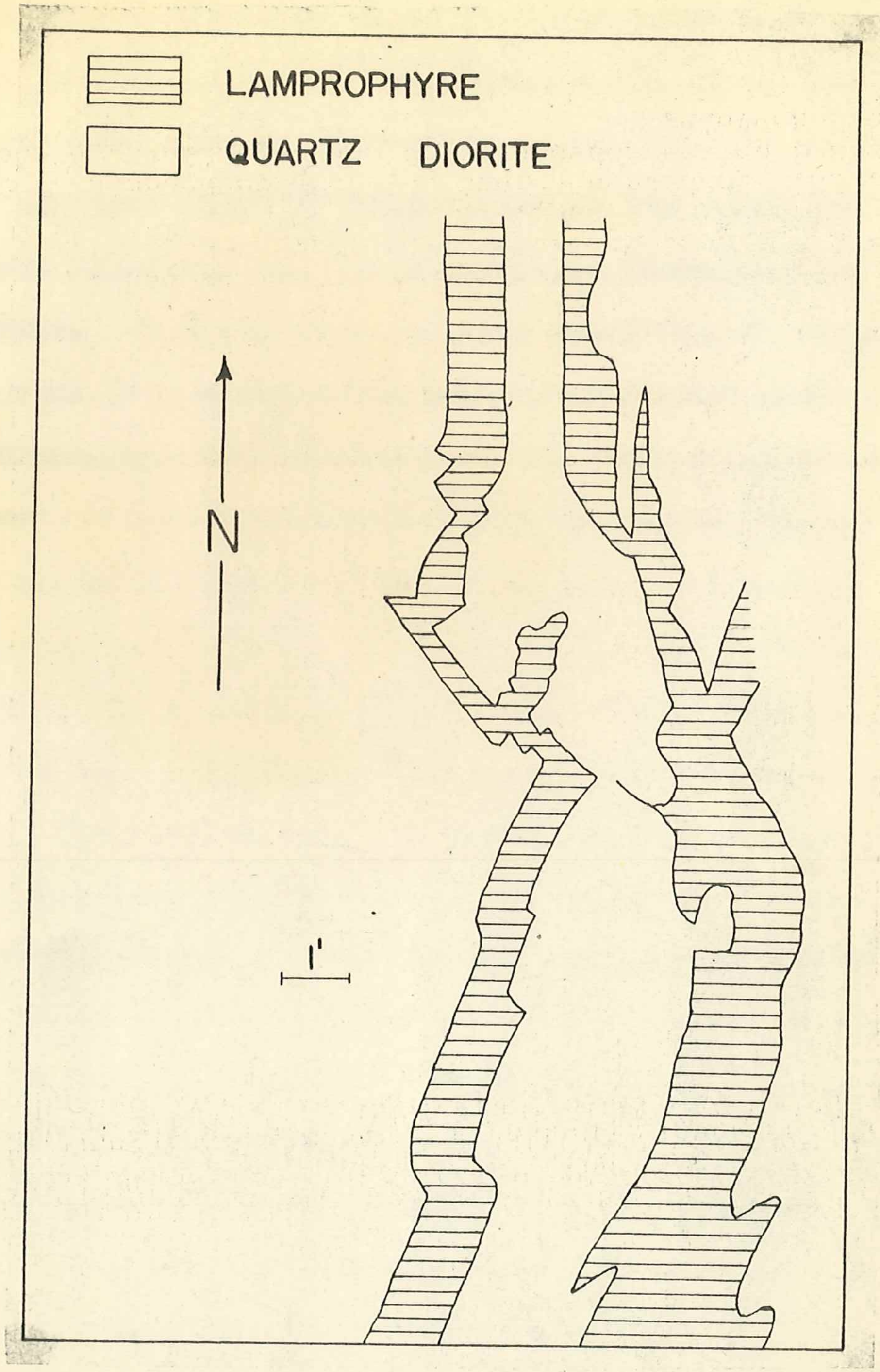

Fig. 21. An outcrop in the West Stock showing the irregular form of many of the lamprophyre dikes.

chilled borders. This means that the rock into which they were intruded was rather cool and that they were chilled rather quickly. Thus they must have been intruded considerably later than the stocks, because the stocks had had time to cool more or less completely.

The marginal stock of lamprophyre at the south end of the Central Stock has all the mineralogic features described above. It contains occasional xenoliths of arkosic tuff, derived from more tuffaceous layers in the tuffaceous arkose.

Fig. 22. Typical lamprophyre. Plane light

PETROLOGY

The rocks of the Fish Lake area may be subdivided into two broad groups in a discussion of their petrology: (1) pre-intrusive rocks and (2) intrusive rocks.

PRE-INTRUSIVE ROCKS

Summary Note

Included in the pre-intrusive rocks are the tuffaceous arkoses, the various kinds of greenstone, the lime-silicate rocks, and marble.

Tuffaceous Arkose

The tuffaceous arkoses are not considered part of this thesis and will be discussed only briefly.

The areal extent of the arkose is not known. Because it is conglomeratic, it was probably deposited fairly close to a granitic area of high relief. The tuffaceous admixture indicates that volcanism was going on nearby.

A contact metamorphic aureole exists in the massive and sheared greenstones and arkoses surrounding the stock. Insufficient specimens were collected to study effects on the arkoses. Those samples obtained show little or no effects - the only sign of alteration being an occasional seam or crack in the rock along which a little recrystallization of the feldspar has occurred. On the geologic map the aureole is shown diagrammatically because not enough evidence was accumulated to map it accurately. Contact metamorphic effects extend at least 1500 feet from the stocks and perhaps over 3000 feet.

Clover Creek Greenstone

Ross(13) has discussed the origin of the greenstones:

> . . . the effusion of Permian andesitic flows accompanied by notable explosive activity . . . the eruptions evidently took place near the sea, as their deposits are associated with marine sediments. Some of them may well have been submarine.

Fig. 3 bears this out.

Two important differences exist between the Clover Creek greenstone as described by Ross on a regional basis and the Clover Creek greenstone in the Fish Lake area. (1) The Clover Creek greenstone near Fish Lake is of basaltic composition with porphyritic textures and occasional diabasic textures (former sills or dikes ?), and finer-grained textures characteristic of basalt. (2) The Clover Creek greenstone near Fish Lake is largely unaltered from its original igneous state; only a few per cent of chlorite (sufficient to color the rock) and epidote has developed. (See page 15 for Ross' description.)

The mode of formation of the greenstone is undoubtedly that described by Ross.

Contact Metamorphic Clover Creek Greenstone

The principal effect of contact metamorphism on the Clover Creek greenstone was the formation of green hornblende, making it more or less amphibolitic.

Near the contact, green hornblende and metamorphic labradorite were formed. Farther out phenocrysts of labradorite had survived the original low temperature phase of greenstone-making and have survived the later thermal metamorphism. The principal effect on the rocks was recrystallization of original chlorite and epidote to green hornblende. Still farther out some pyroxene has persisted and hornblende and epidote are the newly made minerals. The most distant rocks collected exhibit only thin rims of green hornblende on relict pyroxene; these rocks are so unaltered that they still exhibit mostly igneous textures.

The greenstone xenolith in the Northeast Stock exhibits fresh bytownite, evidence of the highest metamorphic temperature indicated in any of the xenoliths; control of this feldspar must have been thermal, because the rock apparently had enough Ca to make as calcic plagioclase as the temperature would permit. Relict plagioclase phenocrysts in this rock are completely altered to exceedingly fine-grained clinozoisite.

Mineral assemblages indicative of the high-grade zone of static metamorphism were developed near the contact between the gabbro stocks and the greenstone. Falling temperature is in evidence at progressively greater distance from the stocks.

Sheared Clover Creek Greenstone

In the petrographic description it was shown that the sheared greenstone consists of amphibolitic greenschist, greenschist in which a little crystalloblastic green hornblende has developed; and schistose amphibolite, amphibolite in which the mafic mineral is entirely green hornblende, mimetic after the foliation of the greenschist and thus only poorly aligned. The feldspar in some specimens of schistose amphibolite is mostly andesine, occasionally rimmed by labradorite. The feldspar in other of the amphibolite specimens appears to have either no zoning or weak normal zoning (more sodic rims).

A problem lies in the origin and distribution of the sheared Clover Creek greenstone. Ross was quoted on page (15) as saying that the greenstones in a few places are schistose. On the geologic map it can be seen that the belt of sheared greenstone is present only along the northeast side of the West Stock. This rock type was not found anywhere else in the area. It is possible that the belt of shearing may continue to the south in the sedimentary rocks; however that possibility was not checked in the field. No prolongation of it could be found in rocks to the northwest;

it may have been faulted out or it may not have been formed there.

The general form of this belt suggests that it has been shouldered aside somewhat by the intrusive. Its south end is interesting in that it was better able to withstand the plucking action of the magma than was the massive greenstone and thus remains as a "finger" projecting into the stock. The shouldering aside is best exhibited just north of the Melhorn Reservoir, where the Little Stock has seemingly bent the sheared greenstone around and pinched it off against massive greenstone. The effects of this shouldering aside should be visible in thin section; unfortunately no specimens were collected in that critical area.

The sheared greenstone is clearly older than the stock; its relations to the stock as well as the presence of sheared greenstone xenoliths within the stock immediately preclude the possible idea that the schistosity was made through shearing induced by the intrusion. As shown in the petrographic description, the original rock was a greenschist, formed by shearing under epizonal temperature.

One possible cause of the localization of such a belt of comparatively intense deformation in an area of mostly undeformed rocks may be somewhat as follows. It has been previously shown that the impure dolomitic limestones were probably present as a lens or lenses in the greenstone. If this lens were of any size it would cause a "weak spot" in the greenstone, a zone of relative incompetence.

Large massive units are generally difficultly deformed if the forces of deformation are not strong, or if neighboring rocks are relatively incompetent and will absorb most of the stress. The manner of yielding to deformation of large competent bodies is sometimes shearing in certain localized zones which absorb the stress, leaving the large part of the rock comparatively undeformed. Thinner units of greenstone to the south, interbedded with quartzites, argillites and limestones were isoclinally folded, according to Fitzsimmons(14). In thinner layers, interbedded with other rocks, the greenstones were much less competent. Also, upper Triassic limestones only a few miles to the north have been isoclinally folded. The relatively incompetent rocks to the north and south were strongly deformed whereas the large greenstone block failed only along a few localized zones.

The localized zones of failure would probably have been in the weakest parts of the rock - in this instance, a large lens of limestone formed a weak spot. Later intrusive magma, working upward and encountering such a weak zone, would tend to follow it.

As shown in the petrographic descriptions, the sheared greenstone is partly relict greenschist and partly amphibolitic. Detailed mapping of the distribution of these rocks would be difficult because they look exactly alike in hand specimen. Probably the only way would be to collect specimens on a grid pattern, examine them petrographically, and plot their distribution on a map at perhaps 200 feet to the inch.

One specimen of greenschist was collected near the contact with the intrusive. Other samples, amphibolitic, were collected farther away from the contact. This shows that rocks adjacent to the intrusive did not respond uniformly to the effects of heating.

The reason for the differing amounts of recrystallization is perhaps somewhat as follows: Rocks have a certain degree of inertia so that simple (dry) heating will not cause recrystallization to begin until temperature is considerably higher than the point at which recrystallization might have begun had other agents such as hot solutions or shearing been present to "trigger" the reaction.

In these rocks some sort of control by fractures must be postulated, because the conductivity of the rock must have been uniform. Thus the admission of hot solutions to certain parts of the rock by fractures would cause that part of the rock to be recrystallized whereas neighboring rocks might remain unchanged.

The presence of andesine with reverse zoning and rims of labradorite in some of the schistose amphibolites is indicative of rising temperature which attained at least equivalence to high-grade temperature. Recrystallization was sufficiently complete to partly free green hornblende from its mimetic alignment after the original greenschist. Temperature was not high enough, however, to recrystallize the still more calcic relict labradorite phenocrysts present in places in the greenschist. Therefore, control of the composition of the newly made plagioclase was probably thermal rather than chemical. If temperature had risen sufficiently high to recrystallize relict calcic labradorite and the newly made feldspar was only andesine, then control of feldspar composition would have been chemical because only enough Ca was present to make andesine whereas temperature conditions would have permitted the formation of calcic labradorite. As the relict calcic labradorite was not recrystallized, it seems likely that the sodic labradorite is as calcic as the temperature conditions permitted; had temperature risen higher, sufficient Ca was probably present to make even more calcic feldspar. To repeat, then, the feldspar composition was probably controlled by temperature rather than by chemical composition.

As previously mentioned, small amphibolitic xenoliths within the stock are more thoroughly recrystallized than amphibolite without the stock. Only vestigal alignment of hornblende grains remains and no relict phenocrysts of plagioclase were found. These rocks were subjected to prolonged heating and recrystallization and there was time for a more complete adjustment, a homogenization of the rock. In the specimens examined the feldspar was andesine. It has been shown previously that temperature within the stocks corresponded to at least the high-grade zone of static thermal metamorphism; it was probably even higher, especially immediately after intrusion. Therefore, it seems that control of feldspar composition there may have been chemical. The rock did not contain sufficient Ca to form more calcic plagioclase under temperature which was high enough to make labradorite. (The original rock may have been andesitic.) The feldspar in thin (1") seams of schistose amphibolite in lime-silicate xenoliths is close to enough Ca to make anorthite if the temperature had permitted; this indicates that transfer of Ca was not active under conditions of static metamorphism, even in a xenolith within a magma. No marked effects of reaction with the magma were noted; they may exist, but were not seen in any of the specimens examined.

Marble

The pure marble xenoliths remained unchanged except for a general recrystallization and coarsening of grain size. This, of course, is what one would expect. In order to make many of the lime-silicate minerals, aluminum, iron, and especially silica would have to be metasomatically added to the marble. Early in the cooling time of the gabbroic or dioritic magma excess silica would not be present (and perhaps not much water, as basic magmas are comparatively "dry"). Aluminum is not transferred metasomatically with ease under any conditions, and is not transferred at all under most. Iron, perhaps, would be available late in the cooling time of the rock as would silica; however, these would be in late deuteric solutions and temperature would probably be too low for the formation of most lime-silicates.

Lime-Silicate Granulite

In the petrographic descriptions it was shown that the lime-silicate granulites contain a mineral assemblage indicative of the pyroxene hornfels facies. Enstatite, grossularite (and vesuvianite), and diopside are predominant. Significant amounts of epidote and green hornblende are present as retrogressive products.

The impure dolomitic limestones were easily recrystallized under the high temperatures available within the stock.

It is probably safe to assume that the xenoliths were raised to the temperature of the surrounding magma. If this is true, the mineral composition of the lime-silicate rocks should provide a clue to the temperature within the stock during its early cooling history.

Enstatite, present in some of the rocks, is an index mineral of the pyroxene hornfels zone of static thermal metamorphism. Diopside may be formed in the hotter part of the medium-grade zone as well as under higher temperatures. Grossularite and vesuvianite may form at somewhat lower temperatures than hypersthene. In other of the rocks primary quartz and calcite are found together. It is generally considered that the quartz-calcite reaction, forming wollastonite, marks the beginning of the pyroxene hornfels zone.

Thus one mineral is present which proves that temperature was high-grade and two other minerals are present which, superficially, seem to show that temperature did not attain the high-grade zone. Several possible explanations are as follows:

(1) Temperature distribution was not uniform within the xenoliths. This possibility can be eliminated as soon as it is mentioned. Temperature within the magma was surely well above that of the high-grade zone; further, conductivity was surely sufficiently effective to heat the xenoliths uniformly-the largest is perhaps a hundred yards in diameter.

(2) Enstatite can form in a narrow temperature interval just below the temperature at which calcite and quartz react to form wollastonite. Again, this possibility can be quickly eliminated. The high temperature within the stock precludes the necessity for postulating a temperature of formation for enstatite below that of the quartz-calcite reaction. Evidence from no other place exists to show that enstatite can form at temperatures lower than that of the quartz-calcite reaction.

(3) Temperature was above that required for quartz-and calcite to react to form wollastonite but the reaction did not occur because hot solutions or shearing were not present to "trigger" the reaction. Surely temperature within the magma was high enough to overcome the natural inertia of the minerals in question, to cause them to react even in

the absence of hot solutions. Therefore, this idea seems unlikely, although remotely possible. The one fact that makes it even remotely possible was cited in the discussion of marble; it was shown there that as the marble was not altered metasomatically, it was probably not penetrated by hot mineralizing solutions.

(4) Perhaps the partial pressure of carbon dioxide rose sufficiently high to prevent the wollastonite reaction from occurring. The magma surrounding the xenoliths was under high pressure; vapor tension must also have been high. Thus it seems reasonable to assume that carbon dioxide liberated by the wollastonite reaction would be unable to escape into the magma. Therefore, it is postulated that quartz and calcite exist together in these high-grade rocks because the partial pressure of carbon dioxide was sufficiently high to prevent the wollastonite reaction from occurring.

It should be mentioned here that the enstatite in these rocks may not be perfectly reliable as a zone indicator. As mentioned in the petrographic description, its 2V is probably less than 10 degrees (the interference figure appears uniaxial at first sight) and the pleochroism appears abnormally strong, although this last may have been only the effect of an unusually thick section. 2V in enstatite commonly ranges from 58-80 degrees (Rogers and Kerr). It is normal in all other respects, including indices of refraction. This optical anomaly might represent an unusually high temperature of formation, an unusually low temperature of formation, some unknown factor of chemical composition, or an abnormal pressure of formation. In the absence of evidence to the contrary, it is probable that the anomalous optical character of the enstatite is not significant with respect to temperature, that the enstatite is still reliable as an indicator of the high-grade zone.

A more difficult problem remains to be considered. From the viewpoint of chemical composition, enstatite is "out of place" in some of these rocks. In the pyroxene hornfels facies a zone of overlap exists between enstatite-hypersthene and diopside in more calcic rocks exactly as exists between cordierite and enstatite-hypersthene in less calcic rocks. No problem exists in those rocks described in which only diopside and minor enstatite are present. However, others described contain, in addition to enstatite and diopside, grossularite and calcite; these rocks are much more calcic than those in which a pure magnesium silicate ordinarily forms. It is true that preferential silication of magnesium is operative in these more calcic rocks; on the other hand, this principle accounts for the formation of diopside in preference to wollastonite in less pure marbles. Therefore, it is impossible to account chemically for the presence of enstatite in association with calcite and grossularite. It is remotely possible that the anomalous optical character of the enstatite might be involved in an explanation.

Retrogression of garnet to epidote occurred during the time of falling temperature. Retrogression of diopside to very fine fibrous brucite(?) was observed on a very minor scale and represents retrogression at low grade temperatures, the last migration of late deuteric solutions along a few scattered veinlets in the rock

INTRUSIVE ROCKS (DIORITE-GABBRO COMPLEX)

Diorite-Gabbro Complex

The intrusive rocks in this area exhibit a variation in composition from olivine-hyperasthene gabbro to (labradorite-augite) gabbro, to hornblende gabbro, to quartz-hornblende gabbro to quartz-hornblende diorite. More acidic rock may exist in the central part of the stock; in the field the assumption was made that the dioritic rocks were reasonably uniform and the central part was not sampled. This was not a valid assumption; however, the fact that later dikes associated with the stock are quartz dioritic in composition tends to bear it out.

The four small stocks are probably cupolas on a larger body in depth. Several lines of evidence support this idea.

(1) Mineralogic content of gabbro in all the stocks is reasonably similar

(2) Calculated chemical compositions of gabbro specimens from the different stocks are similar.

(3) Cognate inclusions in all the stocks are similar.

(4) Intrusive breccias in the West and Central Stocks are similar.

(5) The Central Stock and the Northeast Stock have identical xenoliths of altered sheared peridotite.

(6) Their contiguity is suggestive of a common origin.

If they are indeed cupolas on a larger stock in depth, an immediate hypothesis is suggested concerning the reason for the variation in composition-the crystal fractionation hypothesis.

A large stock would be slowly cooling, while sending magma upward into and perhaps through the cupolas. As it cooled, the magma would progressively become more acidic as more and more mafic minerals settle out, leaving more acidic magma. Additional fresh pulses of intrusive force sent up progressively acidic magma as time passed.

As mentioned previously, these stocks may have intruded the greenstones partly along lines of weakness established by the presence of lenses of marble in the greenstone. It remains to inquire into the manner of intrusion, whether principally stoping or principally shouldering aside of the older rocks.

The only structural element which lends a clue is the sheared greenstone, and as previously mentioned, its form is suggestive of a shouldering-aside by the intrusive rocks.

Daly(15) feels that stoping is the principal mechanism operative in the emplacement of a stock or batholith:

> The presence of foreign inclusions at internal contact belts of stocks and batholiths, and the detailed phenomena associated with those inclusions, are facts of nature expected on the hypothesis. It is implied that the removal of

> blocks from the chamber vault is comparable to the work of a river. The active corrasion of a stream in its youth is rapid and corresponds to the rapid stoping of an intrusive body in its first long stage of high temperature and fluidity . . . The conclusion is drawn that, under the energetic conditions of high liquidity, a magma may open, in the invaded formation, a chamber of size appropriate to a stock or batholith.

If stoping had been predominant, the intrusive rocks should abound in xenoliths of greenstone. However, very few xenoliths of greenstone were observed. A large xenolith of massive greenstone in the Northeast Stock could also be a roof pendant. None were observed in the Central Stock nor in the Little Stock. Two very small xenoliths of sheared greenstone were observed in the West Stock and only one of these was large enough to show on the geologic map. It might be supposed that all the xenoliths had sunk in the magma and would now be out of sight. Daly(16) says: "Blocks of the basic eruptive rocks would sink in all . . . magmas except in a very basic peridotite." However, if the process of intrusion is a continuous one, right down to the time of final freezing, a continuous "shower" of xenoliths should be sinking downward in the magma; surely many of these would be arrested in their downward movement by the final freezing of the magma and be visible in any cross-section of the stock. Furthermore, evidence will be given in the discussion of cognate inclusions to show that upward flow may have been active in the magma and that although xenoliths may have been carried upward, it seems unlikely that they were.

Therefore, it appears possible that the major mechanism of intrusion was a shouldering-aside of the older rocks by the magma. A fact which tends to substantiate this postulate is as follows: Considerable variation exists in the greenstone near the stock; perhaps the manner of failure of the greenstone was breaking into large blocks. This would account for the sudden changes of rock type observed from roche moutonnee to roche moutonnee. Stoping was probably minor.

One relatively large feature probably made by stoping is the "finger" of sheared greenstone projecting into the southeast corner of the West Stock. Much of this material may have been partly incorporated in the magma higher up or lower down; no evidence of incorporation was noted in the adjacent quartz gabbro. The lack of evidence of stoping near a feature clearly made by stoping tends to weaken the arguments presented aginst stoping as the mode of intrusion of the stocks. If stoping was active here and is not in evidence, it may equally well have been operative through-out the stocks and still not be in evidence.

Cognate Inclusions

In the dioritic rocks the cognate inclusions are mostly more basic rocks of similar composition. They were probably formed by the shattering of earlier chilled rock and the inclusion of shattered blocks into the magma. The peridotitic cognate inclusions were formed in similar fashion. The peridotite was probably formed by differentiation of gabbroic magma at chilled contacts.

Daly(17), in support of his stoping hypothesis, offers the following possible mechanism of stoping:

> Another cause of the mechanical destruction of the vault . . . may be found in the special condition of strain existing at . . . contacts. The temperature of the invaded rock is raised by the adjacent magma many hundred degrees Centigrade above the temperature the rock may be assumed to have had before the intrusion began. As much as two per cent of volumetric increase could thus be produced in the solid rock close to the magma. Farther away, although still near the contact, the elevation of temperature and corresponding expansion in the country-rock would be of a much lower order. It is evident that enormous strains would be set up in the relatively thin shell of the vault bounded by the . . . contact. The strains would be comparable to those observed in surface cliffs and quarries exposed to rapid but small changes of temperature, but on a much greater scale. The complex stress induced might conceivably result in the extensive shattering and exfoliation of the country rock.

A similar mechanism might operate to shatter chilled earlier phases of intrusive rock. The broken blocks would then be cognate inclusions.

The intrusive rocks of this area seem to exhibit a continuous sequence showing the formation of cognate inclusions, if only form, and not composition, be considered.

An early stage is shown by gabbro inclusions in quartz diorite (p. 69). These still have fairly angular form as they have not been too long broken and immersed in the magma.

An intermediate stage is shown by hornblende gabbro inclusions in quartz hornblende gabbro (p. 72). Here the inclusions have been immersed in the magma for a considerable time, somewhat softened, and elongated by differential flow. At this stage they exhibit no noticeable mixing with the magma. These inclusions are fairly close to the contact so that if stoping and concomitant upward-carrying of xenoliths of greenstone were active, some greenstone would surely be present among the cognate inclusions.

A late stage is shown by peridotite inclusions in olivine gabbro (p. 50). These inclusions were so softened that they were easily squeezed about by differential flow in the magma. Surprisingly, even these, which seem to have been rather mobile, exhibit no intermixture with the magma.

One might speculate on the basis of this evidence, that magma can do little more with cognate inclusions than soften and reshape them; it cannot assimilate them.

However, Bowen(18) says:

> -we may state that a liquid saturated with any member of a continuous reaction series is effectively super-saturated with all other members of the series; it cannot dissolve them but can only convert them in the phase with which it is saturated.

As the magma was crystallizing out labradorite and augite, any reaction would simply produce more labradorite and augite-thus no marked effects of inter-action should be expected. Textural criteria should be present, as indeed they are. A photomicrograph (p. 66) shows the contact between a cognate inclusion and gabbro. The cognate inclusion appears to be corroded. In addition, a certain amount of recrystallization may have been involved in the softening and changing form of the cognate inclusions. During their recrystallization, the composition of the minerals may have been somewhat changed by reaction with magmatic solutions.

Other Inclusions

Other inclusions are mostly xenoliths of sheared peridotite found in two of the stocks, the Central and the Northeast. Similar inclusions may be present in the other two, but were not found.

In the petrographic description, it was shown that these inclusions consist of sheared, partly serpentinized peridotites.

Gilluly(19) has the following to say about intrusive rocks in the Baker Quadrangle to the southeast:

> The plutonic rocks may be divided, on the basis of their degree of metamorphism and deformation, into two groups, one showing notable cataclastic and metasomatic metamorphism and another in which these features are negligible. The sheared plutonic rocks exhibit a wide range of composition, from ultra-basic to siliceous, but on the whole are chiefly gabbroic.

Ross(20) mentions a mass of amphibolite formed from quartz diorite several miles south of Fish Lake:

> The field relations of this rock are

> essentially similar to those of the . . . diorite . . . the much greater degree of alteration and the fact that there is some evidence of crushing suggests greater age.

Thus it is seen that both regionally and locally pre-orogenic basic intrusive rocks are present. The later intrusive encountered these rocks and carried them upward(?) as xenoliths. They were undoubtedly sheared in the same orogeny as the sheared greenstone.

It is necessary to inquire into the conditions under which shearing occurred. In the petrographic description it was shown that the augite of the peridotites, although strongly traversed by shearing, exhibited no offset in inter-grain boundaries or twinning lamellae. Surely shearing under low-grade conditions would have reduced this rock to a serpentine-chlorite schist.

A possible explanation is as follows. If the basic intrusions were synkinematic (intruded simultaneously with penetrative deformation), it is possible that they were sheared while still hot enough to mostly preserve their mineralogic content. Individual grains were able to maintain themselves by recrystallization simultaneous with shearing.

Intrusive Breccias

The intrusive breccias are found in a small area in the southeast part of the West Stock, a hundred yards northwest of the largest lime-silicate xenolith. Fragments in the breccia include most of the rock-types found in the area as well as some that are not and must have come from depth. The matrix is quartz diorite.

The diversity of inclusions indicates that the entire mass of the breccia came in from some other place. A possible explanation of origin is as follows: The marginal quartz diorite picked up much extraneous material during the act of intrusion, much as the front of a flood of water becomes charged with rock, pieces of wood, and other material lying in a dry stream channel. This material was injected into dikes and differs from normal dikes only in the high content of inclusions.

Quartz Diorite Dikes

The quartz diorite dikes seem to represent a late, dying phase of intrusive activity.

Lamprophyres

The lamprophyre dikes and the small marginal stock of lamprophyre represent the last intrusive activity associated with the stock. A problem arises in this connection. The feldspar of most of the lamprophyre dikes is labradorite; in a few it is andesine. One possible explanation might be that the lamprophyres are remelted basic portions of some of the deeper parts of the stock. As previously mentioned, at least three ages of lamprophyre dikes are present; a more detailed study of these dikes might shed some light on the problem.

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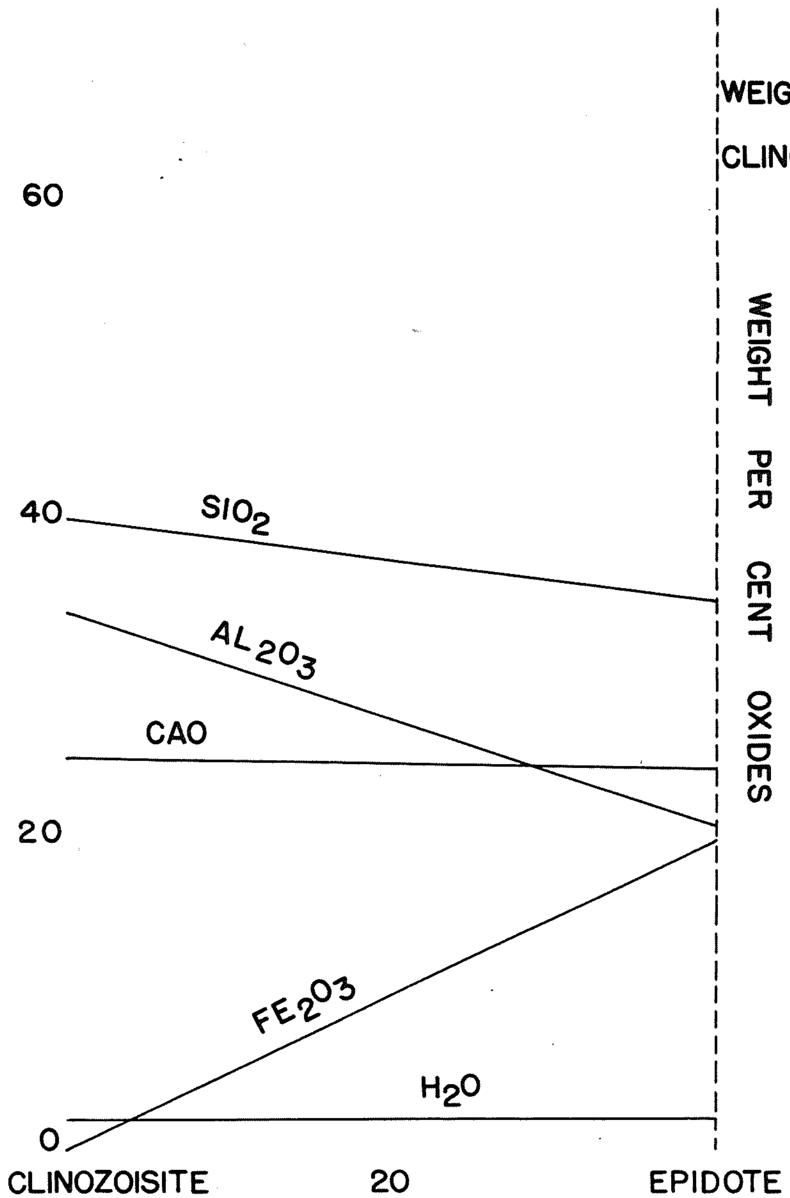
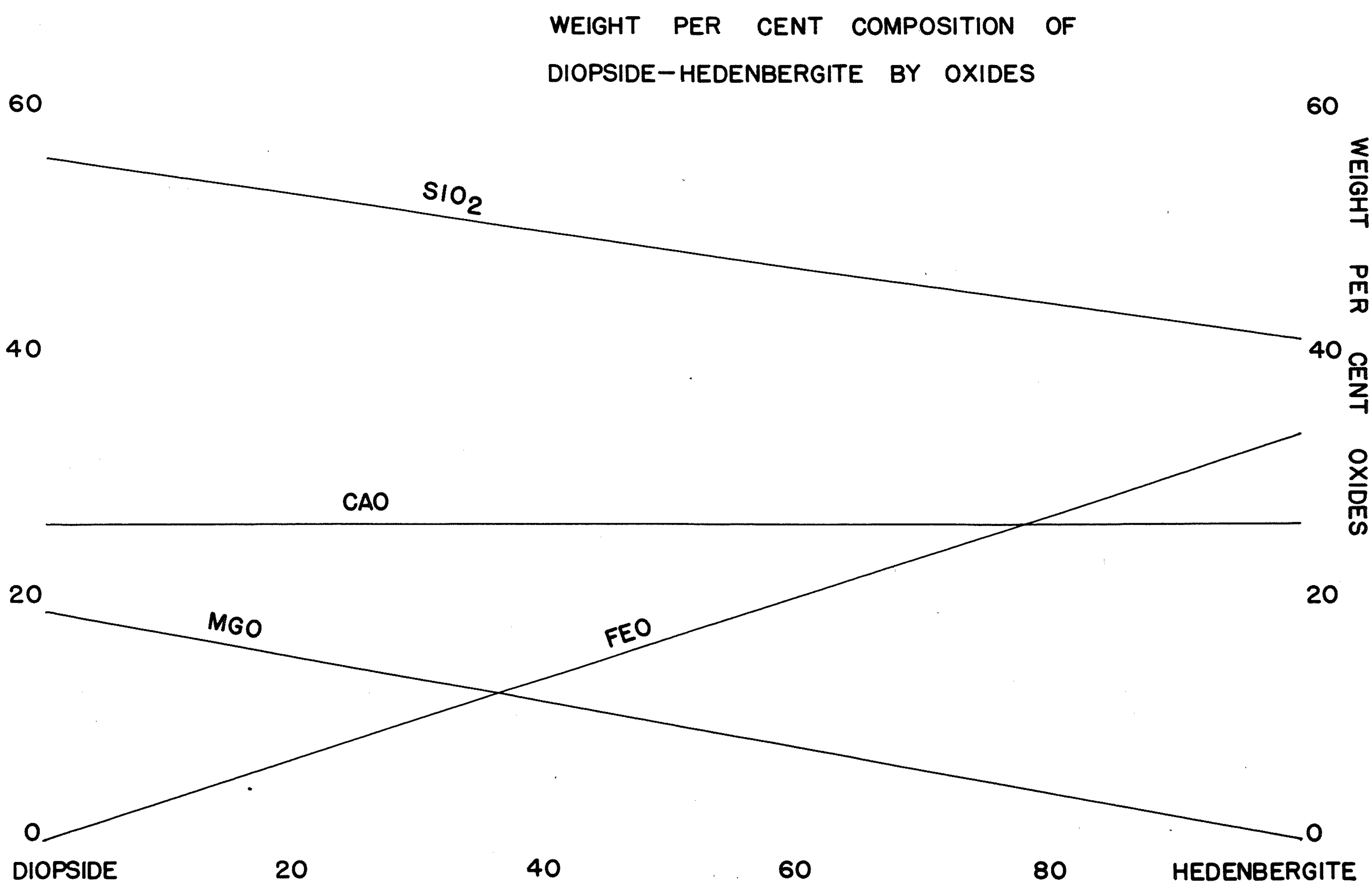
APPENDIX A

Graphs showing the weight per cent composition of several isomorphous minerals by oxides as mentioned on page 6.

WEIGHT PER CENT COMPOSITION OF CLINOZOISITE — EPIDOTE BY OXIDES




WEIGHT PER CENT COMPOSITION OF
DIOPSIDE—HEDENBERGITE BY OXIDES
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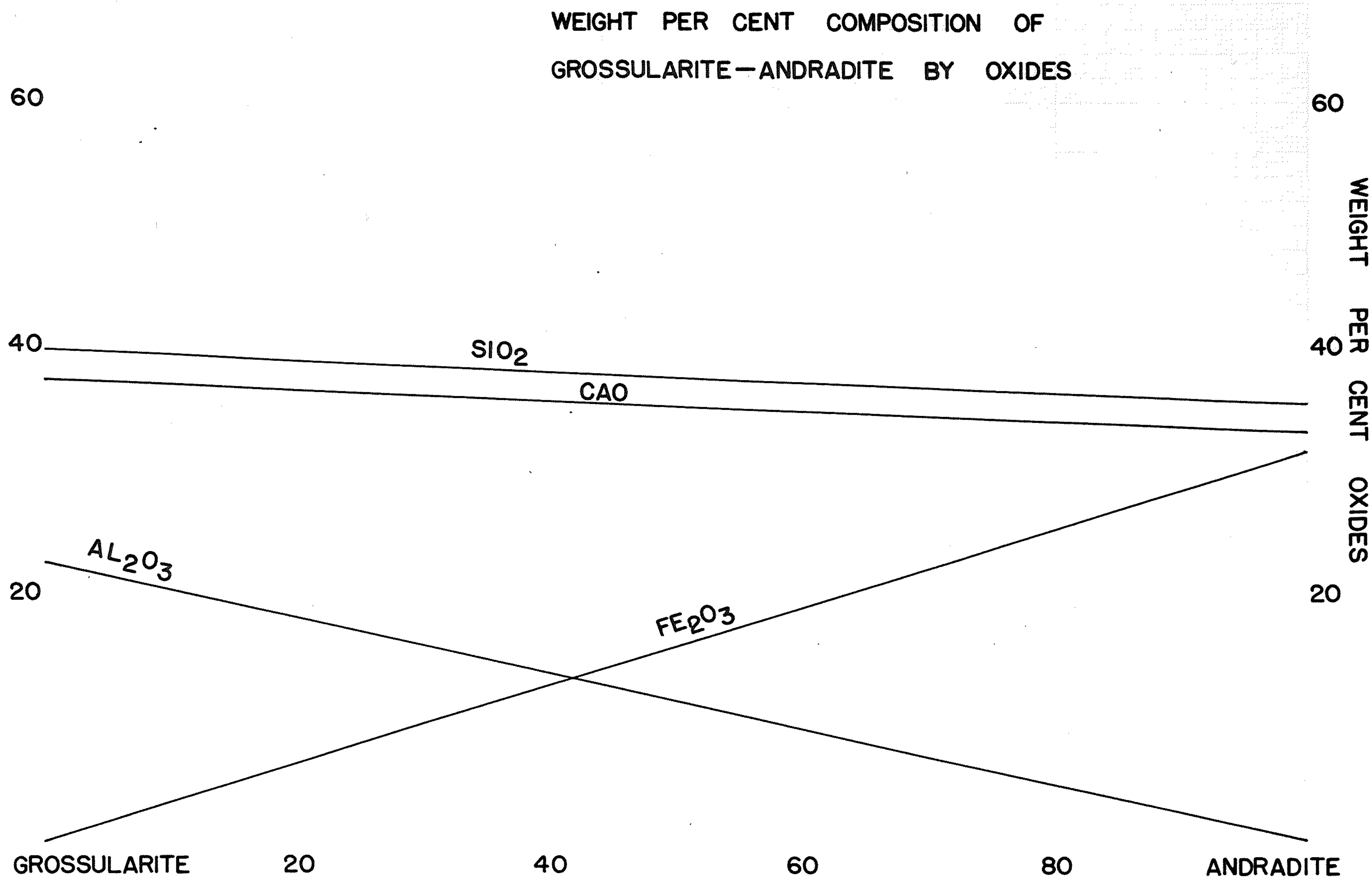
40
20
0
SIO_2
CAO
MGO
FEO
DIOPSIDE
20
40
60
80
HEDENBERGITE
WEIGHT PER CENT OXIDES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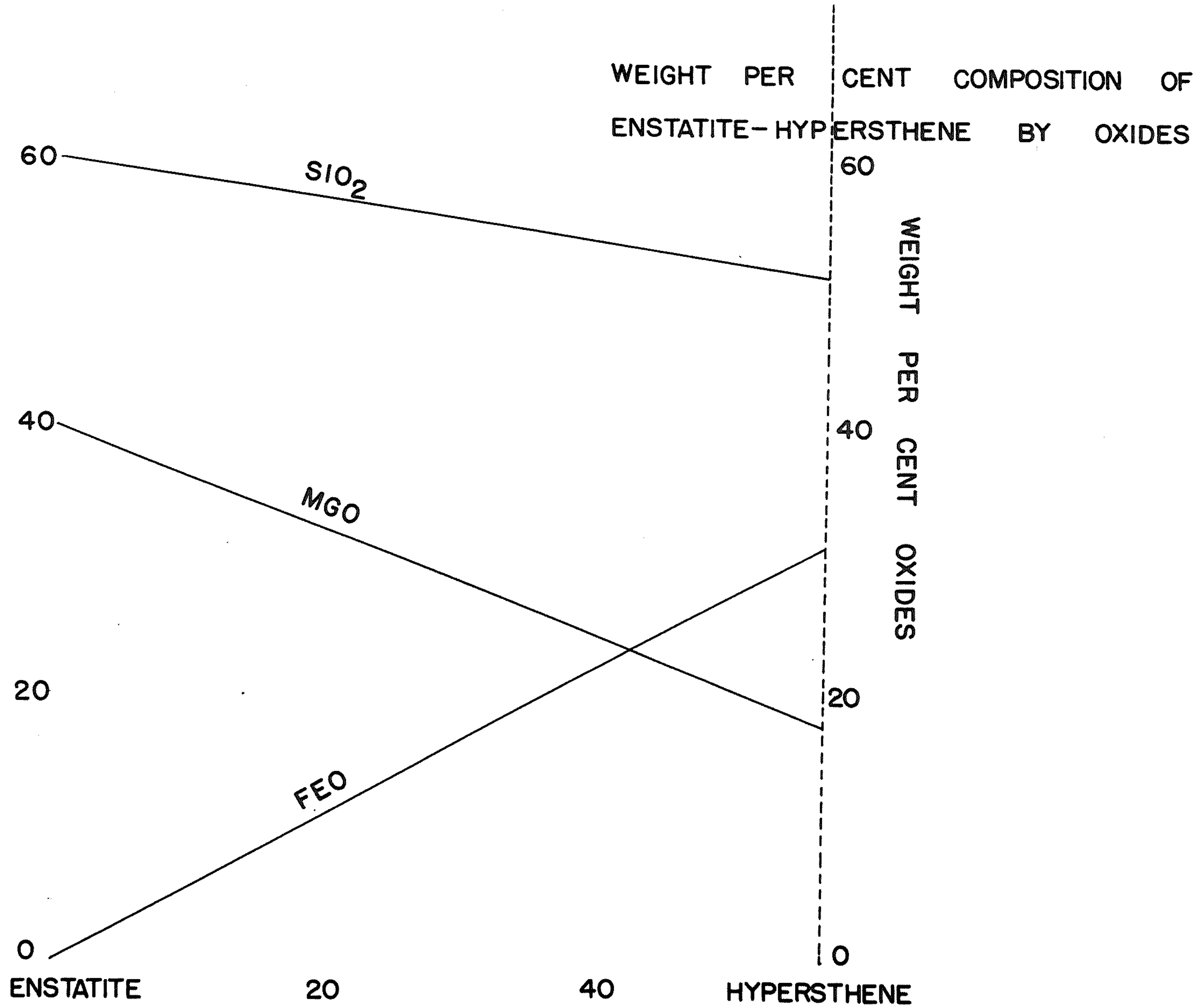
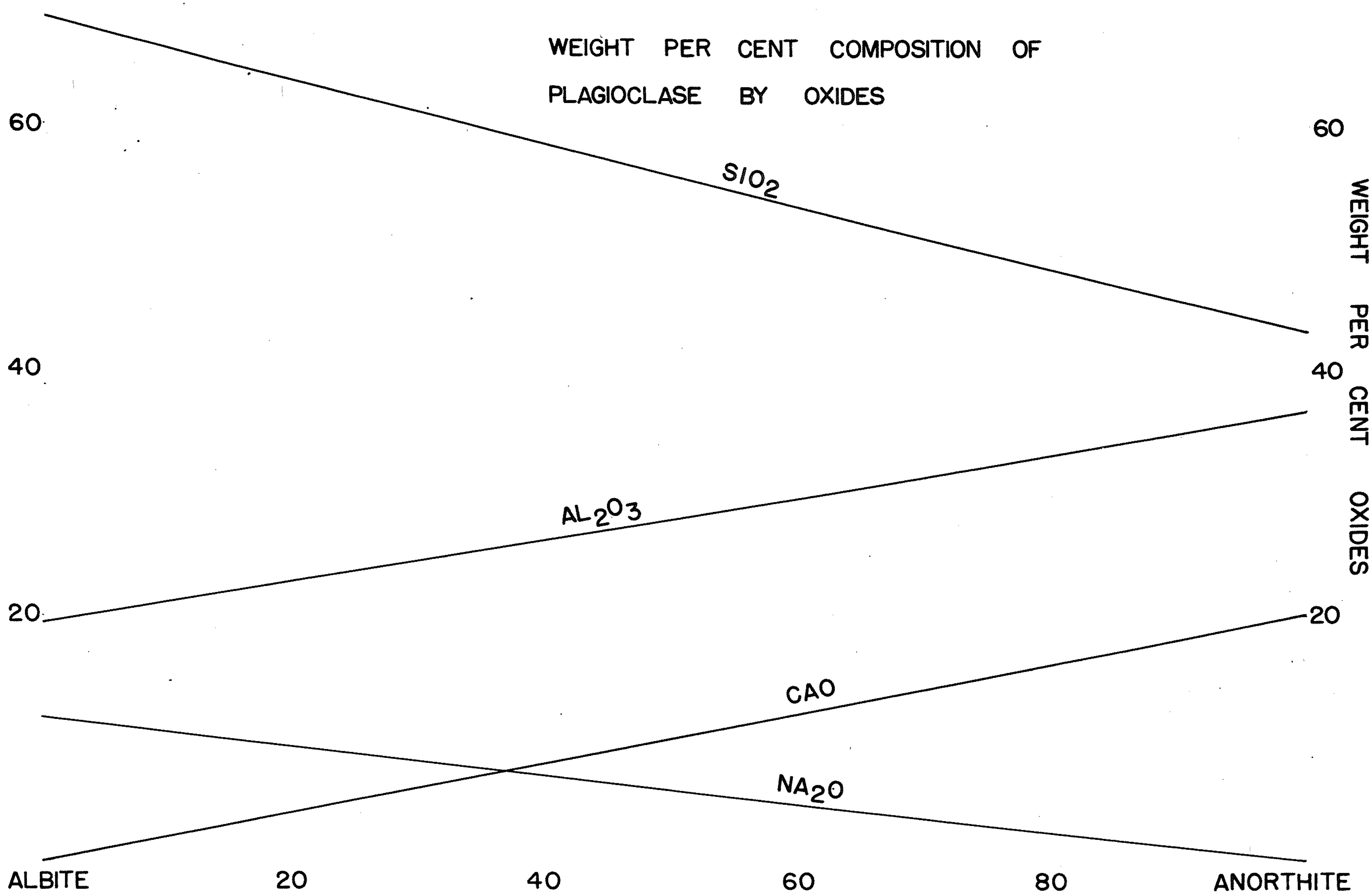
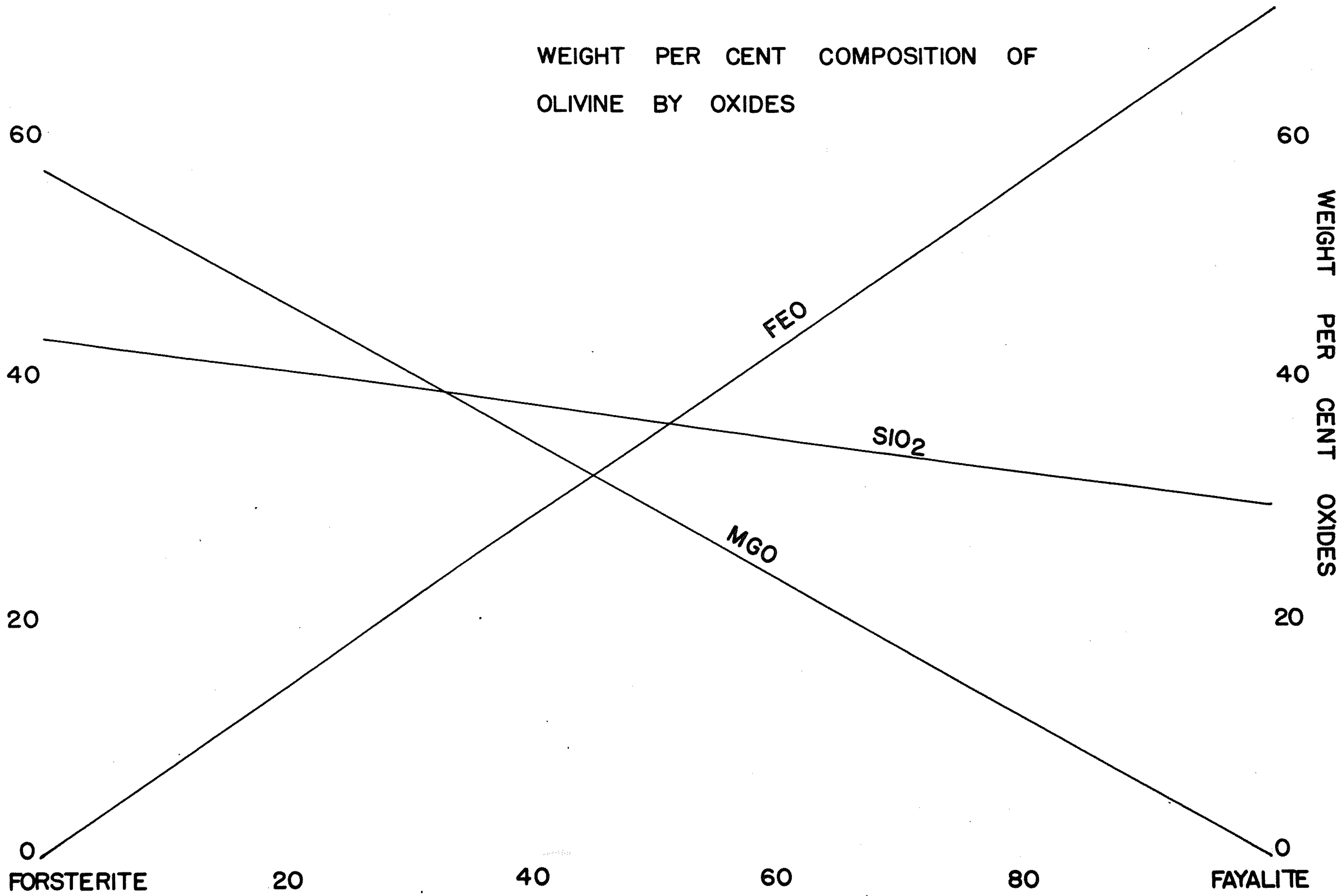
GROSSULARITE—ANDRADITE BY OXIDES
60
40
20
60
40
20
WEIGHT PER CENT OXIDES
SIO_2
CAO
AL_2O_3
FE_2O_3
GROSSULARITE
20
40
60
80
ANDRADITE

WEIGHT PER CENT COMPOSITION OF ENSTATITE-HYPERSTHENE BY OXIDES




WEIGHT PER CENT COMPOSITION OF
PLAGIOCLASE BY OXIDES
60
40
20
60
40
20
WEIGHT PER CENT OXIDES
SIO2
AL2O3
CAO
NA2O
ALBITE
20
40
60
80
ANORTHITE

WEIGHT PER CENT COMPOSITION OF OLIVINE BY OXIDES



GEOLOGIC MAP OF THE FISH LAKE AREA,
SOUTHEASTERN WALLOWA MTNS., OREGON
APPROXIMATE
SCALE IN MILES
0
1/2
1
TOPOGRAPHY BASED ON U.S. FOREST SERVICE AERIAL PHOTOGRAPHS
GEOLOGY BY ROLLAND R. REID 1953
CLEAR CREEK RESERVOIR
MELHORN RESERVOIR
CLEAR CREEK
RUSSELL MOUNTAIN LOOKOUT
ELEV. 7350
LOOKOUT ROAD
TWIN LAKES
TWIN LAKES ROAD
FISH LAKE CREEK
ELEV. 6600
FISH LAKE
LAKE FORK BRANCH
FISH LAKE ROAD
ELEV. 5500
CENO.
QY.
AL
ALLUVIUM AND MORAINAL MATERIAL
MIO.
TB
BASALT
MESO.
LA
LAMPROPHYRE
DG
DIORITE-GABBRO COMPLEX
CI
MASSES OF SHEARED PERIDOTITE
PALEOZOIC
PERMIAN
SK
MASSES OF SKARN
MA
MARBLE
CCA
CLOVER CREEK GREENSTONE, AMPHIBOLITIC
CCS
CLOVER CREEK GREENSTONE, SHEARED
CC
CLOVER CREEK GREENSTONE
CARB.
CS
SEDIMENTARY ROCKS, CHIEFLY TUFFACEOUS ARKOSE
CONTACT LINE, DOTTED WHERE COVERED
INFERRED OR INDEFINITE CONTACT
STRIKE AND DIP OF BEDDING
STRIKE AND DIP OF FOLIATION
VERTICAL FOLIATION
STRIKE AND DIP OF JOINTS
STREAMS
INTERMITTENT STREAMS
RIDGE CRESTS
FOREST SERVICE ROAD