

University of Montana

ScholarWorks at University of Montana

Graduate Student Theses, Dissertations, &
Professional Papers

Graduate School

1959

Border zone petrology of the Idaho batholith in vicinity of Lolo Hot Springs Montana

Lyle Myron Leischner
The University of Montana

Follow this and additional works at: <https://scholarworks.umt.edu/etd>

Let us know how access to this document benefits you.

Recommended Citation

Leischner, Lyle Myron, "Border zone petrology of the Idaho batholith in vicinity of Lolo Hot Springs Montana" (1959). *Graduate Student Theses, Dissertations, & Professional Papers*. 7599.
<https://scholarworks.umt.edu/etd/7599>

This Thesis is brought to you for free and open access by the Graduate School at ScholarWorks at University of Montana. It has been accepted for inclusion in Graduate Student Theses, Dissertations, & Professional Papers by an authorized administrator of ScholarWorks at University of Montana. For more information, please contact scholarworks@mso.umt.edu.

BORDER ZONE PETROLOGY OF THE IDAHO
DIAHOLITE IN VICINITY OF LOLO HOT SPRINGS, MONTANA

By

LYLE L. LEISCHNER

B. A. Montana State University, 1954

Presented in partial fulfillment of
the requirements for the degree
Master of Science

MONTANA STATE UNIVERSITY

1959

Approved by:


Chairman, Board of Examiners


Dean, Graduate School

JUN 2 1959

Date

UMI Number: EP38400

All rights reserved

INFORMATION TO ALL USERS

The quality of this reproduction is dependent upon the quality of the copy submitted.

In the unlikely event that the author did not send a complete manuscript and there are missing pages, these will be noted. Also, if material had to be removed, a note will indicate the deletion.



UMI EP38400

Published by ProQuest LLC (2013). Copyright in the Dissertation held by the Author.

Microform Edition © ProQuest LLC.

All rights reserved. This work is protected against unauthorized copying under Title 17, United States Code



ProQuest LLC.
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106 - 1346

INDEX OF CONTENTS

| | Page |
|---|------|
| ABSTRACT | |
| INTRODUCTION | 1 |
| Location | 1 |
| Purpose of Investigation | 1 |
| Method of Investigation | 1 |
| Previous Work | 3 |
| Acknowledgements | 4 |
| PHYSIOGRAPHY | 4 |
| Topography | 4 |
| Drainage | 5 |
| STRATIGRAPHY | 6 |
| General Characteristics | 6 |
| The Burke, Revett, and St. Regis Formations | 6 |
| The Wallace Formation | 9 |
| Quaternary | 11 |
| IGNEOUS ROCKS | 12 |
| Diorite and Related Rocks | 12 |
| Diorite | 12 |
| Quartz Diorite | 13 |
| Fine Grained Diorite Porphyry | 16 |
| Cognate Inclusion | 18 |
| Hornblendite | 19 |
| Quartz Diorite Porphyry | 21 |

| | Page |
|--|------|
| Quartz Monzonite | 23 |
| General Texture and Composition | 23 |
| The Significance of Perthitic Feldspars in the Quartz Monzonite | 25 |
| Fine Grained Marginal Zone | 27 |
| Coarse Grained Intermediate Zone | 29 |
| The Interior Zone | 32 |
| Dikes Related to the Quartz Monzonite | 35 |
| Aplitic Dikes | 37 |
| Quartz Porphyry Dikes | 37 |
| Quartz Monzonite Porphyry | 38 |
| Granite Porphyry | 40 |
| CONTACT METAMORPHISM | 42 |
| General Mapping | 42 |
| Contact Metamorphic Effects of the Quartz Monzonite | 42 |
| Fabric | 42 |
| Mineral Assemblages and Metamorphic Facies of the Argillaceous Wallace Beds | 43 |
| Contact Metamorphic Effects of the Diorite | 43 |
| Fabric of Surrounding Rocks | 43 |
| Mineral Assemblages and Metamorphic Facies of the Calcareous Wallace Beds | 49 |
| The Occurrence of Scapolite | 53 |
| Mineral Assemblages and Metamorphic Facies of the Lower Belt Quartzites | 55 |
| Metamorphosed Roof Pendants and Inclusions | 55 |

| | Page |
|---|------|
| PEERAGE | 57 |
| STRUCTURE | 62 |
| Folds | 62 |
| Powell Creek Anticline and Syncline | 62 |
| East Fork Pendant | 63 |
| Faults | 63 |
| East Hot Springs Fault | 63 |
| West Hot Springs Fault | 64 |
| Southwest Salley Ridge Fault | 65 |
| Structural Analysis | 67 |
| Joints | 71 |
| Analysis of Joints | 73 |
| BIBLIOGRAPHY | 74 |
| References | 74 |
| Additional Selected References | 76 |

| | Page |
|---|------|
| Fig. 1. Index Map, showing location of Lolo Hot Springs Area | 2 |
| Plate I | 17 |
| Fig. 2. Regeneration phenocryst in fine grained diorite | 17 |
| Fig. 3. Hornblende and biotite in medium grained diorite | 17 |
| Fig. 4. Plagioclase porphyroblast in metamorphosed quartzite | 17 |
| Fig. 5. Diabasic texture in fine grained diorite porphyry | 17 |
| Plate II | 20 |
| Fig. 6. Cognate Xenolith | 20 |
| Fig. 7. Cluster of plagioclase microlites in cognate xenolith | 20 |
| Plate III | 22 |
| Fig. 8. Orthorhombic amphibole in hornblende | 22 |
| Fig. 9. Magnetite in orthorhombic amphibole | 22 |
| Fig. 10. Pyrrhotite in quartz diorite porphyry | 22 |
| Plate IV | 24 |
| Fig. 11. Exposure of the quartz diorite porphyry dike | 24 |
| Fig. 12. Plagioclase phenocrysts in diorite porphyry rock | 24 |

| | Page |
|--|------|
| Plate V | 28 |
| Fig. 13. Perthite-quartz granite of the Marginal Zone | 28 |
| Fig. 14. Exsolution perthite of Marginal Zone | 28 |
| Fig. 15. Replacement perthite of Inner Zone . . | 28 |
| Fig. 16. Modal percentages of the granitic rocks | 30 |
| Fig. 17. Triangular diagram showing normative albite-orthoclase-quartz in the granitic rocks | 30 |
| Plate VI | 34 |
| Fig. 18. Micrographic texture of Interior Zone | 34 |
| Fig. 19. Graphic intergrowth of perthite and quartz in the Interior Zone . . . | 34 |
| Fig. 20. Granophyric intergrowth in aplitic groundmass | 34 |
| Fig. 21. Idealized diagram of pegmatites within the Interior Zone | 36 |
| Plate VII | 41 |
| Fig. 22. Picture of granite porphyry dike rock | 41 |
| Fig. 23. Alteration haloes surrounding feldspar phenocrysts in granite porphyry | 41 |
| Fig. 24. Sagenetic rutile and chlorite in granite porphyry | 41 |
| Fig. 25. ACF diagram representing albite-epidote hornfels facies | 44 |
| Fig. 26. ACF diagram -- pyroxene hornfels facies | 44 |

| | Page |
|--|------|
| Plate VIII | 40 |
| Fig. 27. Fascicular texture in meta- morphosed argillites | 45 |
| Fig. 28. Dark soil developed from weathered hornblende | 45 |
| Plate IX | 47 |
| Fig. 29. Hornblende gneiss near diorite contact | 47 |
| Fig. 30. Hornblende gneiss near diorite contact | 47 |
| Plate X | 48 |
| Fig. 31. Hornblende porphyroblasts near diorite contact | 48 |
| Fig. 32. Spheroidal concretion near diorite contact | 48 |
| Fig. 33. ACF diagram representing hornblende hornfels facies | 51 |
| Fig. 34. ACF diagram for lime-poor hornfels | 51 |
| Plate XI | 54 |
| Fig. 35. Granoblastic texture in hornfelsic rock | 54 |
| Fig. 36. Poikilitic scapolite and sphene in hornfels | 54 |
| Fig. 37. Poikilitic scapolite in hornfels | 54 |
| Fig. 38. Plagioclase porphyroblasts in metamorphose quartzite | 54 |
| Plate XII | 66 |
| Fig. 39. Picture showing jointing within the quartz monzonite | 66 |
| Fig. 40. Fault contact of West Hot Springs fault | 66 |

| | Page |
|--|------|
| Plate XIII | 33 |
| Fig. 41. Picture showing dense forest cover in the area | 68 |
| Fig. 42. Small fault near the quartz monzonite contact | 68 |
| Fig. 43. Point diagram of joint sets | 72 |

Abstract

The area is located along the Lewis and Clark Highway about six miles northeast of Lolo Pass and covers twenty square miles at the contact of the Idaho batholith with the Precambrian limestones, quartzites and argillites of middle and lower Belt series.

A dioritic body ranging in composition from diorite to quartz diorite is present in the southeastern part of the area. Lower Belt quartzites and argillites surrounding the diorite were metamorphosed to an augite-plagioclase-quartz hornfels. The overlying Wallace limestone was metamorphosed to diopsidic augite-scapolite hornfels (pyroxene hornfels facies) near the contact and diopside-hornblende-tremolite-plagioclase-quartz hornfels (hornblende hornfels facies) away from the contact. The diorite, metamorphics and neighboring sediments are cut by dikes of fine grained diorite porphyry, hornblende and quartz diorite porphyry.

A later quartz monzonite intrusion lies to the west and is separated from the diorite by the hornfels zone surrounding the diorite. The textural character in the quartz monzonite is as follows: (1) Fine Grained Marginal Zone--all the feldspar occurs as perthite ($Or_{55}Ab_{45}$), no discrete plagioclase crystals are present, (2) Coarse Grained

Intermediate Zone--the feldspar crystals are larger, more coarsely perthitic, and separate plagioclase crystals are present, (3) The Interior Zone--Graphic texture and many aplite-pegmatite dikes.

Where the quartz monzonite is in contact with the siliceous argillites, it has produced biotite-andalusite-? hornfels (albite-epidote hornfels facies). Two sets of quartz porphyry dikes, one set of quartz monzonite porphyry and a large granite porphyry dike cut the neighboring sediments.

Two high angle faults of northeast trend with large displacement have brought lower Belt quartzites and argillites into contact with middle Belt Wallace limestone. Both are known to cut the quartz monzonite.

INTRODUCTION

Location

The Lolo Hot Springs area is located about thirty-eight miles southwest of Missoula, Montana in Missoula County (Fig. 1). It can be reached by the way of U. S. Highway 93 to Lolo, Montana, eleven miles south of Missoula. The area is transected by the Lewis and Clark Highway twenty-seven miles west of the town of Lolo.

The geologic map presented here (back pocket) contains a four mile square in the northwestern part of T. 11 N., R 23 W. and the adjacent four sections in the northeastern part of T. 11 N., R 24 W.

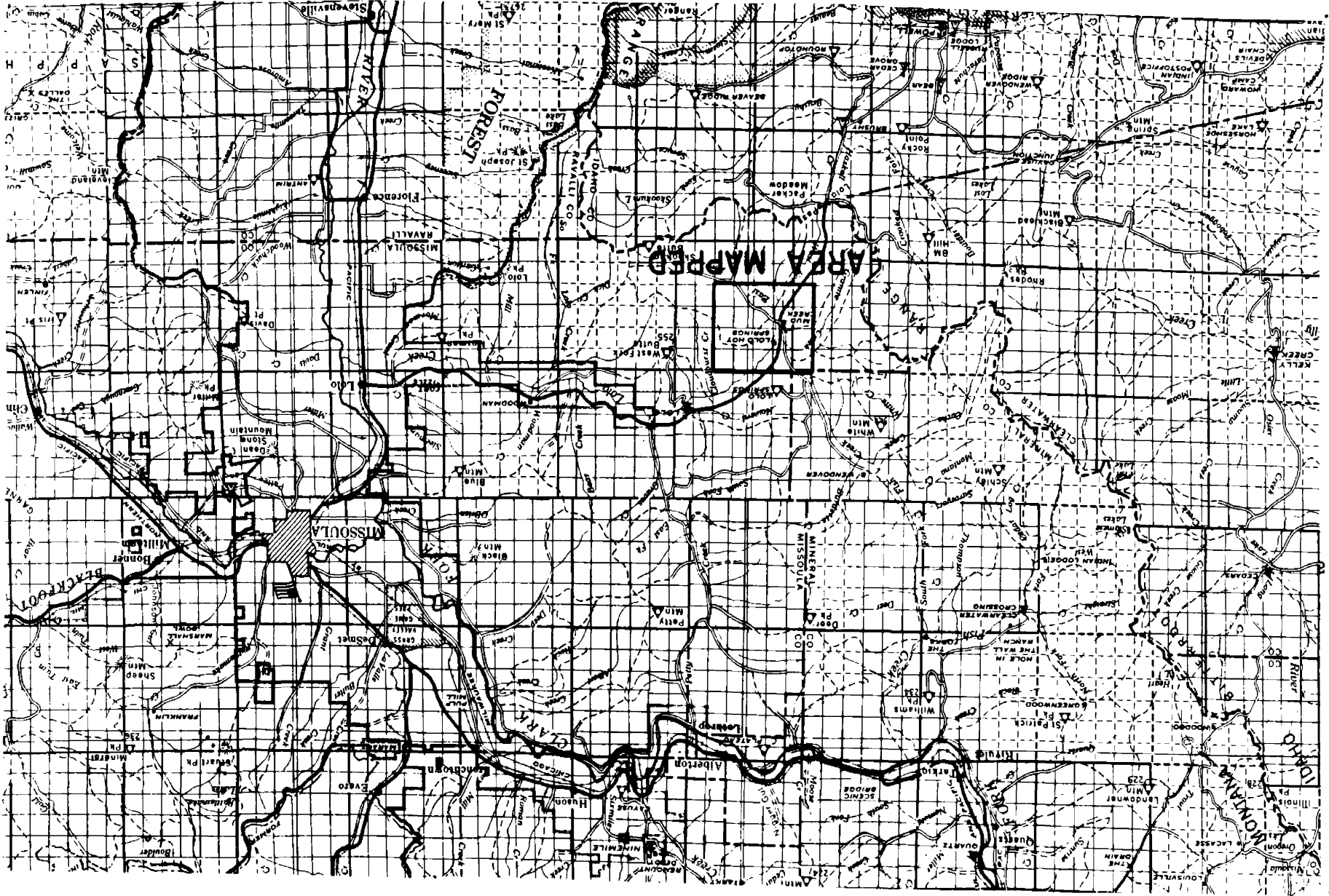
Purpose of Investigation

The purpose of the investigation was to determine the intrusive rock types, their variation, and their contact effect on the intruded Belt sediments. As the mapping progressed, this area proved most interesting because of the great variety of igneous rocks present and the types of metamorphism they produced.

Method of Investigation

Mapping was done on aerial photographs in the field with the aid of a Brunton compass during July and August of 1958. Over one hundred hand specimens were collected during the

Figure 1. Index Map showing Lolo Hot Springs Area



mapping. Fifty thin sections were cut from selected samples and their petrography was studied.

Previous Work

Lindgren (1904) following Lolo Trail in his reconnaissance of the Bitterroot and Clearwater Mountains probably was the first to study the geology of this area. He mentions that the contact of the granitic rocks with the sedimentary series at the Hot Springs has produced biotite-andalusite hornfels and that the quartzites are metamorphosed to a dense flinty structure. He also notes the presence of tourmaline and the sharpness of the contact and concluded that the intrusive character of the granite was established.

Clyde P. Ross and H. W. Burke (1947) compiled an unpublished map which according to Ross (personal communication,) was a hurried reconnaissance made for the completion of the Montana State Geologic map.

E. S. Larsen Jr. and R. G. Schmidt (1958) traversed and mapped the quartz monzonite on their map when doing work on the dating and comparison of the Idaho batholith with the Southern California batholith.

Larsen et al (1958, p. 51) report a mean lead-alpha age of granitic rocks from the Idaho batholith as 108 ± 12 million years. This places the age of the Idaho batholith as early late Cretaceous. From the dates obtained, they have concluded that the emplacement of the batholith took place over

a short time, not over a few million years.

Acknowledgements

Thanks are due to all the faculty of the Geology Department; Dr. Honkala, who suggested the project, Dr. Wehrenberg, who made helpful suggestions and helped acquaint the writer with lower Belt stratigraphy, Dr. Weidman, who spent much time directing and also assisting in the photographic work and map reproduction and to Dr. Hower, who helped the writer in the petrographic mineral identification and who was very free with his time in discussing the petrologic interpretations.

Thanks are also due to Dr. Hans Borner of Gottingen University, West Germany, who also examined many of the thin-sections and made many helpful suggestions, to Larry Toler, who supplied petrographic analyses and data on the composition of the perthite, to my wife who assisted in the typing and to the Northern Pacific Railroad, who supplied the aerial photographs.

PHYSIOGRAPHY

Topography

The area lies west of the Litterroot Range in the southeastern part of the Coeur d'Alene mountains, which Lindgren (1904, p. 13) defined as a range extending from near Lolo

Pass northward to the Coeur d'Alene District. Some writers have included this range within the Bitterroot Range which extends from Lolo Creek about sixty miles south into Idaho.

Drainage

The area is drained by Lolo Creek which heads at Lolo Pass and drains into the Bitterroot River at the town of Lolo. The main tributaries of Lolo Creek are Martin Creek which drains the northeastern part and joins Lolo Creek about one-fourth mile north of the northern boundary, Granite Creek which joins Lolo Creek at the Hot Springs and drains a large area to the west heading in the Coeur d'Alene Mountains and the East Fork of Lolo Creek which joins Lolo Creek about a mile south of the Hot Springs and drains a large area to the southeast. The East Fork of Lolo Creek heads in the Bitterroot Range. Sally, Mud and Lee Creeks are smaller drainages which are confined primarily to the area.

STRATIGRAPHY

General Characteristics

The geologic formations of the Lolo Hot Springs area are metasediments of the middle and lower Precambrian Belt Series.

The stratigraphy of the lower Belt formation in this area correlates most closely with the sediments of the Coeur d'Alene District, Idaho and Mineral County, Montana and for this reason, the same formation names will be used.

The formations exposed in the Lolo area are probably part of the Burke, Revett, St. Regis quartzites and argillites and the Wallace limestone.

Wallace and Hostermann (1956, p. 577) state that there are rock units in each formation of the Belt series which resemble rock units in every other formation of the Belt series, making classification of individual outcrops difficult. Only by judging rock types through a stratigraphic thickness of several thousand feet can an adequate determination be made.

In the area mapped, only the most northern sections are composed of sediments. Outcrops are not plentiful and because of the gradational character of the Belt sediments, all contacts are arbitrary and based of the predominance of a specific lithologic type.

The Burke, Revett, and St. Regis Formations

The Burke, Revett and St. Regis formations are all

argillites and quartzites of various shades of white, grey, green and purple. Ransome and Calkins (1906, p. 34 & 35) state that in the Coeur d'Alene District the Burke formation consists of grey to grey-green quartzites, while the overlying Revett formation is a white vitreous quartzite. Wallace and Hosterman (1956, p. 580) say that in Mineral County, Montana both the Burke and Revett formations are various shades of grey.

From south of Granite Creek to the contact of the quartz monzonite are found massive quartzite beds that are dark grey interbedded with finely laminated green silicious argillites. The argillites consist predominantly of fine grained quartz with sericite and chlorite, and have been assigned to the Burke Formation.

As one proceeds north of Granite Creek, the quartzites become lighter grey and the beds are very massive. The greenish siliceous argillites are not found within these light quartzites and for this reason are believed to correlate to the Revett of the Coeur d'Alene District.

Wallace and Hosterman (1956, p. 582) note a marked change in the St. Regis formation between the Coeur d'Alene District and Mineral County in the vicinity of Lookout Pass. West of the Montana State line, in Idaho, the St. Regis formation is characterized by grey and purple argillites and quartzites. On the east side of Lookout Pass, in Montana, the typical St. Regis is characterized by greenish-grey

argillites with some limy quartzite beds. Wagner (1949, p. 10) states that in the St. Joe District of Idaho, the Revett quartzite passes rather abruptly from thick bedded, white quartzite upward into the impure green and purple banded quartzites that are referred to as the St. Regis formation. The rocks of the St. Regis formation are more quartzitic and contain fewer shale beds than are found in that formation in the Coeur d'Alene District.

Near the northern boundary of the area, along the Fish Creek Lolo Creek road, are good exposures of massive white quartzites interbedded with impure purple and green quartzites and siliceous argillites. The purple beds often contain hematite pseudomorphs after pyrite and fine grained hematite, which gives it a reddish color. In some places, greenish beds of fine grained quartzites or siliceous argillites are found throughout this section, but the predominance of quartzite was recognized. The beds are believed to belong to the lower St. Regis formation and according to Wagner's description, previously discussed, would correlate closely with the St. Regis in the St. Joe District, Idaho. Wallace and Hosterman (1956, p. 580) note the presence of purple-grey quartzites within the Burke and Revett formations of Mineral County, Montana. It is also possible that the beds mapped as St. Regis may be equivalent to Revett of Mineral County. In this case, the St. Regis would be exposed beyond the northern boundary of the area.

Because of an incomplete section of Burke and St. Regis and no definite correlation of the Revett, no attempt was made to estimate the thickness of these formations. The complete section must be very thick, for the beds have a consistent strike and relatively steep northeast dip through several miles of sections from the quartz monzonite contact to beyond the northern boundary.

Wallace Formation

The Wallace formation is exposed in the northeastern part of the area and for several miles to the northeast along the highway. Over this distance, the strike and dip are very consistent, suggesting duplication by faulting or isoclinal folding. Ripple marks noted somewhat north of the area indicate overturned isoclinal folding.

The Wallace formation in the northern part of the Bitterroot Range (Wehrenberg, personal communication) seems to compare closer to the Wallace of this area than descriptions in Mineral County or Districts to the west in Idaho.

A light buff, limy, massive quartzite is well exposed at the highway curve just before entering the area from the north. The quartzite contains some interbedded argillites up to a few feet thick in places. These light buff colored limy quartzites are believed to be upper Wallace formation. Along Martin Creek, the buff limy quartzites are interbedded with blue and grey limy argillites, but the buff rocks seem to

predominate. Further to the south along Powell Creek and to the east of Powell Creek, the grey and blue grey limy argillite beds increase in number and thickness. Still further southeast, the limy argillites are metamorphosed to a light green tremolite-diopside hornfels which will be discussed later under metamorphism.

A small exposure of the buff limestone is present on the west side of the highway in a cut about one thousand feet north of the Fish Creek Lolo Creek road junction with the highway. The limestone is interbedded with soft, grey, limy argillites. To the south near the junction, the argillites become darker colored. Some are dark green or blue to black and are believed to correlate to a dark argillite found near the middle of the Wallace formation in western Montana.

South of the Lewis and Clark Highway junction with the Fish Creek Lolo Creek Road, are brown colored argillite beds with some dark grey quartzites. These are believed to be part of the lower Wallace formation. Thin sections reveal some of these argillites to be fine grained quartzites or siliceous argillites. Excellent exposures are found east of Lolo Creek between outcrops of the quartz porphyry dikes. Here the rocks have a slaty cleavage. The beds near the dikes are metamorphosed to very hard slates. All these beds have a grey-brown color.

In the highway cut next to the quartz monzonite contact,

the dark quartzites are metamorphosed to a flinty quartzite. The argillites near the contact display the results of the metamorphism much more so than the quartzites and will be discussed under metamorphism. In a road material pit east of the old hotel at the Hot Springs, the siliceous argillites have not been as severely metamorphosed and appear as uniformly laminated argillites.

Quaternary

Gravels are present throughout most of the valley floor of Lolo Creek. In places where the valley is wide there are broad meadows that have a well developed soil; the gravels are more confined to the stream channel.

The East Fork of Lolo Creek and also Granite Creek have gravels, cobbles and boulders that are confined mainly to the stream channels. These cobbles and boulders are usually of the more resistant hornfels and quartz diorites in the East Fork, while those of Granite Creek are usually of the quartz monzonite porphyry rocks from the dikes and of the quartzites of the Burke and Revett formations.

Mud Creek and Sally Creek valley floors are covered with alluvial deposits from the adjacent slopes. The alluvium weathers into a dark soil supporting dense vegetation on the creek bottoms. The lower slopes are always heavily forested.

INTRUSIVE ROCKS

DIOIRITE AND DIORITIC ROCKS

Diorite

The dioritic rocks of this area vary greatly in composition, texture, and grain size.

A diorite body in the vicinity of the hornblendite dike (see geologic map) along Sally Creek is a dark fine grained diorite. Plagioclase averaging $Ab_{70}An_{30}$ composes about 60 per cent of the rock. Zoned plagioclase crystals within this rock indicate regeneration (Plate I, Fig. 2). Amphibole with a small amount of augite are the remaining constituents. Part of the amphibole is a hornblende that in places appears to be altered in part to the orthorhombic amphibole gedrite and also anthophyllite.

A diorite porphyry is present in a few outcrops south of Sally Ridge and along the contact on top of Sally Ridge. Sixty per cent of the diorite porphyry is made up of phenocrysts of plagioclase ranging from labradorite ($Ab_{46}An_{54}$) to andesine ($Ab_{65}An_{35}$). The phenocrysts range from a few millimeters to about one centimeter in diameter. The groundmass is composed of small laths of plagioclase, interstitial hornblende and biotite, and a little quartz. The plagioclase phenocrysts are somewhat sericitized; some of the ferromagnesian minerals are altered to chlorite.

Another medium grained diorite is exposed along the East Fork and for about one mile to the north. Near the

diorite contact along the East Fork Road this diorite is exceptionally dark and a blue-green hornblende composes about 50 per cent of the rock. Away from the contact the diorite is lighter colored and hornblende and biotite are present in equal amounts, composing nearly 40 per cent of the rock. Much of the biotite is associated with hornblende in such a manner as to suggest alteration of hornblende (Plate I, Fig. 5). The remainder of the rock is composed dominantly of andesine. Some of the plagioclase crystals are zoned; others are completely free of zoning. The composition of the zoned crystals approaches oligoclase at the rims.

Accessory minerals found throughout all the diorites are apatite, sphene, ilmenite, magnetite, rutile and zircon. Sphene and ilmenite are especially abundant in some rocks. Zircon is present in a few thin sections, but is never abundant. Only a few pleochroic haloes were noted indicating the low radioactive content of these rocks.

Quartz Diorite

Diorites of the types described above probably make up about one-half of the rocks mapped as diorite. The remainder of the dioritic rocks contain quartz in excess of that to be called a true diorite. The quartz content in these diorites varies from less than 10 per cent to as much as 35 per cent. The quartz can be readily noticed in the field as well as in

thin sections. In some cases quartz rich bodies occur within true diorites.

Near the contact of a roof pendant just east of Sally Creek, a medium to fine grained quartz diorite grades into rocks that are exceptionally light colored with little or no hornblende or biotite. Thin section study of this rock showed it to be composed mainly of sutured quartz grains (60-70 per cent) along with oligoclase porphyroblasts, myrmekite and minor biotite (Plate I, Fig. 4). The meta-sediments of the roof pendants are discussed under metamorphism.

Other dioritic rocks that are exceptionally rich in quartz are aligned with the roof pendants and xenoliths, but were found at lower elevations. Several thin sections were made from different outcrops. The quartz content varies considerably, ranging between 10-30 per cent. Andesine or oligoclase composes 50-70 per cent of the rocks; and the remaining 20 per cent of the rock is biotite and hornblende in about equal amounts. Potash feldspar was noted; however, it appears that in most cases the potassium was taken up by the biotite and the rocks have no potash feldspar present. In each of the thin sections observed, augite and epidote were noted in small amounts. The biotite appeared to have a reddish-green birefringence which differs from that of the normal diorite.

Several hundred feet northwest of where the quartz diorite

porphyry dike crosses East Fork, the dioritic rocks were noted to be quartz rich in places and other rocks contained little quartz. A two-inch thin section was cut across a rock noticed to contain alternating light and dark layers and also containing a dark clot. The darker bands consisted of plagioclase laths $Ab_{70}An_{30}$, hornblende and biotite with little or no quartz. This graded into a lighter quartz rich band of which quartz and biotite slivers are the main constituents. The plagioclase was highly sericitized and the biotite of the light band is more birefringent than usual. This band also contained small amounts of augite and epidote. The epidote is associated with the ferromagnesian minerals suggesting an alteration.

The rock appears to be a result of metamorphic differentiation or hybridization. This is believed to be quite common in marginal facies of batholiths.

The dioritic rocks in the eastern part of the area all contain quartz. Most of the higher elevations are capped by roof pendants of siliceous hornfels. In the vicinity of Lost Park Creek, which is beyond the southeast corner of the area, some of the quartz diorites appear to be somewhat gneisose. Thin section analysis of this rock shows augite, much of which has been replaced by epidote and sphene. The biotite and hornblende appears to be sheared into many shreds. Part of the plagioclase occurs as unaltered crystals, but the majority of the crystals are highly corroded. Some

of the plagioclase occurs with quartz forming a myrmekitic intergrowth as that seen in a thin section of the metamorphosed quartzites (Plate I, Fig. 4).

A. L. Anderson (1940 p. 19) noted similar quartz diorites in Kootenai County, Idaho having a similar biotite and suggests that it appears to be a granitized sediment. Groff (1954) and R. E. Anderson (1959) have concluded, on the basis of texture and mode, that many of the gneisses to the east in the Bitterroots are partially granitized meta-sediments.

A. L. Anderson (1930, p. 20) when working in the quartz diorite marginal facies of the Idaho Batholith near Crofino, Idaho states:

"The gneissic shell is many miles broad in places and it is exceedingly difficult to know whether the rock should be classed as sheared batholith or as gneissic sediments as in many places there is apparently a gradual transition of from one to the other."

Fine Grained Diorite Porphyry

A dark fine grained diorite porphyry dike is exposed at the Fish Creek Lolo Creek road cut at the Lewis and Clark Highway junction. The dike is truncated by a small fault to the north. The dike rock differs little in composition from the other fine grained diorites. Andesine laths, some of which are larger than the usual groundmass, give this rock a porphyritic texture; the groundmass has a diabasic texture (Plate I, Fig. 5). Plagioclase composes

Plate I

Fig. 2. Phenocryst of plagioclase (center) within the dark fine grained diorite showing regeneration zoning. Crossed nicols, x 51.

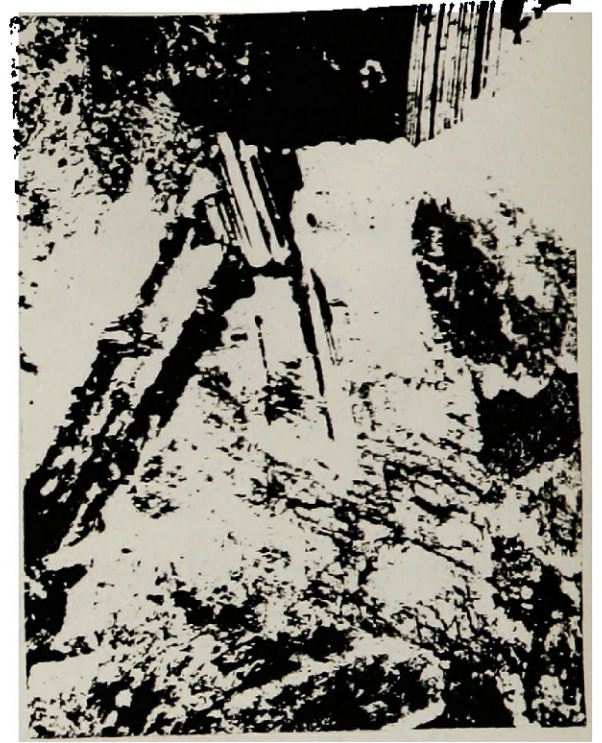
Fig. 3. Biotite associated with hornblende (lower right) suggesting alteration of the hornblende. Thinsection of the medium to coarse grained diorite. Crossed nicols, x 51.

Fig. 4. Incipient plagioclase porphyroblast surrounded by myrmekite (upper center) in a metamorphosed quartzite. Crossed nicols, x 51.

Fig. 5. Diabasic texture of the fine grained diorite porphyry dikes. Andesine phenocryst (lower left). Crossed nicols, x 51.



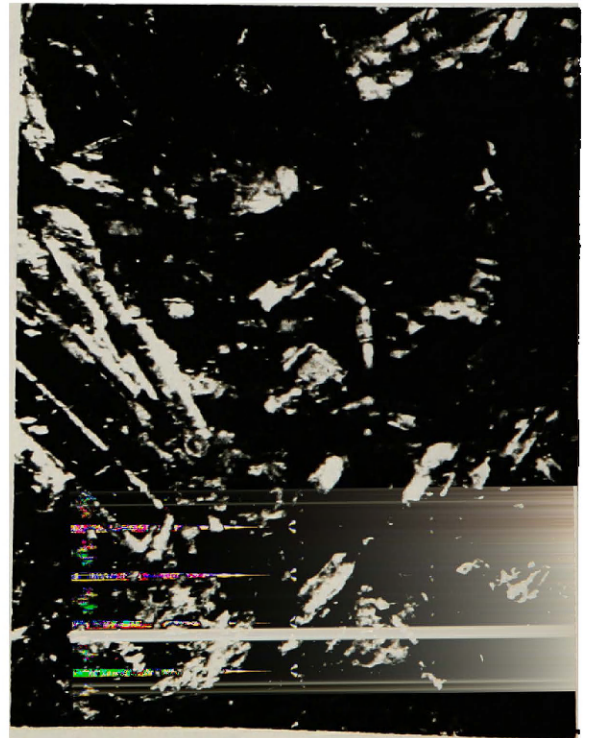
8



8



4



8

about 60 per cent of this rock and a dark hornblende with some augite forms the remainder, giving it a dark color. The feldspars are somewhat sericitized and the ferromagnesian minerals are also altered. Some calcite is also present. Other green-brown fine grained diorite porphyry dikes are located north and south of Martin Creek. Several others that were too small to map were found nearer the diorite. These rocks are much more altered than that from the dike at the Fish Creek Lolo Creek Road and Highway junction, but appear to have been very similar in texture and composition. The phenocrysts are highly sericitized and some are altered to kaolin. The plagioclase of the groundmass is also highly sericitized. Much of the dark minerals is altered to penninite, the chlorite having abnormal blue interference color in thin section. Calcite is also abundant in this rock.

The highly altered state of these dike rocks suggest that they are late phases which were very rich in solutions giving rise to deuteric alteration of all the minerals present.

Cognate Inclusion

A dark very fine grained diorite containing white spots crops out within the medium to coarse grained diorite along the East Fork road cut southeast of the quartz diorite porphyry dike (Plate II, Fig. 6). Other small isolated clots

of dark fine grained diorite occur within the medium grained diorite in this vicinity.

Thin sections of these rocks disclosed it to be composed of microlites of plagioclase with abundant hornblende and minor augite and quartz. The plagioclase was determined to be somewhat more calcic than that of the medium grained diorites surrounding it. The rock appears to be somewhat altered. The white spots consist of microlite clusters of plagioclase with some interstitial quartz (Plate II, Fig. 7). Barth (1952, pp. 315-316) suggests that crystal aggregates such as these may be formed by metamorphic processes.

Tyrrell (1926, p. 95) refers to Bowen's suggestion that the formation of crystal jams or accumulations of early crystallized minerals, as a result of clogging in constricted parts of channels occupied by moving magma, is the cause of cognate inclusions. This phenomenon is believed to be quite common in border facies of batholiths.

Hornblendite

A dike-like body of hornblendite striking about N 15° E is located along Sally Creek within the fine grained dark diorite. Some of the hornblendite is composed predominantly of greenish black hornblende which under the microscope is very pleochroic (green to brown). This hornblende appears very similar to that found in the medium to coarse grained diorite. Augite is present only in minor amounts. Few

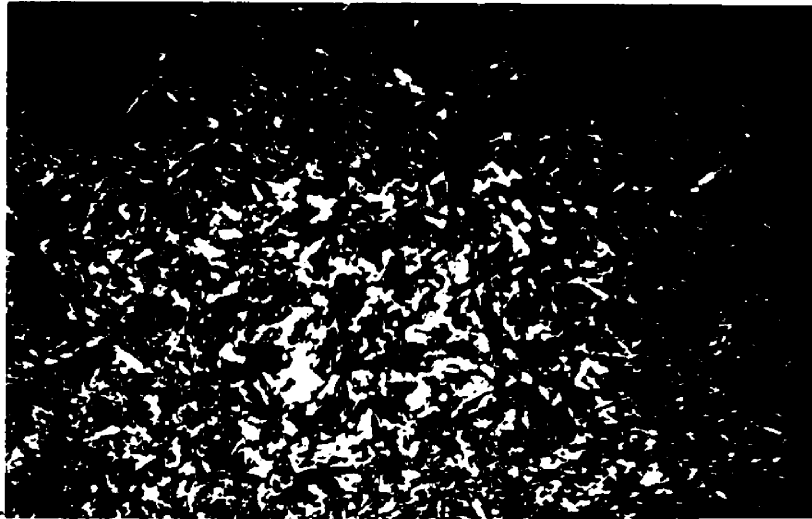
Plate II

Fig. 6. Dark fine grained diorite (right) within lighter medium to coarse grained diorite (left) and believed to be a cognate xenolith.

Fig. 7. A cluster of plagioclase microlites with interstitial quartz present (light center) occurring within fine grained diorite (dark border). Crossed nicols, x 51.



6



7

accessory minerals other than magnetite were noted. Some serpentinization of the hornblende to bastite was noted in a few crystals.

In places the hornblendite is quite altered to the orthorhombic amphibole, gedrite-anthophyllite (Plate III, Fig. 8). Large radiating rosettes of anthophyllite were noticed within some outcrops. Thin sections of these rocks disclosed the anthophyllite to be accompanied by magnetite along many of the fractures and cleavage planes (Plate III, Fig. 9).

Quartz Diorite Porphyry

A quartz diorite porphyry dike striking northeast is present within the dioritic rocks in the southeastern part of the area. A good exposure is found where it is cut by East Fork Creek (Plate IV, Fig. 11). The dike was traced to the southern boundary and for a mile northeast of East Fork. A similar looking porphyry rock was noted on top of Sally Ridge which may be a northeastward continuation.

The dike contains a wide range of phenocrysts with the large ones reaching an inch in length (Plate IV, Fig. 12). The phenocrysts are composed predominantly of oligoclase. Some are well zoned with more calcic cores (andesine). The plagioclase of the groundmass also has a wide range of composition. Some crystals are as calcic as andesine ($Ab_{62}An_{38}$), while others are as sodic as oligoclase ($Ab_{53}An_{17}$). The

Plate III

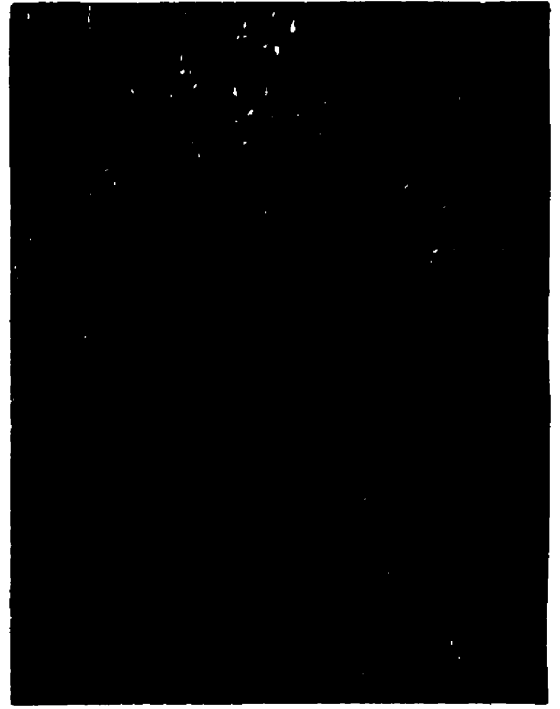
Fig. 8 Photomicrograph showing alteration of hornblende (light) to orthorhombic amphibole (dark upper part and right center). Orthorhombic amphibole right center showing parallel extinction. Crossed nicols, x 51.

Fig. 9, Magnetite (dark) along fracture and cleavage plains accompanying the alteration of hornblende to orthorhombic amphibole. Plain light, x 240.

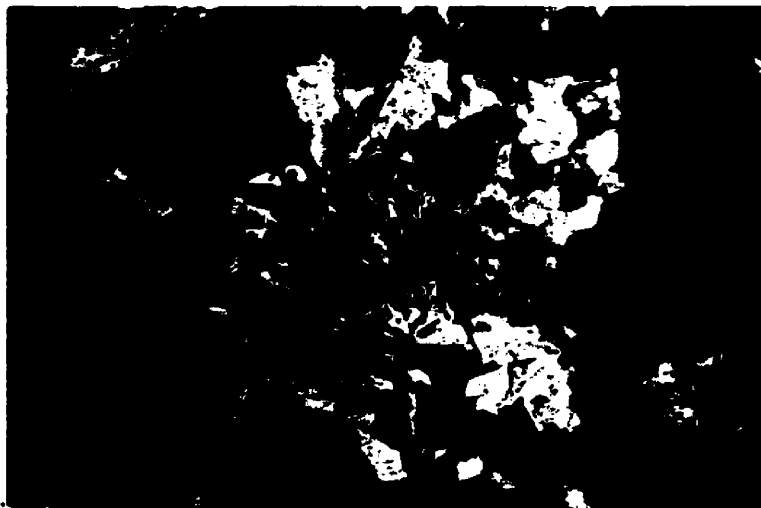
Fig. 10. Interstitial myrmekite within the groundmass of the quartz diorite porphyry. Crossed nicols, x 51.



8



9



10

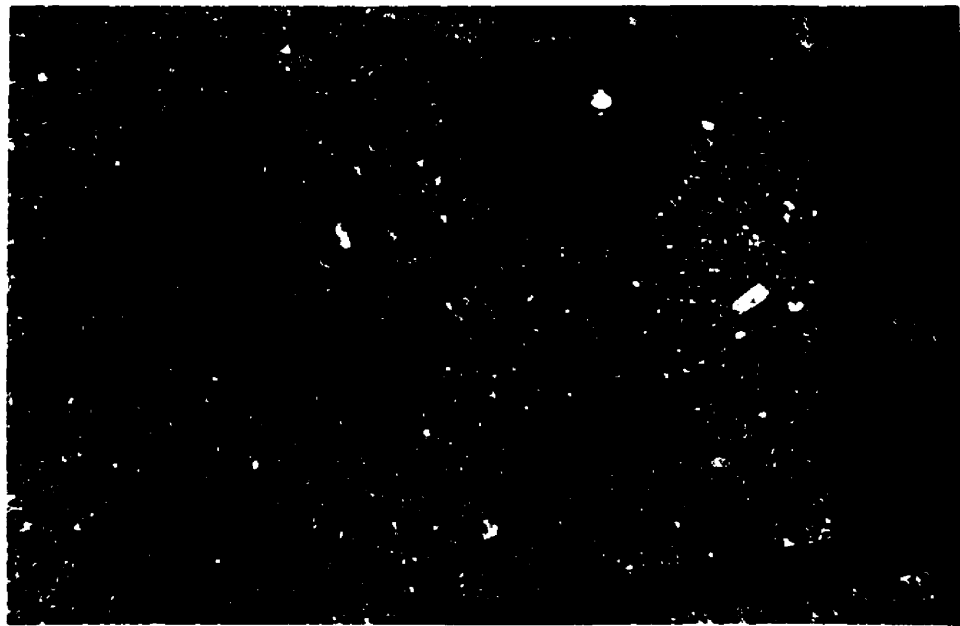
Hornblende and biotite crystals reach 5mm in length; however, most are finely dispersed throughout the groundmass giving it a dark grey color. Quartz composes about 15 per cent of the rock. Much of the quartz occurs as myrmekite, an intergrowth with oligoclase in the groundmass (Plate III, Fig. 10).

Accessory minerals are sphene, apatite, ilmenite and magnetite. Sphene was especially abundant in this rock and was noticed to replace hornblende and biotite.

Plate IV

Fig. 11. An exposure of the quartz diorite porphyry dike where it has been cut by the East Fork of Lolo Creek.

Fig. 12. Plagioclase phenocrysts, some of which reach one inch in length, present within the quartz diorite porphyry dike.



General Texture and Composition

Most of the granitic rocks of the Lolo area are quartz monzonites. These rocks show striking textural variations. At the contact and for about 200 feet into the interior, there is a fine to medium grained border zone which in places is quite porphyritic. This border zone grades inward to a zone of medium to coarse grained quartz monzonite. Beyond the coarse grained zone, the interior is characterized by the presence of graphic texture and many pegmatite bodies.

The quartz content of the granitic rocks averages 30-35 per cent. Much of the feldspar occurs as perthite and will be discussed in greater detail later. All of these rocks contain hornblende and biotite, averaging 3 per cent of the rocks. A hornblende having green pleochroism occurs within the border zone. Biotite predominates in the coarse grained inner zone. Accessory minerals in trace amounts are sphene, ilmenite, magnetite, allanite, apatite and zircon.

The Significance of Perthitic Feldspars in the Quartz Monzonite

Petrographic analyses has shown perthitic feldspars to be important and very interesting constituents within the various zones of the quartz monzonite. The textural character in the quartz monzonite is as follows: (1) Fine Grained

Marginal Zone--all the feldspar occurs as perthite ($Or_{55}Ab_{45}$), no discrete plagioclase crystals are present, (2) Coarse Grained Intermediate Zone--the feldspar crystals are larger, more coarsely perthitic, and separate plagioclase crystals are present, (3) The Interior Zone--graphic texture and many aplite-pegmatite bodies in which the microcline is microperthitic.

The perthite appears to differ within the different zones and a study of this may reveal some of the conditions which produced the various types of perthite.

Perthites have been studied in great detail by Gates (in Emmons, 1953) and more recently by Tuttle and Bowen (1958). It has been demonstrated experimentally by Tuttle and Bowen (1958) that at higher temperatures there is a complete solid solution between the soda and potassium feldspars. Fast cooling of such a solid solution results in perthitic, microperthitic or cryptoperthitic intergrowths of the two feldspars. Gates (1953, chap. 5) believes that the sodic feldspar materials are extremely mobile in the last stages of crystallization and perthite can originate by two processes-- unmixing and replacement-- both giving rise to a different texture. These processes can operate almost simultaneously and all gradations between them are believed to exist.

Fine grained marginal zone

The feldspar of the greyish rock of the marginal zone is almost exclusively perthite and composes 62 per cent of the rock (Plate V, Fig. 13). The perthite composition was determined by X-ray analysis to be near $Or_{55}, (Ab,An)_{45}$. The majority of the perthite crystals within this rock appear as intergrowths of lamellae parallel to one of the cleavage planes, (Plate V, Fig. 14). Sometimes a braided structure occurs.

The formation of perthite here is believed to be by unmixing of an original homogeneous alkali feldspar. The results of Tuttle and Bowen (1958, p. 40) show that granitic rock, in which the feldspar ratio is about $Or_{50}, (Ab,An)_{50}$ and in which all the sodium feldspar is present as a component of perthite formed by unmixing during cooling, must have crystallized above $500^{\circ} C$.

The width of this zone may range from several hundred feet on the eastern margin to only a few feet in the exposures east of the Bar. The variation in width of the border zone is thought to be caused by variations in original depth of the now exposed contact. The wide border zone was developed near the upper part of the intrusive; the narrower border zone at greater depths, allowing more time for recrystallization. The narrow border zone is structurally related to an upthrown block exposing siliceous argillites

of the Wallace formation.

Coarse Grained Intermediate Zone

The quartz monzonite beyond the border zone is characterized by coarse grains (avg. 5mm-1cm). Perthite is still the major feldspar (47 per cent) within this zone, but many individual crystals of plagioclase ($Ab_{87}An_{13}$) are present and compose 20 per cent of the rock.

The amount of exsolution perthite in this zone decreases and many of the crystals are in a state of partial replacement by oligoclase. The replacement appears to take place along earlier perthite veins and possibly some later fractures (Plate V, Fig.15). Some of the potash feldspar crystals are rimmed by oligoclase which presumably has been exsolved from an original homogeneous potash-soda feldspar.

The unmixing in the intermediate zone seems to be more complete and the individual perthite crystals appear to consist of a higher percentage of potash feldspar. Toler (personal communication, 1959) determined by X-ray analysis that soda feldspar constitutes 28 per cent of the perthite, as compared to 45 per cent in the border zone. By knowing the composition of the perthites and the mode, it was possible to compute the percentages of potash and soda feldspars within this rock. The results obtained are very near the potash-soda ratio ($Or_{55}Ab_{45}$) for the perthite granite of the marginal zone (Fig. 16, 17). The per cent quartz and

Ferromagnesian minerals were also approximately the same. These data show that the rocks of the fine grained border zone have approximately the same composition, the only differences being in the distribution of the soda feldspar content.

According to the classification of Tuttle and Bowen (1958, p. 129) the quartz monzonite of the intermediate zone is a subsolvus granite of class IIB in which the albite content of the perthite lies between 50-15 per cent. This class is said by them to represent an intermediate stage between a high temperature and low temperature granite.

It is believed that this rock was initially a hypersolvus granite and during cooling, unmixing of the plagioclase from the original homogeneous solid solution took place to maintain equilibrium. Tuttle and Bowen (1958, p. 128) believe that water content may also be a factor in the formation of two feldspar granites because their experiments show that unmixing of the sodium feldspar takes place in a few days if water vapor is present to flux the reaction.

Tuttle and Bowen (1958, p. 91-93) have shown that some amphiboles are unstable in the presence of excess water vapors and they state that most perthite-quartz granites carry amphiboles as a principal dark mineral, suggesting that the lack of extensive unmixing of the alkali feldspars in these granites may be a result of the low water content of the magma.

The predominance of biotite (stable in the presence of excess water vapor) within the coarse grained inner zone in contrast to the green hornblende of the marginal zone suggests a higher concentration of water in the inner zone which may have contributed to the unmixing. The role of water will be mentioned again when discussing the aplite-pegmatites of the interior zone.

The Interior Zone

About a mile from the contact southwest of the East Fork road junction with the highway and directly west of Lee Creek camping grounds, much of the quartz monzonite has graphic texture consisting of an intergrowth of fluted angular quartz rods on perthite (Plate VI, Fig. 18). Individual plagioclase crystals and all types of replacement perthite are also found within this zone. In some cases only pseudomorphs of perthite crystals which have been almost entirely replaced by highly sodic oligoclase remain. Microplitic cavities and crases lined with smoky quartz crystals containing tourmaline are found throughout these rocks.

Aplite-pegmatite bodies also characterize this interior zone. Sometimes it is possible to see the texture grade from aplitic to pegmatitic (0.5mm-2.5cm) over a few inches (Fig. 21). There is also much graphic texture (intergrowth

of large clear grains of quartz with microcline within the pegmatite bodies (Plate VI, Fig. 19). The pegmatites appear to have no definite pattern, but are dispersed at random in pods, lenses, and tabular bodies. The pegmatites have no discernable effect on their wall rock, but appear to be an accumulation in place. Heinrich (1949, p. 320) has studied some pegmatites in the Boulder Batholith and has reached a similar conclusion.

It is believed this zone, containing the graphic texture and aplite-pegmatites, cooled much slower than the surrounding fine grained border zone and outer coarse grained zone. Here much more of the soda feldspar has been separated from the higher temperature homogeneous potash-soda feldspar. This extensive unmixing is illustrated by the accumulation of the larger microcline crystals which are only slightly perthitic.

Hauerburg (1958, p. 293) studied similar aplite-pegmatites in the Boulder Batholith near Basin, Montana and believes the mineralogy, texture and variation in grain size from aplitic to pegmatitic to be a function of the vapor pressure at the time of crystallization. The vapor pressure would decrease the rate of crystal nucleation, while increasing the rate of crystal growth and promoting coarser grain size.

The phenomenon of the second boiling point in a crystallizing melt and water appears to have played a considerable

Plate VI

Fig. 18. Micrographic texture (perthite and quartz) displayed within rocks of the Interior Zone of the quartz monzonite. Crossed nicols, x 51.

Fig. 19. Graphic intergrowths of perthite and quartz of the Interior Zone of the quartz monzonite. Crossed nicols, x 16.

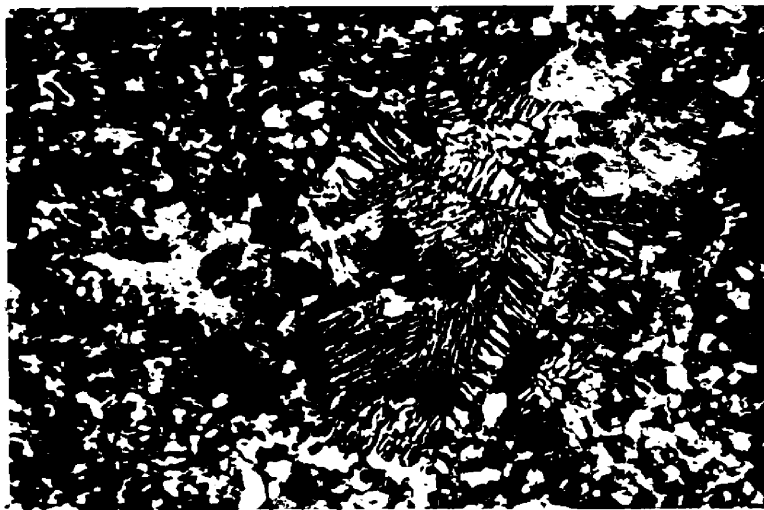
Fig. 20. A granophyric intergrowth appearing as a phenocryst within an aplitic groundmass. Crossed nicols, x 51.



18



19



20

role in textural variations of the interior zone. Birch (1952, p. 141) states that a magma containing water in excess of that taken up by hydrous minerals would steadily become enriched in water during crystallization. If the water was not able to escape due to differential pressure, it would reach a true saturation point. Further crystallization will result in a vapor phase (the second boiling point). It is believed that the water within the interior zone reached the critical state.

Jahns (personal communication) has recent experimental evidence that the formation of aplitic and pegmatitic textures are related to the second boiling point. The aplitic texture of the border in the pegmatites (Fig. 21) is believed to have formed during crystallization prior to the second boiling point. The coarser pegmatitic texture of the pegmatite cores is believed to have formed after the second boiling point was reached.

A higher concentration of water within the pegmatites, may here again be used to explain the almost complete separation of the soda-potash feldspars in the coarse microcline crystals within the pegmatites.

DIKES RELATED TO THE QUARTZ MONOCLINE

Dikes in the Lolo Hot Springs area are numerous and several different sets have been mapped. Each set and its occurrence will be discussed separately. Many of the smaller

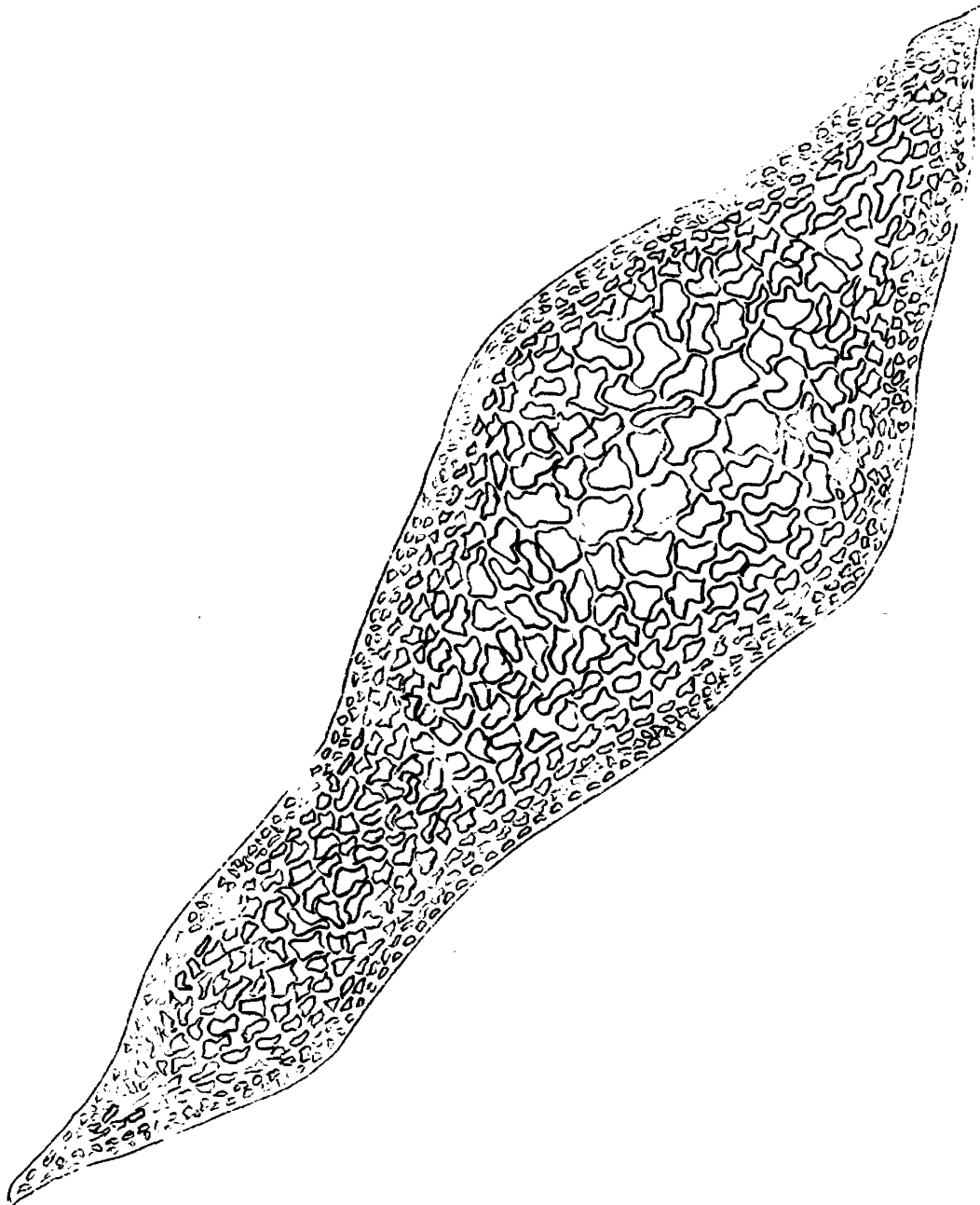


Fig. 21. Idealized diagram of the lens and pod shaped pegmatites present within the Interior Zone of the quartz monzonite in the Lolo Hot Springs Area.

dikes having poor outcrop exposure were not mapped, as they are quite numerous.

Aplitic Dikes

Aplite dikes are plentiful throughout most of the coarse grained quartz monzonite, but few regular dikes of aplite are found in the interior zone containing aplite-pegmatites. The aplites of this zone were discussed with pegmatites of the interior zone. The aplites of the outer zones were noticed to follow jointing. Although they follow more than one joint set, the dominant strike is N 45° E and they usually have a steep dip.

The aplites are typically light colored and have a sugary texture. A few grains of biotite can be seen. Several different grain sizes within a single aplite were observed in thin sections. There is an extremely fine grained groundmass composed of very uniform interlocking grains of alkali feldspar. Some larger granophyric intergrowths of quartz and microperthite reaching 1.5mm give the aplite a porphyritic appearance in thin sections (Plate VI, Fig. 20). Fine grained biotite is also dispersed throughout the groundmass.

Quartz Porphyry Dikes

Part of a quartz porphyry dike is exposed in the highway cut where Granite Creek enters Lolo Creek. The dike

strikes N 47° E and can be traced northeast through the road material pit and on the east side of Lolo Creek are several more which parallel it. Another one is exposed just south of the Fish Creek Lolo Creek Road and highway junction. Several smaller ones north of the old hotel were noted, but not mapped. At no place were these dikes found to cut the quartz monzonite.

The quartz porphyry rocks are light in color and phenocrysts are predominantly quartz. They average 3-5mm in size and compose about 10-15 per cent of the rock. Other phenocrysts are present in this rock. Study in thin section shows these phenocrysts to be granophytic intergrowths of quartz and potash feldspar. The groundmass is a very fine grained granophyre which appears to be exceptionally rich in quartz.

A rock of similar composition; however, containing phenocrysts of sodic oligoclase along with quartz occurs as sills or dikes nearly parallel to bedding on the east side of Lolo Creek south of the mouth of Martin Creek. Because of similar appearance and composition, these were mapped as the same rock type.

Quartz Monzonite Porphyry

Another set of dikes is located in the northwestern part of the area along each side of Granite Creek. These dikes have a similar strike to that of the quartz porphyry

dikes. They are exceptionally numerous and many were not mapped. All of these rocks have a similar megascopic appearance. Only one thin section was cut from these rocks.

The dikes are present around the main body of quartz monzonite, but appear not to cut it. The quartz monzonite dikes are all porphyritic in contrast to the uniform coarse grained texture of the main quartz monzonite body; however, it is not known whether the dikes are complementary or subsequent to the main quartz monzonite body.

This rock is a porphyry in which the phenocrysts compose close to 50 per cent of the rock. A thin section shows the phenocrysts to be predominantly oligoclase ($Ab_{85}An_{15}$); some approach albite. They range in size from 0.5mm to more than 1cm and average 7.5mm. The potash feldspar and perthite phenocrysts in this rock show much replacement by oligoclase. Many of the phenocrysts have highly sericitized borders. Quartz phenocrysts were not observed, the quartz occurring interstitially throughout a groundmass of alkali feldspar microlites. The rock is 15-20 per cent quartz. Many crystals of hornblende and biotite (5-10 per cent of the rock) are found within the groundmass and give it a dark grey-green color. The biotite has a very brown pleochroism and may be a titanium rich biotite, altered crystals show sagenetic rutile. Some ferromagnesian minerals are altered to the oxides, magnetite or ilmenite, along

with bleached biotite and chlorite. Accessory minerals are zircon, apatite, sphene, rutile, ilmenite and magnetite.

Granite Porphyry

A dike of granite porphyry is present north of the diorite contact cutting all of the gneissic rocks surrounding the diorite. The granite porphyry shows no metamorphic effects and therefore is later than the gneisses.

The rock contains abundant phenocrysts of orthoclase, sodic oligoclase and quartz totaling 40-50 per cent of the rock. The phenocrysts are gradational, ranging from 1mm to more than 1.5cm in diameter (Plate VII, Fig. 22). The feldspars are all sericitized and most phenocrysts show rims of alteration (Plate VII, Fig. 23). Some clay minerals are present.

Hornblende and biotite are abundant, but are highly altered to chlorite, penninite and hydrous mica. Much rutile is present, displaying saogenetic structure (Plate VII, Fig. 24), indicating a titanium rich hornblende and biotite.

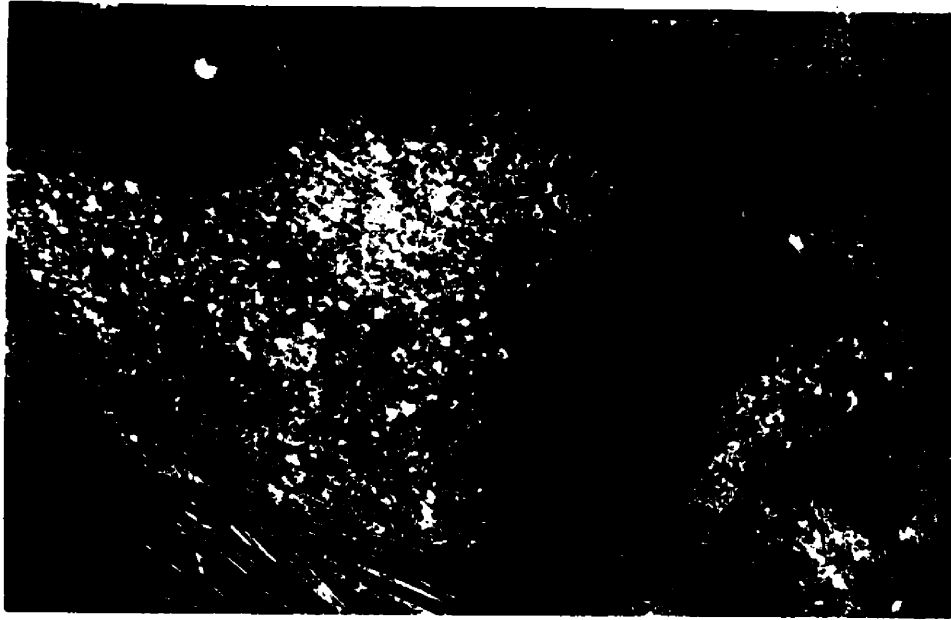
The groundmass is very fine grained and appears to be alkali feldspar with much interstitial biotite and hornblende, giving it a grey color. Apatite, zircon, rutile, ilmenite and magnetite are present as accessory minerals.

Plate VII

Fig. 22. Large feldspar phenocrysts occurring within the granite porphyry dike near the west end of Sally Ridge.

Fig. 23. Alteration haloes surrounding feldspar phenocrysts within the granite porphyry dike. Crossed nicols, x 16.

Fig. 24. Sagenetic rutile (dark needles) within chloritized biotite or hornblende. Crossed nicols, x 51.



22



23



24

General Mapping

The contact effects produced by the quartz monzonite and the diorite are of different magnitude and intensity. This will be discussed in detail below; however, for simplicity in mapping, only one symbol is used for the metamorphic rocks within the area.

CONTACT METAMORPHIC EFFECTS OF THE QUARTZ MONZONITE

Fabric

The contact metamorphic rocks surrounding the quartz monzonite vary considerably, depending upon the type of sediment present. The Wallace formation near the mouth of Granite Creek shows the results of metamorphism for about 1000 feet away from the contact. Close to the contact abundant tourmaline is present and some migmatization of the sediments occurs for distances of a few feet. The siliceous argillites and fine grained quartzites are metamorphosed to flinty quartzites. The more argillaceous beds have developed a banded or fascicular texture (Plate VIII, Fig. 27) in which biotite, muscovite, and chlorite have formed bundles within the quartzites. Lindgren (1904, p. 36 has called this rock a biotite-andalusite hornfels. On the east side of Lolo Creek near the quartz porphyry dikes, the siliceous

argillites have developed a slaty cleavage and are very flinty.

Mineral Assemblages and Metamorphic Facies of the Argillaceous Wallace Beds

The siliceous argillites of the Wallace formation appear to have been extremely high in silica, which along with the presence of Al_2O_3 , FeO , MgO , K_2O , Na_2O and CaO gives rise to pelitic schists near the contact of the quartz monzonite.

The chief minerals of the pelitic schists, in addition to quartz and sodic plagioclase, which can always be present, are andalusite (?), muscovite, chlorite and biotite. The siliceous argillites are deficient in potassium, which is indicated by the absence of an additional phase of K_2O in excess of that used in the formation of biotite. The deficiency in K_2O is also shown by the presence of andalusite (?), which is stable only in rocks deficient in K_2O .

This mineral assemblage can be represented by the ACF diagram (Fig. 25) taken from Fyfe et al (1958, p. 204). The mineral assemblage is that of the albite-epidote hornfels facies (low-grade contact metamorphism).

CONTACT METAMORPHIC EFFECTS OF THE DUNNIE

Fabric of Surrounding Rocks

At no place was a sharp contact found between the

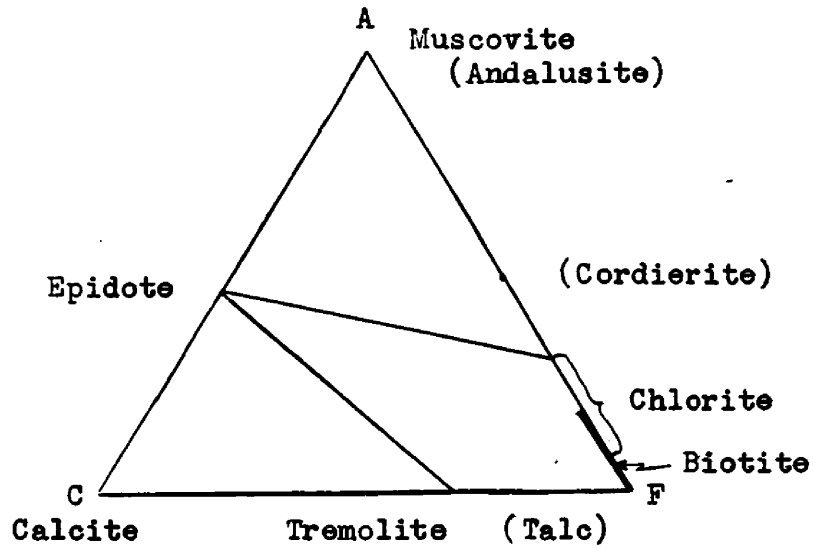


Fig. 25. Albite-Epidote Hornfels Facies. ACF Diagram for Assemblages with Excess Silica -- Quartz and albite are possible additional members of each assemblage. Minerals in brackets are stable only in assemblages deficient in K_2O . (Fyfe et al 1958, p. 204).

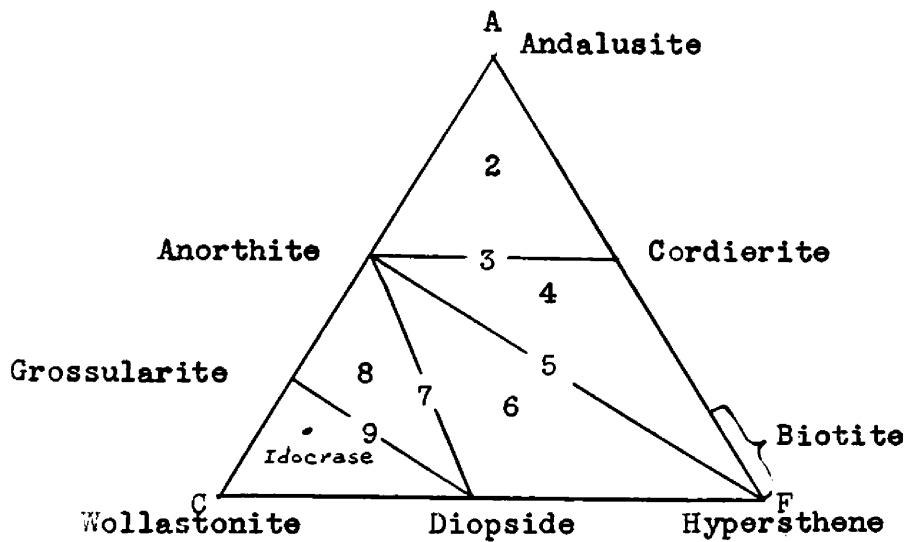


Fig. 26. Pyroxene Hornfels Facies. ACF Diagram for rocks with Excess SiO_2 . Quartz and potassium feldspar are possible additional phases (Fyfe et al 1958, p. 212).

Plate VIII

Fig. 27. Fascicular texture (clusters of mica and chlorite forming blotches) occurring within the hornfels of the siliceous argillites of the Wallace formation near the contact of the quartz monzonite. Crossed nicols, x 16.

Fig. 28. A picture showing dark soil (right) derived from weathering of rocks rich in hornblende.



27



28

diarite and the border rocks. Many of the rocks near the contact are very dark colored and appear to be very rich in hornblende. This rock often weathers to a dark soil (Plate VIII, Fig. 28). Other rocks near the contact are banded with alternating light and dark bands giving the rocks a gneissic appearance (Plate IX, Fig. 29, 30). The dark layers consist of amphibole and augite, while the light layers are quartz and plagioclase. In places the diorite has metamorphosed the surrounding rocks into hornfels containing amphibole, pyroxene and plagioclase. Most show non-directed fabric referred to as granoblastic (Plate XI, Fig. 35). Sometimes large porphyroblasts of hornblende up to one inch in length are found within a fine grained groundmass of augite, hornblende and plagioclase (Plate X, Fig. 31). Spheroidal concretions of hornblende have grown up to a few inches in diameter within some rocks in places (Plate X, Fig. 32).

The banded gneiss, hornblende porphyroblasts and concretions can be explained by processes of metamorphic differentiation and diffusion. Barth (1952, p. 314) states that the definition of metamorphic differentiation is restricted to differentiation effected by diffusion processes, and does not include differentiation by flowing liquids or bodily movement of solid particles. The mechanisms causing diffusion are the difference in chemical activity of the various elements throughout the rocks. Some of the forces

Plate IX

Fig. 29. Alternating light and dark bands near the contact of the diorite giving the rocks a gneissic appearance.

Fig. 30. A metamorphic gneiss near the diorite contact showing a mineral assemblage belonging to the pyroxene hornfels facies (augite-plagioclase left) and also to the hornblende hornfels facies (hornblende-pyroxene-plagioclase right).



29



30



29

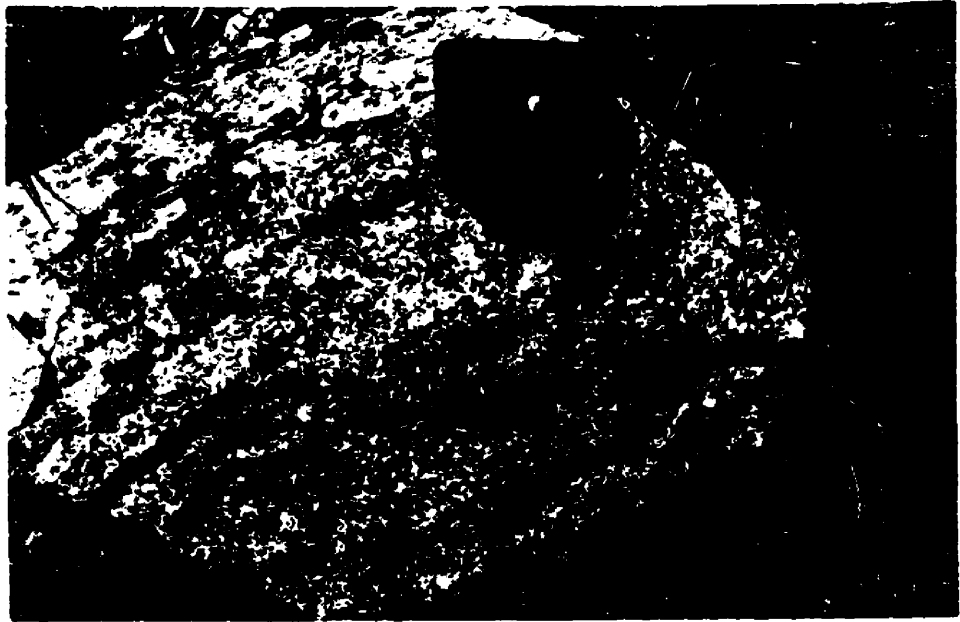


30

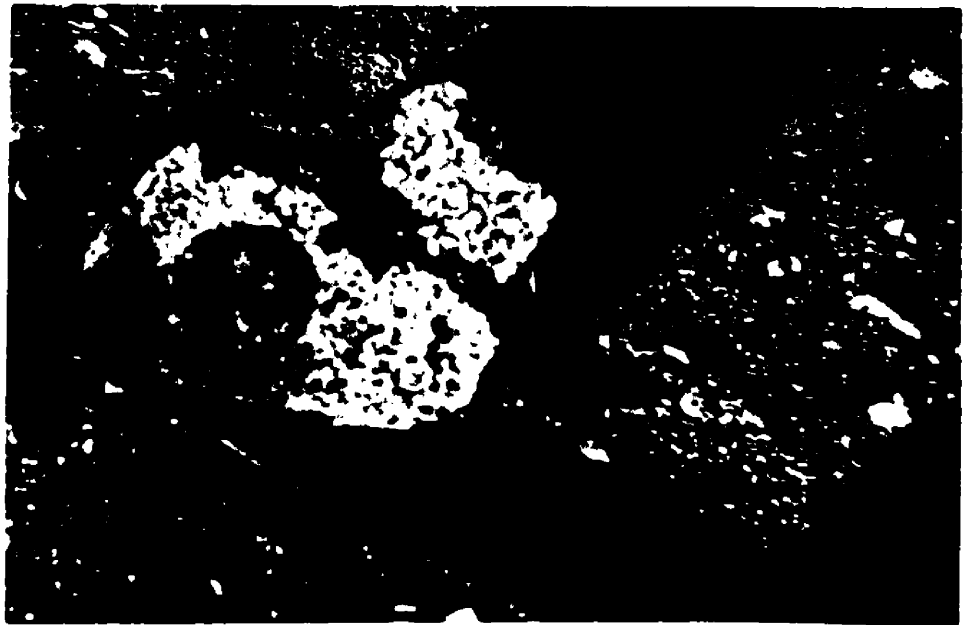
Plate X

Fig. 31. Large hornblende porphyroblasts which have grown within a fine grained groundmass of augite, hornblende and plagioclase.

Fig. 32. A spheroidal concretion of hornblende occurring near the diorite contact in the vicinity of East Fork of Lolo Creek.



31



32

Driving the metamorphic processes would include free energy, temperature, pressure and vapor tension.

Where the dark border is lacking and at the contacts with some of the inclusions, the diorite appears to be steadily lighter in color and richer in quartz until metamorphosed sediments are evident. Lack of good exposures obscure most of the contacts.

Mineral Assemblages and Facies of the Calcareous Wallace Beds

The Wallace formation contains many limy quartzites and argillites which give rise to lime hornfels. Where this formation is lacking lime, the mineral assemblages would better fit the lime-deficient hornfels described under metamorphism of the lower Belt quartzites.

In the northeastern part of the area, the diorite contact with the limy quartzites and argillites of the Wallace formation has developed a zoned metamorphism which makes a very interesting study. Iron and some magnesium are believed to have been present throughout most of the Wallace formation. There is always sufficient quartz present to form highly silicified hornfels.

Near the contact of the diorite some rocks are found to contain diopsidic augite or salite as the only dark mineral (25-50 per cent). Plagioclase forms about 15-50 per cent of the rock. Some rocks may contain up to 60 per cent quartz.

Augite in this case shows the presence of some FeO and MgO within these rocks. This mineral assemblage can be represented by the ACF diagram in Figure 26 (Fyfe et al, 1958, p. 211). The diagram is for the pyroxene hornfels facies, the mineral assemblage of the contact metamorphosed calcareous rock within the Wallace formation falling into class 7.

In some places amphibole, as well as pyroxene is present at the contact with the diorite. These are somewhat lower grade metamorphism and correspond to the hornblende hornfels facies. The mineral assemblage found in these rocks varies in percentages, but the assemblage is consistent in five thin sections over a distance of a mile from the contact. The minerals present are augite, tremolite and plagioclase. The composition of the feldspar varies from andesine ($Ab_{35}An_{65}$) to sodic oligoclase. In many rocks quartz is an additional phase and may compose up to 60 per cent of the rock. This assemblage can be represented by the ACF diagram (Fig. 33) taken from Fife et al (1958, p. 206).

Scapolite is present within many of the rocks in both the pyroxene hornfels and hornblende hornfels facies. When discussing the mineral assemblage, scapolite will be considered equivalent to plagioclase. Its occurrence will be discussed at the close of the discussion on the metamorphism of the Wallace.

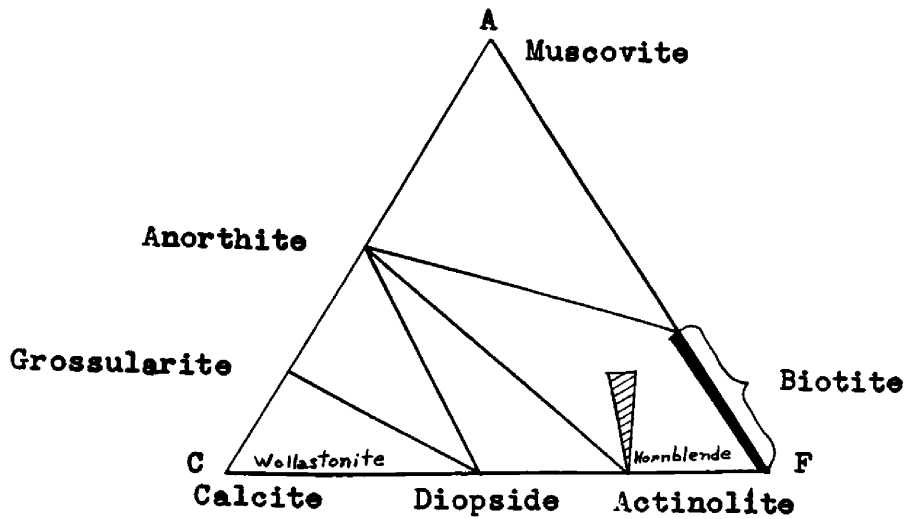


Fig. 33. Hornblende Hornfels Facies. ACF Diagram for rocks with excess SiO_2 and K_2O . Quartz and microcline are possible additional minerals (Fyfe et al 1958, p. 206).

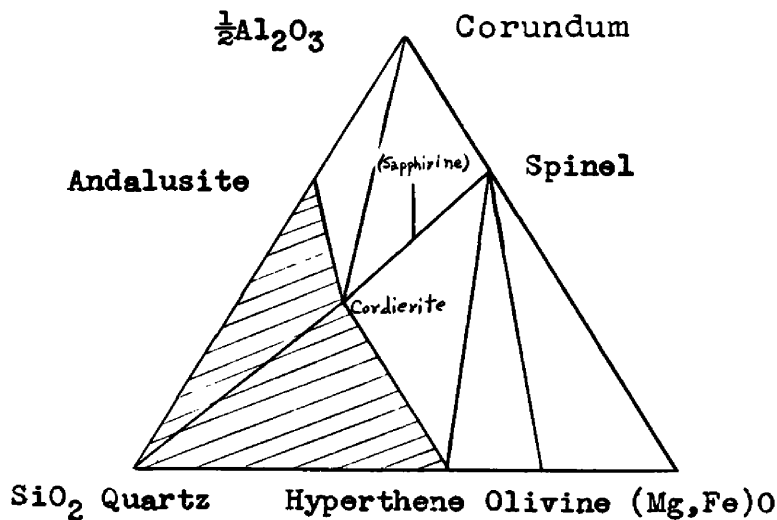


Fig. 34. Equilibrium assemblages of mineral phases in lime-poor hornfelses. Stippled area: field of normal pelitic sediments (From Barth 1952, p. 275--After C.E. Tilley, Min. Mag., 1923).

Sphene was noted to be abundant throughout most of the hornfels in the area. In some cases, the typical wedge shaped crystals are present, but most of the sphene occurs as anhedral grains disseminated throughout the rock (Plate XI, Fig. 36).

The effects of metamorphism were noted to end rather abruptly in the northeastern part of the area. A thin section of a rock near the outermost visible limit of contact metamorphism was noted to contain diopside-tremolite-calcite-quartz. This assemblage fits neither the low grade albite-epidote hornfels facies found in the outer zones of contact metamorphic rocks, nor the hornblende hornfels facies. According to Fyfe et al (1958, p. 205) the above assemblage represents a transition stage between the hornblende hornfels facies and the albite-epidote hornfels facies.

The reason for the lack of the outer low grade metamorphic zone is not known; however, the transitional assemblage indicates decreased temperatures. The abrupt contact with which the metamorphic zone ends and the lack of an outer zone suggests that much of the metamorphic zone surrounding the diorite may be underlain by diorite. The large metamorphic zone covering one mile away from the contact of the diorite, most of which belongs to the hornblende hornfels facies may result from a heat source at depth.

The Occurrence of Scapolite

Scapolite occurs near the contact and at some distances from the contact. It is found within the fine grained hornfels and also within the light bands of the gneisses. In thin sections it appears as very large poikilitic crystals often inclosing small crystals of pyroxene or amphibole giving rise to sieve texture (Plate XI, Fig. 36, 37). In some samples scapolite is the predominant mineral along with diopside and or tremolite.

The irregular occurrence of the scapolite within only certain places of the metamorphic zones is not understood. Barth (1952, p. 284) believes that scapolite represents a low temperature plagioclase. Fyfe et al (1958, p. 160) say that this relationship may not be valid at all pressures.

Because scapolite occurs at some distances from the contact as well as next to the contact, it is possible that the process of scapolitization is more complex and involves halides, either in solution or in a gas phase, as suggested by Fyfe et al (1958, p. 160). If this is so, it is quite possible that much of the metamorphic zone in the northeastern part of the area is underlain by diorite. It is also possible that the scapolitization may be associated with the later intrusion of the quartz monzonite.

Plate XI

Fig. 35. Granoblastic texture (plagioclase crystals, augite and amphibole) shown in many of the hornfels near the contact of the diorite contact. Plain light, x 51.

Fig. 36. Poikilitic scapolite (white), diopsidic augite and sphene (dark wedge shaped crystals) displayed within the hornfels near the diorite contact. Plain light, x 51.

Fig. 37. Poikilitic scapolite, diopsidic augite and tremolite occurring within hornfels near the diorite contact. Crossed nicols, x 51.

Fig. 38. Plagioclase porphyroblasts occurring within a metamorphosed impure quartzite. Lower two porphyroblasts at extinction (dark). Crossed nicols, x 51.



35



36



37



38

Mineral Assemblages and Metamorphic Facies of the Lower Belt Quartzites

Where the diorites are in contact with the lower Belt formations, the quartzites in places are bleached very white and in some rocks porphyroblasts of plagioclase up to 5mm in diameter are present, giving the rock a porphyritic appearance (Plate II, Fig. 38). Petrographic investigation shows the quartz grains to be sutured; quartz is the major constituent, composing up to 60-75 per cent of these rocks. Some biotite and oligoclase usually form the remainder of these rocks. Allanite and sphene are present in small amounts.

This mineral assemblage would fall within the stippled area of the ACF diagram for lime-deficient hornfelds (Fig. 34) Barth (1952, p. 274) explains biotite $K(Mg,Fe,Al)_3(Si,Al)_4O_{10}(OH)_2$ as a possible substitute for hypersthene in the presence of water and K_2O .

Metamorphosed Roof Pendants and Inclusions

Both roof pendants and inclusions occur within the diorite. A large xenolith separates the diorite from the quartz monzonite. The pendants and inclusions are metamorphosed to hard hornfels which generally are very resistant to weathering and thus form much of the higher elevations. Sometimes the roof pendants are exposed, but many times the tops are mantled by float. Some of the rocks are

bleached quartzite; most are fine grained light green hornfels.

In the metamorphic rocks separating the quartz monzonite and diorite south of East Fork of Lolo Creek thin sections and immersion oil investigations show that ferroaugite composes approximately 50 per cent and plagioclase 15 per cent of the rock; the remainder is quartz. This is a high grade metamorphic rock of the pyroxene hornfels facies. Some of the rocks contain orthoclase as an additional phase indicating the presence of K_2O .

The siliceous argillites containing abundant iron found within the lower Burke or Pritchard could give rise to mineral assemblages such as those described above.

CONCLUSIONS

Petrographic study of rocks of the Idaho-Batholith border zone in this vicinity shows a wide variation in rock types.

The dioritic rocks range from fine grained diorite, in which amphibole constitutes about 50 per cent of the rock, to a diorite porphyry containing large calcic andesine phenocrysts, to lighter medium to coarse grained diorite composed of andesine and hornblende and biotite (40 per cent) in about equal amounts. Granitic rocks varying from fine to medium and coarse grained quartz monzonite to granite porphyry are also present.

In addition, the two major intrusions of diorite and quartz monzonite have produced a contact aureole in a thick section of the surrounding Beltian sediment that ranges over several metamorphic facies. The spacial relationship, the mineralogical character and contact effects will be summarized in order to shed some light on the mode of origin and development of these two major intrusives.

The most striking and significant evidence concerning the origin of both the diorite and the quartz monzonite is the contact metamorphic zones surrounding each intrusion. The aureole surrounding the diorite grades, from the contact out, through the familiar high to low grade thermally metamorphosed sequence: pyroxene hornfels → hornblende hornfels → an assemblage transitional between the hornblende hornfels

and the albite-epidote-hornfels facies. The aureole surrounding the quartz monzonite consists solely of the low grade albite-epidote-hornfels facies. Both the contact zones are of only limited extent, grading into the virtually unmetamorphosed normal Belt sediments. From this evidence alone it is possible to conclude that both bodies have been injected (and were therefore mobile) at relatively high temperatures into a low temperature zone (the unmetamorphosed sediments). That is to say, they are both igneous. Several other characteristics of both bodies point out their igneous origin. These will be described below.

A number of other features allow a more detailed account of the emplacement of the diorite. The diorite appears to have been intruded along a north-south trending structure. This is shown by the north-south alignment of pendants and the contact paralleling the north-south trend of the East Fork Pendant which extends several miles south of the area. The variation in the mineralogical composition of the diorite, the porphyritic texture of some diorite bodies, zoning indicating regeneration (Plate I, Fig. 2), plus the cognate xenolith of early crystallized masses suggests that the diorite resulted from a series of intrusions. The dioritic magma may have been available to be tapped and the intrusion resulted from a series of diastrophic movements.

The quartz dioritic rocks are confined mainly to the southeastern part of the area. It was pointed out (p.14)

that in some of the roof pendants there appears to be a gradation from diorite to quartz diorite and finally into metamorphosed quartzites. There is also an alignment of roof pendants with quartz rich diorite outcropping within the normal diorite. In this case, it appears there is some reaction between the diorite and the quartzites of the roof pendants, producing quartz rich diorites. The quartz diorites were noted to contain abundant biotite with minor hornblende; augite and epidote are sometimes present. The ferromagnesian minerals of the normal diorites are hornblende and biotite in about equal amounts. Some rocks in the eastern part of the area are extremely rich in quartz and have a gneissose texture. These may have a metamorphic origin.

There is a great deal of evidence supporting igneous origin for the quartz monzonite. The one feldspar granite (perthite discussed p. 27) of the fine grained marginal zone is good evidence supporting magmatic origin. Tuttle and Bowen (1958, p. 116) have presented much experimental evidence that granites of this texture represent rocks intermediate between volcanic and plutonic ~~salic~~ rocks. Where the contact is exposed, it is usually quite sharp and it is possible sometimes to see near the border fragments of altered wall rock which have been incorporated during the intrusion. There are many offshoots extending into the surrounding country rock

for a short distance from the contact.

Although the contact is sharp, there is usually some modification of the wall rock. At some places, porphyroblast of feldspars are found within the wall rock up to a few feet from the contact. Where the fine grained border zone is present phenocrysts or (porphyroblasts) are also present. Turner and Verhoogen (1951, p. 289) believe that porphyroblasts of the two above types are both of metasomatic origin brought about by the crystallizing magma. They believe that porphyroblasts within the surrounding rock are metasomatic replacements of country rock, while the "phenocrysts" porphyroblasts within the fine grained marginal zone are probably replacements of the early crystallized border. Turner and Verhoogen (1951, p. 286) state that reactions such as these are common over short distances at granitic contacts.

The composition similarity of the marginal zone and coarse grained intermediate zone, regardless of the distribution of the soda content (as exsolution perthite or as individual plagioclase crystals) suggests that these rocks were both crystallized from a homogeneous melt. The overall composition of the quartz monzonite (Fig. 16, 17) represents the lowest melting point composition in the system $KAlSi_3O_8 - NaAlSi_3O_8 - SiO_2 - H_2O$ (Futtle and Bowen 1958 p.74).

The presence of biotite in the coarse grained intermediate zone in contrast to the hornblende of the marginal

zone suggests that the magma originally was not over-saturated with water, but as crystallization took place, the magma steadily became enriched in water. The unmixing of the perthite may also have been aided by water concentration. The pegmatitic texture of the interior zone also agree well with the experiments of Jahns (personal communication) resulting from a crystallizing melt in which conditions were such that the second boiling point was reached. All of the evidence supports a magmatic origin for the quartz monzonite.

Only the northeastern part of the quartz monzonite body lies within the area mapped. The exact size of this body is not known; however, it is known to extend several miles toward the south and west. Anderson (1930) has mapped part of the quartz monzonite core of the Idaho Batholith and states that in places this core has fingers which cut the marginal facies of the Batholith. It is possible that this may be part of the quartz monzonite core of the Idaho Batholith, or it could also be an outlying stock.

STRUCTURE

The Precambrian Belt sediments surrounding the quartz monzonite and diorite strike about N 50°-70° W and most dip quite steeply to the northeast. Bedding within a pendant present between the quartz monzonite and diorite and pendants within the diorite appears to strike more in a north-south direction.

Two parallel high angle faults striking about N 45° E are present in the northwestern part of the area and cut both the quartz monzonite and surrounding sediments. A third fault cutting both the quartz monzonite and hornfels near the intrusives is in part occupied by a granite porphyry dike. Many smaller high angle faults are found in the siliceous argillites near the quartz monzonite contact at the Hot Springs (Plate XIII, Fig. 42), but appear not to have had a large stratigraphic throw.

FOLDS

Powell Creek Anticline and Syncline

A small local anticline and adjacent syncline with a northwest trend is located in the northeastern part of the area southeast of Powell Creek and therefore designated the Powell Creek anticline and syncline. The structure seems to be very local and intense metamorphism suggests that it resulted from intrusive forces at depth, rather than lateral

compression. Near the diorite contact, bedding within the hornfels which seems to be overturned to the south may be a result of intrusive tongues wedging the beds apart.

It is also possible that these beds are not overturned, but that there is a large fold north of the diorite contact which has duplicated the Wallace formation.

East Fork Pendant

A pendant within the batholith located between the diorite and quartz monzonite south of East Fork of Lolo Creek may be the remnant of a north plunging anticline. It is also possible that it is the limb of a fold which was affected by intense deformation during the intrusion of the diorite and the later quartz monzonite. A hornfelsic rock collected near the top of the ridge was of the high temperature pyroxene hornfels facies, suggesting this pendant may be partially underlain by diorite. The pendant was considerably restricted a short distance north of East Fork of Lolo Creek by the diorite intrusion; however, a narrow metamorphosed zone separates the diorite from the quartz monzonite to the north.

FAULTS

East Hot Springs Fault

A large high angle fault striking northeast, located

just east of Lolo Creek will be called the East Hot Springs fault. A gouge zone about 100 feet thick is exposed southeast of the Lolo Bar, where this fault is cut by a logging trail. The trace of this fault shows it to be dipping nearly vertically. The fault cuts the quartz monzonite and is aligned with Mud Creek, the erosion of which was very likely controlled by the soft gouge produced by the fault.

East of the Hot Springs and for about one mile to the north, this fault has brought what are believed to be metamorphosed upper Wallace beds in the southeast block into contact with what are believed to be argillites of the lower Wallace formation west of the fault.

The fault is known to continue to the northeast. A good exposure of sheared Wallace lithology is found where this fault is exposed in the highway cut one-fourth mile north of the area. A pronounced saddle in the ridge north of Martin Creek, along with other alignments to the south which can be seen on the air photographs, were used to trace this fault between the known exposures.

West Hot Springs Fault

Another high angle fault is located about one mile northwest of the East Hot Springs fault and runs parallel to it. This fault appears to dip slightly to the west.

A large breccia and gouge zone about 1,000 feet wide is

present where this fault is exposed in the highway curve about one-fourth mile north of the area (Plate XII, Fig. 40).

The West Hot Springs fault has brought Burke, Revett and St. Regis formations in the west block into contact with the Wallace formation in the east block. The quartz monzonite contact has been offset left laterally about one mile by the fault.

The extent of the East and West Hot Springs faults to the north is not known; however, faults having a similar strike are shown to the northeast on the Tectonic Map of the United States (Longwell et al, 1944).

Southwest Sally Ridge Fault

A high angle fault striking about N 60° E is located on the southwest end of Sally Ridge and will be called Southwest Sally Ridge fault. This fault is in part occupied by a large granite porphyry dike. The fault causes a slight right lateral separation of the quartz monzonite contact, but no large offsetting of the calcareous hornfels of the Wallace formation was noted.

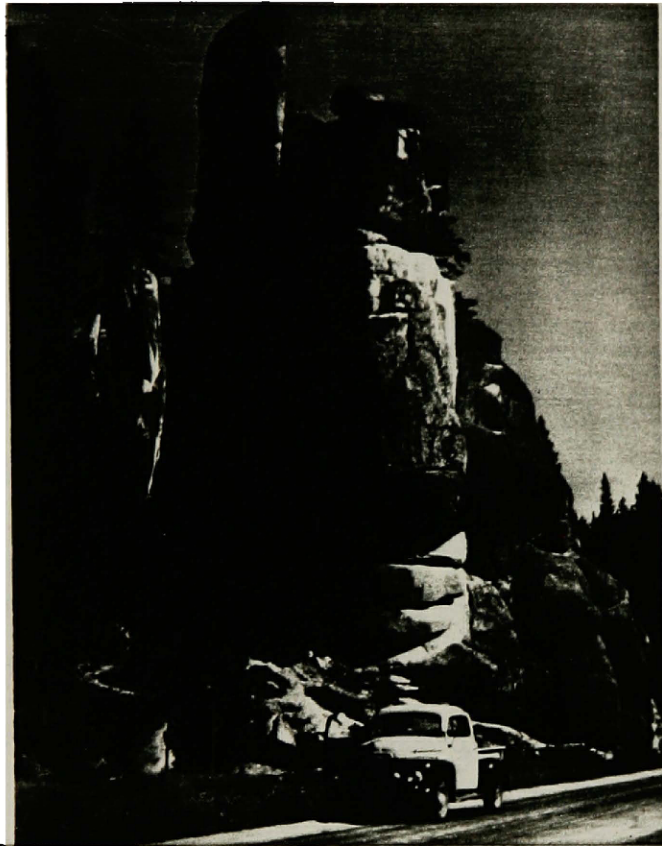
A good exposure of this fault shows a gouge zone about 50 feet wide in a logging trail near the contact of the quartz monzonite; however, it could not be traced through the soft weathering rocks of the quartz monzonite. The dike was found to cross the west end of Sally Ridge and was lost in timber to the north.

.. Plate XII

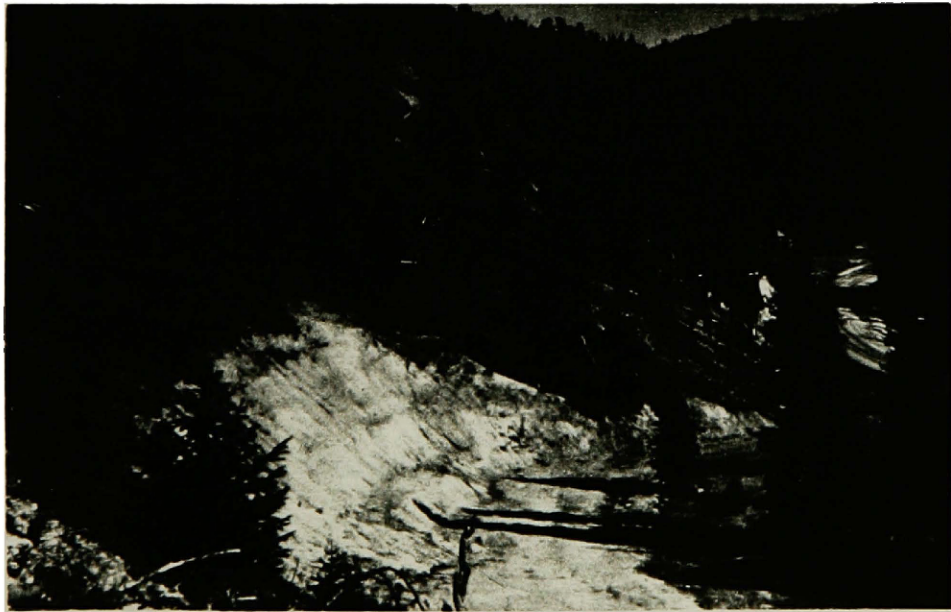
Plate XII

Fig. 39. View looking north from the highway near the plunge and showing the prominent north striking set of joints giving rise to large castle rock outcrops.

Fig. 40. View looking northeast showing the fault contact between the Wallace (buff colored rock-right) and St. Regis (grey rocks-left) formations in the highway curve one-fourth mile north of the area.



39



40

STRUCTURAL ANALYSIS

The Precambrian rocks in the batholith border zone have undergone several phases of deformation in addition to metamorphism and later faulting. This makes the structure very complex and difficult to interpret. Poor exposures and very dense timber cover (Plate XIII, Fig. 41) makes it impossible to decipher all the structural details. The following proposal, which is based on the data gathered during the mapping, is a possible solution to the structural problems within this area. A better understanding of the structural picture may be worked out as others do work in adjacent districts, compiling a regional picture of the fault system. Such a field study may solve the problem of duplication of the Wallace formation across several miles of exposures northeast of the area.

The highly calcareous hornfels near the intrusive contact east of the East Hot Springs fault in contrast to pelitic schists west of this fault suggests that the beds to the east of the fault are probably metamorphosed calcareous beds of the upper Wallace formation, while these to the west of the fault are probably stratigraphically lower in the formation. If this is true, it appears the block west of the East Hot Springs fault has gone up relative to the east block.

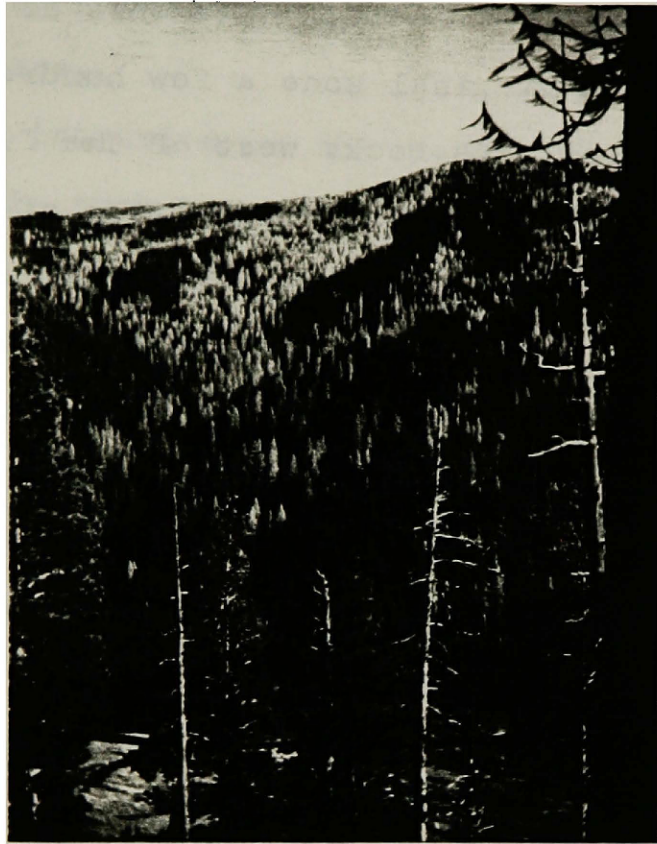
Evidence supporting this interpretation (p.27) is the presence of coarse grained quartz monzonite texture extending

Plate XIII

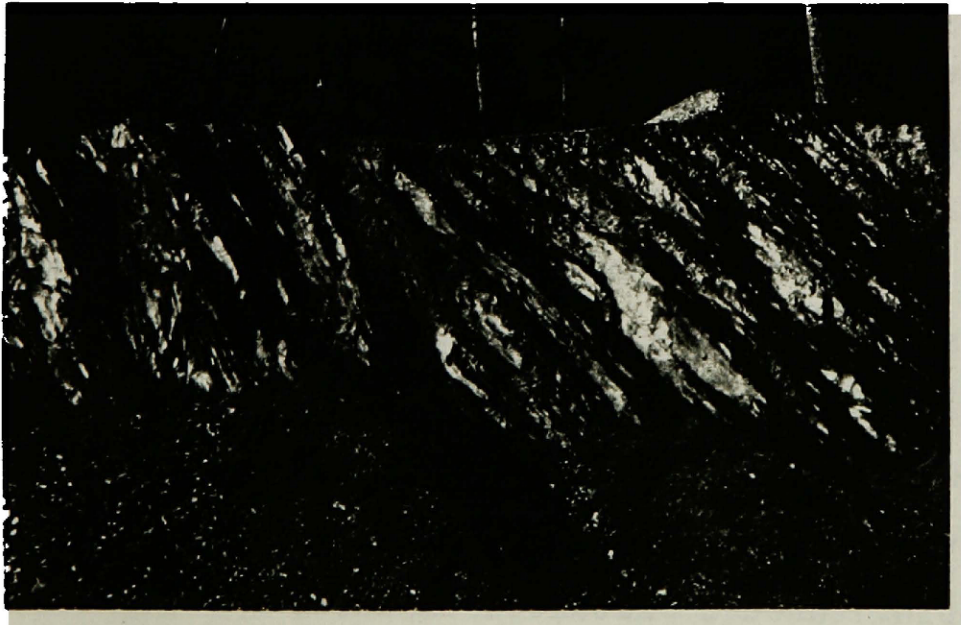
Plate XIII

Fig. 41. A view looking east from the highway across Lolo Canyon toward the Powell Creek drainage. Picture shows the dense forest cover of the north slopes in the Lolo area.

Fig. 42. View looking west showing a small fault within the argillaceous beds of the Wallace formation near the quartz monzonite contact at the Hot Springs. Note the steep dip (left) of the beds closest to the quartz monzonite contact.



41



42

to within one foot of the contact of the pelitic schists west of the East Hot Springs fault, while east of the fault, there is a fine grained marginal zone a few hundred feet wide. This would suggest the rocks west of the fault were at a much greater depth during crystallization of the magma. A large thickness of sediments would have served well as an insulator and allowed more time for crystallization.

The formations exposed to the west of the West Hot Springs fault are the Burke, Revett and lower St. Regis, while east of the fault the Wallace formation is exposed. This right lateral separation indicates the northwest block has gone up relative to the southeast block. The right lateral separation could be a result of a high angle west dipping reverse fault or a high angle gravity fault.

Although there has been right lateral formational offset by this fault, the quartz monzonite contact has been offset left laterally about one mile. Offsetting the formations right laterally and the quartz monzonite contact left laterally by vertical movement alone would require the quartz monzonite contact with the sediments to dip considerably to the south at depth. This may be possible; however, Turner and Verhoogen (1951, p. 268) state that contacts between plutonic and adjoining rocks are vertical or steep dipping through distances in thousands of feet. If this is true, it would be more logical to assume that the left lateral separation of the quartz monzonite contact

and the right lateral separation of the belt formation resulted from two different types of movement occurring at different times.

Before the intrusion of the quartz monzonite the West Hot Springs fault probably was a west dipping reverse fault. Such a movement would have resulted in the right lateral formational separation. The latest movement, subsequent to the quartz monzonite intrusion, probably was strike slip in which the quartz monzonite contact was displaced left laterally.

It is believed that the Granite Porphyry Fault is a small tensional fault having only a small amount of displacement. The intrusion of the granite porphyry dike may have been contemporaneous with or subsequent to faulting.

The most recent deformation, which gave rise to the offset of the quartz monzonite contact, probably was due to a compressional force from a southern direction. Wagner (1949, p. 26) also noted forces acting from this direction in the St. Joe District of Idaho.

There appears to have been an earlier east-west stress prior or at the time of the intrusion of the quartz monzonite and diorite. This is shown by a north strike of bedding within the East Fork pendant. This stress may have somewhat controlled the intrusion of the diorite because the diorite seems to parallel a north-south striking structure. Wagner (1949, p. 26-37) has also recognized this earlier

east-west stress in the St. Joe District, Idaho, which produced some north-south trending folds. In the Idaho District, the earlier north-south trends have been almost completely obliterated by the more recent north-south stress.

Other deformation may have occurred; however, pre-Laramide displacements probably have been obliterated by the emplacement of the Idaho Batholith and more recent faulting, or are concealed by dense forest cover.

Joints

During the mapping, all of the joint sets of each outcrop were mapped in considerable detail. Primary flow structure was usually obscured by weathered surfaces or lichens covering the outcrops, making it impossible to map primary flow.

The poles of the joint sets were plotted with different symbols to delineate jointing within the diorite and quartz monzonite (Fig. 43). The joints within the quartz monzonite and diorite form a system consisting of two sets. One steep dipping set striking from $N 10^{\circ} W$ to $N 10^{\circ} E$ is quite pronounced. A perpendicular set striking $N 70^{\circ} - 80^{\circ} E$ is less well expressed or developed. There is also a steep dipping set of joints diagonal to the N-S and E-W joints. This set of joints strikes about $N 45^{\circ} E$ and was noticed to have several aplite dikes following it. In some outcrops, shallow dips along the north striking joints develop sheeting

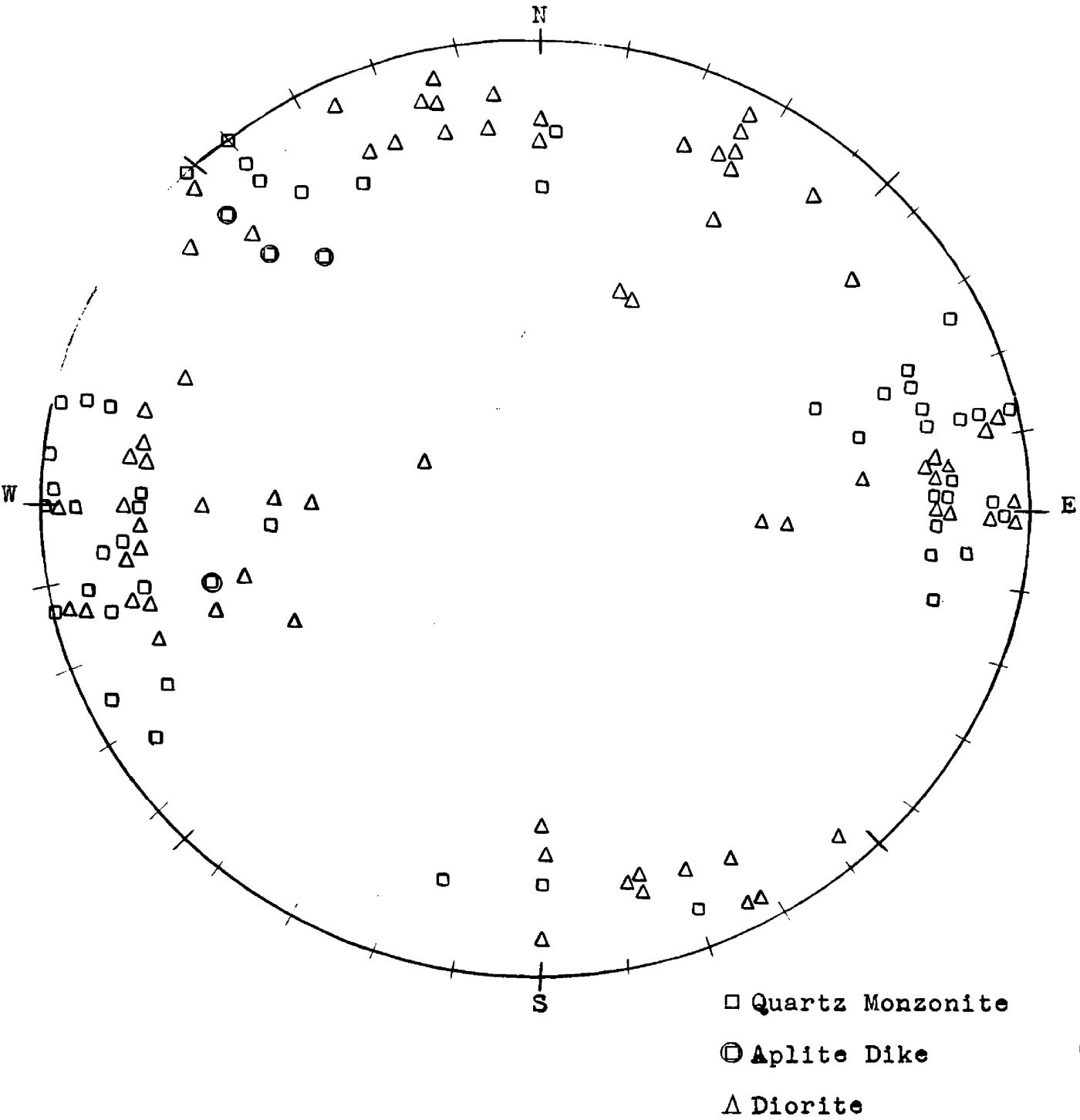


Fig. 43. Point diagram of joint poles showing the trend of the joint sets within the diorite and quartz monzonite in the Lolo Hot Springs Area.

which is common in granitic bodies.

Erosion facilitated by weathering, ease along the north-south joints, often leaves large unjointed blocks forming castle rock outcroppings such as those located near the plunge (Plate XII, Fig. 59). The north joint set, which is easily discernable on the air photographs, probably controls much of the minor drainage in the area.

Analysis of Joints

It has already been pointed out that aplite dikes have been injected along the N 45° E joint set. According to Balk (1937) p. 41) this is evidence for a primary age related to the intrusion of the magma and not due to later compressive forces.

Balk (1937) states that longitudinal joints parallel the direction of primary flow and cross joints are perpendicular to primary flow. A diagonal set of joints also develops at about 45° to the primary flow direction.

It is not possible to state which joints in the Lolo Area are the longitudinal and which are cross joints because of the lack of detailed flow structure; however, the sets appear to be primary and well developed through-out the igneous rocks.

BIBLIOGRAPHY

References

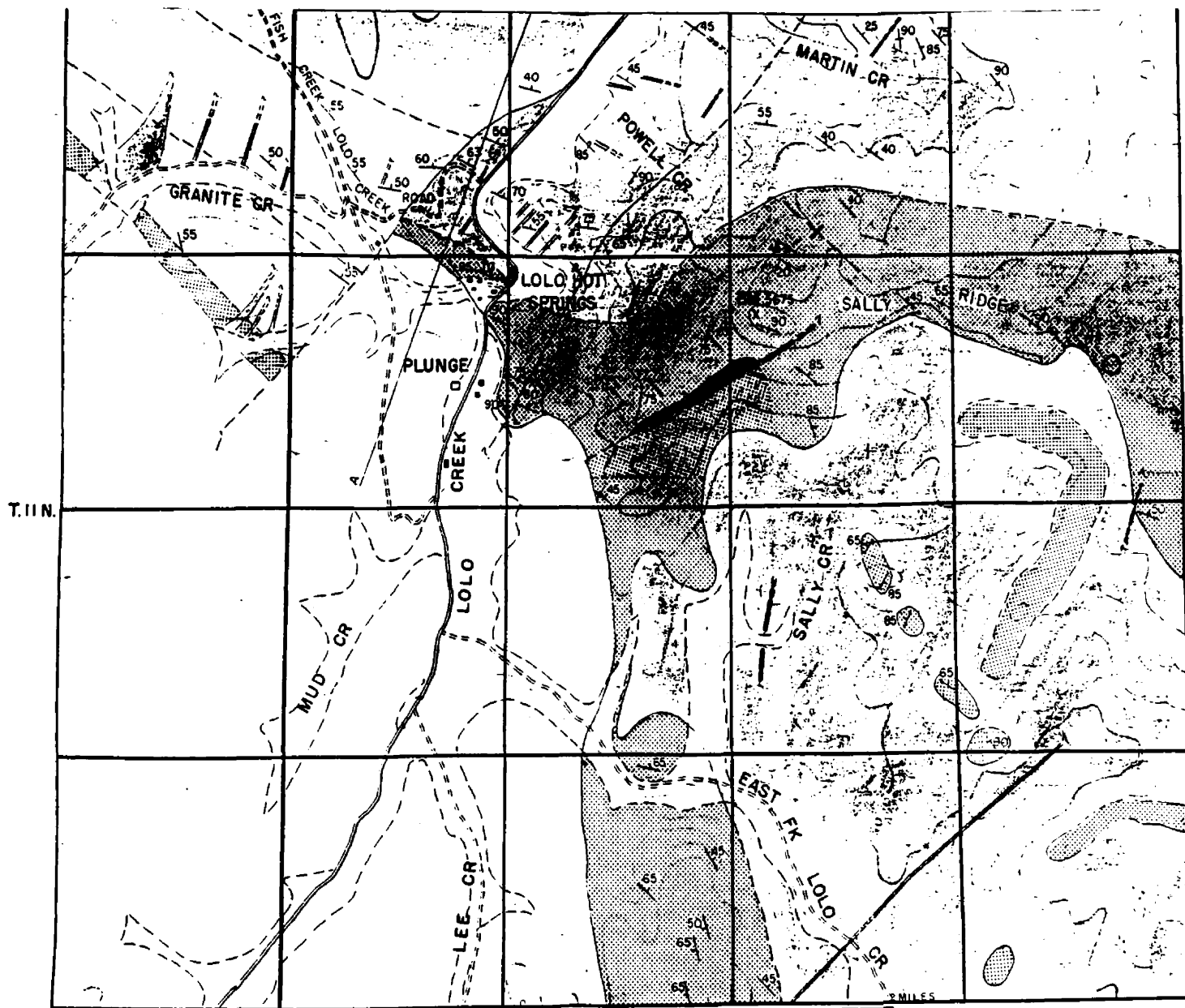
- Anderson, A. L., 1930, The Geology and Mineral Resources of the Region About Orofino, Idaho: Bureau of Mines and Geology Pamphlet 34.
- _____, 1940, Geology and Metaliferous Deposits of Kootenai County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 53.
- _____, 1952, Multiple Emplacement of the Idaho Batholith: Journal of Geology Vol. 60, p. 255-264.
- Anderson, R. E., 1959, Geology of the Eastern Portion of Bass Canyon, Bitterroot Range, Montana: Montana State Univ. Masters Thesis.
- Balk, R., 1937, Structural Behavior of Igneous Rocks: Geol. Soc. Am. Memoir 5.
- Barth, T. F., 1952, Theoretical Petrology: John Wiley & Sons Inc., New York.
- DeSitter, L. U., 1956, Structural Geology: McGraw-Hill Book Company Inc., New York.
- Emmons, R. C., 1953, Selected Petrogenic Relationships of Plagioclase: Geologic Society of America Memoir 52.
- Fyfe, W. S. and et al, 1958, Metamorphic Reactions and Metamorphic Facies: Geol. Soc. of Am. Memoir 73.
- Groff, S. L., 1954, Petrography of the Kootenai Creek Area, Bitterroot Range, Montana: Montana State University Masters Thesis.
- Heinrich, E. Wm., 1949, Pegmatites of Montana: Economic Geol. Bull. Vol. 44, pp. 307-335.
- Jahns, R. H., 1959, Personal Communication.
- Larsen, E. S. and et al, 1958 Lead-Alpha Ages of the Mesozoic Batholith of Western North America: Geol. Surv. Bull. 1070B.
- _____, and Schmidt, R. G., 1958, A Reconnaissance of the Idaho Batholith with the southern California Batholith: Geol. Surv. Bull. 1070A.

- Lindgren, W., 1904, A Geological Reconnaissance Across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: U. S. Geol. Surv. Professional Paper 27.
- Longwell, C. R., 1944, Tectonic Map of the United States: Am. Assoc. of Petroleum Geologists.
- Neuerburg, George J., 1958, Diagenetic Alteration of Some Aplite-Pegmatites of the Boulder Batholith, Montana and Its Possible Significance to Ore Deposition:
- Ransome, L. R., and Calkins, F. C., 1908, The Geology and Ore Deposits of the Coeur d'Alene District, Idaho: U. S. Geol. Surv. Paper 62.
- Ross, C. P. and Burke, H. W., 1947, Lolo Area, U. S. Geol. Survey Unpublished Map.
- Toler, L. G., 1959, Weathering of a Quartz Monzonite Near Lolo Hot Springs, Missoula County, Montana: Montana State Univ. Masters Thesis.
- Tuttle, O. F., and Bowen, N. L., 1958, Origin of Granite in the Light of Experimental Studies in the System $\text{NaAlSi}_3\text{O}_8 - \text{KAlSi}_3\text{O}_8 - \text{SiO}_2 - \text{H}_2\text{O}$: Geol. Soc. of Am. Memoir 74.
- Turner, F. J. and Verhoogen, J., 1951, Igneous and Metamorphic Petrology: McGraw-Hill Book Co., Inc., New York.
- Tyrrrell, G. W., 1926, The Principles of Petrology: E. P. Dutton and Co., Inc., New York.
- Wagner, W. R., 1949, The Geology of Part of the South Slope of the St. Joe Mountains, Shoshone County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 82.
- Wallace, R. E. and Hosterman, J. W., 1956, Reconnaissance Geology of Western Mineral County, Montana: Geol. Survey Bulletin 1027-M.

Additional Selected References

- Anderson, A. L., 1942 Endemorphism of the Idaho Batholith: Geol. Soc. America Bulletin Vol. 53, pp. 1099-1126.
- _____, 1948, Role of the Idaho Batholith During the Laramide Orogeny: Econ. Geol. Vol. 43, pp. 84-99.
- Billings, Harland P., 1942, Structural Geology: Prentice-Hall, Inc., New York.
- Clapp, C. H. and Deiss, C. F., 1931, Correlation of Montana Algonkian formations: Bull. Geol. Soc. America Vol. 42, pp. 673-696.
- Emmons, W. H., and Calkins, F. C., 1913, Geology and Ore Deposits, Philipsburg Quadrangle, Montana: U. S. Geol. Survey Prof. Paper 78.
- Langton, C. M., 1935, Geology of the northeastern part of the Idaho Batholith and adjacent region in Montana: Jour. Geology, Vol. 43, No. 1, pp. 27-60.
- Ross, C. P., 1950, The Eastern Front of the Bitterroot Range, Montana: U. S. Geol. Survey Bull. 974 E, pp. 135-175.
- Wahlstrom, Ernest E., 1955, Petrographic Mineralogy: John Wiley and Sons, Inc., New York.
- Weed, W. H. and Pirsson, L. V., 1896, Geology of the Castle Mountain Mining District, Montana: U. S. Geol. Survey Bull. 139, p. 58-95.

ORIGINAL COPY
CONTAINS FULL-SIZE
COLOR MAP IN BACK
POCKET. (LEGEND ON
REVERSE SIDE.)




CONTOUR INTERVAL 200 FEET
SCALE 1" = 2000'

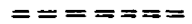
BASE MAP ENLARGED FROM
FOREST ATLAS, LOLO FOLIO,
MONTANA


BORDER ZONE PETROLOGY OF THE IDAHO BATHOLITH IN THE
VICINITY OF LOLO HOT SPRINGS,
MONTANA

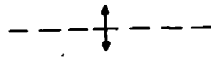
LEGEND


SYMBOLS

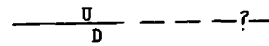

Lewis and Clark Highway

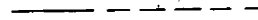

Gravel roads and logging trails



Bench Mark



Anticlinal Axis


Strike and Dip Symbol


Fault--dashed where approximately located and ? where questionable


Formational contact--dashed where approximate. All sedimentary contacts are arbitrary.


Stream


Intermittent Stream



Alluvium

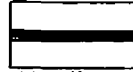


Quartz Monzonite



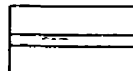
Dike

Granite Porphyry



Dikes

Qtz. Monzonite Porphyry



Dikes

Quartz Porphyry



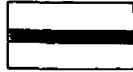
Dioritic Rocks

Dark fine grained diorite, medium to coarse grained diorite, diorite porphyry and quartz diorite



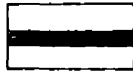
Dike

Qtz. Diorite Porphyry



Dikes

Fine Grained Diorite Porphyry



Dike

Hornblendite



Wallace Limestone

Light buff, limy, massive quartzites and interbedded blue-black argillites. Also brown argillites interbedded with grey quartzites



St. Regis

Massive light grey quartzites interbedded with impure purple and green quartzites or siliceous argillites



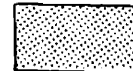
Revett

Massive light grey to almost white quartzites



Burke

Dark grey quartzites interbedded with finely laminated green siliceous argillites and fine grained quartzites



Metamorphosed Lower Belt

Siliceous hornfels containing some augite-epidote-plagioclase-biotite

Quartz Monzonite and Related Rocks

Diorite and Related Rocks

Precambrian limestone, quartzites and argillites of middle and lower Belt series

ORTH 1/21 0