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PETROLOGY AND ORIGIN OF PRECAMBRIAN METAMORPHIC ROCKS IN THE EASTERN RUBY MOUNTAINS SOUTHWESTERN MONTANA

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PETROLOGY AND ORIGIN OF PRECAMBRIAN METAMORPHIC ROCKS IN THE EASTERN RUBY MOUNTAINS, SOUTHNESTERN MONTANA

by

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ABSTRACT

Precambrian schists and gneisses are exposed in much of the Ruby Mountains of southwestern Montana. The major rock types include abundant quartz-feldspar gneiss, hornblende gneiss, amphibolite. quartzitic gneiss, and marble. Minor rock types important in the study area include anthophyllite gneiss, hornblende-pyroxene-plagioclase gneiss, quartz-hypersthene-garnet granulite, iron-formation, and hornblende-hypersthene granulite. These rocks form a concordant series folded into a broad, open antiform-synform pair in the study area.

The marble, quartzitic gneiss and iron-formation in the area clearly originated as sedimentary units. The hornblende gneiss assemblage was also found to be dominantly sedimentary in origin. Evidence for this includes its association with marble and quartzitic gneiss, the latter intimately mixed within it, the presence of meta-conglomerates, and the abundance of quartz making the composition distinctly different from normal igneous rocks. A petrographic estimate of composition for one amphibolite showed it to most resemble a dolomitic shale. It is possible that some amphibolites in the area are metamorphosed dikes and sills. The uniform granitic composition and lack of structures in the quartz-feldspar gneiss suggest an igneous origin for this unit.

Metamorphism in the area exceeded the sillimanite-orthoclase zone of the amphibolite facies as indicated by the presence of sillimanite, perthite, and calcic plagioclase An42. The presence of the assemblage quartz-hypersthene-garnet, and textures indicating the reaction anthophyllite ↔ enstatite + quartz show that conditions ran locally into the orthopyroxene zone of the granulite facies. These probably represent areas locally undersaturated in water.

The area went through two phases of regional deformation. The first event, roughly contemporaneous with the highest metamorphic grades, produced similar-style, tight isoclinal folds and the regional foliation. Subsequent to that, the area was folded into a large, concentric, open antiform-synform pair trending northeasterly and plunging at moderate to steep angles. Small super-imposed folds of undetermined age relationship to the second event also exist.

ACKNOWLEDGMENTS

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TABLE OF CONTENTS

LIST OF TABLES

KJS

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Pre-beltian rocks underlie much of the Ruby Range of southwestern Montana. They include hornblende gneisses, amphibolites, mica schists, quartzites, marbles and quartz-feldspar gneisses. Marbles and quartzites clearly represent metasediments. Bielak (1978) has shown that hornblende gneisses and amphibolites in the region are separable into distinct metasedimentary and metaigneous units respectively. The Dillon Gneiss unit has so far resisted the clear designation as metaigneous or metasedimentary. Although it was originally mapped as a "granite gneiss" by Heinrich (1953), recent investigations have called that interpretation into question. Garihan (1973 and 1974), and Garihan and Williams (1976) have postulated a mudstone or shale rich in illite and quartz as a possible sedimentary parent. In each case though, lack of hard evidence prevents any final conclusion. The resolution of this problem is important before a reasonable pre-metamorphic history can be postulated.

The purpose of this study was to map a portion of the contact between the Dillon Gneiss and overlying metasedimentary units. By determining through field relationships and petrographic analysis the original nature of the Dillon Gneiss, I could go on to suggest a premetamorphic depositional environment that resulted in the present rock assemblage. Another purpose of this study was to determine the metamorphic and deformational history of the area. The study area was chosen for its lack of retrograde effects and interesting structure. Well developed retrograde effects would tend to mask prograde mineralogy and equilibrium textures essential to determining the highest temperature and pressure conditions reached.

Location

The Ruby Range lies east of Dillon along the Beaverhead-Madison County line in southwestern Montana (Fig. 1). The Hinch Creek map area covers about 18 square kilometers on the eastern edge of the range. The Ruby River and the range front bound the area on the east. Vertical faults bringing the basement against Paleozoic sedimentary rocks bound the area on the west. The area includes portions of the Alder, Laurin Canyon, Metzel Ranch, and Ruby Dam 7 1/2-minute quadrangles.

Physiography

The area has been uplifted to elevations approaching 2135 meters by differential movement on range-bounding vertical faults. Activity on the faults dates from the Eocene or Oligocene until the present time (Garihan, 1973). Gently rolling upland surfaces cut by deep drainages characterize the area. Sage and grass cover most of the surface but groups of juniper and pine are scattered about, especially on north facing slopes. Greasewood chokes the upper portions of many gullies. Major drainages include Hinch Creek, Dry Hollow, and Beatch Canyon. They all flow northeastward normal to the range front. Hinch Creek has an elevation of 1615 meters at its exit from the range giving a total relief in the area of 520 meters.

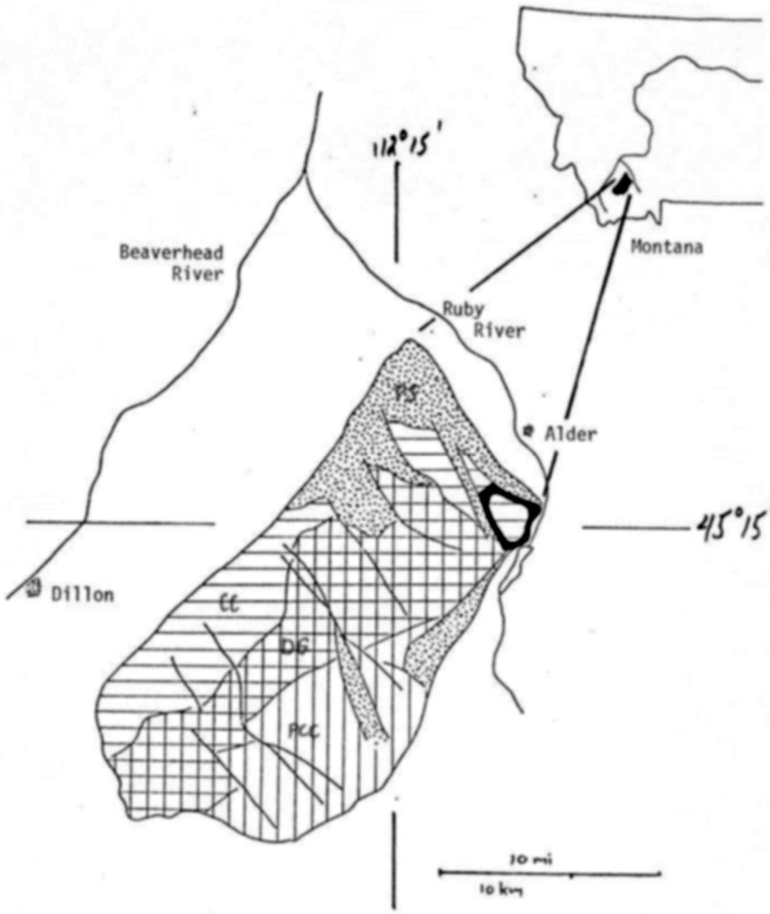

Figure 1. Schematic index map of the Ruby Mountains showing the Pre-Cherry Creek (PCC), Dillon Gneiss (DG), Cherry Creek (CC) units and overlaying Paleozoic sediments (PS) with the Northwest-trending faults. The heavy outline indicates the study area.

Previous Studies

Earliest descriptions of the region were made by Hayden (1872) who noted excellent exposures of banded gneiss, hornblende gneiss, and veins of feldspar and quartz. Peale (1896) described the rocks along Cherry Creek in the Gravelly Mountains. Equivalents of the Cherry Creek Group form much of the basement along the northwest flank of the Ruby Range.

Winchell studied the Crystal Graphite deposits near Dillon in 1911. In 1914 he published a general survey of the important mining districts of the Dillon one degree quadrangle. Klepper (1951) described the southern Ruby Range in a general reconnaissance of southwestern Montana The first detailed studies of the Ruby Mountains were made by Heinrich (1948, 1949a, 1949b, 1950, 1960, and 1963).

Recent studies in the range include the following: Tysdal (1970) mapped the Paleozoic section in the northern Ruby Range; Okuma (1971) studied the petrology and structural geology in relation to talc deposits in the southern Ruby Range; Garihan (1973, 1974, 1976a, and 1976b) studied the structure, petrology, and talc deposits of the central Ruby Range; Dahl (1978) determined metamorphic conditions using electron microprobe geothermometry and geobarometry; Desmarais (1978) studied the origin of the ultramafic bodies; Bielak (1978) examined the origin of amphibolites. Wooden (1973), Giletti (1966), and James and Hedge (1980) have obtained radiometric dates of rocks from the Ruby Range.

Included in the area of this study is some mapping done by James and Hier (1960) of the Kelly iron deposit, and Berg (1976) of the portion between Hinch Creek and the Ruby Reservoir. All previous mapping in the present area was reviewed in the field for this study.

CHAPTER II

METAHORPHIC ROCKS

General Statement

The Ruby Range is a block of basement rock uplifted since Eocene or Oligocene time. The range core contains crystalline schists and gneisses unconformably overlain at the northern end by Paleozoic sediments (Fig. 1). The crystalline complex consists of broad belts of different rock types that parallel the northeast trend of the range. From northwest to southeast they are grouped into three units: 1) the "Cherry Creek" Group, 2) the "Dillon Granite Gneiss", and 3) the "Pre-Cherry Creek" rocks (Heinrich, 1960). The regional foliation strikes northeast parallel to the units and dips northwest placing the Cherry Creek Group highest structurally. The uppermost part of the Cherry Creek is not exposed in the Ruby Range (Garihan, 1973).

Cherry Creek.

The Cherry Creek group occupies the northwest side of the range and contains several different rock types. Peale first described it near Ennis, Montana in 1896. It crops out regionally in the Gravelly, Madison, Tobacco Root, Greenhorn, and Ruby Ranges. The presence of marble distinguishes it from other similar units. The various rock types of the Cherry Creek Group include:

1) marble

2) calc-silicate schist

3) quartzite

4) hornblende gneiss and amphibolite

5) quartzofeldspathic gneiss

6) sillimanite schist

7) biotite schist and gneiss

8) chlorite schist

9) iron formation

Dillon Gneiss.

The Dillon Gneiss commonly contains elongate stringers of quartz, perthitic microcline, and plagioclase imparting a conspicuous banding to the rock. It forms a sheet-like mass of quartz-feldspar and biotite-quartz-feldspar gneiss separating the Cherry Creek from the Pre-Cherry Creek units. Heinrich (1960) originally named it the "Dillon Granite Gneiss". Garihan and Williams (1976) have proposed renaming it the "Dillon Gneiss" because the igneous nature of the unit is not firmly established.

Pre-Cherry Creek.
The Pre-Cherry Creek rocks crop out along the southeast side of the range. Heinrich (1960) used the name to distinguish these from the marble bearing Cherry Creek unit to the north-west. The various rocks are mostly gneissic, coarse grained. migmatitic and discontinuous along strike. The main rock types include:

1) quartz-feldspar gneiss

2) biotite-garnet-quartz-feldspar gneiss

3) biotite-garnet gneiss

4) hornblende-quartz-feldspar gneiss

5) hornblende gneiss and amphibolite

Field Description and Petrography:

The field work for this study took place during parts of the summers of 1978, and 1979. Petrographic study of thin-sections was made from representative samples. Rock slabs and chips were etched in hydrofluoric acid and stained with sodium cobaltanitrite as an aid in distinguishing and estimating feldspar percentages. Marbles were stained with Alizarine Red S to distinguish calcite from dolomite (Friedman, 1959). Anorthite content was determined with the bisectrix method in combination with extinction angles on cleavage fragments immersed in oils.

Marble.
Marbles in the Hinch Creek area form resistant marker beds. They form rounded outcrops easily recognized by their characteristic tan to grey-weathered surface commonly covered by orange lichen.

Mappable units range from 4 to over 500 meters thick. The width of beds varies along strike. Unrecognized folding or plastic flowage causes much of the thickness variations and makes it impossible to measure true thickness. In the southeast corner of section 32, beds of marble as thin as 0.5 meters interbed with hornblende gneiss and quartz-feldspar gneiss.

The layering in much of the marble ranges from 5 centimeters to over a meter in thickness. Differential weathering along the parting surfaces defines most of the layering, especially in pure marbles. In quartz bearing varieties, beds and stringers of quartz up to 20 meters thick also define the layering. Bedding everywhere parallels the foliation. Compositional differences, the presence of concordant quartzite beds, and interlayering with quartz-feldspar gneiss and hornblende gneiss on a small scale indicate that the compositional layering represents original sedimentary bedding. In some massive marbles the quartz lenses and beds 2-20 millimeters thick are isoclinally folded and broken (Fig. 2). The marble flowed plastically during deformation while the more competent quartz beds folded and broke. Bedding in the marble generally persists along strike, but on the noses of some folds it stretches and pinches out into lenses best observed in the Hinch Creek valley about 2 kilometers from the range front.

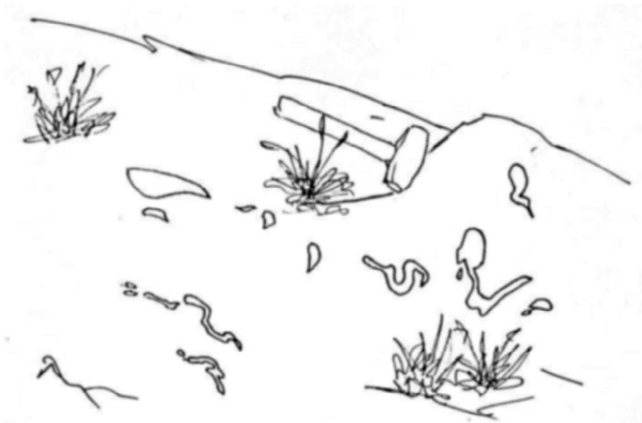

Figure 2. Fo1ded and broken lenses of quartz within fine-grained structureless marble. The head of the hammer is approximately 10 cm long.

Coarse grained dolomitic marble predominates in the area with grain sizes ranging from 0.l to 5 millimeters. Compositions include pure dolomite marble and quartz-bearing calcite marble containing up to 15% quartz. Quartz grains show strain shadows and some subgrain development. Some contain rounded inclusions of calcite and/or microcline. Accessory minerals include muscovite, microcline, and hematite. Calc-silicate marbles contain calcite, dolomite, diopside, serpentine, phlogopite, graphite, and garnet (Fig. 3).

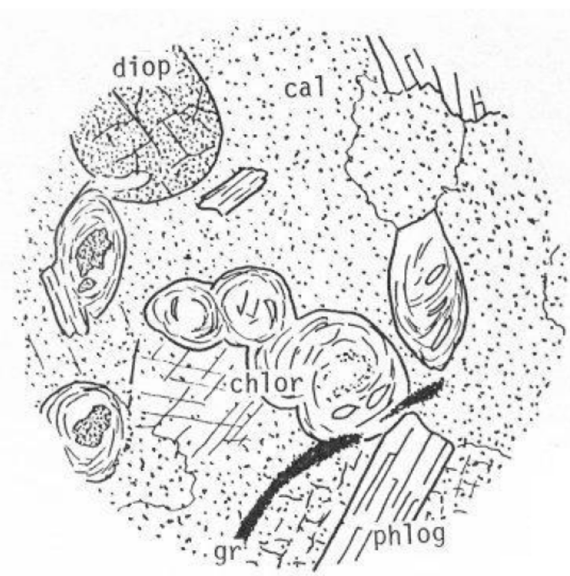

Figure 3. 1MT22. Calc-silicate marble showing diopside, relict grossular garnet altering to chlorite, phlogopite mica, graphite and dolomite.

The unit apparently originated as beds of limestone with local thin beds of quartz. In several locations undeformed layers of quartz were found within it but for the most part deformation and recrystallization destroyed the primary sedimentary structures leaving the grey massive marble as it now exists.

Tremolite rock.

The rock is a mass of ragged tremolite crystals 3 to 5 mm long (Fig. 4). Crystals up to 15 mm exist in places. Tremolite has difficulty in nucleating and commonly forms as coarse-grained, unoriented crystals. Calc-silicates normally lack preferred orientations and may differentiate into monomineralic masses at high grades of regional metamorphism (Spry, 1969).

In outcrop the rock forms a low, massive, and very resistant bed or lens. It is discontinuous along strike and weathers tan to brown, brown on a fresh surface. It is most likely genetically related to the adjacent marble unit.

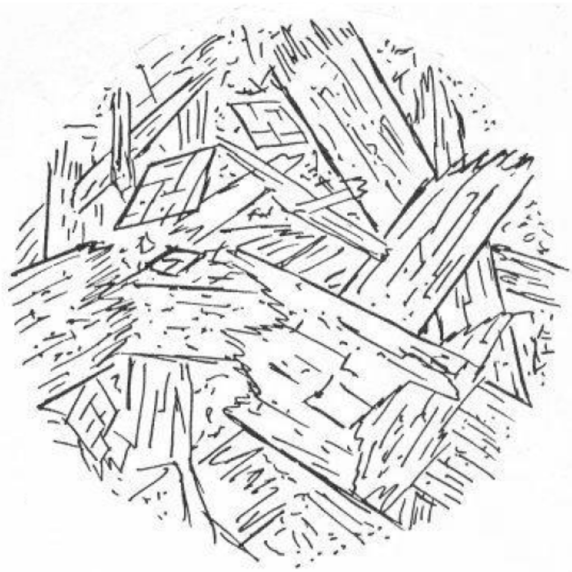

Figure 4. 1MT21B. Randomly oriented grains of tremolite.

Quartz-feldspar gneiss.

Quartz-feldspar gneiss occurs most commonly as a conspicuously foliated or banded rock with a distinctive orange-pink color on the weathered surface. Bands of elongate quartz and feldspar define the foliation. Where present, biotite is disseminated or, more commonly, concentrated in bands a few millimeters to many centimeters thick. Biotite parallels the foliation and helps define it. Biotite-quartz-feldspar gneiss is less common and on the average more calcic than "normal" quartz-feldspar gneiss.

The gneiss in the center of the antiform (see map), contains a few beds of hornblende gneiss concordant to the foliation. In general, it has uniform composition and color except near the hornblende gneiss contact. The two units become interlayered at the contacts. The southeastern body of gneiss varies in color from gray to orange-pink and contains abundant biotite in some exposures and none in others. It contains numerous, scattered, and concordant beds of hornblende gneiss and amphibolite from 0.5 to 10 meters thick which cannot be followed along strike due to poor exposure.

Severely deformed migmatites crop out locally and augen gneiss is fairly common throughout. Augen range from 0.5 to 5 centimeters. Porphyroblasts of garnet from 0.2 to 2 centimeters form a spotted appearance in many outcrops. Garnets are disseminated or form concentrations in either the quartzofeldspathic or more commonly in the biotite-rich layers.

Structurally these gneisses form the lowermost unit in the area. They occupy the center of the antiform and the edge of the synform. The foliation everywhere parallels the contacts with marble or hornblende gneiss. The gneiss makes sharp contacts with the marble, but it grades into, and interbeds with the hornblende gneiss. Gradation consists of increasing amounts of mafic minerals, especially hornblende and biotite with conspicuous light and dark layers. Hornblende, where present, generally appears in quantities of 10% or more and is used as the basis for distinguishing hornblende gneiss from quartz-feldspar gneiss.

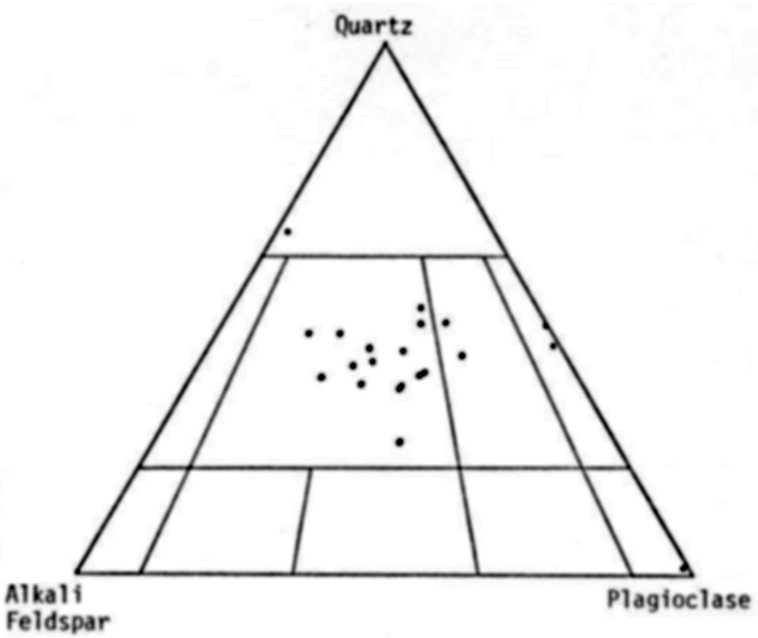

Figure 5. Modal compositions of quartz-feldspar gneiss plotted on an I.U.G.S. quartz, alkali feldspar, plagioclase variation diagram (from Streckeisen, 1973).

Compositions of the unit concentrate near the center of a quartz-plagioclase-alkali feldspar variation diagram (Fig. 5). They show some variation in composition across the diagram, ranging from quartz-plagioclase to quartz-plagioclase-microcline gneisses. Assuming isochemical metamorphism, this indicates a fairly homogenous unit with the average bulk composition of granite.

Table 1. Modal analyses of quartz-feldspar gneiss
Volume % visually estimated from thin section

Sample #	07	11	12	18b	16	27c	13a	02	14	18a	05a	32
Quartz	45	45	50	45	45	39	37	35	35	35	25	25
Microcline	40	35	5	16	20	35	30	30	35	28	35	10
Plagioclase	15	19	45	31	29	24	20	34	27	35	22	34
Sericite	tr	tr	--	4	2	1	6	1	--	--	17	25
Garnet	tr	--	tr	4	3	--	7	1	3	tr	1	--
Biotite	--	tr	--	tr	tr	1	--	--	tr	2	tr	3
Muscovite	--	--	tr	--	tr	tr	tr	--	--	--	--	1
Hematite	tr	1	--	tr	tr	tr	--	tr	tr	--	--	--
Magnetite	--	--	--	--	--	--	tr	--	--	--	--	--
Apatite	--	--	--	--	--	--	tr	--	tr	tr	--	tr
Chlorite	--	--	--	tr	tr	--	--	--	tr	--	--	2
Hornblende	--	--	--	--	--	--	tr	--	--	--	--	--
Rutile	--	--	--	--	tr	tr	--	--	--	--	--	--
Sillimanite	--	--	--	--	--	--	--	--	--	--	--	--
Zircon	--	--	--	tr	tr	--	tr	tr	tr	--	--	--

Table1 . Continued
Modal analyses of biotite-quartz-feldspar gneiss

Sample #	17	01	77	28a	27b	27j	27g	03	04	05c
Quartz	40	40	35	36	36	40	36	30	35	1
Microcline	24	30	25	23	14	15	19	1	--	tr
Plagioclase	30	14	35	25	33	24	1	39	36	67
Sericite	--	11	--	10	4	1	--	--	4	8
Garnet	1	tr	--	--	tr	7	24	10	5	1
Biotite	5	5	5	6	13	13	17	20	20	20
Muscovite	--	--	--	1	--	--	tr	--	tr	--
Hematite	--	--	--	--	--	--	tr	tr	--	tr
Magnetite	--	--	--	--	--	--	--	--	tr	--
Apatite	tr	tr	tr	--	tr	--	--	--	--	tr
Chlorite	--	--	--	tr	--	--	tr	--	tr	3
Rutile	--	--	tr	--	--	--	--	--	--	--
Sillimanite	--	--	--	--	--	--	3	--	--	--
Zircon	tr	tr	--	tr	--	tr	tr	tr	tr	tr

Quartz ranges from one fourth to one half of the rock (Table 1). Except for augen, it usually forms the largest grains but sizes are seriate from 5 millimeters down to very fine. Crystals normally are elongate and strained. They have irregular and amoeboid shapes with lobes growing into and enveloping adjacent minerals. In some cases this leaves relict inclusions within the quartz (Figs. 6 & 7).

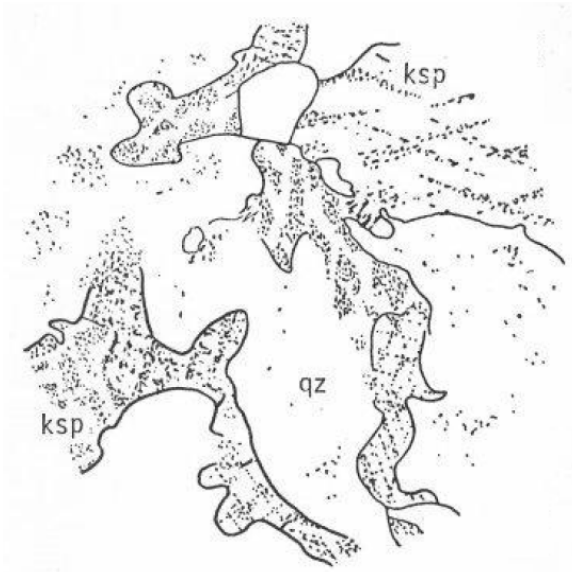

Figure 6. 1MT13A. Large ameboidal grains of quartz embaying smaller grains of microcline.

Figure 7. 1MT13F. Ameboidal quartz grains embaying microcline and hornblende.

Potassium feldspar normally forms about one third of the rock with microcline the dominant variety. Shapes vary from minor elongate to equigranular grains, some with 120° triple junctions. Some specimens show strong development of ribbon and patchy microperthite. The albite in many cases has exolved to the edge of the grain

(Fig. 8). Microcline augen grow to as large as 3 centimeters. Plagioclase, An27-33, ranges from minor amounts up to two thirds of the rock. Minor to almost complete sericite alteration exists in the mineral, but is normally less than 10%. Many plagioclase grains have a zoned edge adjacent to microcline which the sericite nowhere invades. Twinning is present but not abundant.

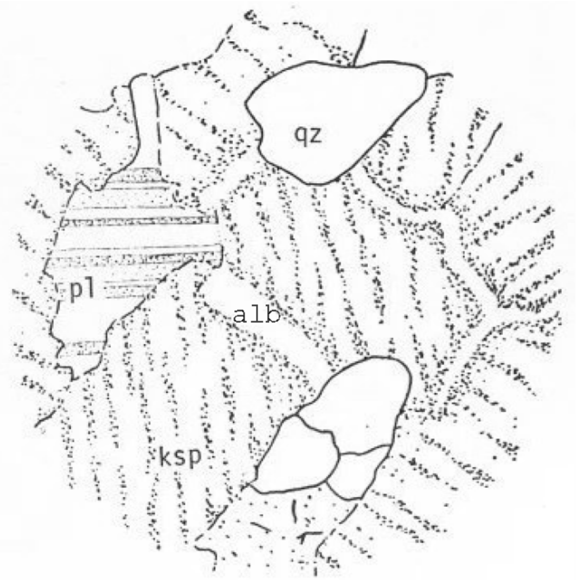

Figure 8. 1MT13D. Quartz-feldspar gneiss. Large perthite grains with albite exolved to the edges.

Biotite grains characteristically define the foliation, but-in some cases show no preferred orientation. Pink almandine garnet ranges up to one fifth of the rock, occurring as anhedral to euhedral, fractured poikioblasts (Fig. 9). It forms compositional layers usually associating with biotite layers.

Accessory sillimanite occurs in one thin-section (279), as euhedral end-sections associated with the garnet-biotite layer (Fig. 10). In hand specimen sillimanite occurs as parallel blades up to 5 millimeters long associated with biotite and radiating blades growing on the foliation surface which apparently shows that they grew during or after formation of the foliation. Other accessory minerals include rounded zircon, apatite, hematite, chlorite altering from biotite, magnetite, and rutile.

The origin of the quartz-feldspar gneiss presents a special problem. Throughout most of the Ruby Range, no firm evidence has been found to indicate an igneous or sedimentary parent. The contacts between the gneiss and adjacent rocks, especially marble, lack cross-cutting relationships. Garihan and Williams (1976) suggested a sedimentary parent of a mudstone or a shale rich in illite and quartz to explain the granitic composition.

Figure 9. 1MT01. Texture in garnet-biotite-quartz feldspar gneiss showing suboriented grains of biotite and broken grains of garnet.

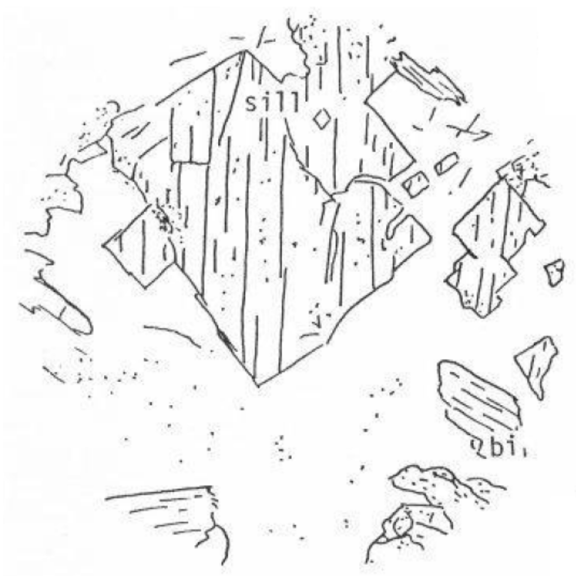

Figure 10. 1MT27G. High magnification view of sillimanite end-sections forming a lineation in the sample.

The quartz-feldspar gneiss/marble contact in the study area also shows no cross-cutting relationships. The two become interbedded in the south-central part of the area. This could result from either interbedding of original sediments or rhyolite volcanics, intrusion of granite sills into the marble, or isoclinal folding. Synkinimatic intrusion in the catazone takes place with minor disturbance of the wall rock (Buddington, 1959).

The granitic composition of the unit argues in favor of a plutonic origin. The Dillon Gneiss is an extensive unit in the Ruby Range. It would take a very thick pile of sediments to form the gneiss. It is structureless and compositionally uniform. No compositional layering was found, no lenses or beds of conglomerate could be located. Metaconglomerates were found in some hornblende gneiss units showing their ability to survive the metamorphism (Fig. 11). No primary sedimentary structures have been found in the gneiss even after many regional and detailed studies in the Ruby Range. Because of this, I feel that a plutonic origin is the most permissible conclusion.

Figure 11. Metaconglomerate within hornblende gneiss. Exposure is too poor to determine the original attitude and position of sedimentary layer. Pebbles are quartz.

Hornblende-gneiss assemblage.

Structurally, the hornblende-gneiss unit sits just above the marble and grades "upsection" into quartzitic gneiss and biotite-quartz-feldspar gneiss. In the northwest corner of the map area the unit becomes very thick and contains the Kelly Iron Formation mapped in detail by James and Wier (1960). Quartzitic gneiss beds occur both in the hornblende gneiss and marble units.

The assemblage forms abrupt contacts with the marble but grade concordantly into the quartz-feldspar gneiss. Near the "contact" the volume of microcline in the rock is much greater than in the rest of the assemblage. The presence of hornblende defines the unit although there exist several minor related rock types within it. Because of their variety and distinctiveness, they are described separately in this section.

Hornblende gneiss and amphibolite.

This dominant rock type of the assemblage normally crops out as a medium grained banded gneiss. Massive “salt and pepper" amphibolite beds are made up almost entirely of hornblende and plagioclase. These crop out within the lower part of the assemblage and locally within the quartz-feldspar gneiss unit. Grain sizes range from 0.1 to 5 millimeters with 1 or 2 millimeters most common. Layers consist of dark hornblende-rich and light quartzofeldspathic lithologies from a few millimeters to over a meter thick. Garnets in some cases concentrate in mafic layers. The unit forms poor outcrops that are best exposed in gullies or ridges. The layers are compositionally distinct parallel to the foliation. In places they are isoclinally folded with an amplitude ranging from 2 to 50 meters (Fig. 12). This is best observed on the north side of Hinch Creek in section 32. Foliation passes through the noses of the folds. Folding within the unit makes the original thicknesses of beds impossible to determine. Metaconglomerates are noted in several locations within hornblende gneiss units (Fig. 11).

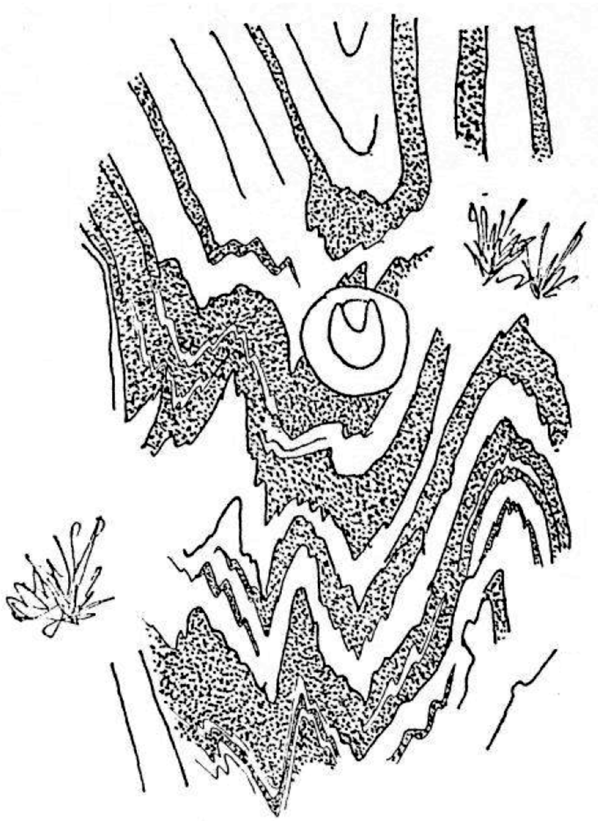

Figure 12. Isoclinal folding in interlayered hornblende and quartz-feldspar gneiss. The fo1ding is not apparent on the vertical portion of the outcrop (the top of the figure). The brim of the hat is approximately 35cm wide.

Hornblende content ranges from minor amounts to nearly one half of the gneiss and 60% in amphibolite (Table 2 and Fig. 13). Anhedral to euhedral crystals define the foliation and in some cases a lineation The crystals commonly contain inclusions of biotite or rounded quartz. Crystals show brown to dark green pleochroism except in amphibolite sample 34 where it is blue-green to green near garnet. This suggests decreased availability of ferrous iron near the iron-rich garnet. In hornblende this lightens the pleochroism from dark olive-green and brown to light shades of blue~green and green (Troger, 1979). Hornblende also appears to be altering to diopside in some rocks as evidenced by diopside crystals with hornblende cores.

Table 2. Modal analyses of hornblende gneiss and amphibolite
Volume % visually estimated in thin-section

Sample #	13d	13b	13f	9	30a	13e	19a	30c	31	06*	34
Hornblende	10	10	17	71	20	20	18	30	40	62.0	60
Quartz	30	34	40	14	30	30	35	27	20	9.7	--
Microcline	25	25	13	--	--	30	--	5	--	--	--
Plagioclase	35	30	30	35	35	20	29	20	38	25.7	25
Sericite	tr	tr	tr	3	tr	--	1	tr	tr	tr	10
Biotite	tr	tr	tr	--	7	tr	2	10	tr	--	tr
Garnet	--	1	--	12	8	--	10	8	2	0.9	3
Diopside	--	--	--	18	--	--	5	--	tr	--	1
Apatite	tr	tr	tr	tr	tr	--	tr	tr	tr	tr	tr
Zircon	tr	tr	tr	--	--	--	tr	tr	--	--	--
Rutile	tr	--	tr	--	--	--	--	--	--	--	--
Magnetite	--	--	tr	1	--	--	tr	--	tr	1.5	tr
Hematite	--	--	--	--	tr	--	--	tr	--	--	--
Epidote	--	--	--	--	--	--	--	--	--	--	1

*Thin-section count of 534 points

Figure 13. 1MT06. Texture in amphibolite section 06 showing hornblende plus plagioclase.

Plagioclase is more calcic in the gneiss at An42. The anhedral to subhedral grains show minor sericitization, but sericite may replace up to one third of the plagioclase. Near microcline, the plagioclase rims are zoned and the sericite does not invade these rims. In one amphibolite, recrystallized plagioclase grains have common 120° grain junctions.

Quartz is an important, although variable constituent in the gneiss, but minor in the amphibolite. Grains have strain shadows, with elongate to equigranular shapes. The grains become larger on the average and more ameboidal with increasing quartzofeldspathic content of the rock. Garnet is minor but generally present in the rock. Porphyroblasts often contain inclusions of quartz, plagioclase, and in some cases hornblende. Garnets are commonly fractured and broken. The fragments spread out along the foliation and long dimensions lie parallel to it. Foliation wraps around the porphyroblasts in some samples. As in the quartz-feldspar gneiss, garnets sometimes show disequilibrium textures with biotite (Fig. 14). Symplektite on garnet was noted in sample 19a (Fig. 15). In some samples equilibrium textures exist between the two.

Figure 14. 1MT04. Disequilibrium textures between garnet and biotite. They are separated by a plagioclase rim.

Biotite ranges up to 10% but rarely amounts to more than one percent. It generally grows parallel to foliation, but may show no preferred orientation (Fig. 16). In some rocks it shows disequilibrium textures such as those with garnet described above. It may also have a ragged, splintery appearance and wormy intergrowths of quartz or plagioclase.

Perthitic microcline is normally absent in the rock, but may become important near contacts with quartz-feldspar gneiss. Diopside is important in some samples as described above under hornblende. Other accessory minerals include apatite, rounded zircon, minor rutile, magnetite, hematite, and in one sample, secondary epidote.

Figure 15. 1MT19A. Symplektite on garnet in the presence of biotite. Garnet plus hornblende show equilibrium textures elsewhere in the section.

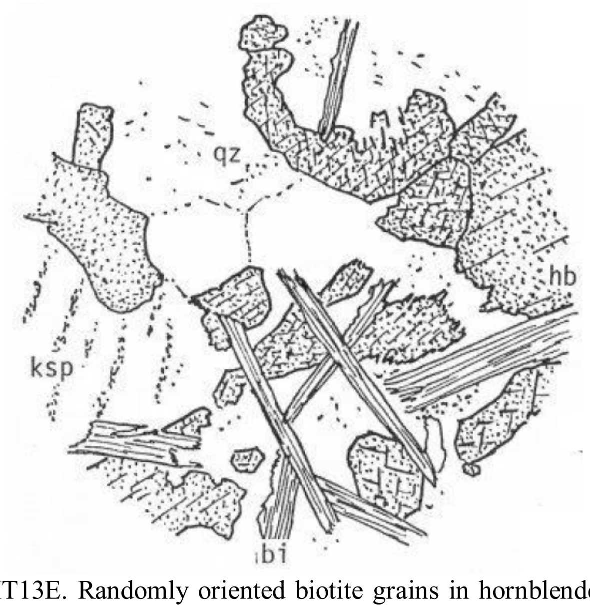

Figure 16. 1MT13E. Randomly oriented biotite grains in hornblende gneiss. Note the perthite grain which is present in samples taken near the contacts with quartz-feldspar gneiss.

The hornblende gneiss beds vary greatly in mineralogy and texture, and generally contain abundant quartz (Table 2). The beds are compositionally layered and grade into other units. Because of the textural and mineralogical variations and concordant beds grading into other units, I conclude that they are derived from a calcareous shale. A shaley limestone derivative would contain less quartz. The large amount of quartz eliminates the possibility of metamorphosed basalts because the composition departs too radically from a natural basalt.

Amphibolites in the study area are more basic in composition than the hornblende gneiss, but they are not necessarily metamorphosed basic volcanics. A petrographic estimate of the composition of sample 06 shows it to resemble most closely a dolomitic shale (Table 3). Bielak (1978) found that amphibolites in the Winnipeg Creek area could be separated into both meta-sedimentary and meta-basalt units. This is most likely the case in the Hinch Creek area as well. Many amphibolite units have massive, uniform textures whereas the hornblende gneiss is generally streaky, quartz bearing, and in places conglomeratic. The entire assemblage consisted of minor basic volcanics interbedded with calcareous shales. Volcanics could have formed at the same time as deposition or intruded later as sills. The assemblage was then subjected to upper amphibolite-facies metamorphism.

Table 3.

	1	2	3	4	5
SiO_2	55.9	55.43	55.4	58.17	50.7
TiO_2	0.2	0.46	0.5	0.80	2.0
Al_2O_3	12.7	13.84	13.8	17.26	14.4
Fe_2O_3	2.0	4.00	4.0	3.07	3.2
FeO	5.0	1.74	1.7	4.18	9.8
MnO	0.2	tr	---	---	0.2
MgO	9.9	2.67	7.7	3.24	6.2
CaO	10.1	5.96	11.0	6.93	9.4
Na_2O	2.3	1.80	1.8	3.21	2.6
K_2O	0.3	2.67	2.7	1.61	1.0
H_2O	1.0	5.56	1.2	---	---
P_2O_5	0.1	0.2	0.2	0.21	---
Other	---	6.15	---	---	---

1. Oxide approximation of modal amphibolite (this study)
2. Average shale (Clarke, 1924, page 552)
3. Average shale from 2 recalculated with one part in six pure dolomite, results after removal of volatile constituents and renormalization to 100%
4. Average andesite (Hyndman, 1972, page 166)
5. Average continental tholeiite (Hyndman, 1972, page 171)

Table 4 provides modal analyses for the minor lithologies encountered in the study area, discussed next.

Table 4. Modal analyses of minor lithologies
Volume % visually estimated in thin section

Sample #*	21b	3xa	15b	08	30f	38	37a	42	10	05b	33	28b	36
Quartz	--	25	--	5	29	35	15	--	--	70	94	20	20
Microcline	--	--	--	--	--	--	40	--	--	1	--	79	75
Plagioclase	--	--	46	45	--	--	--	--	--	24	5	1	5
Garnet	--	10	5	2	34	42	--	--	--	--	tr	--	--
Biotite	--	tr	--	5	--	--	tr	--	--	--	tr	tr	--
Anthophyllite	--	55	--	--	--	--	--	--	--	--	--	--	--
Hornblende	--	--	28	7	--	--	--	50	58	--	--	--	--
Tremolite	100	--	--	--	--	--	--	--	--	--	--	--	--
Diopside	--	--	13	25	--	--	--	--	--	--	--	--	--
Hypersthene	--	--	8	11	37	17	--	50	35	--	--	--	--
Enstatite	--	10	--	--	--	--	--	--	--	--	--	--	--
Graphite	--	--	--	--	--	--	15	--	--	--	--	--	--
Spinel	--	--	--	--	--	--	--	7	--	--	--	--	--
Sericite	--	--	tr	--	--	--	10	--	--	--	--	--	--
Fe Oxides	tr	--	tr	1	tr	6	5	tr	tr	tr	--	--	--
Apatite	--	--	tr	--	--	--	--	--	--	--	--	--	--
Rutile	--	tr	--	--	--	--	--	--	--	--	tr	--	--
Serpentine	--	--	--	--	--	--	--	tr	--	--	--	--	--
Muscovite	--	--	--	--	--	--	--	--	--	5	tr	--	tr

*21b. tremolite rock
3xa. garnet-enstatite-quartz-anthophyllite gneiss
15b & 08. hornblende-pyroxene-plagioclase gneiss
30f & 38. quartz-hypersthene-garnet granulite
37a. graphite gneiss
42 & 10. hornblende-hypersthene granulite
05b & 33. quartzitic gneiss
28b & 36. pegmatite

Garnet-enstatite-quartz-anthophyllite gneiss.
This bed crops out as a dark purplish-brown rock with foliation defined by oriented anthophyllite grains. Hornblende gneiss concordantly surrounds the bed. It is very hard and resistant to weathering and therefore caps the ridge where it crops out. This rock type was found only once in the study area.

Parallel anthophyllite grains dominate the mineralogy. Growing in the anthophyllite are skeletal enstatite crystals with quartz inclusions (Fig. 17). This texture suggests the reaction:

Anthophyllite ↔ 7 Enstatite + Quartz + H2O (Winkler, 1974)

Anthophyllite reacts at nearly 800°C over most pressures under condition; of PH2O equals Pload. Because the prograde reaction yields water, it would be favored where PH2O is less than Pload and would react at lower temperatures.

Sieve textured garnets are an important part of the rock. Inclusions in them weakly to strongly parallel the foliation with no evidence of rotation. The porphyroblasts are irregular in outline and elongate parallel to the foliation. Cordierite is absent. Rabbit (1948, p. 314) lists an anthophyllite gneiss from the "Ruby Dam area" which also has no cordierite. I believe it is from the same outcrop as I know of no other in the vicinity. Accessory minerals include biotite and rutile.

Figure 17. 1MT3XA. Skeletal enstatite growing on anthophyllite from the anthophyllite gneiss sample 3xa

Hornblende-pyroxene-plagioclase granulite.
This rock type crops out in two places about one kilometer apart. Sample 15b was collected from a bed about a meter thick within the quartz-feldspar gneiss. Plagioclase-rich layers about l millimeter thick define a crude foliation concordant with that of the enclosing gneiss. Sample 08 was collected near the contact between the quartz-feldspar and hornblende gneisses with which it is also concordant. Both samples have average grain sizes in the range of 0.1 and 2 millimeters.

Essentially unaltered plagioclase dominates the rock type. It occurs both as a mosaic of recrystallized grains commonly intersecting at 120° angles and as a wormy intergrowth in garnet (Fig. 18). Quartz is minor to absent in the rock, small amounts occurring as mosaic grains intersecting each other and plagioclase grains at 120° angles. Diopside forms up to a quarter of the rock and also occurs as a mosaic of recrystallized grains intersecting at 120° angles.

The other minerals in this rock show common disequilibrium textures. Hornblende and hypersthene make up small to moderate amounts of the rock. In one grain of sample 15b a hypersthene grain has a diopside core. This could result from the replacement of diopside by hypersthene or by the simultaneous growth of both. The lack of other disequilibrium textures between the two suggests the second case. Hornblende has gradational contacts with hypersthene, and hypersthene grains with hornblende cores exist (Fig. 19). These gradational contacts suggest disequilibrium. They are not in contact in sample 08 because of the small amounts of each. Biotite and garnet are minor constituents in this rock type and display mutual disequilibrium textures. Biotite grains embay the garnets and a plagioclase rim always separates the two. Accessory minerals include magnetite and apatites.

Figure 18. 1MT15B. Wormy intergrowths of plagioclase into garnet in hornblende-pyroxene-plagioclase granulite.

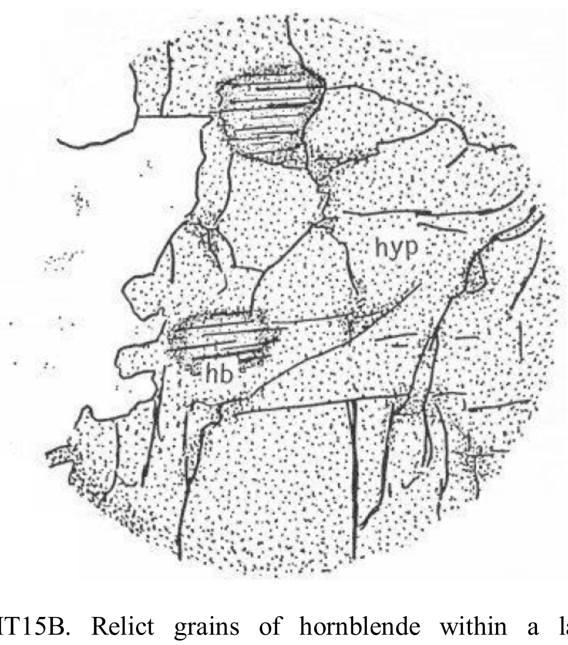

Figure 19. 1MT15B. Relict grains of hornblende within a large grain of hypersthene. The gradational contact suggests replacement of hornblende by hypersthene.

The disequilibrium textures indicate the following transformations:

Hb → Hy	(relict Hb within Hy)
Pl → Ga	(wormy Pl surrounded by Ga)
Bi + Ga → Pl	(Pl separates Bi and Ga)
Pl is recrystallized	(120° junctions)
Di is recrystallized	(120° junctions)
Q2 is recrystallized	(120° junctions)

(Note: Ab = Albite, Alm = Almandine, An = Anorthite, Bi = Biotite, Cp = Clinopyroxene, Di = Diopside, Ga = Garnet, Hb = Hornblende, Hy = Hypersthene, Op = Orthopyroxene, Or = Orthoclase, Pl = Plagioclase, and Qz = Quartz.)

Dewaard (1965a and b, 1967), lists the following reactions for the entrance into the granulite facies in metabasites:

2 Bi + 12 Qz ↔ 8 Op + Alm + 4 Or + 4 H2O
700° C minimum at l0kb, PH2O Pload

Hb + 4 Qz ↔ 3 Op +Cp + Ab + H2O
700° C minimum at 10kb, PH2O Pload

Op + An ↔ Cp + Alm + Qz
760° C minimum at l0kb, PH2O Pload

The second two may be combined defining the entrance to the pyroxene-granulite subfacies from the hornblende subfacies (Buddington, 1966; Dewaard, 1967).

Hb + An + Op ↔ Alm + Cp + Ab + H2O

All these minerals make up the composition of sample 15b. Sample 08 contains biotite but no orthoclase.

The rock has a basic composition similar to a basalt or andesite. The reactions listed occur in a water-undersaturated environment. This is more probable in a basalt rather than a "basaltic" sediment. They occur as beds parallel to the compositional layering possibly indicating basalt flows or sills prior to metamorphism. Both beds strike at large angles away from the northwesterly trend of diabase dikes found in other parts of the Ruby Range. I conclude that they were basalt flows or sills within the original sedimentary package.

Quartz hypersthene-garnet granulite.
This rock type crops out in two locations. The individual textures and weathering characteristics differ in some respects such as grain size and banding, but have most points in common petrographically. The rock of sample 38 weathers red-brown from the abundant hematite and it forms low, massive outcrops. Garnet porphyroblasts 3 to 4 millimeters stand out in hand-specimen. Poor exposure makes

it impossible to map the actual dimensions but hematite-stained soil covers a broad area around the outcrops.

Sample 30f represents a bed about l meter thick that contains pyroxene-poor layers 1 to 10 millimeters thick and magnetite layers 1 to 2 millimeters thick which parallel both the major bed and the foliation and appear to be remnant sedimentary layers. This rock type locally contains banded iron-formation. The bed behaved competently during deformation breaking into tabular blocks which retained their shape as the adjacent layers wrapped around their ends. The bed lies in a sequence of quartzitic gneiss, hornblende gneiss, and garnet-biotite-quartz-feldspar gneiss beds.

Garnet is the most abundant mineral in this rock type. In section 38 garnet porphyroblasts grow up to 4 millimeters across with quartz inclusions and in one grain a zircon inclusion. Magnetite and hematite rim many garnets. This possibly results from excess ferric iron not used by the growing garnet. Hematite forms by secondary oxidation of the magnetite. The rock is rich in iron, but the garnets now make up 42% of it. The iron was concentrated in the space left over. In section 30f, garnets are poikioblastic and some are sieve textured. They contain quartz inclusions except in the pyroxene-poor layers. They do not form porphyroblasts in this section.

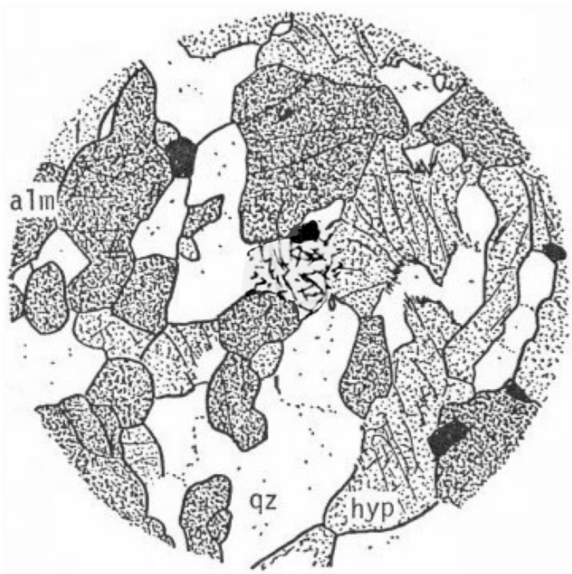

Figure 20. 1MT30F. Quartz-hypersthene-garnet granulite. Section showing the granulitic texture.

Hypersthene and quartz commonly occur as a mosaic of recrystallized grains intersecting at 120° angles. In sample 38 the quartz shows strain shadows and the hypersthene is twinned indicating post crystallization strain in the rock. Sample 38 is porphyroblastic whereas sample 30f is qranulitic with a mosaic of grains intersecting at 120° angles (Fig. 20). No disequilibrium textures are apparent in either sample.

The abundant quartz and iron oxides in both samples, plus the bedded nature and associated quartzitic gneiss, hornblende gneiss, and garnet-biotite-quartz-feldspar gneiss beds around sample 30f indicate a sedimentary parent for this lithology. Magnetite layers l to 2 millimeters thick represent original banded iron layers. The iron was disseminated within the sample 38 parent sediment. This rock has a higher silica and lower magnesium content than in sample 30f. The mineral paragenesis exists entirely within the orthopyroxene zone of the granulite facies. This reflects the water content of the lithology as well as the temperature and pressure conditions because adjacent rock types have almandine amphibolite facies mineralogies.

Hornblende-hypersthene granulite.
There are two varieties of hornblende-hypersthene granulite which differ both in their appearance in outcrop and in thin section. Sample 10 represents a minor type best exposed on the ridge overlooking Dry Hollow from the southeast where it is exposed as a dark, massive bed lying concordantly within hornblende gneiss and quartz-feldspar gneiss. It consists of large amounts of hornblende and hypersthene and a minor amount of spinel. It contains stringers of felsic material with dark shelvages which evidently formed through local metamorphic differentiation. The rock is massive with a mosaic texture having many 120° angles at grain intersections. Disseminated crystals of dark green spinel give it a speckled appearance in thin-section. Secondary serpentinization occurs along fractures.

The spotted granulite of sample 42, a rock composed of equal parts hornblende and hypersthene accompanied by accessory magnetite and spinel, occurs as concordant and discordant layers and dikes. In one place it occurs as a dike accompanied by many parallel aplite veins emplaced along a fault. Weathered surfaces are black and spotted with brown ovals between 2 and 3 centimeters long and half as wide which commonly parallel the foliation. They mark large crystals of hypersthene which poikilitically contain hornblende and are surrounded by it. The hornblende matrix forms a polygonal mosaic structure with grains intersecting at 120° angles and without preferred orientation. The dikes appear to have been emplaced before the F1 deformation. Apart from the orientation of the oval spots, they seem to have behaved competently and were not greatly affected by the F1 event.

Quartzitic gneiss.
Abundant quartzitic gneisses occur within the hornblende gneiss and marble units. They normally occur as beds between 1 and 30 meters thick, but this increases to as much as 400 meters thick in the northern part of the area. The thick portions locally contain iron-formation, the largest of which was mapped by James and Nier (1960) on the Kelly Ranch. The gneiss is composed mostly of quartz but may grade into quartzofeldspathic beds resembling the quartz-feldspar gneiss. Variations in feldspar content and color banding mark layers parallel to the foliation which is defined by the elongate grains of feldspar and quartz (Fig. 21). Differential weathering conspicuously emphasizes small isoclinal folds in some exposures.

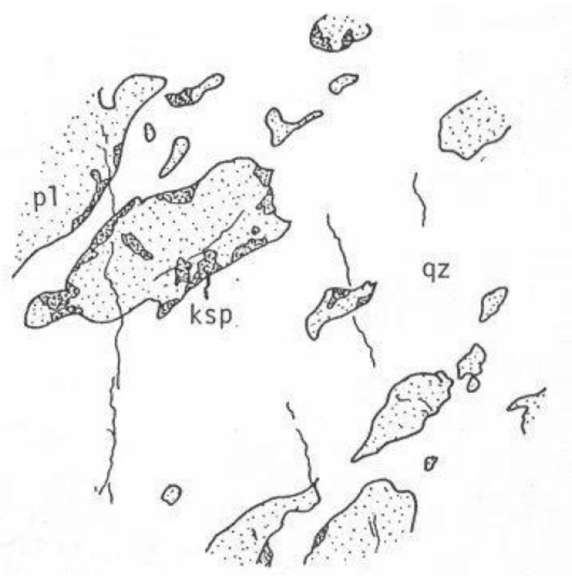

Figure 21. 1MT05B. Quartzitic gneiss. Wide-angle view in reflected light showing elongate feldspar grains within qua Feldspar grains consist of plagioclase (light stipple) with minor orthoclase along the edges (coarse stipple).

The unit appears to have originated as sedimentary accumulations of impure sand. The presence of iron-formation indicates that at least some of the deposition occurred under water. Although the mechanism of deposition of iron-formation is not well agreed upon, most experts feel that they represent marine chemical precipitates. The cyclic nature of banded iron deposits is probably due to cyclic changes in the depositional environment (Trendall, 1973).

Pegmatite.

Pegmatite veins of a few centimeters to dikes over 20 meters thick occur throughout the area. They exist as massive, coarse grained, pink colored rocks. Microcline forms over three-fourths of the rock and quartz, commonly graphically intergrown with the microcline, makes up most of the difference. Plagioclase is minor at 1-5%. Migmatitic areas have much associated pegmatite which appears to be locally derived. The major F2 folding affects the smaller pegmatites and these do not appear fresh. The largest pegmatites cross-cut all structures and lithologies and appear the freshest in outcrop. I feel the older pegmatites formed locally during the metamorphism. The fresh pegmatites intruded post metamorphically, possibly related to Tertiary plutonic activity in the general region. Small plutons are found in the Tobacco Root and Highland Ranges, and the Boulder batholith lies beyond them to the north.

CHAPTER III

METAMORPHISM

Regional Metamorphism

Basement rocks in the Ruby Mountains underwent high-grade regional metamorphism. Okuma (1971), Garihan (1973), and Dahl (1977), established that conditions reached the upper amphibolite facies and ran locally into the granulite facies. Similar conditions existed regionally throughout southwestern Montana including the Highland Mountains (Gordon, 1979), the Tobacco Root Mountains (Cordua, 1973), the Madison Range (Thompson, 1960), and the Beartooth Mountains (Van de Kamp, 1969). Metamorphic conditions in the Hinch Creek area also reached the upper amphibolite facies and locally the granulite facies. The higher grades most probably represent areas locally undersaturated in water. The overall metamorphic conditions in the area still were higher than in the main part of the range to the southwest (Dahl , 1977).

Equilibrium assemblages, or mineral paragenesis as defined by Winkler (1976), were used along with disequilibrium assemblages to determine the metamorphic grade. Disequilibrium textures resulting from prograde reactions helped greatly. Lack of appropriate assemblages makes it impossible to put narrow pressure limits although the temperature limits are well defined. The criteria used to determine that equilibrium was reached are: 1) all minerals in thin-section must be somewhere in contact, 2) they lack disequilibrium textures, and 3) the assemblage contains no incompatible phases when plotted in an ACFmK diagram. Also, common 120° equilibrium/recrystallization grain junctions were noted in many samples. The following equilibrium assemblages occur in the area:

quartz-feldspar gneiss assemblage:
- quartz-plagioclase-perthite
- quartz-plagioclase-microcline
- quartz-plagioclase-perthite-garnet
- quartz-plagioclase-perthite-biotite
- quartz-plagioclase-perthite-biotite-garnet
- quartz-plagioclase-biotite

hornblende gneiss assemblage:
- quartz-plagioclase-perthite-hornblende
- quartz-plagioclase-hornblende-garnet-diopside
- quartz-plagioclase-hornblende-garnet-biotite
- plagioclase-hornblende-garnet-diposide
- hornblende-plagioclase-quartz-garnet
- hornblende-plagioclase-garnet

granulite assemblage:
- hypersthene-garnet-quartz
- hypersthene-spinel

Figure 22, shows the assemblages plotted on an ACFmK diagram. The assemblage: quartz-perthite-garnet-biotite-sillimanite-plagioclase cannot be listed as in equilibrium. The small amount of sillimanite prevents it from being in contact with each other mineral. The pairs sillimanite plus potassium feldspar and sillimanite plus quartz lack disequilibrium features so the conditions probably reached the sillimanite-orthoclase zone of the amphibolite facies.

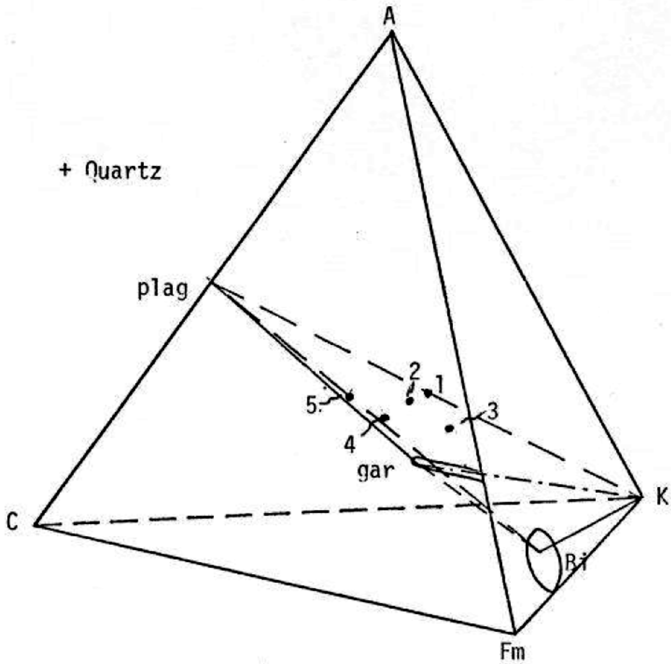

Figure 22a.
ACFmK diagram of equilibrium mineral assemblages
Average rock compositions shown are:
1) Quartz-Plagioclase-Perthite,
2) Quartz-Plagioclase-Perthite-Garnet,
3) Quartz-Plagioclase-Perthite-Biotite,
4) Quartz-Plagioclase-Perthite-Garnet Biotite,
5) Quartz-Plagioclase-Biotite.

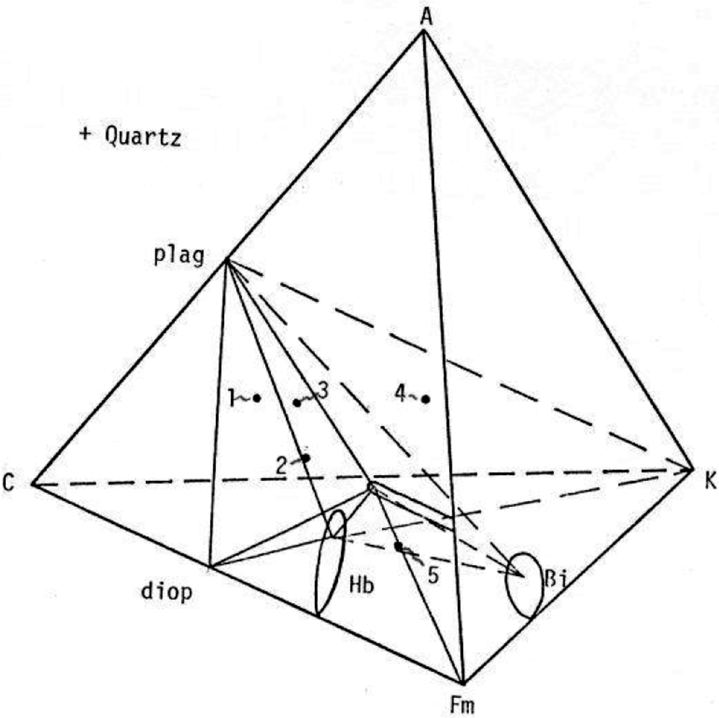

Figure 22b.
ACFmK diagram of equilibrium mineral assemblages
Average rock compositions shown are:
1) Quartz-Plagioclase-Hornblende-Garnet-Diopside,
2) Hornblende-Plagioclase-Quartz-Garnet,
3) Quartz-Plagioclase-Hornblende-Garnet-Biotite,
4) Quartz-Plagioclase-Perthite-Hornblende,
5) Hypersthene-Garnet-Quartz

In addition, the following disequilibrium textures proved very useful in recognizing reactions and defining the metamorphic conditions:

hypersthene grains with relict hornblende cores (Figure 19)

wormy plagioclase surrounded by garnet (Figure 18)

biotite and garnet separated by plagioclase (Figure 14)

skeletal enstatite growing on anthophyllite (Figure 17)

Lastly, many general characteristics of the rocks and minerals indicate high-grade conditions. Important characteristics include:

K-feldspar is perthitic

hornblende is a dark olive-green

biotite pleochroism ranges from orange to deep red, almost black

many samples have a granulitic texture

plagioclase composition ranges from An27 toAn42

non-injection migmatites are common in the study area

The presence of perthite and hypersthene with quartz restricts the lower temperature conditions of the rock. At pressures between 5.5 and 6.5 kb, the minimum temperatures for the formation of both perthite and hypersthene with quartz are around 750°C in water saturated rock, PH2O = Pload (Fig. 23). The temperature could have been somewhat lower in the case of where PH2O < Pload. The paragenesis hypersthene-garnet-quartz indicates that the highest grades reached the orthopyroxene zone in rocks of appropriate composition. These samples have massive, granulitic textures as well. Since the majority of the rocks in the area reached the upper amphibolite facies, the presence of higher grade assemblages most probably represent areas locally undersaturated in water.

The disequilibrium assemblage anthophyllite-quartz-garnet-enstatite defines the upper temperature limit. According to the phase rule, being on the reaction boundary reduces to one the number of degrees of freedom, eg, the temperature is defined at any pressure, or vice-versa (Hyndman, 1972). For pure magnesian anthophyllite and enstatite, the reaction temperature between 5.5 and 6.5 kb pressure is just above 800°C where PH2O = Pload (Fig. 24). The reaction anthophyllite ↔ 7 enstatite + quartz + water, yields water and would react at lower temperatures in PH2O < Pload conditions. In addition, the presence of ferrous iron in the minerals as is the actual case will also generally lower the reaction temperature.

The disequilibrium textures between biotite and garnet discussed in Chapter II (page 38) also help define the upper temperature limit in PH2O < Pload conditions. The unbalanced reaction Hb + An + Op ↔ Alm + Cp + Ab + H2O defines the entrance to the granulite facies at approximately 760°C @ 10kb for conditions undersaturated in water (Buddington, 1966; Dewaard, 1967). Because of the steepness of the P/T reaction curves at high grades, the temperature at 6kb is probably not significantly different.

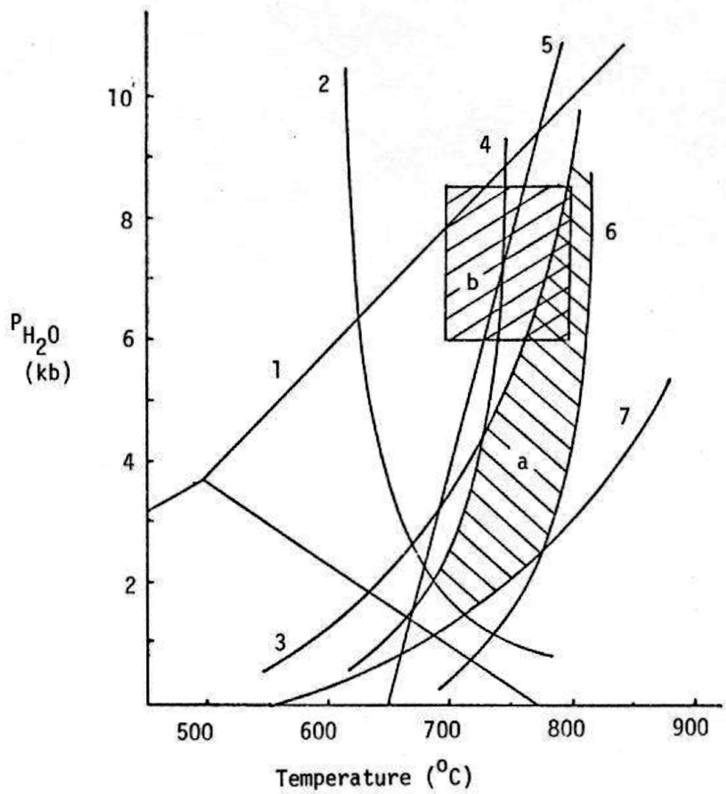

Figure 23. Temperature-pressure diagram showing the field of metamorphism for this study (a) and the field determined by Dahl (1977) for the Kelly Iron-Formation (b). Reactions shown are:
1) Ky ↔ And ↔ Sill (Holdaway, 1971),
2) minimum melting curve for common granite (Thompson and Alger, 1977),
3) Mus + Qz ↔ Ksp + Sill + H2O, (Beach, 1973)
4) formation of hypersthene (Hyndman, 1972, p. 313),
5) Ksp ↔ Perth (Huang and Wyllie, 1975),
6) Anth ↔ Ens + Qz + H2O (Winkler, 1976, p. 162)
7) breakdown of Hb + Qz (Hyndman, 1972, p. 313).

Although these reactions represent PH2O < Pload conditions, it must be remembered that most of the area probably was saturated in water. The conditions were above the minimum melting temperature for the system quartz-plagioclase-orthoclase + water. Anatectic melting in water saturated rocks of granitic composition must have occurred. Migmatites found locally throughout the area support this conclusion.

Dahl (1977) has performed electron microprobe geothermometry and geobarometry on rocks from the Kelly iron deposit in the area. The results based on his work indicate a temperature of 745 ± 50°C, and a pressure of 6.0 to 8.5 kb (Fig. 23). Little in the way of pressure limits were found in the present study but the temperature limits are well defined. The actual temperatures reached during metamorphism were probably slightly higher than those indicated by Dahl. Figure 23 shows the data given by Dahl and may be compared to the results of the present study.

Retrograde Metamorphism

The effects of retrograde metamorphism are not strong in the study area. Moderate to little or no alteration exists in most sections studied. The types of alteration found include chlorite after biotite, sericite in plagioclase, epidote in one amphibolite section, serpentine in fractures of ultramafic rocks.

The minerals produced indicate greenschist facies or lower conditions. The time of retrograde metamorphism could have been during the waning stages of the high-grade event, or a later low-grade event. In any case, the effects are minor to nonexistent in the area. On1y sericite alteration in plagioclase commonly is present in most sections studied.

CHAPTER IV

STRUCTURE

Multiple deformations have occurred in the basement of the Ruby Range. The earliest folds F1, are characterized as similar and isoclinal with the development of axial plane schistosity (Garihan, 1973). The fold axes plunge northeast at moderate angles. The second folding, F2, formed broad open folds coaxial with F1 in the central and northern Ruby Range. Open to isoclinal F2 folds not coaxial with F1 exist in the southern Ruby Range (Okuma, 1971). Okuma found evidence of an F3 deformation folding both F1 and F2. This F3 fold axis trends north-south.

Faults in the range generally trend north northeast and cut all the folds. Exposure in fault zones is poor and most are located by juxtaposition of rock units or traced from air photographs. Precambrian diabase dikes follow some of these faults in the southern Ruby Range. I have seen no evidence to indicate whether dikes intruded along Precambrian faults, of whether the faults are Tertiary in age and followed the dikes as planes or weakness.

Folding

Garihan (1973) showed that two periods of folding occurred in the basement immediately to the southwest of the Hinch Creek study area. Both sets are recognized in the study area and his terminology is retained.

F1 structures. The earliest recognized period of deformation produced similar style isoclinal folds on a scale of several centimeters to several tens of meters (Fig. 12). The best exposures of this occur along the north side of Hinch Creek valley in section 32. The folding also produced axial-plane schistosity and regional foliation through the recrystallization and growth of new minerals. Quartz and feldspar commonly occur as elongate grains that parallel the foliation and compositional layering. Compositional layering parallels foliation except along the noses of isoclinal folds. Structural transposition is possible throughout the area, but was only found on a scale of a few tens of meters or less.

F2 structures. The second deformation has formed the conspicuous northeast plunging antiform/synform pair which dominates the area. The axis of this major structure strikes between 055° and 065° and plunges between 50° and 70° (Fig. 24). The structure forms a broad, open fold. Marble units behaved competently during the deformation, pinching off and flowing into small lenses along the tight noses of some folds. Thin quartz lenses and layers may be folded and broken within structureless marble.

I subdivided the area into thirteen structural subdomains in order to analyze smaller scale changes and variations in the gross overall structure (Fig. 25). The basis for subdividing the area consists of:
1) domain boundaries should parallel structural or lithologic boundary, and

2) the structures within a domain should show a single consistent pattern. The analysis is based on lower hemisphere poles to the regional foliation plotted on a Schmidt equal-area stereo net (Fig. 26a-m). Measurements on F1 fold axes were not taken but the beta values obtained from the stereo nets correspond to and are plotted on Figure 25. The concentration of data varies from one domain to another and affects the reliability of interpretation.

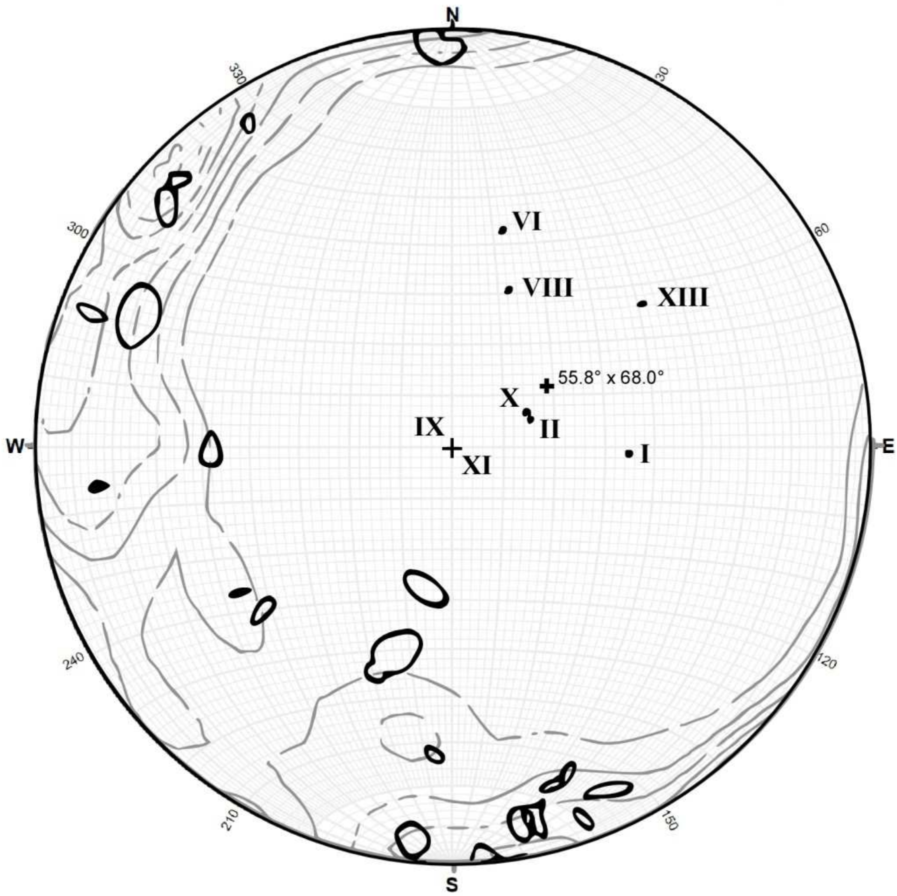

Figure 24. Lower-hemisphere diagram showing the maximum concentration contours of poles to foliation from each domain plotted together along with measured beta points showing the average fold axis attitude found in eight of the domains (labeled). Average of eight Beta: 55.4°, 65.6°.
[2021 Addendum: Contours for full dataset analysis (343 measurements), Beta: 55.8° by 68.0°, Best fit great circle (strike, dip RHR = 145.8°, 22.0°. Appendix 8]

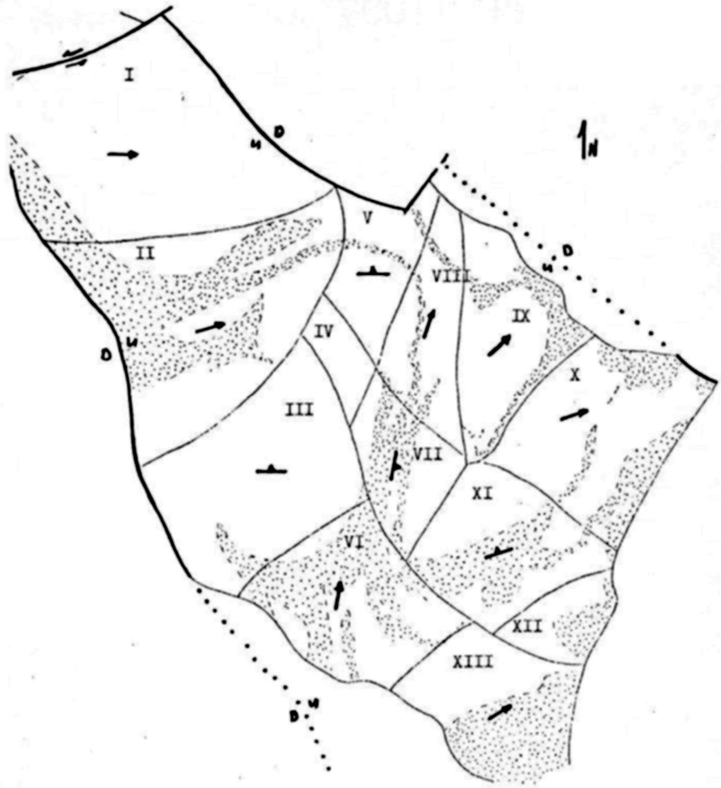

Figure 25. Map of the study area showing the domain subdivisions, and the average attitude of inferred fold axes and foliations within each domain.

Domain	Beta strike	dip	quad	points
I	94	56	E	14
II	73	74	E	27
III				18
IV				5
V				14
VI	13	46	N	31
VII				19
VIII	19	58	N	45
IX	47	90		35
X	71	74	E	55
XI	70	85	W	15
XII				5
XIII	56	42	NE	17
Average	55.4	65.6	NE	239

Domain I.

Domain I consists mostly of hornblende gneiss and quartzitic gneiss metasediments. James and Wier (1960) have mapped the Kelly Ranch showing an east-plunging synform with the major iron deposit exposed in the center. Quartzitic gneiss surrounds the iron formation and grades away from the synform core into hornblende gneiss. This domain differs from the dominant structural pattern of most of the remainder of the study area to the southeast. Structures trend east- west rather than northeast-southwest. A weakly defined girdle of poles to foliation agrees with the attitude of the synform mapped by James and Wier.

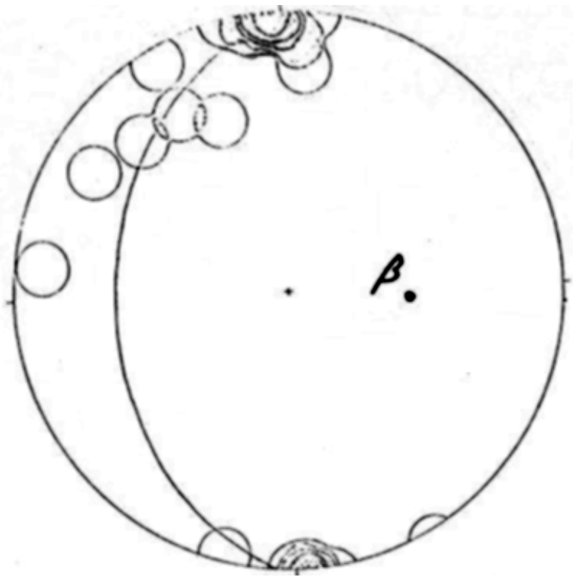

Figure 26a. Domain I
Contour interval: 35%
28
21
14
7
Beta value: 094°, 56°E
14 points total

Domain II.
This domain forms the transition between the east-west structure of Domain I and the northeast-southwest structures to the east. Again the girdle of poles to foliation is not well defined. The marble units form important structural marker beds within the domain. They strike between 050° in the eastern part of the domain to 090° in the western part. Lack of data prevents further subdivision of the domain.

The domain contains the western limb of the broad antiform. It dips steeply to the north and northwest. The marble continues to the west where it folds around the iron formation, creating the synform of domain I.

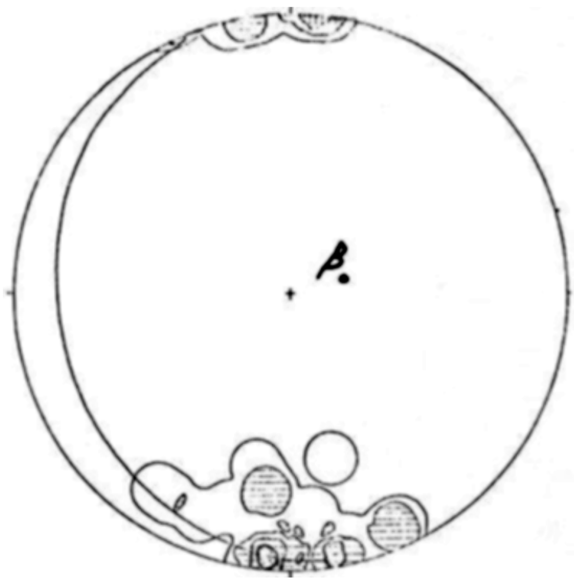

Figure 26b. Domain II
Contour interval: 25%
18
11
4
Beta value: 073°, 74°E
27 points total

Domain III.

Fairly uniform quartz-feldspar gneiss dominates the domain with marble and hornblende gneiss included in the southern part. Poles to foliation form a cluster indicating an average attitude for all the foliation planes. To the south, the foliation in the hornblende gneiss strikes more northwesterly. This domain is separated from domain VI by the lack of north-south and northwest-southeast structures, and by the contact between the marble and the quartz-feldspar gneiss.

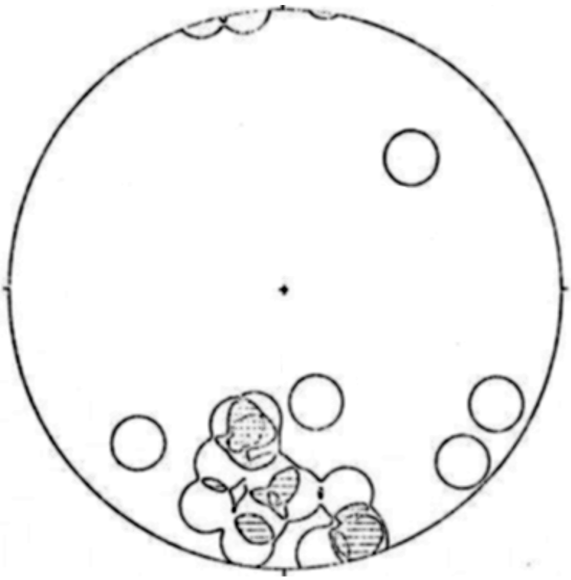

Figure 26c. Domain III
Contour interval: 17%
11
5
Cluster center: 183°, 30°S
Average strike and dip: 093°, 60°N
18 points total

Domain IV.

Domain IV exists in the negative sense that it does not fit well into any adjacent domain. Structurally it resembles domain VII representing north-south foliation dipping east. Physically it lies in the core of the antiform. This position relates it more with domains III and V. Defined by only five points, its significance remains uncertain.

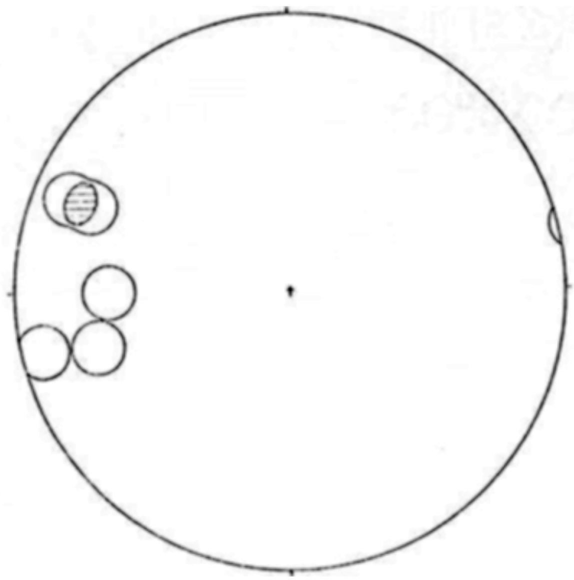

Figure 26d. Domain IV
Contour interval: 40%
20
5 points total

Domain V.

This occupies the nose of the antiform. The marble forms the best marker bed cutting across the domain and dipping north. Poles to the foliation appear to form a small circle of 14° radius about a point 181°, plunging 9° south. The small circle suggests a superimposed smaller scale open fold upon the main fold. Without more and different kinds of data, the direction and plunge of the axis cannot be found. For the major structure, the foliation dips north outward from the antiform. Due to the narrowness of the domain, not enough variation exists to indicate the direction and plunge of the axis of the antiform.

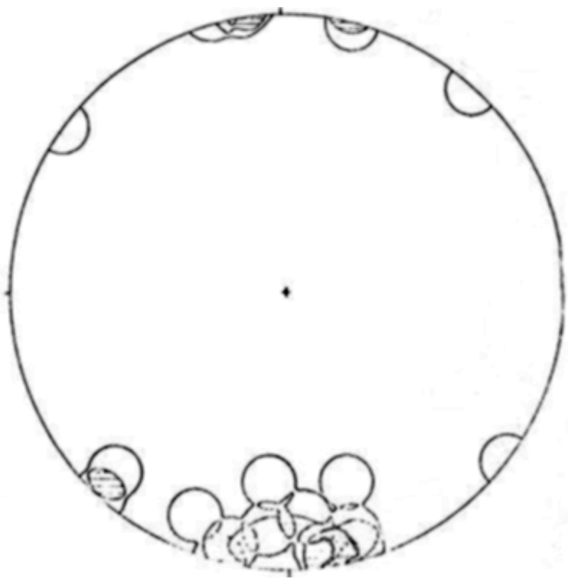

Figure 26e. Domain V.
Contour interval: 28%
21
14
7
Small circle diameter: 14°
Center: 181°, 9°S
Average strike and dip: 091°, 81°N
14 points total

Domain VI.

This domain contains the interlayered marble and quartz-feldspar gneiss at the nose of the synform. Marble beds clearly follow around the synform near the nose, but to the southwest they trend north-south. The data loosely defines a girdle of poles to foliation on the stereo net. The exact map location of the axis is not easily placed because of the openness of the fold in the domain. To the north- west the nose becomes tighter and the axis more clearly defined.

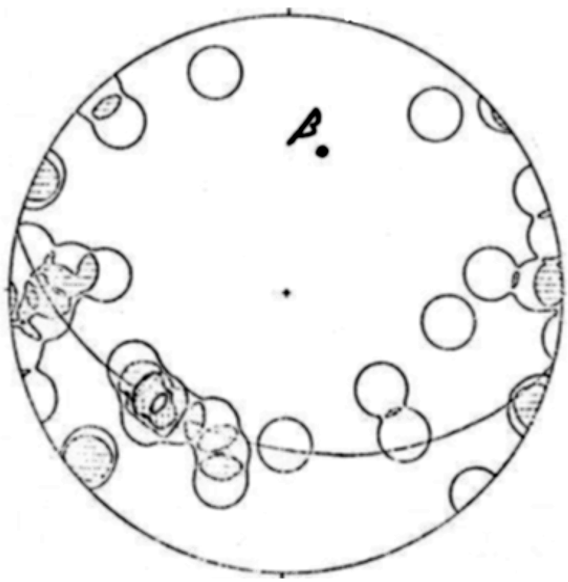

Figure 26f. Domain VI
Contour interval: 13%
10
7
4
Beta value: 013°, 46°N
31 points total

Domain VII.

This domain, along with domain VIII covers the central limb of the antiform synform pair. The change in thickness of the marble along with the flattening and ending of the western marble bed forms the basis of the subdivision of the limb. Domain VII covers the south half of the limb. The marble unit separates the hornblende gneiss on the east from the quartz-feldspar gneiss on the west.

Poles to foliation form a small circle 32° in diameter around a point oriented 103°, plunging 20° west. This results from a small superimposed open fold on the main structure. As in domain V, the data is insufficient to determine the direction and plunge of the fold axis. The relative ages between this fold and the major fold cannot be shown. Both are post F1.

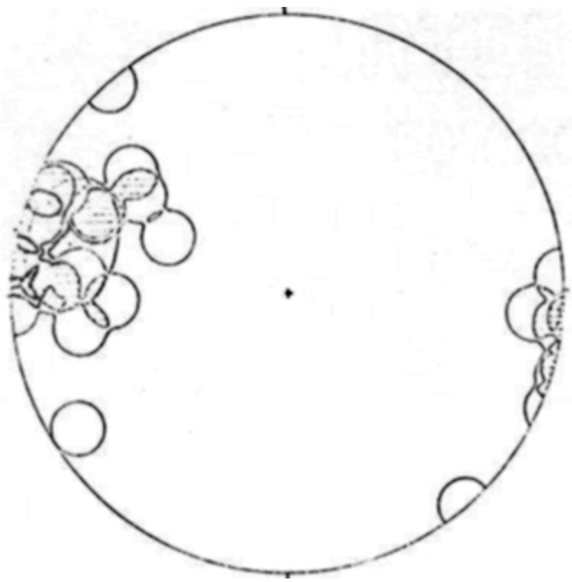

Figure 26g. Domain VII
Contour interval: 21%
16
11
6
Small circle diameter: 16°
Center: 103°, 20°W
Average strike and dip: 013°, 70°E
19 points total

Domain VIII.
The northern half of the central fold limb dominates domain VIII. The beds of both domains VII and VIII dip east towards the Synform. Combined with the outwardly dipping beds of domains V and II, the four domains define the western fold as an antiform. The marble beds mark the shape of the antiform in outcrop.

The west half of the girdle of poles to foliation shows up on the stereo net. The beds dip steeply, generally over 60° and commonly in the upper 70's. This increases in the center of the synform where the fold axes plunge nearly vertical.

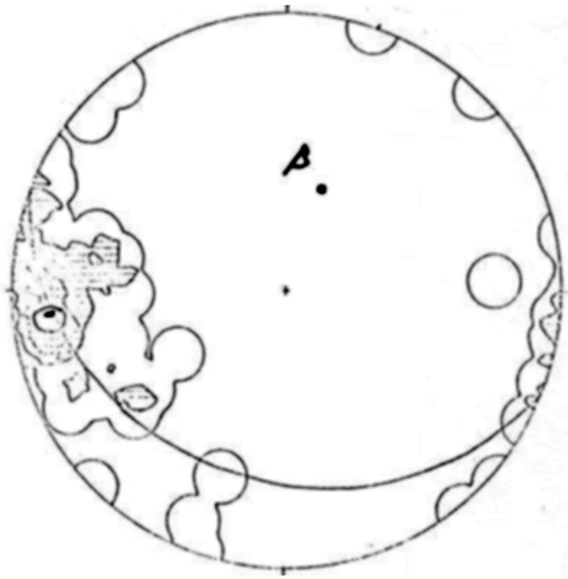

Figure 26h. Domain VIII
Contour interval: 19%
15
11
7
3
Beta value: 019°, 58°N
45 points total

Domain IX.

Domain IX occupies the center of the synform bounded by the marble on the east and the quartzitic gneiss on the west. A small ultramafic body crops out in the center of the domain on the axis of the fold. Desmarais (1978) found that other ultramafic bodies in the Ruby Range commonly lie on the axes of folds. He concluded that they were mobile during the folding phase, possibly being emplaced at that time. Metasedimentary units dominate the domain. The marble marker bed reveals an interesting structure. The east arm of the marble thickens and folds back across the axis of the main fold. Because the foliation bends around with the marble, this fold occurred after F1, probably related to the F2 phase of deformation. The relative ages between the limb fold and the main fold are uncertain. It was folded during or before the main phase because the main fold also folds the marble limb where they cross. A critical area adjacent to the northeast is covered and limits interpretation.

Poles to foliation concentrate in groups along the perimeter of the stereo net. The northwestern concentration indicates that the axial plane strikes approximately 45° northeast, but the fold axis plunges nearly vertically.

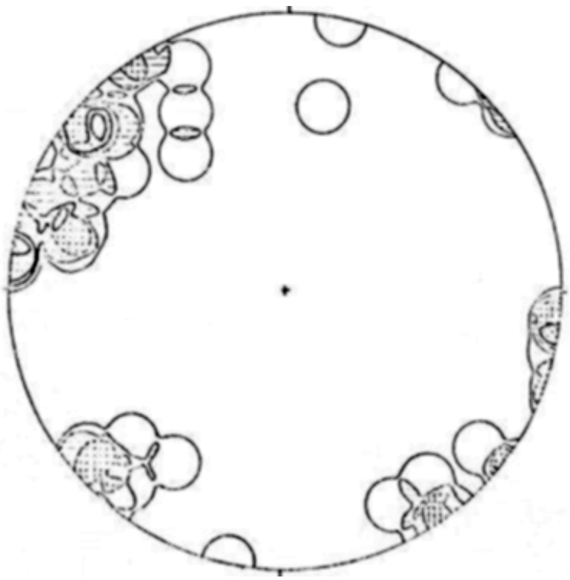

Figure 26i. Domain IX
Contour interval: 15%
12
9
6
3
Beta value: 047°, near vertical
35 points total

Domain X.

This domain consists of the northern half of the synform's eastern limb. Rock types range from hornblende gneiss on the west to marble, hornblende gneiss, and amphibolite on the east. Some bedding in the domain, especially near Hinch Creek is isoclinally folded by F1 deformation.

The foliation dips steeply to the east on this limb showing that it is slightly overturned. Poles to foliation form a partial girdle, enough to weakly define a beta position. A smaller wave on the main fold shows up on the map as the bulge to the northwest in marble and anthophyllite beds.

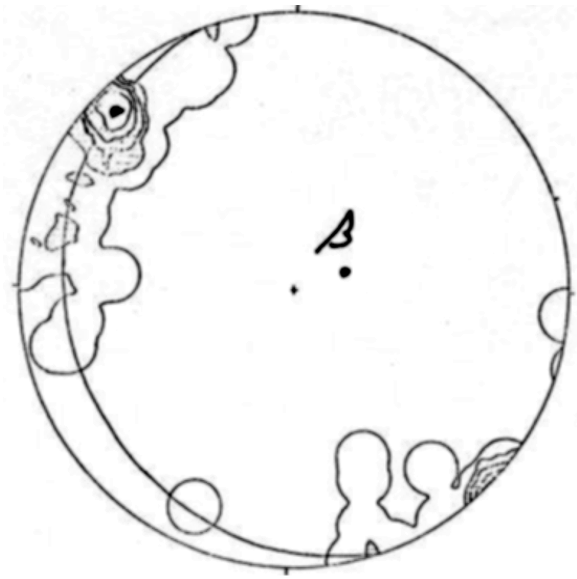

Figure 26j. Domain X
Contour interval: 31%
25
19
13
7
1
Beta value: 071°, 74°E
55 points total

Domain XI.
Domain XI indicates the south half of the synform's eastern limb. I based the subdivision on the fact that foliation in this area dips steeply northwest while the foliation of domain X dips steeply southeast. Both are near vertical. The boundary follows the prominent cross-cutting pegmatite and is in line with the domain VII and VIII boundary. Poles to foliation plot loosely as a cluster. This gives an average strike of 070°, and a dip 85° northwest.

Minor isoclinal folds exist within the domain, mostly within the marble unit. This results in thickening the marble bed on this limb. Insufficient data prevents me from assigning an F1 or F2 designation to these smaller folds. The noses are broken and poorly exposed.

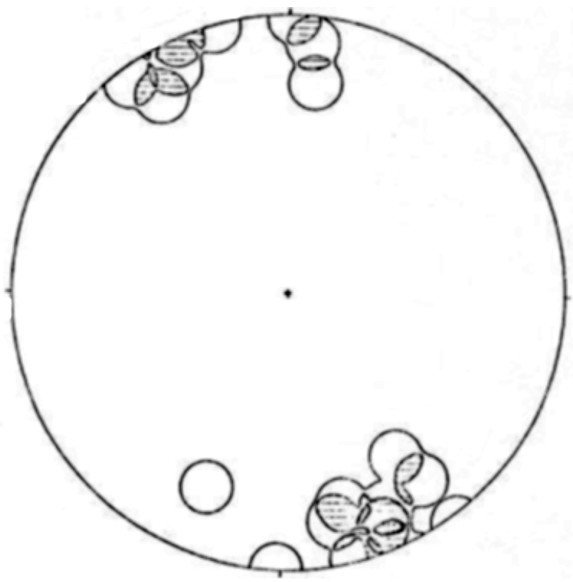

Figure 26k. Domain XI
Contour interval: 20%
13
6
Cluster center: 160°, 5°S
Average strike and dip: 070°, 85°NW
15 points total

Domain XII.

This domain, as in the case of domain IV, exists in a negative sense of not fitting with adjacent domains. Physically this is represented by a marble unit extending into the quartz-feldspar gneiss. It does not connect to adjacent marble units within the area. The five points defining the domain are not interpretable.

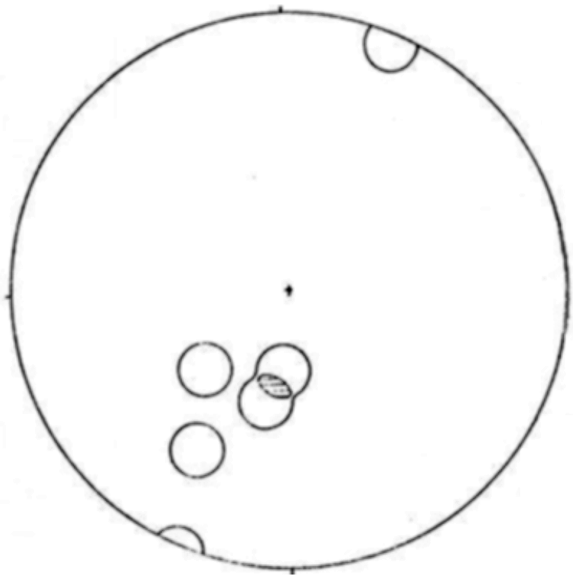

Figure 261. Domain XII
Contour interval: 40%
20
5 points total

Domain XIII.

This domain occupies the southern corner of the map area. The thick marble unit dominates it on the south, balanced by quartz-feldspar gneiss to the north. Isoclinal folding and possible plastic flowage cause thickening in the marble. One isoclinal fold was mapped within the marble atop the east-west trending hill in the center of section 8. Lack of exposure makes it impossible to determine the extent or attitude of this isoclinal folding. The trend of fold axes and the position of the domain relates this to the east limb of the synform. The northwest trend separates this domain from the more north- south trending domain VI.

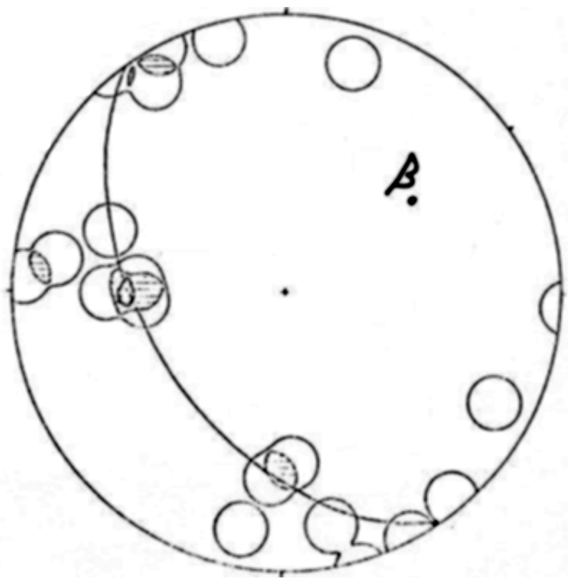

Figure 26m. Domain XIII
Contour interval: 18%
12
6
Beta value: 056°, 42°NE
17 points total

Summary of folding.

The earliest folding, F1, in the area occurred as isoclinal similar-style folds. Garihan (1973) found the fold axes to plunge northeast at "moderate" angles, moderate to steep in this study. The deformation coincided with the highest grades of metamorphism as indicated in Chapter III. This deformation was accompanied by mineral growth and recrystallization to create the regional foliation found in the area.

The second deformation, F2, folded the foliation and compositional layering, resulting in the broad northeast-plunging fold that dominates the structure of the area. The presence of smaller scale folds complicates the interpretation. The age relationships are unknown between these and the F2 fold. These are smaller in scale and not found throughout the study area; this suggests a relationship with the F2 rather than a separate regional folding event. No evidence was found for a third folding phase in the area.

Faulting

Within the study area two northwesterly trending faults were mapped but neither could be traced along strike more than a few tens of meters. Other faults in the area were indicated by gossens and prospect pits with exposed malachite and limonite in the shear area. Hornblende-hypersthene granulite occupies one fault. It probably represents a small serpentinite dike injected prior to metamorphism. This shows that some faulting occurred before the onset of metamorphism and deformation.

Major faults bound the area on two sides. To the west the study area sits against Paleozoic sedimentary rocks in contact with the basement along north-northwesterly vertical faults. These faults, active in the Tertiary period form a part of a series of northwest "master" faults mapped by Tysdal (1970) (Figure 1). On the north the Tertiary range-bounding fault system brings the basement into contact with Paleozoic sedimentary rocks. The faults here are covered by surficial sediments.

CHAPTER V

CONCLUSION

The rocks within the area represent a package of metasedimentary with some interlayered metavolcanic units. During high grade metamorphism the region was intruded by a granitic pluton which now forms the structurally lowest unit. The metasedimentary lithologies of the area include hornblende gneiss, sillimanite-garnet-biotite-quartz-feldspar gneiss, quartzitic gneiss, iron-formation, and marble representing respectively: carbonaceous mudstone or shale, pelitic sediments, sandstone, iron-formation, and limestone. Interlayered with these in the structurally lower part of the section are amphibolites representing metavolcanic flows or sills. whether they existed as a primary unit of the sequence as flows, or were intruded as sills at a later time is unknown. The rock recrystallized completely during metamorphism, destroying any primary structures. It is possible that both flows and sills are represented.

The sedimentary sequence starts at the base with marble and works upsection through metavolcanics and hornblende gneisses with thin layers of quartzitic and quartz-feldspar gneisses. The quartzitic gneiss becomes dominant and in the Kelly Ranch it contains banded iron-formation. Iron-formation also occurs in units crossing Hinch Creek to the south. The two iron-formations are at approximately the same structural level although the Kelly area contains much more quartzitic gneiss. The thickness of this gneiss may be controlled by isoclinal folding or the angle of exposure causing real or apparent differences in thicknesses between the units in the two areas. The structural positions permit a tentative correlation between the two. Above the iron-formation is a second marble layer followed by more quartzitic gneiss and thin layers of hornblende gneiss. Due to isoclinal folding and possible plastic flowage during the deformation, the true thicknesses of the original sedimentary units is unknown.

The origin of the quartz-feldspar gneiss has long been a problem. Nowhere in the Ruby Range has definite proof of either a sedimentary or plutonic origin been found. In the Hinch Creek study area the gneiss lies concordantly below the main marble unit. It shows no cross- cutting relationships, but in the southern part of the area it interbeds with the marble. This bedding partially results from isoclinal folding but may also be due to original sedimentary layering, or intrusion of granitic melt as sills. Synkinimatic intrusion deep in the crust would not be expected to cause much cross-cutting or deformation of the country rock (Buddington, 1959). It is not unreasonable to conclude that all or much of the quartz-feldspar gneiss was formed as a granitic magma. The temperature and pressure conditions determined in the study area were well above the minimum melting curve for water-saturated granite (Fig. 23). Migmatitic areas are found throughout the study area indicating partial melting. The granitic composition and lack of any relict sedimentary features also points towards a possible plutonic origin

The major pre-metamorphic rock types were limestone, sandstones, pelitic sediments, and shales. Volcanic rocks make up a minor and possibly post-depositional contribution to the package. The presence of iron-formation and limestone indicates deposition in a shallow marine environment. Shales and calcareous shales have a deeper or quieter environment of deposition. The package therefore most likely represents a marginal sea or shelf-type of environment. The lack of abundant volcanics suggests deposition during a period of minor or no tectonic and thermal activity, an inactive or trailing margin in the modern sense. The same case exists throughout much of the basement of southwestern Montana. Common rock types are repeated over and again, quartz-feldspar gneiss, biotite-sillimanite schist, marble, hornblende gneiss, and amphibolite. The shelf area was regional in extent. The direction to the source area is unknown.

Sometime after deposition the entire pile was subjected to regional deformation and metamorphism. These may or may not have begun at the same time. The highest levels of temperature and pressure were reached during or after the first period of deformation with the growth of sillimanite on the F1 axial plant. Intrusion of the Dillon gneiss "pluton“ occurred synkinimatically with F1. Crystallization during the deformation imparted a strong gneissic fabric to most of the unit. Textures and mineralogies found within the study area indicate that temperatures during metamorphism reached between 750° and 800°C with a pressure range between 2 and 8kb. Results of geobarometry done by Dahl (1978) show pressures of 6 to 8.5kb. If correct, the temperature range would be more restricted, between 750 and 800°C (Fig. 23). These conditions are found within the upper amphibolite to lower granulite facies. This agrees with metamorphic conditions reported from all the ranges with basement exposed in southwest Montana. This common high grade metamorphism throughout the region suggests a common period of metamorphism.

Much of the region experienced greenschist facies retrograde metamorphism. No evidence exists to show whether this was a late stage of the major event, or a separate younger event. The effects of this metamorphism in the study area are weak to nonexistent. After the first folding event a second deformation folded the foliation into a broad north-east plunging fold set. The age relationship between this and the greenschist metamorphism is unknown. The second deformation includes a smaller set of superimposed folds of undetermined relative age. No further folding occurred in the study area, but Okuma (1971) reports a north-south trending F3 fold in the southern Ruby Range.

Table 5. Interpreted geochronology of events affecting the basement lithologies in the Ruby Range, southwestern Montana.

Age (m.y.a.)	Event	Evidence
Eocene to present	Movement on northwest trending master faults and range bounding faults. Emplacement of basalt plugs.	Displacement of all lithologies from Precambrian units to recent valley-fill sediments.
1200	Exposure of the basement to the surface.	Basement metamorphic clasts incorporated into the lower Belt sedimentary rocks (Obradovich and Peterman, 1973).
1400-1700	Intrusion of diabase dikes on a northwest trend normal to the range axis.	Metamorphism in the dikes ranges from greenschist to unaltered. The intrusions may or may not have followed a Precambrian plane of weakness. Wooden (1975) reports a 1450my Rb-Sr isochron from a fresh diabase.
1600	"Ending" of the greenschist facies metamorphism	1600my is the most common K-Ar mica date reported from the Ruby Range (Giletti, 1966). Mica blocking temperatures range from 150° to 300° (Fountain, personal comm.). Winkler (1974) puts a temperature range for the greenschist facies between 200° and 500°C. By 1600my the temperature had fallen into, and possibly below the greenschist facies.
		Falling temperatures were probably due to slow uplift and erosion of the basement.
	F_3 folding (southern Ruby Range only)	Folds both F_1 and F_2, not coaxial with either. Folds trend north-south (Okuma, 1971).
	F_2 folding tight to open folds, rarely isoclinal. Associated with F_2 is another smaller-scale folding of uncertain age relationship.	Folds F_1 to form a broad northeast-plunging antiform-synform pair in the study area.
		No evidence was found to show whether the greenschist facies is a late stage of the high-grade event, or a separate younger event.
	Intrusion of basic dikes and sills.	These cut F_1 and are folded by F_2 (Garihan, 1973.
	Highest grades of temperature and pressure reached after F_1.	Metamorphism in the dikes locally reaches the granulite facies. They were intruded after F_1, but still during the regional metamorphism.
	Pegmatite intrusions during F_1.	Heinrich (1960) found pegmatites foliated and concordant with F_1 structures. These are not found in the present study area.
	Beginning the upper amphibolite to lower granulite facies metamorphism.	No evidence was found to show whether the metamorphism began at the same time as the F_1 folding phase. Sillimanite crystals growing on the F_1 schistosity show that the sillimanite-orthoclase zone was reached during F_1.
		Rb-Sr whole-rock dates of 2700-2800 my are reported in the Ruby and adjacent ragnes (Giletti, 1966; Catenzaro, 1967; Wooden, 1975; Wooden and others, 1978; James and Hedge, 1980).
	Synkinematic intrusion of the Dillon gneiss during F_1.	Crystalization during the deformation imparts the gneissic fabric in the unit.
2800	F_1 folding isoclinal, similar-style folds with axial-plane schistosity. Folds plunge northeast at moderate angles.	Develops the regional foliation by recrystallization and growth of new minerals oriented parallel to F_1.
	Pre-syntectonic emplacement of ultramafic bodies.	Desmarais (1978) found that these bodies were probably crystallized, intruded, and serpentinized before the beginning of regional metamorphism. They behaved competently during metamorphism and their association with the noses of folds indicates mobility during folding.
pre-2800	Deposition of sedimentary units and intrusion of volcanic sills and flows. The sedimentary units indicate a shelf-type environment.	Shelf-type character of the sedimentary package. Limestones and magnetite iron-formation indicates shallow marine deposition.

The last major event affecting the basement before it was exposed at the surface was the intrusion of a series of diabase dikes and sills. The process covered a long time span and affected the entire southwest Montana region (Wooden and others, 1978). The intrusion period went from 1700 my to 1400 my in the basement rock (wooden, 1975) and possibly to as recently as 1200 my in the Belt Supergroup (Obradovich and Peterman, 1973). The earliest dikes were intruded and metamorphosed during the regional greenschist facies event. Fresh diabase from the Ruby Range gives a Rb-Sr isochron of 1450 my, therefore the greenschist facies event had ended by then. No diabase occurs in the study area.

In conclusion, the rocks from the Hinch Creek study area formed in a shelf-type depositional environment. Neither the top, nor the base of this package is found within the study area. The entire package was subjected to intense deformation and upper amphibolite-facies metamorphism. This was followed by greenschist facies metamorphism and a second regional folding. This resulted in the broad antiform-synform pair which dominates the area. The area has been uplifted and exposed by vertical faults active since Tertiary time. Several Tertiary basalt plugs have punched up through the basement terrain but caused no observable deformation.

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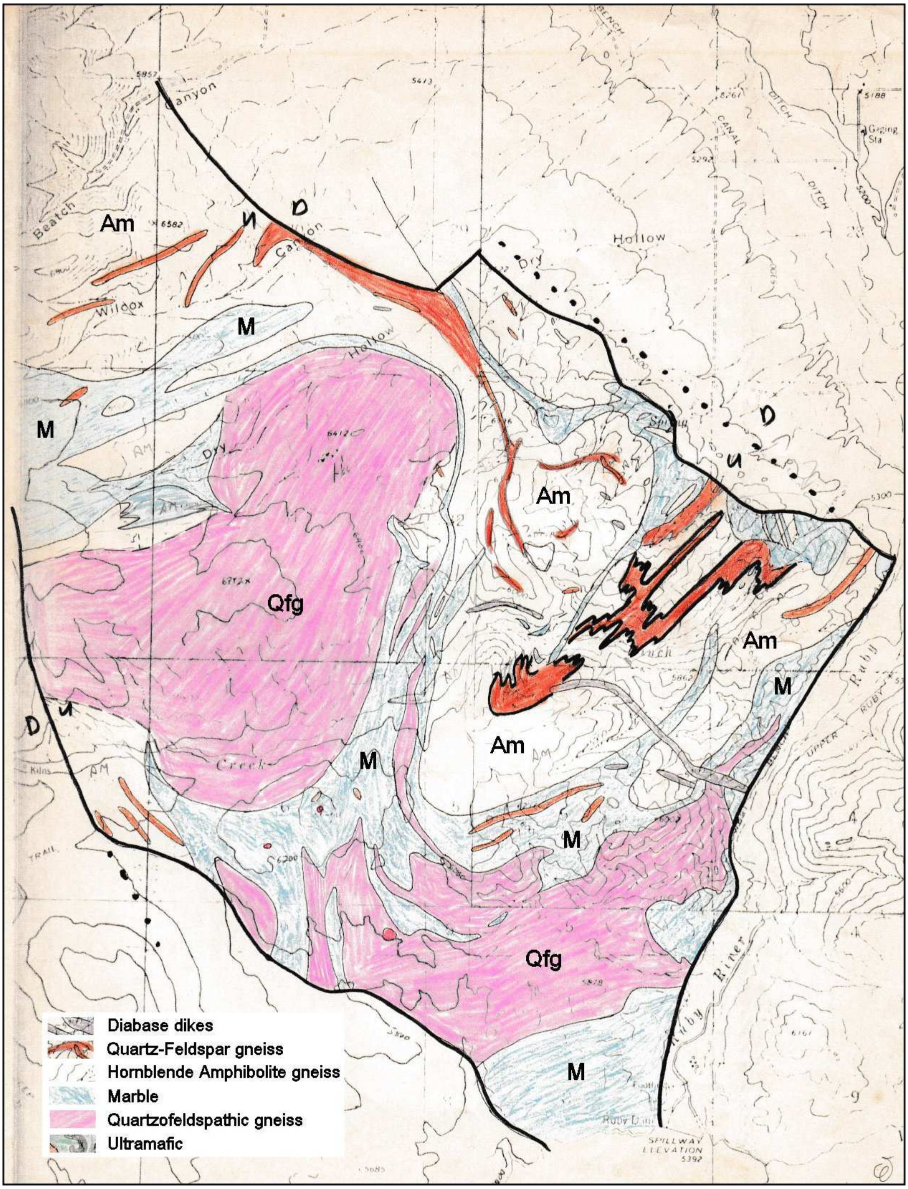
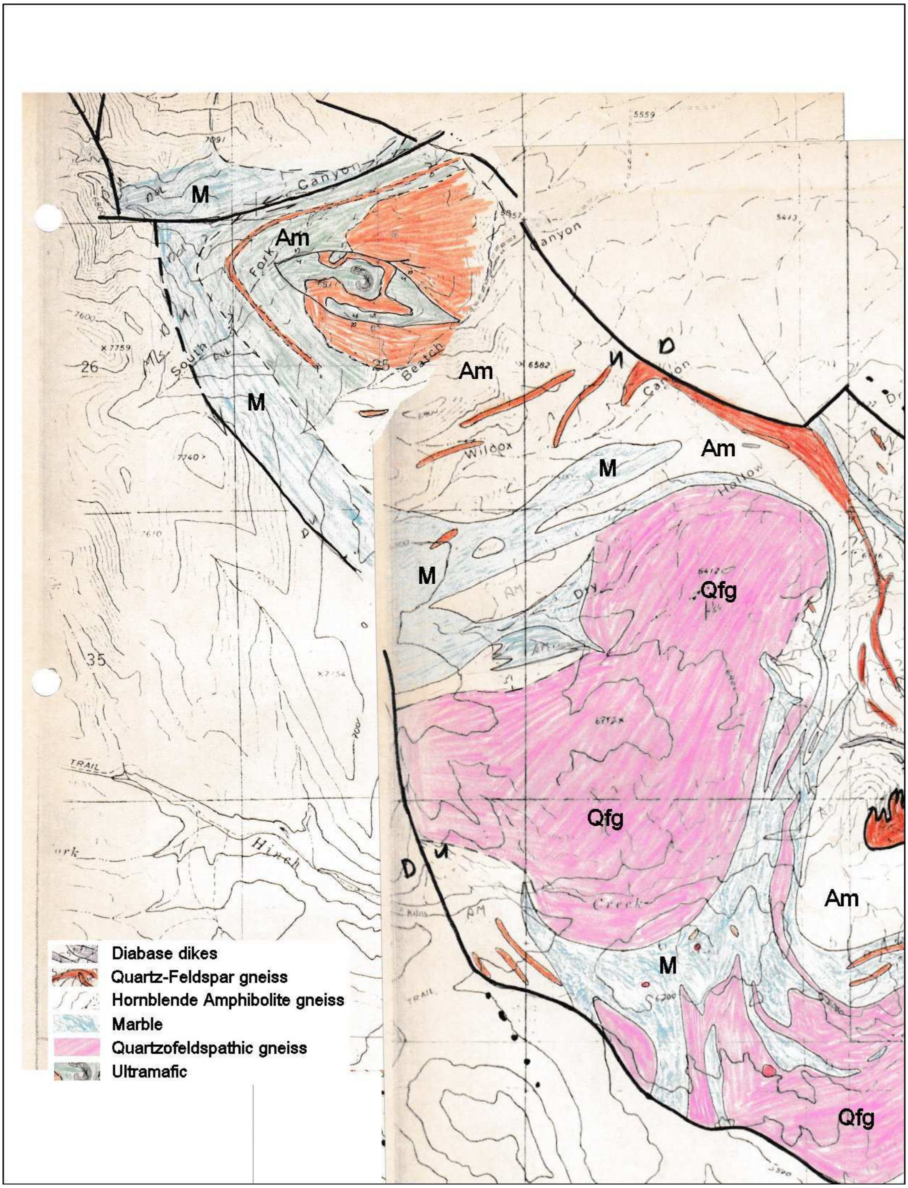
KJS

Appendix 1: Field Geological Map



Main field area



Northwest field area

Appendix 2: Selected station descriptions

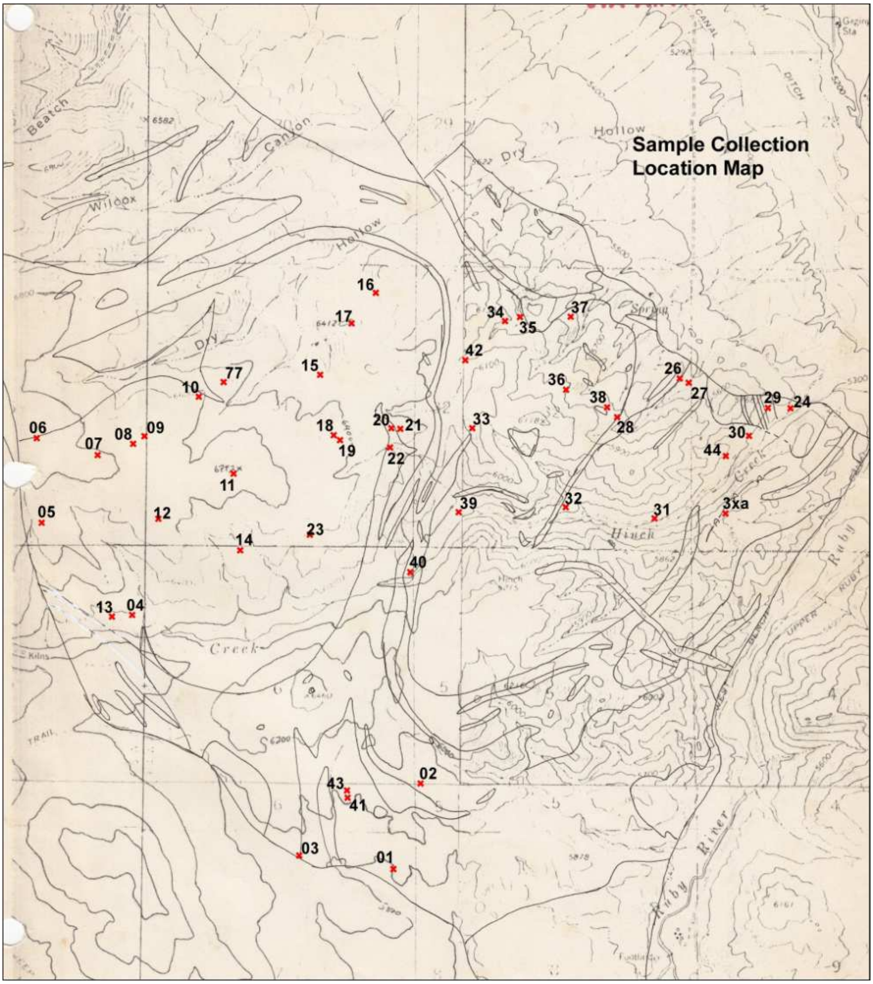
Station	Description
4	Amphibole bouden w/Quartzofeldspathic Gneiss
5	Quartzofeldspathic Augen Gneiss
36	Chert breccia (overburden)
60a	Hornblende Granulite stringer in Quartzofeldspathic Gneiss
60b	Biotite Quartzofeldspathic Augen Gneiss
87a	Migmatite Quartzofeldspathic Gneiss broken up pods of amphibole
87b	Meta Conglomerate
249	Migmatite and meta Conglomerate? in Hornblende Gneiss
260a	Banded Quartzofeldspathic Gneiss
260b	Folds in Biotite Quartzofeldspathic Gneiss
273a	Fold in Quartzitic Gneiss within marble
273b	Folded Quartzitic Gneiss within marble
278a	
278b	
285a	Folds and mafic pods within Quartzofeldspathic Gneiss
285b	Garnet Biotite Quartzofeldspathic Gneiss, meta Conglomerate? w/amphibole bouden
286a	
286b	
294a	Hornblende Hypersthene spotted Granulite
294b	
296a	Isoclinal folds within Hornblende Gneiss
296b	Isoclinal folds in banded Hornblende Gneiss
297	Folded stringer within Hornblende Gneiss. Quartz pods and folded stringers within massive marble
299	Quartz pods and folded stringers within massive marble
320	Ultramafic within Hornblende Hypersthene Granulite
321	Hornblende pyroxene Granulite in fault
418	Hornblende Gneiss/Quartzofeldspathic Gneiss/Quartzitic Gneiss gradational contact
420	Meta Conglomerate? within Hornblende Gneiss
450a	Marble/Quartzofeldspathic Gneiss / Hornblende pyroxene Granulite contact
450b	Quartzofeldspathic Gneiss / Hornblende Hypersthene Granulite contact with foliation cut
453	Low marble outcrop
461a	Isoclinal folds in Hornblende Granulite
461b	Banded Iron formation Kelly area
467	"Cross bed" within Quartzofeldspathic Gneiss
477	Broken up amphibolite within migmatite
494a	Compositional layering in Quartzofeldspathic Gneiss
494b	Banded Biotite Quartzofeldspathic Gneiss
494c	Biotite Quartzofeldspathic Gneiss/Marble contact
494d	Meta Conglomerate
494e	Isoclinal folds in Hornblende Granulite

494f	Layering and parting in Marble
494g	Cross-cutting Pegmatite
494h	Isoclinal folds in Hornblende Gneiss
495a	Meta Conglomerate
495b	Quartzitic Gneiss and meta Conglomerate
496	Hornblende Gneiss / Quartzitic Gneiss contact
497a	Meta Conglomerate, graded bedding?
497b	Meta Conglomerate
497c	Meta Conglomerate
498	Garnet Biotite Quartzofeldspathic Gneiss
499a	Quartzitic Gneiss or folding in Garnet Biotite Quartzofeldspathic Gneiss
499b	Pegmatite?
499c	Pegmatite
501	Streaky Garnet Hornblende Gneiss
502a	Dark soil, ultramafic body
502b	Margin of Ultramafic body
503	Hornblende Garrnet Gneiss / Quartzofeldspathic Gneiss / Garnet Pyroxene Gneiss Hornblende Gneiss layered outcrop
505a	Marble / Quartzofeldspathic Gneiss / Hornblende Gneiss contact
505b	Banded Hornblende Gneiss
505c	Folding in Biotite Quartzofeldspathic Gneiss
505d	Isoclinal folding similar folding in Hornblende Gneiss
506	Anatexis in Quartzofeldspathic Gneiss
507	Hornblende Gneiss / Biotite Garnet Quartzofeldspathic Gneiss contact
508a	Meta Conglomerate in Hornblende Gneiss
508b	Quartzitic Gneiss
509	Panaroma across valley

Appendix 3: Samples by Station number

Sample			Station	
1MT	1	/	1	KS78
1MT	2 - 2A	/	4	KS78
1MT	3	/	60	KS78
1MT	5	/	64	KS78
1MT	6	/	67	KS78
1MT	7	/	69	KS78
1MT	8	/	70	KS78
1MT	9	/	72	KS78
1MT	10	/	74	KS78
1MT	11	/	81	KS78
1MT	12	/	83	KS78
1MT	13A-F	/	87	KS78
1MT	14	/	90	KS78
1MT	15A-B	/	96	KS78
1MT	16	/	102	KS78
1MT	17	/	103	KS78
1MT	18A-B	/	107	KS78
1MT	19	/	108	KS78
1MT	20	/	109	KS78
1MT	21	/	111	KS78
1MT	22	/	112	KS78
1MT	23	/	116	KS78
1MT	24A	/	118	KS78
1MT	25	/	122	KS78
1MT	26	/	125	KS78
1MT	27 - 27B	/	126	KS78
1MT	28A-B	/	131	KS78
1MT	29	/	141	KS78
1MT	30A-F	/	142	KS78
1MT	31	/	147	KS78
1MT	32	/	151	KS78
1MT	33	/	156	KS78
1MT	34	/	162	KS78
1MT	35	/	163	KS78
1MT	36	/	172	KS78
1MT	37	/	214	KS78
1MT	38	/	223	KS78
1MT	39	/	238	KS78
1MT	40	/	316	KS78
1MT	41	/	361	KS78
1MT	42	/	294	KS78
1MT	43	/	361	KS78
1MT	44	/	420	KS78

Appendix 4: Sample Collection Location map



Appendix 5: General mineral formulae:

Biotite:	K(Mg,Fe++)3AlSi3O10(F,OH)2
Phlogopite:	KMg3AlSi3O10(F,OH)2
Hornblende:	(Ca,Na)2-3(Mg,Fe,Al)5(Al,Si)8O22(OH,F)2
Tremolite:	Ca2(Mg5.0-4.5Fe2+0.0-0.5)Si8O22(OH)2
Muscovite:	KAl2(AlSi3O10)(F,OH)2, or (KF)2(Al2O3)3(SiO2)6(H2O)
Calcite:	(CaCO3)
Dolomite:	CaMg(CO3)2
Almandine:	Fe3Al2(SiO4)3
Plagioclase:	NaAlSi3O8 to CaAl2Si2O8)
Microcline:	(KAlSi3O8)
Diopside:	MgCaSi2O6
Hypersthene:	(Mg,Fe)SiO3
Chlorite:	(Mg,Fe++,Fe+++,Al)6(Si,Al)4O10(OH)8
Sillimanite:	Al2SiO5
Ilmenite:	FeTiO2
Hematite:	Fe+++2O3
Magnetite:	Fe3O4
Anthophyllite:	(Mg,Fe++)7Si8O22(OH,F)2
Cortierite:	(Mg,Fe++)2Al4Si5O18 usually Mg>Fe

Appendix 6: Petrographic Sample Analyses.

Sample: 1MT28B / 131KS78

Hand Specimen: Pegmatite

Grain Size:		
Color:	Pink	
Texture:	Graphic Qtz-K-spar Pegmatite Vein	
Mineral %:	Qtz	20%
	K-spar	80%

Thin Section:

Drawing:

Mineral	%	Properties:
Quartz	20	Strained, graphically intergrown into the K-spar grain
Microcline	79	One grain! All twinned, some fractures filled with plagioclase → perthite?
Plagioclase	1	Minor, sericite bearing, twinned
Biotite	tr	One grain

Texture: Igneous, a graphic quartz, microcline pegmatite vein.

Facies (equilibrium assemblage):

Sample: 1MT36 / 172KS78

Hand Specimen: Pegmatite

Grain Size:	3 mm to several cm
Color:	Pink
Texture:	Pegmatite, quartz grown graphically into k-spar with some associated plagioclase.
Mineral %:	Qtz 20%
	Plagioclase 5
	K-spar 75
	Muscovite tr

Thin Section:

Drawing:

Mineral	%	Properties:
Quartz	20	Strained, edges smooth to lobate
Plagioclase	5	One zoned large crystal with mymerkite radiating outward, rounded crystals to aggregates of small crystals, twinning present as in sericite.
K-spar	75	One large crystal, minor fracturing and defects.
Muscovite	tr	On four fractures and larger crystals associated with quartz.

Texture: Graphic intergrowths of strained quartz in K-spar. Plagioclase is twinned, zoned and contains some Mymerkite.

Facies (equilibrium assemblage):

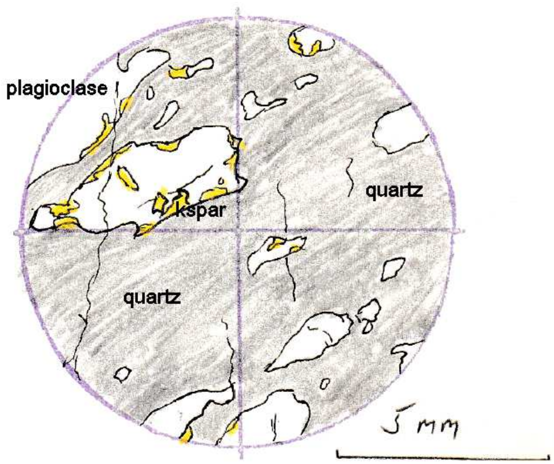
Plagioclase-Quartz-K-spar-Muscovite

Sample: 1MT05B / 64KS78

Hand Specimen: Plagioclase-bearing Quartzite

Grain Size:	1 – 8 mm	
Color:	Grey	
Texture:	Streaked out coarse grains of quartz and plagioclase parallel to foliation. Quartz dominates and the grains of plagioclase "float" in a quartz matrix. k-spar in minor, associated with the plagioclase, often on the quartz/plagioclase grain boundary and extending into the plagioclase grain.	
Mineral %:	Qtz	70%
	Plagioclase	25
	K-spar	3-5

Thin Section:



Drawing:

Etched and stained slab under reflected light. K-spar-yellow, plagioclase – white, quartz – grey.

Mineral	%	Properties:
Quartz	70	Large grains growing around and enclosing all others, ameboidal shaped.
Plag (An)	25	Largely sericitally altered.
Muscovite\ Sericite /	5	Secondary growth in plagioclase.
K-spar	1	Very small grains of microcline associated with plagioclase.

Texture: This rock is dominated by very large ameboidal, strained grains of quartz surrounding sercitically altered grains of plagioclase. The alteration is extensive and there are fairly large grains of muscovite associated with the sericite. Along the edges but growing into the plagioclase are small grains of microcline, irregularly shaped.

Facies (equilibrium assemblage):

Sample: 1MT30B / 142KS78

Hand Specimen:	Foliated, feldspar-bearing quartzite.		
Grain Size:		1 – 5 mm	
Color:		White - grey	
Texture:		Foliated, weakly defined by compositional layering. Lenses and stringers of k-spar and plagioclase stand out in an etched surface. This is essentially a foliated feldspar-bearing quartzite.	
Mineral %:		Qtz	90%
		Plagioclase	1-2
		K-spar	10

Thin Section:

Drawing:

Mineral	%	Properties:
Quartz	±90	Fine to coarse, elongate, ameboidal, strained, contains numerous small to medium inclusions..
Microcline	10	Perthetic, grid-twinned, augen to 7 mm, small rounded aggerates, albite exolved to the edges of many smaller grains.
Plagioclase	1-2	Twinned, moderately sercitized, aggregates form small layers parallel tp foliation and contain biotite and chlorite?.
Biotite	tr	Also as strings of crystals parallel to foliation included within quartz. Yellow/red, no preferred orientation, within plagioclase crystal aggregate.
Chlorite	tr	Green color, associated with biotite and plagioclase.
Hematite	tr	Red stain coating quartz mostly.
Zircon	tr	

Texture: Seriate grain size, quartz grains elongate, ameboidal with inclusions. Microcline tends to form rounded aggregates and augen, it is perthitic. Plagioclase tends to form elongate aggregates parallel to foliation and is moderately sericitized. Biotite appears as small inclusions in quartz parallel to foliation and randomly oriented within a plagioclase aggregate. Hematite forms coatings on grains and is concentrated mostly in one area.

Facies (equilibrium assemblage):

Quartz-plagioclase-microcline-biotite

Sample: 1MT33 / 156KS78

Hand Specimen: Plagioclase-bearing quartzite.

Grain Size:	1 – 2 mm		
Color:	Grey		
Texture:	Foliated, weakly defined by elongate, or strung-out crystals of plagioclase within the dominant quartz.		
Mineral %:	Qtz	90%	
	Plagioclase	9	
	Biotite \	1	
	Garnet /		

Thin Section:

Drawing:

Mineral	%	Properties:
Quartz	±90	Very large elongate crystals, strained, with irregular or interlobate edges. Medium crystals also contain inclusions of all other minerals.
Plagioclase	5	Moderate-strong sericite alteration, twinning, small rounded crystals within and between quartz crystals.
Sericite		Alteration in plagioclase.
Muscovite	tr	Fibrous to crystalline, $\gamma - \alpha$ 0.036, some is associated with the sericite.
Biotite	tr	Yellow/red-black, medium to fine grains parallel to foliation and in clumps, alteration to chlorite.
Chlorite	tr	Colorless/green pleochroism, fibrous to crystalline, anomalous blue colors.
Garnet	tr	Opaque, pinkish, alteration to chlorite.
Hematite	tr	Opaque, shiny to red, specular.
Rutile	tr	Rounded edges, square cross-section common.
Zircon	tr	

Texture: Very large grains of quartz elongate parallel to foliation, interlobate to rounded edges with inclusions of the other minerals. Biotite inclusions are small and oriented parallel to foliation. Plagioclase occurs mostly as rounded small to medium grains within and inbetween the quartz.

Clumps or aggregates of plagioclase + hematite + muscovite + biotite + garnet etc occur in two places between the quartz grains. Biotite and garnet are both altering to chlorite and plagioclase is altering to sericite.

Facies (equilibrium assemblage):

Plagioclase-Quartz-Biotite Muscovite possibly secondary

Sample: 1MT07 / 69KS78

Hand Specimen: Quartzofeldspathic Gneiss

Grain Size:	3 – 7 mm av, down to 0.5 mm	
Color:	Grey	
Texture:	Foliation defined by the elongation of grains and by layers of quartz and feldspar 3-10 mm thick. Garnets are associated with the quartz layers. Layers are not well defined and have very small lateral extent, no more than 3 to 4 times their thickness.	
Mineral %:	K-spar	40%
	Plagioclase	10-15
	Quartz	15
	Pink Garnet	1-2

Thin Section:

Drawing:

Mineral	%	Properties:
Quartz	45	Somewhat fractured, strain shadows common, grains elongate.
Microcline	40	Gridiron twinning, internal fracturing in larger grains, perthite exsolution along some edges.
Plagioclase	15	Anorhtite. Some Albite twins, sercitically altered except along edges touching the k-spar. Compositionally zoned?
Garnet	tr	Fibrous to crystalline, $\gamma - \alpha$ 0.036, some is associated with the sericite.
Biotite	tr	Small euhedral but fractured and broken.
Sericite	tr	Alteration in plagioclase (see above).
Hematite	tr	Red to opaque, along grain boundaries.

Texture: Seriate grainsize but roughly divided onto two sections. Layers of fairly large k-spar and large elongate strained quartz, and layers of moderately large to fine grained quartz + feldspar with microcline dominating. Grains here are equigranular, angular, and interlocking. Some myrmekite is present and wome grains are crushed and broken.

Facies (equilibrium assemblage):

Plagioclase-K-spar-Quartz, + Garnet ?

Sample: 1MT11 / 81KS78

Hand Specimen: Quartzofeldspathic Gneiss

Grain Size:	0.1 – 2 mm		
Color:	Grey - pink		
Texture:	Foliated, defined by elongate quartz crystals. Feldspar (Plag + K-spar) is also streaked out in aggregates and alternates with quartz.		
Mineral %:	Quartz	40%	
	Plagioclase	10-15	
	K-spar	40	

Thin Section:

Drawing:

Mineral	%	Properties:
Quartz	45	Very elongate, contains inclusions of k-spar and plagioclase, small to large ameboidal, especially on the ends.
Microcline	35	Gridiron twinning, perthite exolved out to edges of some grains.
Plagioclase	19	Minor plagioclase twinning, some sericite (1-2% of plagioclase) alteration, some mirmykite present. Most of the plagioclase has reaction rims next to k-spar and the sericite does not invade this. 20-85-90 (-).

Texture: Seriate grain sizes from coarse (usually quartz) to very fine (all minerals). The quartz in growing very elongate grains which grow around and enclose other grains. Some 120 ° grain junctions but not common. The plagioclase is mostly untwined though larger grains show it. Sericite is usually present. Bordering k-spar, the plagioclase shows a reaction rim and the sericite does not invade this. Most smaller grains are equigranular, all sizes growing together, enclosing each other and interstitial. Very distinctive, there should be a word for this!

Facies (equilibrium assemblage):

Quartz-Plagioclase-K-spar

Sample: 1MT12 / 83KS78

Hand Specimen: Quartzofeldspathic Gneiss

Grain Size:	0.1 – 2 mm
Color:	Grey
Texture:	Lineated defined by elongated quartz grains. Occasional associations of garnet + biotite, or just garnet porphyroblasts up to 5 mm, not seen in thin section.

Mineral %:

Quartz	40%
Plagioclase	50
K-spar	5-10
Garnet	tr
Biotite	tr

Thin Section:

Drawing:

Mineral	%	Properties:
Quartz	50	Strained, ameboidal with inclusions.
Plagioclase	45	Anorthite. Some plagioclase twinning, reaction rim next to k-spar. Some myrmekite, no sericite.
Microcline	5	Gridiron twinning.
Muscovite	tr	Alteration in plagioclase.
Garnet	tr	

Anorthite:

Section on (010) ⊥ to (001)
Looking down Z (pos BxA fig) ⊥ to γ
X direction ‖ to cleavage
Y direction ⊥ to cleavage
X and Y both lower than 1.550 index
Extinction measured against trace of 001 = 16.5
Bisectrix method (⊥ γ, a vs 001 = 16.5°) = An42
Cleavage flake method (⊥ 001, on 010, extinction Vs 001 = 16.5°) = An46

Texture: Seriate grain sizes with the largest being quartz. Quartz is ameboidal, embayed and with inclusions. This section cut normal to the lineation. K-spar, quartz and plagioclase are all grown together and all equant, angular to rounded. Cataclastic crushed grains.

Facies (equilibrium assemblage):

Quartz-Plagioclase-K-spar. Biotite, Garnet

Sample: 1MT05A / 64KS78

Hand Specimen: Quartzofeldspathic Gneiss

Grain Size:	1 – 5 mm
Color:	Pink
Texture:	Foliated as defined by elongation of quartz and feldspar grains, also somewhat layered in quartz/plagioclase rich and k-spar rich bands 3-10 mm thick. K-spar also forms pods or lenses that pinch out. Also defining the foliation are layers 1-2 mm thick of fine grained garnet.
Mineral %:	K-spar 40%
	Plagioclase 40
	Quartz 20
	Garnet 1-2

Thin Section:

Drawing:

Mineral	%	Properties:
Microcline	50	Gridiron twins, subgrain development?
Plagioclase	45	Anorthite. Albite twins, sericite alteration.
Quartz	5	Strain shadows.
Garnet	1	Pink to red (in dissecting microscope)
Sericite \	17	Alteration in plagioclase. In some places it has grown into large enough crystals to be seen as muscovite.
Muscovite/	tr	Alteration in plagioclase.
Biotite	tr	Black mica associated with garnet seen in the dissecting microscope.

Texture: Quartz grains are the largest and are elongate parallel to the foliation. They often enclose grains of feldspar. Strain shadows are commonly oriented parallel to the foliationas well. Microcline grains are smaller, seriate sizes and are fractured forming smaller grains under the stress. Plagioclase crystals are easily defined by the sericite alteration and plagioclase twinning in some of them. No garnet is present in the thin section.

Facies (equilibrium assemblage):

Quartz-Plagioclase-K-spar. Garnet, Biotite

Sample: 1MT02 / 04KS78

Hand Specimen: Quartzofeldspathic Gneiss

Grain Size:	1 – 5 mm	
Color:	Grey/Pink	
Texture:	Massive, coarse grained. Granular grains equigranular and there is little size variation. The rock weathers to pink.	
Mineral %:	K-spar	60%
	Quartz	40
	Garnet	1

Thin Section:

Drawing:

Mineral	%	Properties:
Quartz	35	Strained, seriate size range, larger grains tend to be ameboide, replacing other grains.
Microcline	30	Gridiron twins, perthite common and some grains have exolved the albite to the grain boundary.
Plagioclase	35	Anorthite. Albite twinning present, extensive sericite alteration.
Sericite	2	Alteration in plagioclase.
Almandine	1	Small broken garnet grains, slightly pinkish.
Zircon	tr	high birefringence, Z ^C parallel, uniaxial (+).
Hematite	tr	Bright red in reflected light. Grains interstitial to quartz grains.

Texture: Seriate grain size, especially in the quartz and k-spar. The grain boundaries are irregular. Quartz grains tend to be ameboide, growing into surrounding grains, mostly k-spar as it is the most abundant mineral. K-spar is dominantly microcline but perthite is common. Albite has been exolved to the edges of many grains. Plagioclase is also present, generally as smaller grains and contains sericite. Garnet grains are small (0.5-1 mm), rounded and fractured. A few are poikilitec but not commonly.

Facies (equilibrium assemblage):

Quartz-Microcline-Plagioclase-Garnet

Sample: 1MT14 / 90KS78

Hand Specimen: Quartzofeldspathic Gneiss

Grain Size:	0.1 – 1 mm		
Color:	Pink		
Texture:	Medium to fine grained, foliation defined by layers of garnet and/or quartz, 1-2 mm.		
Mineral %:	K-spar	35%	
	Quartz	30	
	Plagioclase	30	
	Garnet	3-5	

Thin Section:

Drawing:

Mineral	%	Properties:
Quartz	35	Strained, ameboide with inclusions, elongate grains present.
Microcline	35	Gridiron twinning.
Plagioclase	27	Twinning present, reaction rims. Sericite absent.
Biotite	tr	Alteration to chlorite.
Hematite	tr	
Zircon	tr	Uniaxial (+).
Apatite	tr	

Anorthite:

BxO (-) looking down X, $\perp$ to α

Extinction Vs 001 = 9.5°

Bisectrix method = An27

Texture: Seriate but not coarse grained. Interlocking, inclusions, embayed crystals, generally equant grains. Garnets are poikeoblastic and so is some quartz (larget grains). Two zircons, one rounded and one possibly euhedral. There is a trace of biotite that is all or partially antered to chlorite.

Facies (equilibrium assemblage):

Quartz-Plagioclase-Garnet-Microcline

Sample: 1MT18B / 107KS78

Hand Specimen: Quartzofeldspathic Gneiss

Grain Size:	0.1 – 5 mm	
Color:	Pink-Grey	
Texture:	Layered feldspar / quartz-feldspar 3-20 mm thick with garnet porphyroblasts 3-5 mm in diameter. Medium grained, roughly equant shaped grains.	
Mineral %:	Quartz	40%
	Plagioclase	35
	K-spar	20
	Garnet	1-3

Thin Section:

Drawing:

Mineral	%	Properties:
Quartz	45	Strained, ameboidal with inclusions, elongate, fine to coarse grains, seriate.
Plagioclase	35	Some plagioclase twinning present, fairly extensive sericite alteration. Reaction rims next to k-spar. 10% of plagioclase sericitized.
Microcline	16	Gridiron twinning. Some alteration to muscovite.
Garnet	4	Fractured grains.
Biotite	tr	Alteration to chlorite (or muscovite?).
Hematite	tr	Red to specular in reflected light.
Zircon	tr	Rounded fractured grains.

Texture: Seriate, equigranular, interlocking, ameboidal and included quartz grains, altered plagioclase and fractured garnet.

Facies (equilibrium assemblage):

Quartz-Plagioclase-K-spar-Garnet

Sample: 1MT16 / 102KS78

Hand Specimen: Garnet Quartzofeldspathic Gneiss

Grain Size:	0.1 – 5 mm		
Color:	Pink		
Texture:	Foliated, layers of feldspar and quartz ± garnet 1-10 mm thick. Quartz grains elongate parallel to foliation.		
Mineral %:	Quartz	40%	
	K-spar	30	
	Plagioclase	25	
	Garnet	2-3	

Thin Section:

Drawing:

Mineral	%	Properties:
Quartz	45	Strained, all sizes. Larger grains elongate, ameboidal with inclusions and embayed grains of feldspar.
Plagioclase	31	Albite twinning, moderate to extensive sericite alteration. Reaction rims and sericite-free next to k-spar. Some myrmekite.
Sericite	5	Alteration of plagioclase.
Microcline	20	Gridiron twinning. Larger grains may be fractured internally.
Garnet	3	Pink in thin section.
Biotite	tr	Mica, brown, yellow to black pleochroism, altering to hematite + chlorite.
Hematite	tr	
Chlorite	tr	Pleochroic green/clear.
Zircon	tr	Euhedral.
Rutile	tr	Uniaxial (+) Square end sections, colorless, extremely fine grained, high relief and birefingeance.
Apatite	tr	

Texture: Seriate grain sizes, interlocking, ameboidal quartz, plagioclase and k-spar grains. K-spar shows some fracturing in the larget grains, plagioclase has reaction rims next to k-spar.
There is a mica that is extensively altetred to hematite + possibly chlorite or chloritoid. Plagioclase is moderately altered to sericite with some muscovite forming.

Facies (equilibrium assemblage):

Quartz-Plagioclase-Microcline-Garnet

Sample: 1MT15A / 96KS78

Hand Specimen: Quartz Feldspar Gneiss

Grain Size:	0.5 – 5 mm	
Color:	White, Brown on weathered surface	
Texture:	Foliated as defined by bands of biotite plus red almandine garnet. Quartz forms some of the larger grains but is not prominent. Most grains 0.1-1 mm. Quartz-biotite-garnet layers 3-10 mm thick.	
Mineral %:	Quartz	25-35%
	Feldspar	70
	Biotite	1-2
	Garnet	1-2

Thin Section:

Drawing:

Mineral	%	Properties:
Microcline	40	Gridiron twinning.
Quartz	35	Slight to unstrained, replacing and enclosing other grains of k-spar.
Garnet	3	Pink, Poikilitic but not much there. Concentrated along a band/layer.
Biotite	tr	Associated with the garnet layer. Length shows strong absorption E/W. Shades of green to brown / black E/W.
Muscovite	tr	Interstitial to the Quartz and microcline and growing as sericite in some plagioclase. A secondary replacement along grain boundaries.
Plagioclase	20	Anorthite. Albite twinning, about 1% of plagioclase altered to seracite.
Zircon	tr	

Texture: Seriate grain sizes with the larger grains generally made up of quartz. Shapes are ameboide, fluted and highly irregular. Quartz is growing into and enclosing neighboring grains. Some of the plagioclase grains have myrmekite intergrowths. Garnet is in fragmental grains that are somewhat poikilitic but not much owing to their small size. Mostly surrounded by quartz. These are probably parts of once larger grains.

Biotite grains have ragged ends and clump together, possibly altering to chlorite.

In one place muscovite is growing interstitially to the quartz/k-spar grains, mostly among the k-spar. It is a secondary mineral, alteration of k-spar along grain boundaries.

Facies (equilibrium assemblage):

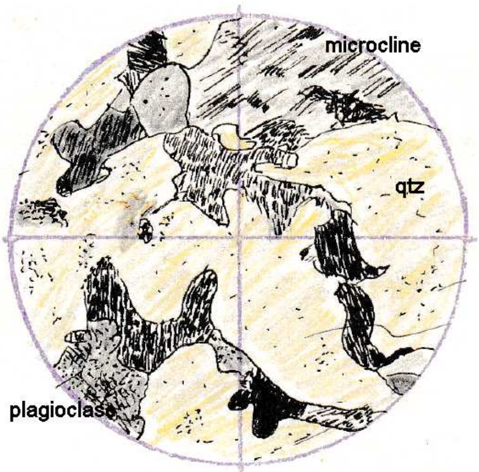
Microcline-Quartz-Garnet-Plagioclase

Sample: 1MT13A / 87KS78

Hand Specimen: Garnet bearing Quartzofeldspathic Gneiss

Grain Size:	1 – 2 mm		
Color:	White, with freckles of garnet		
Texture:	Medium grained, equigranular and layered. Layering is defined by the sub-euhedral garnet crystals.		
Mineral %:	Quartz	30-40%	
	Feldspar	50-60	
	Garnet	10	

Thin Section:



Drawing:

Mineral	%	Properties:
K-spar	30	Microcline-gridiron twinning common. Also perthetic k-spar.
Quartz	37	Straw yellow, slight to moderate undulose effect.
Plagioclase	20	Anorthite. Albite twinning rare, sericitically altered in part.
Garnet	7	Isotropic, pink color, poikilitic grains.
Zircon	tr	Rounded grains, high birefringence.
Magnetite	tr	Associated with the garnet layer. Length shows strong absorption E/W. Shades of green to brown / black E/W.
Myrmekite	tr	
Sericite	6	Alteration of plagioclase.
Apatite	tr	
Hornblende	tr	

Texture: Medium grained, sub-anhedral grains of quartz and feldspar intergrown with rounded edges. Grain size variable with the quartz forming some of the largest, (quartz growing and enveloping the other grains). They are growing into each other and within each other in lobate forms. Microcline being surrounded by quartz is most common.

The garnets are sub-euhedral and poikilitic with inclusions of microcline, quartz and plagioclase. Assuming that the sericite was originally plagioclase, the felsic composition falls into the minimum melting field for a granite.

Facies (equilibrium assemblage):

Plagioclase-Microcline-Garnet

Sample: 1MT27C / 126KS78

Hand Specimen: Quartzofeldspathic Gneiss

Grain Size:	0.1 – 3 mm	
Color:	Pink	
Texture:	Moderate to coarse grained, foliated as defined by extremely streaked out (long dimention 5 to 6 times the short) quartz and to a lesser extent feldspar also.	
Mineral %:	Quartz	35%
	Plagioclase	30
	K-spar	30
	Biotite ?	5

Thin Section:

Drawing:

Mineral	%	Properties:
Quartz	39	Small to large, extremely elongate and strained grains. Too long to be ameboidal, but some contain inclusions.
Microcline	35	Rounded to angular, numerous 120 ° triple grain junctions, seriate.
Plagioclase	25	Small to moderate sericite alteration (~5% of plagioclase), some plagioclase twinning.
Biotite	1	Small grains parallel to foliation.
Muscovite	tr	Associated with sericite.
Hematite	tr	Opaque, red in reflected light.
Rutile	tr	Uniaxial (+) on square end section.

Anorthite:

BxA (+) looking down Z, ⊥ to γ

Extinction Vs 001 = 6.0°

Bisectrix method = An33

Texture: Seriate grain sizes, quartz grains are very streaked out and microcline are recrystallized and show 120 ° triple grain junctions very commonly. Plagioclase also shows 120 ° junctions and it is somewhat altered to sericite.

Facies (equilibrium assemblage):

Quartz-Plagioclase-K-spar-Biotite

Sample: 1MT18A / 107KS78

Hand Specimen: Quartzofeldspathic Gneiss

Grain Size:	0.1 – 0.5 mm fine grained	
Color:	Grey	
Texture:	Gneissic compositionally layered 1-10 mm based on the presence or absence of biotite flakes. Biotite shows no preferred orientation.	
Mineral %:	Quartz	35%
	Plagioclase	35
	K-spar	30
	Biotite	1-3
	Garnet	tr

Thin Section:

Drawing:

Mineral	%	Properties:
Quartz	35	Slightly strained and fractured.
Microcline	28	Gridiron twinning.
Plagioclase	35	Albite twinning, minor to no sericite.
Biotite	2	Red-yellow to black, red on basal plane.
Garnet	tr	Pinkish broken grains.
Apatite	tr	

Anorthite:

BxA (+) looking down Z, $\perp$ to γ

Extinction Vs 001 = 5.0°

Bisectrix method = An32

Texture: Fine grained, very granular texture, layering shows best in hand sample where grey biotite-bearing layers stand out against white quartzofeldspathic layers. Biotite grains show no preferred orientation and therefore did not grow in a stressed environment.

Facies (equilibrium assemblage):

Sample: 1MT32 / 151KS78

Hand Specimen: Biotite-Bearing Quartzofeldspathic Gneiss

Grain Size:	0.5 (bio) – 4 (plag) mm
Color:	Grey
Texture:	Medium grained, foliated but not well layered. Rounded grains of plagioclase surrounded by quartz + biotite. K-spar forms minor augen (1.5 cm) and the foliation wraps around them.

Mineral %:

Quartz	30%
Plagioclase	30-40
K-spar	12-20
Biotite	10-15

Thin Section:

Drawing:

Mineral	%	Properties:
Biotite	3	Yellow to deep red-brown.
Plagioclase	34	Anorthite. Much sericitic alteration.
Quartz	25	Undulose.
Microcline	10	20~40° (-) Gridiron twinning present in some grains.
Muscovite	1	Plagioclase → Muscovite, Biotite → Muscovite.
Sericite	25	Whitish mica, plagioclase → sericite.
Chlorite	2	Biotite → Chlorite. Greenish with anomalous blue colors.
Apatite	tr	
Chlorotoid	tr	20 - 60° (+)

Texture: Massive, seriate grain sizes. Though in hand specimen the plagioclase forms the largest grains, this is not apparent in thin section. Most k-spar is grouped into bands parallel to foliation. Biotite is altering to muscovite and chlorite. It is mostly oriented parallel to foliation. Most of the quartz is strained and elongate grains are parallel to foliation. Plagioclase is altering to sericite and some muscovite. Grains are rounded, angular, or ameboide. Some triple-junctions, especially in k-spar groups, are 120° equiangular.

Facies (equilibrium assemblage):

High grade: Biotite-K-spar-Plagioclase-Quartz

Secondary: Chlotite-Muscovite-Quartz

Sample: 1MT28A / 131KS78

Hand Specimen: Quartzofeldspathic (Gneiss)

Grain Size:	0.5 – 2 mm	
Color:	Grey	
Texture:	Massive, equiangular with biotite in no preferred orientation.	
Mineral %:	Quartz	35%
	Plagioclase	35
	K-spar	30
	Biotite	1-2

Thin Section:

Drawing:

Mineral	%	Properties:
Quartz	35	Strained, ameboidal, mymerkitic.
Microcline	30	Twinned, mymerkitic.
Biotite	1-2	Yellow to red-black, felty, partially replaced by chlorite in a few grains.
Muscovite	tr	Variable relief, colorless.
Sericite	10	Extensive alteration in plagioclase.
Chlorite	tr	Biotite → Chlorite.
Zircon	tr	Pleochloric halos in biotite.
Plagioclase	25	Extensive sericitic alteration. Minor twinning, mymerkite reaction rims near k-spar.

Texture: Seriate, quartz is strongly ameboidal and contains inclusions. There is mymerkite developed along many plagioclase/microcline borders and other intergrowths between plagioclase and k-spar. All grain boundaries are highly irregular. There is much sericite alteration in the plagioclase. There are also inclusions of quartz within feldspar.

Facies (equilibrium assemblage):

Quartz-Plagioclase-Microcline-Biotite

Sample: 1MT17 / 103KS78

Hand Specimen: Quartzofeldspathic Gneiss

Grain Size:	0.1 – 1 mm
Color:	Pink-grey, layered
Texture:	Foliated, defined by lenses of quartz/feldspar about 7 mm thick maximum and several ca long before pinching. Otherwise quartz/feldspar/biotite. The biotite grains are not well aligned to the foliation.

Mineral %:

Quartz	40%
Plagioclase	30
K-spar	25
Biotite	5
Pink garnet	tr

Thin Section:

Drawing:

Mineral	%	Properties:
Quartz	40	Strained, some grains elongate parallel to foliation.
Microcline	24	Gridiron twinning.
Plagioclase	30	Albite twinning. No sericite.
Biotite	5	Pale brown/yellow to deep brown or black. Felty, no preferred orientation.
Garnet	1	Small broken grains.
Zircon	tr	
Apatite	tr	

Texture: Fine grained, foliation or layering is defined compositionally. Biotite does not show any preferred orientation and did not grow in a stressed environment. Quartz and feldspar grains are variable in size though never large, and grains are equant. In one place quartz shows some elongation parallel to foliation.

Facies (equilibrium assemblage):

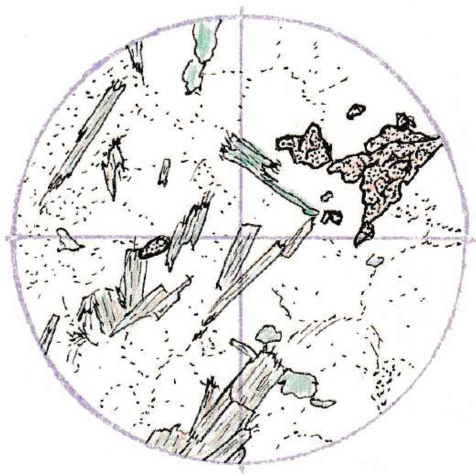
Quartz-Plagioclase-K-spar-Biotite-Garnet

Sample: 1MT01 / 1KS78

Hand Specimen: Biotite-Bearing Quartzofeldspathic Gneiss

Grain Size:	0.1 – 3 mm
Color:	Pink
Texture:	Banded (~1-2 mm think), light pink and white layers alternating with dark. Garnet bearing.
Mineral %:	Biotite %
	K-spar
	Garnet

Thin Section:



Drawing:

Mineral	%	Properties:
Biotite	5	Yellow/green (n/s), Black (e/w). Defines the foliation.
Microcline	30	Gridiron twinning.
Plagioclase	14	An25. Albite twinning. Some sericite alteration.
Sericite	11	
Quartz	40	Strain shadows.
Garnet	tr	Isotropic, pale pink color, severly embayed.
Zircon	tr	High $\gamma - \alpha$.
Mymerkite	tr	
Apatite	tr	Grey, low $\gamma - \alpha$, hexagonal end section.

Texture: Fine grained, >1 mm av. Foliated as defined by orientation of groups and bands of biotite crystals. Several garnets are present and are deeply embayed with inclusions of quartz, feldspar, and biotite. Plagioclase is myrmekitelly ingrown with quartz and there is much sericite alteration in it. Microcline is dominant and shows strong gridiron twinning.

Facies (equilibrium assemblage):

Biotite-Microcline-Plagioclase (An 25)

Sample: 1MT77 / 77KS78

Hand Specimen: Biotite-Bearing Quartzofeldspathic Gneiss

Grain Size:	0.1 – 0.5 mm
Color:	Pink to grey
Texture:	Foliated or lineated (difficult to tell) as defined by biotite flakes and elongation of quartz grains. Fine grained and granular, the biotite gives this rock a speckeled look. It it cut by a pegmatite vein.

Mineral %:

Biotite	10%
K-spar	30
Plagioclase	30
Quartz	30

Thin Section:

Drawing:

Mineral	%	Properties:
Quartz	35	Slightly strained.
Plagioclase	25	RI ~ 1.55, 2V near 90° (pos?). Albite twinning not common but present. No sericite.
Microcline	25	Gridiron twinning prominant.
Biotite	5	Yellow to black.
Rutile	tr	Square end section gives unaxial (+) figure, high relief.
Apatite	tr	Hexagonal end sections, low $\gamma - \alpha$.

Texture: Fine grained, weakly foliated or lineated. Equant grains. Seriate grain size distribution, but none get very large. Some of the larger grains of quartz or plagioclase tend to be ameboidal. Mostly locking or rounded grains.

Facies (equilibrium assemblage):

Plagioclase-K-spar-Quartz-Biotite

Sample: 1MT27B / 126KS78

Hand Specimen: Biotite-Bearing Quartzofeldspathic Gneiss

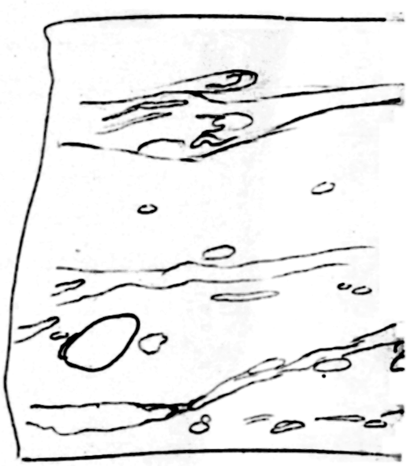
Grain Size: 0.1 – 1 mm, augen to 1 cm

Color: Grey

Texture: Fine grained, foliated as defined by biotite flakes with lenses and layers of quartz-feldspar up to 2 cm, but 3-5 mm average.

This rock strongly resembles a meta-sediment to me with pebbles up to 1 cm and a cross-bed. Possibly as arkose with felsic sand layers that are starting to form augen in places. The biotite wraps around augen and garnets.

Drawing:



Thin Section:

Drawing:

Mineral	%	Properties:
Quartz	30	Strained, elongated in felsic bands with strings of inclusions. 120° junctions.
Microcline	20	Gridiron twinning. 120° junctions.
Plagioclase	40	Minor twinning, 120° junctions. Moderate to little (10%) sericite alteration.
Biotite	10	Green-brown / yellow. Green/yellow near garnet. Grows into and wraps around garnet.
Garnet	1	
Apatite	tr	

Texture: Augen are aggregates of large equigranular plagioclase crystals with 120° junctions. Felsic layers consist of large elongate quartz grains plus plagioclase and microcline. The quartz is elongate, strained with trains of inclusions (biotite mostly) along foliation. The major part of the rock consists of biotite, equagranular quartz, plagioclase and microcline with a very slight tendancy to be elongate parallel to foliation. Poligonal to interlobate, 120° junctions common. Biotite becomes distinctly greenish next to the garnets.

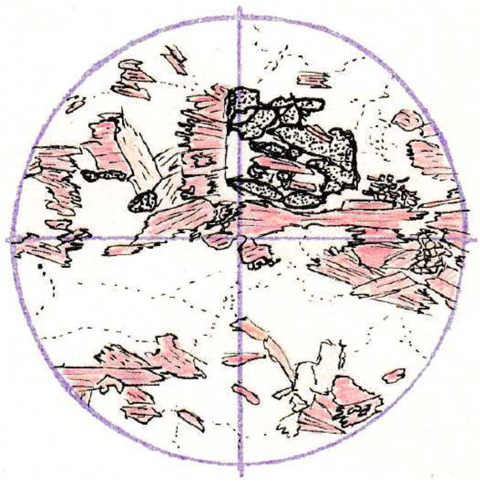
Facies (equilibrium assemblage):

Biotite-Garnet-K-spar-Plagioclase-Quartz

Sample: 1MT27J / 126KS78

Hand Specimen:	Garnet Biotite Quartzofeldspathic Augen Gneiss	
Grain Size:	0.1 – 7 mm	
Color:	Grey/black	
Texture:	Banded augen gneiss. K-spar augen ~7 mm to 2 cm. Mafic layers are garnet bearing and quartz-feldspar layers contain the augen. Layers 3-10 mm thick.	
Mineral %:	Quartz	40%
	Plagioclase	25
	K-spar	10-15
	Biotite	10
	Garnet	10

Thin Section:



Drawing:

Mineral	%	Properties:
Quartz	40	Elongate parallel to foliation and bent arouns augen, ameboidal with inclusions.
Microcline	15	Gridiron twinned, perthite common, the augen show strain shadows, 120° junctions.
Plagioclase	25	Some plagioclase twinning and sericite alteration (~2% of plag). 120° junctions.
Biotite	13	Yellow / brown-red. Small grains parallel to foliation. In equilibrium with garnet. Shows some wormy intergrowths of plagioclase on edges of some grains.
Garnet	7	Small grains, broken, associated with biotite layers. Garnet grows around biotite or both grow in equilibrium.
Zircon	tr	Halos in biotite.

Texture: Banded, layers of quartz plus feldspar 1-15 mm thick with augen of k-spar, strained, interlayered with biotite/garnet rich layers. Garnets grow around and include biotite grains and show no disequilibrium textures. The biotite has fairly common wormy intergrowths of k-spar or plagioclase either on the edges or all

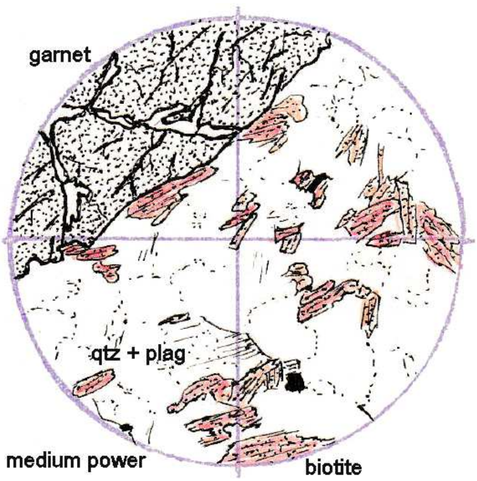
through the grain. Not associated with garnet/biotite contacts, it seems to be more probably a disequilibrium with the temperature/pressure conditions in the rock.
Quartzofeldspathic layers have 120 ° triple junctions, elongate and strained quartz and a seriate grain size distribution.

Facies (equilibrium assemblage):
Garnet-Biotite-Plagioclase-K-spar-Quartz

Sample: 1MT03 / 60KS78

Hand Specimen:	Garnet Biotite Quartz Feldspar Gneiss	
Grain Size:	0.5 – 10 mm	
Color:	Grey/pink	
Texture:	Fine to very coarse grained, banded with thin layers (1 mm) of mostly biotite and thick layers (5-15 mm) of quartz plus feldspar and garnet. The garnets are pink and round 2-10 mm in diameter. This contains a lens about 2cm thick of quartz ± feldspar with minor garnet.	
Mineral %:	Quartz	20%
	Plagioclase	40
	Biotite	20
	Garnet	20

Thin Section:



Drawing:

Mineral	%	Properties:
Quartz	30	Strain shadows. Forms larger crystals.
Plagioclase	39	Relief slightly higher that for quartz, no sericite alteration.
K-spar	1	Very low relief (<plag) and small grains, interstitial to most others. Some gridiron twinning.
Garnet	10	Large grains ~1-5 mm, well formed, slightly poikilitic.
Biotite	20	Very pale to dark red, orientation defines the foliation. In equilibrium with garnet.
Zircon	tr	High $\gamma - \alpha$ and forms halos in biotite.
Hematite	tr	Red in reflected light.

Texture: Seriate grain sizes with garnet porphoryoblasts. Garnets are well formed and somewhat poikiletic. The biotite crystals bend around and are partially included in some garnets. Biotite defines the foliation.

Quartz grains are larget usually and the edges are somewhat lobate, but not commonly so. Plagioclase grains are smaller on the average. The quartz/plagioclase grains are subrounded, seriate, and granulitic. Some of the boundaries around the plagioclase are accented wioth biotite (?).

K-spar grains are very small and always interstitial between the quartz and plagioclase.

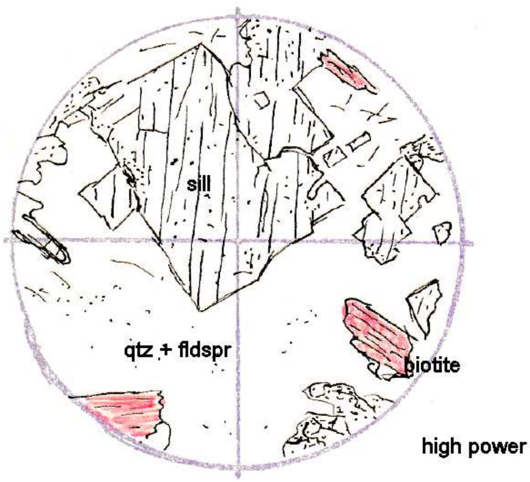
Facies (equilibrium assemblage):

Garnet-Biotite-K-spar-Plagioclase-Quartz

Sample: 1MT27G / 126KS78

Hand Specimen:	Biotite Garnet Quartzofeldspathic Gneiss	
Grain Size:	1 – 5 mm	
Color:	Grey	
Texture:	Banded and foliated. Felsic layers 1-3 mm, contain quartz and feldspar, vary in thickness and are wavy. Mafic bands contain quartz, feldspar, biotite and garnet porphryoblasts. Garnets are pink and 3-5 mm across.	
Mineral %:	Quartz	40%
	K-spar	30
	Biotite	20
	Garnet	10

Thin Section:



Drawing:

Mineral	%	Properties:
Biotite	15	Very pale yellow (n/s), red/brown (e/w).
Sillimenite	tr-1	2V ~ 30° (+). Good end sections.
Garnet	15	Moderate to un-poikioblastic, euhedral, pinkish.
Quartz	35	Grains equigranular to elongate parallel to foliation and undulose. Angular boundaries.
K-spar	35	pethitic mostly, some grains have gridiron twins.
Plagioclase	tr	Minor on stained slab.
Muscovite	tr	
Chlorite	tr	
Hematite	tr	Red in reflected light.
Zircon	tr	High $\gamma - \alpha$ and forms halos in biotite.

Texture: Granular texture, seriate grain size. Quartz grains are elongate parallel to the foliation in places. Biotite forms the major foliation and they wrap around the garnets that grow to 5 mm as poikioblastic euhedral grains. Partly associated (this may be more apparent than real) with the biotite is fairly coarse grained sillimenite (which is still very fine grained compared to the other minerals). In this section nearly all of the sillimenite crystals are seen on end, thus defining a lineation on the foliation. Some of the k-spar is strongly perthitic.

Facies (equilibrium assemblage):

K-spar-Sillimenite-Garnet (Alm)-Biotite ?

Sample: 1MT05C / 64KS78

Hand Specimen: Biotite Plagioclase Gneiss

Grain Size:	0.1 – 3 mm, Garnets up to 7-8 mm	
Color:	Grey	
Texture:	Foliation defined by orientation of biotite, and by slight compositional layering. Medium to fine grained with a few garnet porphyroblasts. Grains are rounded and mostly around the same size.	
Mineral %:	Biotite	25%
	Quartz \	70
	Plagioclase /	
	K-spar	1-2
	Garnet	5

Thin Section:

Mineral	%	Properties:
Biotite	20	Tan to red/brown. Seems to be altered in places parallel to C-axis and not pleochroic. Altered biotite is associated with a band of altered plagioclase.
Plagioclase	75	An20. 2V~80°, RI~1.54. Fairly extensively (to 10%) altered to sericite.
Sericite	/	Alteration in plagioclase.
Quartz	1	Strain shadows. These grains are very small and can be seen most easily by their similar relief and cleaner "look" than plagioclase.
Garnet	1-2	Does not seem to be in equilibrium with biotite. See 1MT04. Pink in hand specimen.
Zircon	tr	
Apatite	tr	
Hematite	tr	
Chlorite	3	Secondary alteration in biotite, associated with extensive sericitization in plagioclase.
K-spar	tr	Visible in stained slab, but I do not recognize it in thin section.

Texture: Moderately fine grained and foliated as defined by biotite. Plagioclase equigranular and rounded. Biotite is not in equilibrium with garnet. Some alteration is present in a layer parallel to foliation causing secondary alterations in biotite and plagioclase.

Facies (equilibrium assemblage):

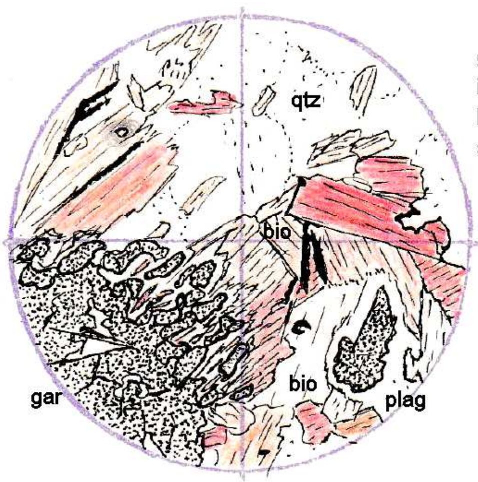
Biotite-Plagioclase-Quartz-Ksapr(?)

Sample: 1MT04 / 62KS78

Hand Specimen:	Garnet-bearing Biotite Quartz-Feldspar Gneiss	
Grain Size:	0.5 – 1 mm, augen to 15 mm.	
Color:	Black with cream colored augen (plag)	
Texture:	Foliated, defined by orientation of elongated quartz grains and biotite grains. It is garnet bearing and also has large (1.5 cm) augen of plagioclase. Garnets 3-7 mm.	
Mineral %:	Quartz	40%
	Plagioclase	45
	Garnet	3-5 pink
	Biotite	10

Thin Section:

Drawing:



garnet / biotite intergrowths, biotite and garnet separated by plagioclase

medium power

Mineral	%	Properties:
Quartz	35	Elongate parallel to foliation with strain shadows.
Plagioclase	40	An. 2V~80°, Much alteration (to 10%) to sericite.
Sericite	/	Alteration in plagioclase.
Garnet	5	Pinkish, isotropic, poikiolitic.
Biotite	20	Biotite altering to chlorite. Also, biotite is interfingering into garnet, but is everywhere separate from garnet by a rim of plagioclase.
Zircon	tr	Halos in biotite. High $\gamma-\alpha$.
Chlorite	tr	Secondary alteration in biotite.
Magnetite	tr	Skeletal grains between biotite.
Muscovite	tr	Clear, micaceous, variable relief.

Texture: Medium to fine grained, seriate size distribution of quartz and plagioclase. Quartz forms elongate crystals and interlocking aggregate layers parallel to foliation. It is mostly strained.
Plagioclase is highly sericitically altered in places, especially in the pods of plagioclase crystals. Pods, or lenses stretched out parallel to foliation.

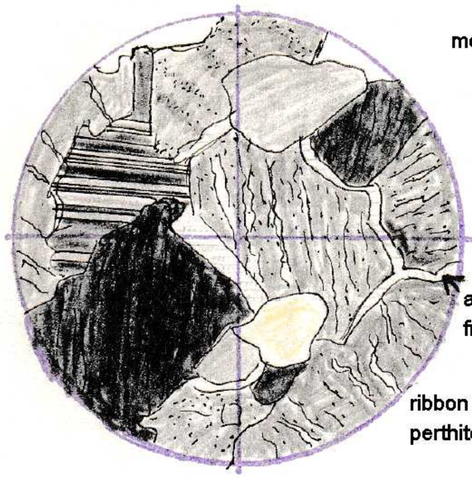
The reaction Biotite → Plagioclase + Garnet (Alm) is evidenced by intergrowths of garnet and biotite where they are separated by plagioclase, see drawing.
In a few places the biotite seems to be altering to chlorite, perhaps chlorite + muscovite (to account for the potassium).

Facies (equilibrium assemblage):
Garnet-Quartz-Plagioclase

Sample: 1MT13D / 87KS78

Hand Specimen:	Hornblende Quartzofeldspathic Gneiss	
Grain Size:	1-5 mm.	
Color:	White/yellow with black hornblende	
Texture:	Foliated, poorly defined by hornblende pods and crystals. Felsic minerals equant and granulated. Some tendancy for more elongate grains to be oriented to foliation.	
Mineral %:	Hornblende	5-10%
	Quartz	20-30
	Feldspar	60-70

Thin Section:



Drawing:

Mineral	%	Properties:
Hornblende	10	Green / brown.
Biotite	tr	Red/black to yellow absorbtion. Corroded slightly on edges.
Quartz	30	Undulose extinction. Invading and engulfing other minerals.
Plagioclase	35	(An) Albite twinning common.
Seracite	tr	About 1% of plagioclase altered to seracite.
K-spar	25	Perthitic.
Albite	tr	Exolved to the edges of many k-spar grains.
Zircon	tr	Rounded grains, uniaxial (+).
Rutile	tr	Tetrahedral grains, uniaxial (+), TiO_2.
Apatite	tr	

Texture: Seriate grain size and intergrown ameboide quartz grains engulfing feldspar. Some quartz grains are severly strained and aligned along the foliation. Quartz growth is also replacing the hornblende.

K-spar is strongly perthitic and many grains are rimmed by exolved albite.

Facies (equilibrium assemblage):
K-spar-Plagioclase-Hornblende

Sample: 1MT13B / 87KS78

Hand Specimen:	Hornblende Quartzofeldspathic Gneiss	
Grain Size:	0.5-4 mm.	
Color:	White	
Texture:	Medium grained with larger (2-6 mm) grains of hornblende. Foliated as defined by hornblende and garnet and by elongation of felsic grains.	
Mineral %:	Hornblende	5%
	Quartz	30-35
	Feldspar	60
	Garnet	2-3

Thin Section:

Drawing:

Mineral	%	Properties:
Quartz	34	Straw yellow and undulose.
Plagioclase	30	Albite twinning and sericite (1%) alteration.
Orthoclase	25	Dusty, very low relief. Some 70-80° (-), perthite?.
Hornblende	10	Brown / green.
Biotite	tr	Red / orange.
Zircon	tr	
Apatite	tr	
Garnet	1	(not seen in thin section)

Texture: Grain sizes seriate from <0.1 to 5 mm. Mostly quartz / feldspar intergrowths with little crystal shape (mostly anhedral). The hornblende is together in clumps and the grains well formed.

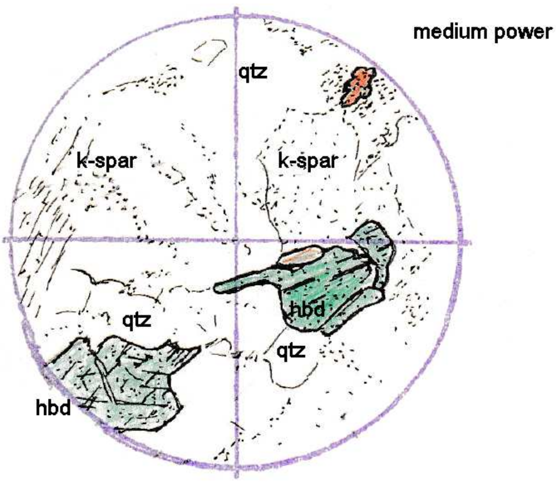
Facies (equilibrium assemblage):

Plagioclase-K-spar-Hornblende-Garnet

Sample: 1MT13F / 87KS78

Hand Specimen:	Hornblende Quartzofeldspathic Gneiss
Grain Size:	1-3 mm.
Color:	Banded black and tan/white.
Texture:	Foliated and layered. Layers defined by hornblende bands but these layers do not pass all the way through the rock. Layers 1-20 mm thick.
Mineral %:	Hornblende 25%
	Quartz
	Feldspar
	Plagioclase

Thin Section:



Drawing:

Mineral	%	Properties:
Hornblende	17	Green/yellow to brown/green. Amphibole cleavage.
Quartz	40	Slight to unstrained, growing around other minerals.
K-spar	13	Perthite with albite exolved to rims around many grains.
Plagioclase	30	(An). +Albite exolved from k-spar.
Sericite	tr	Alteration of plagioclase, <1%.
Biotite	tr	
Rutile	tr	Tetrahedral, uniaxial (+).
Apatite	tr	
Magnetite	tr	
Zircon	tr	

Texture: Grains intergrown with rounded grain boundaries. Mineral growth taking place along boundaries and perhaps within other grains. Quartz is growing around and enveloping crystals of feldspar and hornblende. The quartz is growing at the expense of the other minerals. Growth begins along grain boundaries.

The k-spar is perthitic with rims of albite having exolved completely out of the crystal.

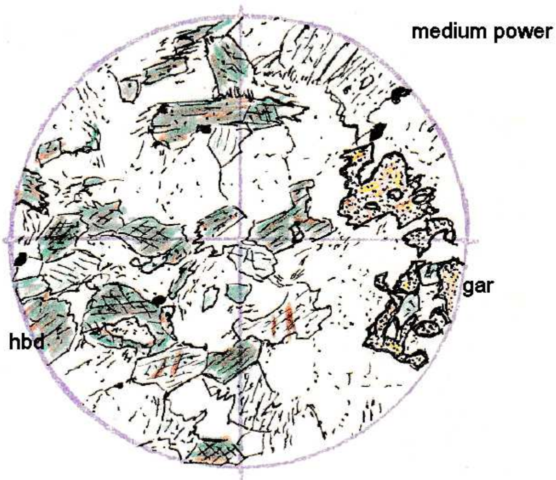
Lots of ion mobility, especially silica which is replacing everything else.
Plagioclase → Quartz
K-spar → Quartz
Hornblende → Quartz

Facies (equilibrium assemblage):
Plagioclase-K-spar-Hornblende

Sample: 1MT09 / 72KS78

Hand Specimen:	Garnet Hornblende Clinopyroxine Quartz Feldspar Gneiss
Grain Size:	<1-2 mm
Color:	Black
Texture:	Foliated with bands of felsic minerals <1 to 3 mm thick. Garnets are pink and found only in the mafic bands.
Mineral %:	Hornblende 30-35%
	Garnet 15-20
	Quartz 10
	Feldspar 40

Thin Section:



Drawing:

Mineral	%	Properties:
Hornblende	15	B dark brown/green A pale yellow/green C dark green [Ca2Na(MgFe++,Fe+3Al)5(Si6Al2)O22(OH,F)2].
Plagioclase	40	(An).
Sericite	3	Alteration of plagioclase.
Quartz	15	
Diopside	15	(Augite?) 2V~55-60(+), Z^C 41°, Bi 0.025. Very pale yellow/green to pale blue/green. [CaMgSi2O6-Ca(MgFe++)Si2O6]
Garnet	10	Isotropic, pale pink.
Apatite	tr	
Opaques	2	

Texture: Fine grained (0.1 mm) and equigranular, (the opaques are generally about ¼ the size of the rest). Foliation is defined by bands of quartz plagioclase surrounded by dominant hornblende. Pyroxene is dominant in-between the bands and the garnets are

scattered. Most hornblende crystals are lineated (mostly end sections). The diopside is forming from ? hornblende.
Grains are equidimentional and not oriented with respect to the foliation. Good 120° triple junctions in-between diopside grains, plagioclase and diopside + opaques.

Facies (equilibrium assemblage):
Hornblende-Plagioclase (An28)-Diopside/Almandine

Sample: 1MT30A / 142KS78

Hand Specimen:	Biotite Garnet Quartzofeldspathic Hornblende Gneiss
Grain Size:	0.5-5 mm
Color:	Grey
Texture:	Layered (mafic and felsic rich) and foliated. Large porphyroblasts of garnet (red) confined mostly to the mafics. Augen are forming in the felsic layer. Felsic layers are 1-5 mm thick.

Mineral %:		
	Hornblende \	30-40%
	Biotite /	
	Quartz \	50-60
	Feldspar /	
	Garnet	5-10

Thin Section:

Drawing:

Mineral	%	Properties:
Hornblende	20	β dark green/brown, α light yellow, γ dark green.
Biotite	7	NS – yellow, ew dark red/brown.
Garnet	8	Seive texture to very broken up. Pinkish.
Quartz	30	Strain shadows common. Grains elongate parallel to foliation.
Plagioclase	35	Albite twins, sericite alteration, 2V~80°(+) (labrodorite?).
Sericite	tr	Alteration of plagioclase, ~1%..
Apatite	tr	
Hematite	tr	Opaque, red in reflected light.

Texture: Inequigranular with grains in the felsic bands much larger than in the mafic. Garnets are porphryoblastic and poikioblastic.
The foliation as defined by elongate quartz, biotite and hornblende wraps around the garnet. Grain shapes in the felsic layers are elongate parallel to foliation, irregular, interfingering to ameboide. Biotite generally euhedral, hornblende sub to euhedral. Biotite and garnet in equilibrium.

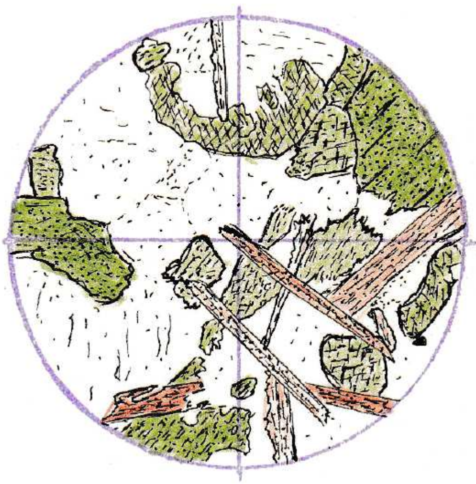
Facies (equilibrium assemblage):

Biotite-Hornblende-Plagioclase-Garnet

Sample: 1MT13E / 87KS78

Hand Specimen:	Hornblende Quartzofeldspathic Gneiss
Grain Size:	0.5-5 mm
Color:	Pink to black
Texture:	Foliated and layered 2 mm to 2cm+ with hornblende porphyroblasts in the felsic layers and hornblende dominant in the mafic layers.
Mineral %:	Hornblende 20%
	Quartz 25
	Plagioclase 25
	K-spar 30

Thin Section:



Drawing:

Mineral	%	Properties:
Hornblende	20	Pale to dark olive green.
Biotite	tr	Yellow to deep brown.
K-spar	30	Strongly perthitic, exsolution within (perthite) and to the edges of grains (albite).
Quartz	30	large, ameboidal grains with inclusions to small equant grains.
Plagioclase	20	Twinning present but not common. Somewhat more common with hornblende due to absence of quartz and k-sapr. Some myrmikite also.

Texture: Foliation not seen in thin-section, biotite grains randomly oriented as are hornblende. Seriate grain size distribution. Quartz grains ameboidal, lobate and with inclusions. K-spar strongly prthitic both within and albite is exolved to the edges. Plagioclase has minor sericite and reaction edges next to k-spar.

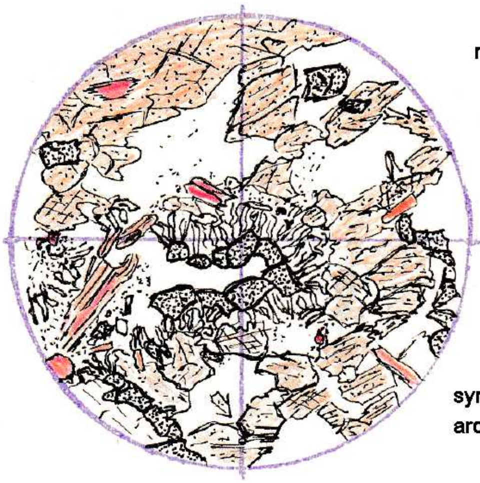
Facies (equilibrium assemblage):

Biotite-Hornblende-Quartz-Plagioclase-K-spar

Sample: 1MT19A / 108KS78

Hand Specimen:	Quartz rich Garnet Diopside Hornblende Gneiss	
Grain Size:	0.1-2 mm	
Color:	Grey to black	
Texture:	Granular, massive with a quartz-feldspar vein running through.	
Mineral %:	Hornblende	25%
	Garnet	
	Quartz	30
	Plagioclase	30

Thin Section:



Drawing:

Mineral	%	Properties:
Garnet	10	Extensively fractured with some quartz inclusions. Not in equilibrium with biotite.
Biotite	2	Yellow to deep red.
Hornblende	18	Yellow α, brown β, brown γ. γ-α 0.022, Z^C 25°, 80°(-).
Diopside	5	Z^C 19°, γ-α 0.022, 2V55°(+), colorless.
Plagioclase	30	Albite twinning, sericite alteration moderate ~2%.
Quartz	35	Strained, ameboidal with inclusions, some 120° grain junctions.
Magnetite	tr	Opaque, shiny in reflected light.
Apatite	tr	
Zircon	tr	Uniaxial (+), very high γ-α.

Texture: Hornblende grains are largest along with quartz, everything elas moderate to fine grained, massive, granular. Quartzofeldspathic vein shows typical seriate, ameboidal, interlocking grains but without any k-spar. Hornblende – garnet dominate the rest of the rock. Garnet fractured, small crystals some with inclusions of quartz or plagioclase (plagioclase grains are ‘ringed’ by garnet in several places). Garnet commonly shows dis-equilibrium features, especially in the presence of biotite. Features are wormy intergrowths along the edges.

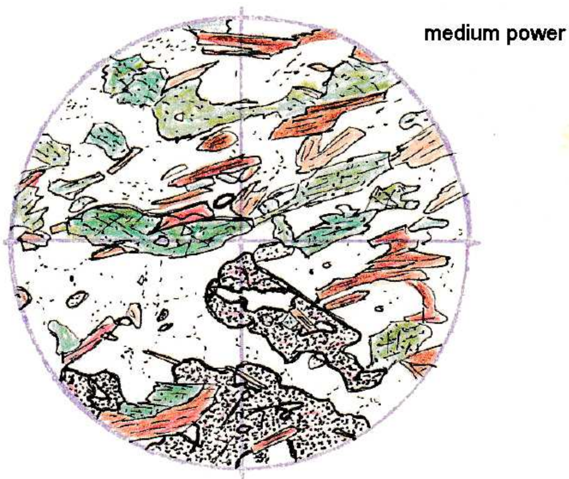
Facies (equilibrium assemblage):

Hornblende-Diopside-Garnet-Quartz-Plagioclase

Sample: 1MT30C / 142KS78

Hand Specimen:	Garnet Biotite Hornblende Quartzofeldspathic Gneiss
Grain Size:	0.5-1 mm
Color:	Black, layered
Texture:	Layered and foliated bands of quartz about 3-4 mm and contain k-spar. Generally very fine grained. Contains pink almandine garnet, especially in dark parts.
Mineral %:	Hornblende 40% Quartz \ 60 Plagioclase / K-sapr Garnet

Thin Section:



Drawing:

Mineral	%	Properties:
Hornblende	30	Green/dark green/dark green brown. Elongate parallel to foliation.
Biotite	10	Yellow, red/brown/black.
Garnet	8	Pink, sieve texture.
Plagioclase	20	An, sericite alteration moderate ~2%.
Sericite	tr	
Quartz	27	Some grains elongate and parallel to foliation, undulose.
K-spar	5	
Apatite	tr	
Hematite	tr	
Zircon	tr	

Texture: Strongly foliated, defined by parallel orientation of hornblende, biotite and elongate quartz grains. Some garnet is also stretched with trains of inclusions parallel to foliation. Garnets have a sieve texture but are too irregular to see patterns in the inclusion arrangement. Garnets are confined to the mafic bands (~50% mafics). Foliation wraps around the garnets.

Facies (equilibrium assemblage):
Hornblende-Biotite-Garnet-Plagioclase

Sample: 1MT35 / 163KS78

Hand Specimen:	Diopside Garnet Hornblende Plagioclase Gneiss		
Grain Size:	1-3 mm		
Color:	Grey-black.		
Texture:	Strongly lineated, defined by hornblende crystals and plagioclase streaks. Hornblende crystals only slightly longer than they are wide but definitely lineated.		
Mineral %:	Plagioclase	50% +	
	Hornblende	50 -	
	Garnet	tr	

Thin Section: Cut normal to lineation.

Drawing:

Mineral	%	Properties:
Plagioclase	50	Uniform and twinned, some zoning, very minor sericite.
Garnet	10	Pinkish, sieve to massive, numerous wormy intergrowths and disequilibrium textures with hornblende.
Hornblende	35	α–γ pale green, β –olive green brown., γ-green.
Diopside	5	2V50-60° (+), Re 0.025-0.026, colorless, γ–α
Hematite	tr	
Apatite	tr	
Biotite	tr	Yellow/red pleochroism, looks like an alteration mineral.

Texture: Seriate grain size, hornblende grains largest. Plagioclase crystals mostly equant with common 120° triple junctions. Hornblende equant to elongate, mostly end or nearly end sections. An euhedral, in equilibrium with diopside but possibly not in equilibrium with garnet. Garnet grains are massive to sieve textured, generally they are very irregular in shape with wormy intergrowths separations from hornblende. Hornblende and garnet are in contact elsewhere.

Diopside plus garnet are in equilibrium as evidenced by grains in contact and in one place at least there is a 120° boundary between two diopside and a garnet grain, sharp contact.

NO Quartz.

Facies (equilibrium assemblage):

Plagioclase-Hornblende-Diopside-Garnet?

Sample: 1MT31 / 147KS78

Hand Specimen:	Hornblende Quartzofeldspathic Gneiss	
Grain Size:	0.1-2 mm	
Color:	Black.	
Texture:	Foliated, banded with lenses and stringers of quartz plus feldspar 1-10 mm but variable in thickness along their length. Some garnet bearing layers also occur but are hard to see.	
Mineral %:	Hornblende	40% +
	Quartz	20 –
	Plagioclase	40
	Garnet	tr-1

Thin Section:

Drawing:

Mineral	%	Properties:
Quartz	20	Uniform, some strained.
Plagioclase	38	Plagioclase twinning common, minor sericite, some zoning present.
Hornblende	40	β green/brown, α pale green, γ green. 2V70-80°(-), twinning present.
Diopside	tr	Z^C 41°, 2V60°(+), $\gamma-\alpha$ 0.026, colorless.
Garnet	2	Seive textured, pinkish.
Apatite	tr	
Magnetite	tr	
Biotite	tr	Yellow/red elongate ragged fibrous crystals, only a few.
Sericite	tr	

Texture: Foliated with layers of quartz and plagioclase 1-5 mm thick. Foliation is only weakly defined by the hornblende, but an abundance of end sections is evidence for foliation and possibly a lineation.

Hornblende grains, especially larger ones contain inclusions (rounded) and all the biotite grains are associated with hornblende and growing within the hornblende. That is, hornblende is growing around the biotite. The biotite grains are ragged, splintery with some wormy intergrowths of quartz or plagioclase. Garnets are sieve textured but show no evidence of rotation during growth.

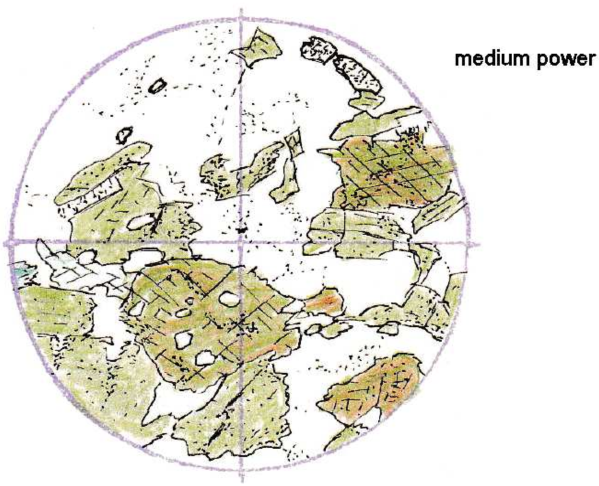
Facies (equilibrium assemblage):

Quartz-Plagioclase-Hornblende-Garnet

Sample: 1MT06 / 67KS78

Hand Specimen:	Banded Amphibolite	
Grain Size:	0.1-0.5 mm	
Color:	Black, streaked with white.	
Texture:	Foliated, defined by hornblende, may be lineated. Also contains streaked out plagioclase grains and some pink garnet (minor). Quartz in present, perhaps in minor amounts. Plagioclase staining shows up trace amounts of k-spar. Plagioclase plus quartz forms layers parallel to foliation and generally segregating the felsic grains from the hornblende.	
Mineral %:	Hornblende	60%
	Plagioclase	35
	Quartz	3-5
	Garnet	1-3

Thin Section:



Drawing:

Mineral	%	Properties:
Hornblende	60	β brown, olive green, α pale green, γ green. Grains prisms to end sections, poikikitic with inclusions of quartz, rounded.
Plagioclase	40	An42. Sericitized in places. RI~1.54, 2V~85-90°(-).
Quartz	1-2	Small grains mostly near hornblende.
Garnet	1	pinkish, sieve textured and broken grains.
Magnetite	1	Clumps associated with hornblende.
Apatite	tr	Grey, hexagonal end sections to short prisms.
?	tr	One small grain, γ–α ~0.025, high relief, parallel extinction.

Anorthite:

BxA (+) looking down Z, ⊥ to γ

Extinction Vs 001 =

Bisectirx method = An42

Texture: Foliated defined by elongation of hornblende prisms and plagioclase layers. Both prisms and end sections are visible so there is no lineation present. Some layers of fairly extensive secondary sericitization in plagioclase pass through the rock parallel to foliation. Plagiclase grain boundaries commonly show 120° junctions indicating equilibrium conditions during growth. Garnets are poikeioblastic with numerous small inclusions of quartz, plagioclase and hornblende. Garnets are not wel formed and are broken and elongate parallel to foliation.

Facies (equilibrium assemblage):

Hornblernde-Plagioclase-Garnet

Sample: 1MT34 / 162KS78

Hand Specimen: Amphibolite

Grain Size: 0.1-3 mm

Color: Black

Texture: Foliated with a quartz feldspar layer bent back on itself, more properly a lineation then.

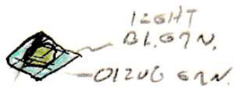
Mineral %:

Hornblende	50%
Plagioclase	40
Quartz	10
Garnet	tr

Thin Section:

Drawing:

Mineral	%	Properties:
Quartz		Unrecognizable in thin section, present on etched chip.
Plagioclase	25	Twinning common, sericite moderate to extensive. Deformed twins.
Sericite	10	Alteration in plagioclase.
Hornblende	60	α yellow , β brown, , γ brown to green/brown. Blue-green near garnet. Crystals zoned along long axis, olive in core, light blue-green near edges.
Garnet	2	Pinkish, poikilitic, wormy intergrowths. Hornblende is blue-green in the presence of garnet and there are disequilibrium textures present.
Diopside	1	Z^C~39°, γ–α 0.025, 2V50-60°(+), colorless, RI 1.67-1.68~
Epidote	1	γ–α 0.021, Z^C23°, high relief, colorless, anomalous bleu colors, 2V>50°(-), twinned.
Magnetite	tr	Opaque, shiny in reflected light.
Apatite	tr	
Biotite	tr	Yellow/red, thin needles. Associated with garnet? In hornblende.



Texture: Seriate, no preferred orientation of hornblende crystals. Numerous wormy intergrowths of plagioclase into hornblende and garnet indicate disequilibrium. Also the hornblende has a different color in the presence of the garnet. Normally olive green to brown, it is bleu-green to green near garnet.
There is a plagioclase-rich ptygmatic fold present with associated epidote and hornblende altering (?) to diopside. The hornblende is again a light blue-green to green, not the normal olive green to brown. Extensive sericite alteration in the plagioclase and in one place the twins look deformed.

Facies (equilibrium assemblage):
nada

Sample: 1MT06A / 67KS78

Hand Specimen:	Amphibolite	
Grain Size:	1-3 mm	
Color:	Black	
Texture:	A weak foliation defined by the streaked orientation of felsic areas.	
Mineral %:	Hornblende	50%
	Plagioclase\	50
	Quartz /	

Thin Section: (lost)

Drawing:

Mineral	%	Properties:
Hornblende	60	Olive green / pale green / dark green.
Garnet	2	Seive textured with plagioclase.
Plagioclase	20	(An) Sericitically altered.
Sericite	13	Fairly extensive, complete in some parts of the slide, nearly absent in another.
Quartz	5	
Apatite	tr	
Magnetite	tr	Confined to hornblende-rich areas.

Texture: Layered (1-4 mm) no preferred orientation among the grains within each layer. The hornblende is irregularily shaped and larger grains are somewhat poikioblastic. Felsic grains are equigranular and triple junctions commonly meet at 120°. The garnets are poorly formed and poikioblastic, inclusions commonly slightly oriented.

Facies (equilibrium assemblage):
Hornblende-Plagioclase-Garnet

Sample: 1MT21A / 111KS78

Hand Specimen:

Grain Size:	0.1-2 mm
Color:	Black
Texture:	Lineated, defined by amphibole and a layer of quartz feldspar 6-7 mm thick. A weathered surface has slightly foliated salt-and-pepper hornblende plus plagioclase.
Mineral %:	

Thin Section:

Drawing:

Mineral % Properties:

Texture:

Facies (equilibrium assemblage):

Sample: 1MT21B / 111KS78

Hand Specimen: Tremolite rock (Tremolitite)

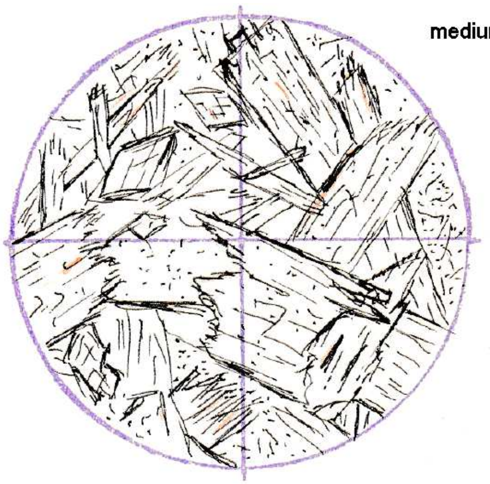
Grain Size: 1-3 mm

Color: Tan - brown

Texture: Amphibole prisms massed in a felty texture, randomly oriented. There is no layering or banding, compositional or otherwise.

Mineral %: Tremolite 100%

Thin Section:



medium power

Drawing:

Mineral	%	Properties:
Tremolite	100	Z^C 20°, $\gamma-\alpha$~0.026, very slight greenish pleochroism and stronger association on γ. 2V 85-90° (±), relief variable, moderate n/s, moderate-high e/w. Amphibole end-sections (green dot). [$Ca_2(Fe)\ Mg_5Si_8O_{22}(OH)_2$] (-) crystal: BxA on prismatic section (-) BxO on end section (+) α colorless β colorless γ very pale green-yellow
Magnetite	tr	

Texture: Intergrown tremolite prisms with no preferred orientation, (felty). $Ca_2Mg_3Si_8O_{22}(OH)_2$ Iron is present but in very small amounts (Z^C~20°)
$Ca_2(Mg, Fe^{++})_5Si_8O_{22}(OH)_2$

Facies (equilibrium assemblage):
Tremolite

Sample: 1MT3XA / 60KS78

Hand Specimen:	Garnet, Ortho-Pyroxene, Quartz, Anthophylite Gneiss		
Grain Size:	0.1-2 mm		
Color:	Brownish-purplish		
Texture:	Foliated due to elongation of brown? Amphibole. A very hard rock, was difficult to break a piece off the outcrop.		
Mineral %:	Anthophylite	55%	(MgFe++)7Si8O22(OH,F)2
	Quartz	25	SiO2
	Enstatite	10	MgSiO3
	Garnet	10	Fe++3Al2Si3O12

Thin Section:

Drawing:

Mineral	%	Properties:
Quartz	25	Strained, contains inclusions, generally surrounds garnet.
Garnet	10	Pinkish, poikioblastic, irregular outline and elongate parallel to foliation.
Anthophylite	55	2V~90°(+), RI~1.6-1.7, γ-tan, $\alpha+\beta$ colorless. $\gamma-\alpha$ 0.022 Z^C0°, gives flash figure. Amphibole cleavage.
Rutile	tr	Deep red, high relief, parallel extention.
Biotite	tr	Yellow – red/brown.
Enstatite	10	RI~1.7-1.75, 2Vhigh. Skeletal poikioblastic crystals, $\gamma-\alpha$ 0.013, Z^C parallel.
Cordierite?		

Texture: Moderate grain size, foliated as defined by anthophyllite and strings of quartz grains. Garnet grains are sieve textured with the inclusions weakly to strongly defining the foliation. The garnets themselves are irregular in outline and elongate parallel to foliation. They are for the most part separated from the anthophyllite by quartz growing in a poikioblastic skeletal pattern. The inclusions are quartz for the most part although it seems to be attacking the anthophyllite. I see no plagioclase anywhere.

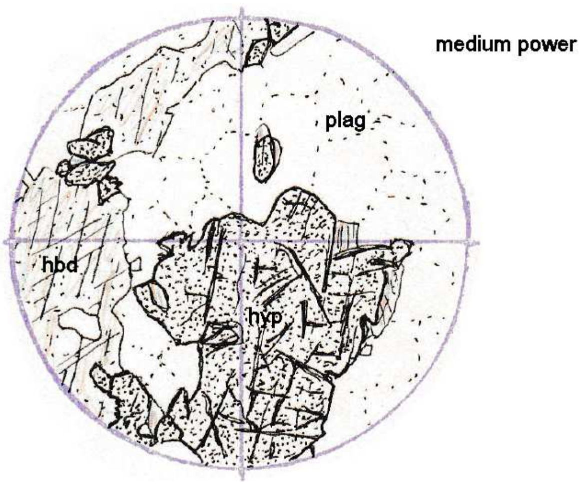
Facies (equilibrium assemblage):

Quartz-Garnet-Anthophyllite-Enstatite?

Sample: 1MT15B / 96KS78

Hand Specimen:	Hornblende, Pyroxene, Plagioclase Granulite	
Grain Size:	0.5-2 mm	
Color:	Black	
Texture:	Salt and pepper amphibolites. Massive with no preferred orientation.	
Mineral %:	Hornblende	60%
	Plagioclase	40

Thin Section:



Drawing:

Mineral	%	Properties:
Hornblende	25	β deep brown, α yellowish brown, γ medium brown, (greenish?). Z^C 20°. Hbd→Pyx.
Plagioclase	45	(An40). Common 120° grain boundaries.
Hypersthene	10	2V(+)70°, Z^C5 max.
Diopside	15	2V(+)40°-50°, Z^C40°max.
Garnet	5	Wormy, deeply embayed. Intergrowths of plagioclase into the garnet. Gar ↔ Plag
Magnetite	tr	
Sericite	1	Alteration in plagioclase.
Apatite	tr	
	Hb + Q ↔ Op + Cp + Pl + H_2O	

Texture: Massive, randomly oriented grains with small variations in grain size. Triple junctions between plagioclase are commonly around 120° each. Mafic minerals tend to be slightly larger that the plagioclase. Hornblende is reacting to form pyroxene. The garnet has numerous intergrowths of plagioclase and is out of equilibrium. There are two types of pyroxene, diopside and hypersthenes. In one place I note a relic grain of diopside completely enclosed in hypersthenes and I infer that the diopside is reacting to form hypersthene.

Sericite is a common secondary alteration of plagioclase.

Hbd →Hyp→Diop
Gar→Plag↓
Sericite

Facies (equilibrium assemblage):
Hypersthene-diopside-Plagioclase

Sample: 1MT08 / 70KS78

Hand Specimen: Pyroxene, Plagioclase Granulite

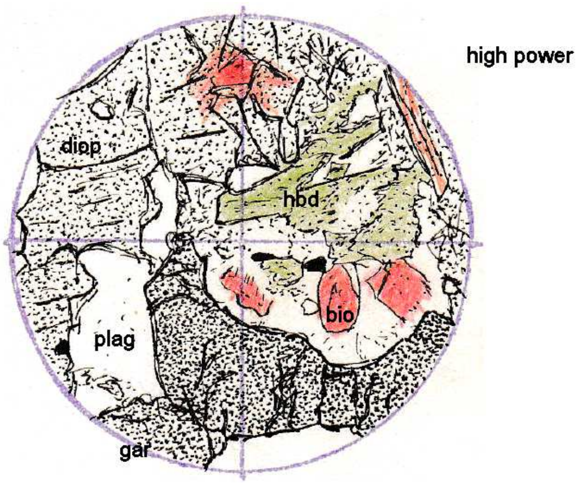
Grain Size: 0.1-1 mm

Color: Black

Texture: Fine grained, granular, massive.

Mineral %: %

Thin Section:



Drawing:

Mineral	%	Properties:
Plagioclase	45	Numerous 120° triple junctions.
Quartz	5	$\gamma-\alpha$ 0.009.
Garnet	2	Broken, isotropic, high relief grains not in equilibrium, not in contact with biotite.
Biotite	5	Yellow/deep red.
Hornblende	7	Gren/pale pleochroism, amphibole end sections.
Diopside	25	45-50°(+), $\gamma-\alpha$ 0.028, γ^C =43°, several 120° grain boundaries between adjacent pyroxenes.
Magnetite	1	Opaque, silvery in reflected light.
Hypersthene	11	2V high (-) Clear-pink pleochroism.

Texture: Fine grained, granular and massive. The grains commonly show 120° bourdary angles in plagioclase, quartz, and also somewhat in the pyroxene. There seems to be no evidence of instability between hornblende and garnet, garnte plus diopside, hornblend plus diopside. There is a distinct separation of biotite and garnet by plagioclase and I feel that the biotite and garnet are not stable. The sample is very fresh showing little or no secondary alterations.

Facies (equilibrium assemblage):

Hornblende-Hypersthene

Sample: 1MT38 / 223KS78

Hand Specimen: Hypersthene, Garnet, Quartz Granulite

Grain Size:

Color:

Texture:

Mineral %: %

Thin Section:

Drawing:

Mineral	%	Properties:
Quartz	35	Strained.
Garnet	42	Poikilitic (randomly placed) grains up to 4 mm.
Hypersthene	17	γ:Z-17°, δ=0.038 →gives flash figure. α colorless, β 2V~80-85(-), γ pale tan. Twinning very common.
Magnetite	tr-1	Opaque, shiny.
Zircon	tr	Rounded grains, high δ.
Hematite	5	Magnetite →Hematite. Stain in-between grains.

Texture: Porphyroblastic grains up to 4 mm with randomly dispersed quartz grains (plus one zircon) within. Massive, granulitic, 120° grain junctions between quartz grains common. Hypersthene is very twinned and shows extention to 17° due to strain.

Magnetite is interstitial, commonly "prismatic", rims garnets and is altering to hematite. Hematite is common interstitially and gives the weathered rock a red color.

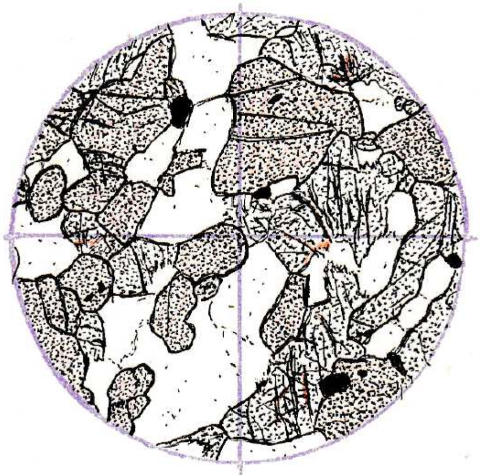
Facies (equilibrium assemblage):

Hypersthene zone

Sample: 1MT30F / 142KS78

Hand Specimen:	Quartz, Hypersthene, Garnet, Granulite
Grain Size:	0.1-2 mm
Color:	Black
Texture:	Foliated with layers, garnet-rich or quartz-rich. Thin layers rich in magnetite also.
Mineral %:	%

Thin Section:



Drawing:

Mineral	%	Properties:
Quartz	29	Strained, elongate along quartz-rich layers, otherwise equant crystals.
Garnet	34	Anhedral to euhedral, mostly sieve textured except in the quartz-rich layers. Rounded in the quartz-rich layers.
Magnetite	tr-1	Layers of interstitial, anhedral, opaque grains, silvery in reflected light.
Hypersthene	37	Pale green to pink pleochroism. γ-α 0.011-0.013, Parallel extinction. 2V~60°(-).

Texture: Polygonal with mostly 120° grain boundaries. Garnet is the dominant mineral, mostly sieve textured except in the coarser grained garnet plus quartz layers where it is without inclusions and mostly rounded in outline.

Mostly granular with equant grain dimentions, common 120° junctions, no preferred orientation. Significantly, I find no feldspar of any kind in thei sample.

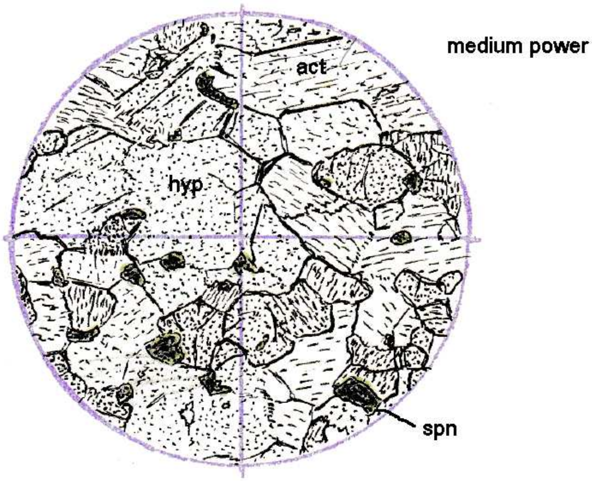
Facies (equilibrium assemblage):

Hypersthene-Garnet-Quartz

Sample: 1MT10 / 74KS78

Hand Specimen:	Hornblende, Granulite
Grain Size:	0.1-1 mm
Color:	Black, weathers brown.
Texture:	Dense and possibly massive (difficult to say)
Mineral %:	%

Thin Section:



Drawing:

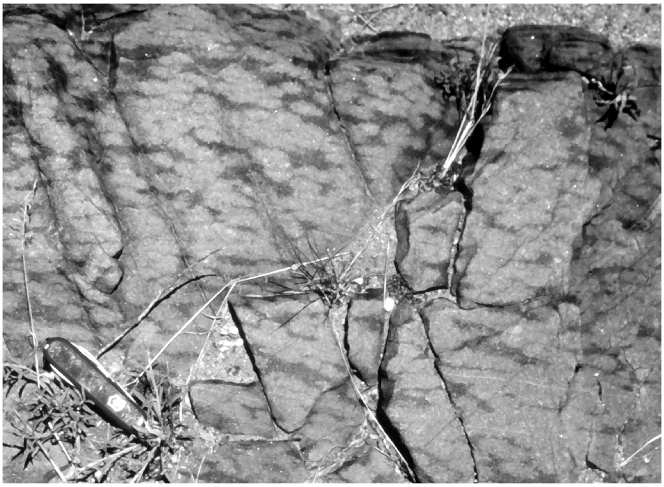
Mineral	%	Properties:
Hypersthene	35	2V~85-90°(-). Twinning fairly common, pale yellow/pink color. End section gives (+) BxO figure.
Actinolite	52	γ:Z 21°, δ~0.025-0.027 →flash figure. 2V 80-85(-), α very pale green to colorless, β pale green, γ green. Amphibole cleavage.
Spinel	7	Very dark olive green, nearly opaque, isotropic?
Serpintine	5	Some serpentinization along a fracture and between some grains.
Magnetite	1	Opaque grains.

Texture: Massive, inequigranular, equidimentional grains, largely recrystallized (120° grain triple junctions common), granulitic rock. The actinolite is low Fe++ (γ:Z and 2V more nearly that of tremolite but pleochroism of actinolite), shows some twinning.
It is in good equilibrium with the hypersthenes and the hypersthene is on average smaller grained. Spinel is deep green and fine grained and speckles the rock.

Facies (equilibrium assemblage):
Actinolite-Hypersthene-Spinel

Sample: 1MT42 / 294KS78

Hand Specimen: Hornblende-Hypersthene spotted Granulite



Grain Size:	Fine		
Color:	Brown spotted, black interstitial.		
Texture:	Large oval brown spots (2-4 cm) dominate, in-between is a black weathering matrix. The long dimention of the spots are aligned parallel to foliation. In places trhe spots almost coalesce.		
Mineral %:	Hypersthene	80-90%	tan
	Hornblende	10-20	black

Thin Section:

Drawing:

Mineral	%	Properties:
Hornblende	52	2V 85°(+), BxA(+). α pale green to colorless, β green brown, γ green. δ=0.029, γ:Z=19°. Amphibole cleavage, relief moderate ~1.65.
Hypersthene	35	2V~60-65°(-). Pinkish to colorless. δ 0.020, γ Z=11, moderate to high relief.
Magnetite	1	Opaque, shiny in reflected light.
Spinel?	tr	Dark olive brown, nearly opaque.

Texture: No real reaction textures. Hypersthene crystals are aligned crystalligraphically to one another. Hypersthene with relect hornblende cores and inclusions. Both hornblende and hypersthenes show common 120° grain boundaries of recrystallization.

Granulitic, no preferred orientation, larger hypersthenes grains contain hornblende poikiolitically.

Hornblende → Hypersthene.

Hornblende and hypersthenes are in equilibrium, hornblende is out of equilibrium with quartz. So:
Hornblende + Quartz → Hypersthene

Facies (equilibrium assemblage):
Hornblende-Hypersthene

Sample: 1MT20 / 109KS78

Hand Specimen: Marble

Grain Size: 3-5 mm
Color: White, weathers tan.
Texture: Very coarse interlocking grains.
Mineral %: Calcite 100%

Thin Section:
Drawing:

Mineral	%	Properties:
Calcite	99	Slow ray bisects the acute angle on twin planes. Very little twinning present.
Quartz	1-2	Rounded grains, strained and much subgrain development.

Texture: Interlocking grains of calcite showing very little twinning. Quartz grains are round to angular, showing much subgrain development.

Facies (equilibrium assemblage):
Calcite

Sample: 1MT26 / 125KS78

Hand Specimen: Quartz-bearing Marble

Grain Size:	1-3 mm	
Color:	White-grey.	
Texture:	Massive, interlocking grains of calcite.	
Mineral %:	Calcite	100%
	Quartz	tr

Thin Section:

Drawing:

Mineral	%	Properties:
Calcite	85	Slow ray bisects the acute twin angle.
Quartz	15	Strained with rounded inclusions of muscovitre, calcite, and k-spar. Subgrain development.
Muscovite	tr	Variable relief, colorless, no pleochroism.
Microcline	tr	Small grains, gridiron twinning.
Biotite	tr	One very relict grain within quartz.
Hematite	tr	Red in reflected light, small opaque laths parallel to foliation. Pale red to white (ilmenite?).

Texture: Mostly interlocking crystals of calcite with quartz as aggregates or subgrains. The quartz aggregatesare slightly elongate and tend to form a possible foliation. They contain numerous inclusions of rounded calcite, sometimes the calcite and quartz are intergrown.

Facies (equilibrium assemblage):

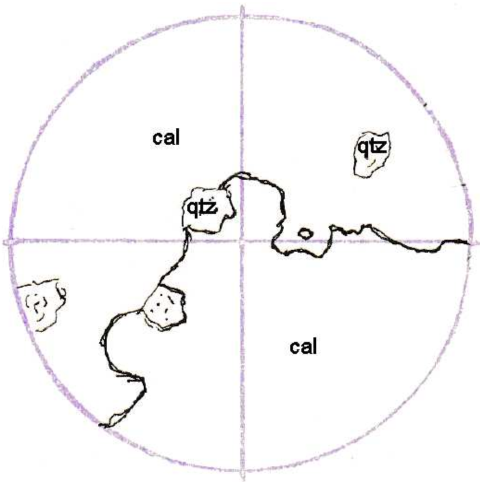
Quartz-Calcite-K-spar-Ilmenite

Sample: 1MT24A / 118KS78

Hand Specimen: Quartz-bearing Marble

Grain Size:	3-7 mm	
Color:	White, cream on weather surface.	
Texture:	Very coarse grained marble.	
Mineral %:	Calcite	100%

Thin Section:



Drawing:

Mineral	%	Properties:
Calcite	99	
Quartz	1	
Muscovite	tr	

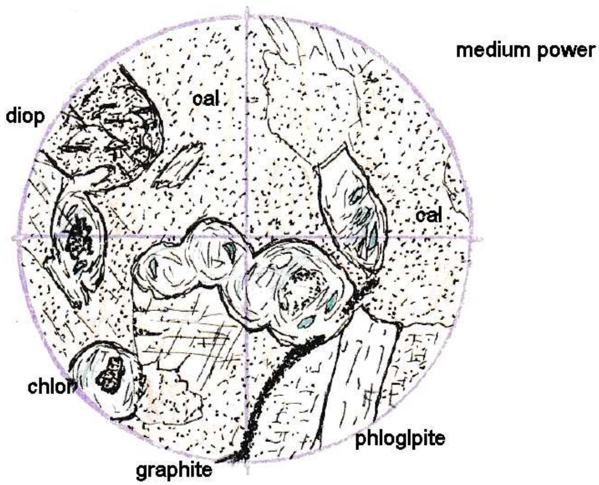
Texture: Very coarse grained with irregular and rough grain boundaries. Quartz is in small blebs within grains or interstitial. Muscovite is mostly imbedded.

Facies (equilibrium assemblage):

Sample: 1MT22 / 112KS78

Hand Specimen:	Diopside Marble	
Grain Size:	~1 mm mica, 2-5 mm calcite	
Color:	Light grey.	
Texture:	Medium grained marble with numerous green grains of diopside and muscovite. The diopside seems soft and altered in layers. The grains and spots within and between the calcite grains.	
Mineral %:	Calcite	90%
	Muscovite	3-5
	Diopside	5

Thin Section:



Drawing:

Mineral	%	Properties:
Phlogopite	3	Pale tan yellow / colorless ns, variagle relief.
Diopside	5	Round grains interbedded and interstitial in dolomite.
Calcite	85	Fast ray bisects the obtuse angle of twins.
Chlorite	1	Pleochroic green parallel to extinction. Diopside → calcite.
Graphite	1	Dusty, elongate groups both interstitial and imbedded.
Serpentine	5	Fibrous, pale yellow to green, 1st order yellow, associated with chlorite (green), not pleochroic.
Hydrogossomer	tr	Isotropic, high relief, 1.7-1.75, colorless.

Texture: Large grains of calcite with rounded imbedded grains of diopside, most of which is altered to chlorite. Massive texture, there are euhedral laths (primary?) pf phlogopite, again without preferred orientation. The graphite is in needle-like powdery masses.

Facies (equilibrium assemblage):

Calcite-Diopside-Phlogopite

Sample: 1MT40 / 316KS78

Hand Specimen:	Marble
Grain Size:	0.1-3 mm
Color:	Grey.
Texture:	Massive, speckled with calc-silicate. Minerals diopside and a dark mineral (chlorite?).
Mineral %:	%

Thin Section:

Drawing:

Mineral	%	Properties:
Calcite	85	Slow ray bisects the acute cleavage angle.
Chlorite	1-2	Alteration of diopside, green to olive, fibrous, parallel extinction.
Diopside	tr-1	Rounded grains, fractured. δ 0.020 colorless, moderate to high relief.
Phlogopite	tr	Colorless to tan, micaceous.
Graphite	tr	Opaque, dusty, interstitial.
Hydrogossomer	tr	High relief, lack of cleavage, isotropic.
Serpentine	14	Green to pale yellow, not pleochloric.

Texture:

Facies (equilibrium assemblage):

Appendix 7: Strike and Dip data by station

Sta	strike	dip	dir
1	177	44	NE
1	152	19	V
4	90	45	N
37	45	41	NW
38	165	43	NE
39	110	50	NE
40	15	45	NW
41	40	44	NW
42	5	56	E
43	17	75	SE
44	180	74	E
46	50	85	E
47	23	90	
48	25	90	
49	72	72	SE
50	175	77	E
51	45	78	SE
52	10	50	NW
53	5	68	SE
54	178	81	W
55	130	49	NE
56	130	72	SW
58	153	51	NE
59	174	64	SW
61	110	55	NE
62	74	34	NW
63	103	46	NE
64	95	60	N
70	76	51	NW
71	96	62	NE
72	120	75	NE
73	97	81	NE
74	81	90	
81	133	65	NE
82	98	80	NE
83	134	56	SW
84	110	70	NE
85	94	57	NE
87	103	39	NE
89	28	76	NW
90	96	70	NE
92	73	74	NW
93	110	42	NE
95	73	84	NW
96	0	56	E

97	167	82	E
98	164	63	E
101	86	69	N
103	75	78	NW
104	103	82	NE
105	5	87	E
107	23	76	SE
108	23	68	SE
111	135	68	SW
111	135	90	
112	5	79	W
116	87	62	N
118	105	56	NE
119	88	47	N
121	123	58	NE
122	126	78	NE
124	5	90	
125	36	84	SE
126	10	78	SE
126	25	81	SE
126	25	72	SE
129	55	90	
130	65	78	SE
132	29	76	SE
133	52	74	N
133	52	90	
134	35	63	SE
135	43	90	
136	43	78	SE
138	45	90	
139	42	77	SE
142	68	65	NW
143	44	84	SE
144	68	74	SE
145	42	84	SE
146	63	72	SE
147	37	72	SE
149	39	90	
150	47	84	SE
151	16	67	SE
152	18	84	SE
154	111	79	NE
156	170	81	E
157	159	74	E
158	4	76	E
159	148	54	NE
160	175	62	E
161	5	66	E

162	11	69	E
163	42	74	SE
164	53	51	SE
166	141	82	E
167	169	77	E
168	154	77	E
169	151	79	E
170	174	90	
171	38	84	SE
174	44	77	SE
175	21	82	SE
176	36	80	NW
177	7	90	
178	38	70	SE
179	43	77	SE
180	38	81	SE
181	36	65	SE
182	54	90	
187	18	70	E
189	4	90	
190	67	90	
191	166	78	E
192	165	73	E
193	170	69	E
196	35	74	SE
197	48	83	SE
199	152	86	E
200	154	84	E
201	23	90	
203	44	78	NW
204	50	85	E
205	57	82	SE
206	52	82	SE
208	62	90	
209	41	85	SE
210	49	90	
211	58	90	
212	101	85	SW
213	77	79	SE
215	29	90	
216	55	85	SE
217	3	62	E
218	54	85	SE
219	35	79	SE
221	95	75	N
224	76	85	SE
225	40	81	SE
226	39	85	SE

227	44	80	SE
228	41	90	
229	38	85	SE
230	57	73	SE
232	56	90	
233	113	75	NE
234	3	61	E
236	73	90	
237	51	70	NW
239	5	85	E
240	15	84	E
241	25	80	SE
242	17	85	E
245	28	90	
246	178	75	E
248	124	63	SW
249	51	87	SE
250	141	60	NE
251	108	60	N
252	16	85	SE
253	8	61	E
254	15	80	E
256	139	83	E
259	10	90	
259	153	68	NE
260	174	80	E
261	169	85	E
262	175	70	E
264	19	90	
265	179	80	E
266	108	90	
267	177	65	W
268	24	85	SE
270	177	90	
272	7	90	
273	23	65	SE
274	5	65	E
275	148	80	NE
276	136	56	NE
277	145	52	NE
278	5	90	
278	156	58	NE
280	149	38	NE
282	15	61	E
283	136	81	NE
284	170	80	E
286	13	72	E
288	58	90	

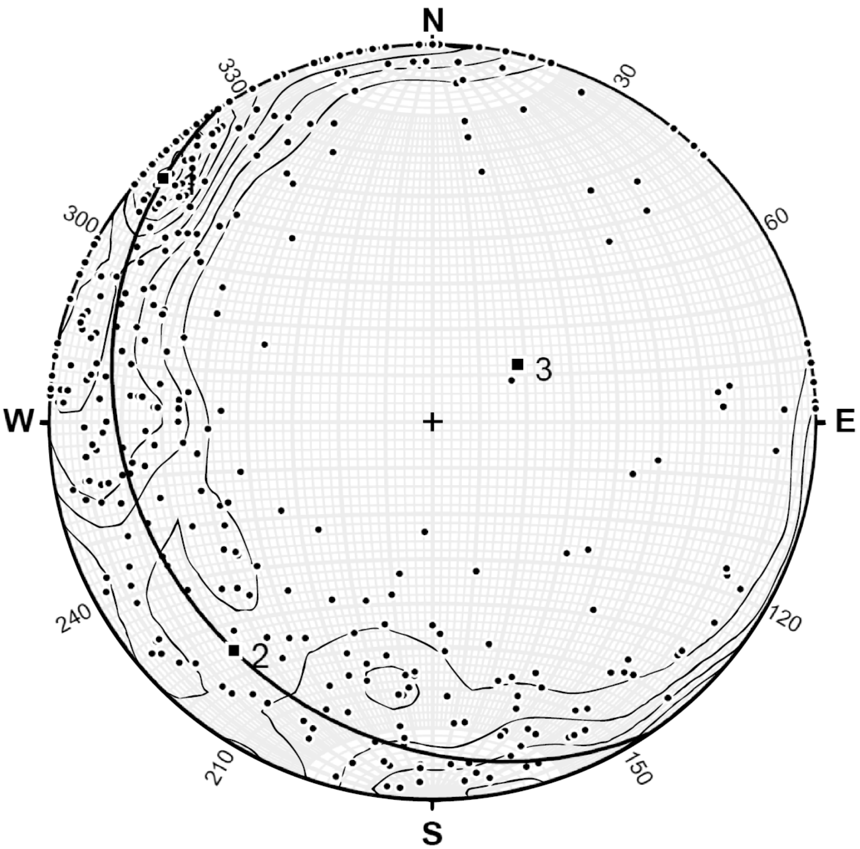
289	39	81	SE
290	62	75	NW
291	12	90	
293	140	85	NE
294	24	84	SE
295	8	75	E
296	160	68	NE
297	145	67	NE
299	128	78	NE
300	101	90	
301	122	63	NE
303	26	70	SE
304	60	62	SE
305	101	57	SW
306	129	90	
309	172	68	NE
310	178	49	NE
311	163	53	NE
312	7	54	E
313	176	78	E
314	41	85	E
315	169	75	E
316	178	64	E
317	158	50	E
318	171	65	E
318	171	90	
319	127	61	E
320	81	85	N
321	50	90	
322	43	78	NW
323	73	65	NW
325	84	69	N
326	76	90	
327	101	53	N
329	64	80	NW
330	105	90	
331	83	83	N
332	85	85	N
333	133	90	
334	134	78	NE
339	48	90	
340	75	84	NW
342	113	75	NE
343	73	60	NW
344	172	52	E
345	25	40	SE
346	175	55	E
351	111	64	NE

352	66	90	
353	119	45	NE
354	50	55	NW
355	104	60	NE
356	158	48	NE
357	140	50	NE
358	168	90	
362	46	90	
363	146	52	NE
367	139	57	NE
368	141	81	NE
369	178	90	
370	76	60	N
371	173	67	W
374	55	70	NW
375	74	90	
379	33	55	SE
380	22	65	SE
387	66	80	NW
388	106	69	NE
389	92	80	N
390	97	90	
391	111	76	NE
392	97	62	N
393	84	80	N
395	70	65	SE
396	83	85	S
397	94	79	S
398	87	85	S
399	61	84	SE
400	79	90	
401	123	75	NE
402	97	87	N
403	83	90	
403	94	85	S
405	67	80	N
406	92	85	N
408	66	90	
409	95	87	N
410	7	80	E
411	33	72	SE
412	47	64	SE
413	60	65	SE
414	87	80	N
415	88	90	
416	95	73	N
417	96	57	N
418	68	61	NW

419	43	81	SE
421	21	76	SE
422	170	71	E
423	3	56	E
424	8	79	E
425	76	90	
426	53	85	SE
427	64	74	NW
428	77	73	NW
429	66	80	NW
430	53	72	NW
431	74	68	N
432	95	80	S
434	91	90	
435	97	65	S
436	57	73	SE
437	63	80	SE
439	31	79	SE
440	46	79	SE
441	39	68	SE
442	47	81	SE
443	42	78	SE
444	14	81	E
445	72	90	
446	72	76	NW
447	43	65	SE
448	47	76	SE
449	29	81	N
457	92	81	N
458	77	80	N
459	89	85	S
460	90	90	
462	96	69	S
463	105	87	N
465	151	68	NE
466	9	85	E
468	0	56	E
469	8	75	E
470	3	46	E
473	19	58	E
474	136	34	NE
477	27	53	E
478	120	56	NE
479	102	34	N
480	114	85	S
481	94	24	N
482	94	56	N
483	62	90	

484	78	74	N
485	87	51	N
486	3	86	E
487	50	85	NW
488	106	75	S
489	90	90	
490	75	85	S
491	58	78	S
492	100	75	N
493	27	75	NW

Appendix 8: Single domain Structural Analysis (3/2021)



----- Kamb Contouring | 3/30/2021 at 7:38 PM-----
Data set name = Ruby Mts, SW Montana
Contour Int. = 1 sigma; Counting Area = 100.0% of net area
Expected Num. = 0 Signif. Level = 3 sigma

----- Fisher Mean Vector | 3/30/2021 at 9:02 PM-----
Data set: Poles to Imported Planes (lower hemisphere)

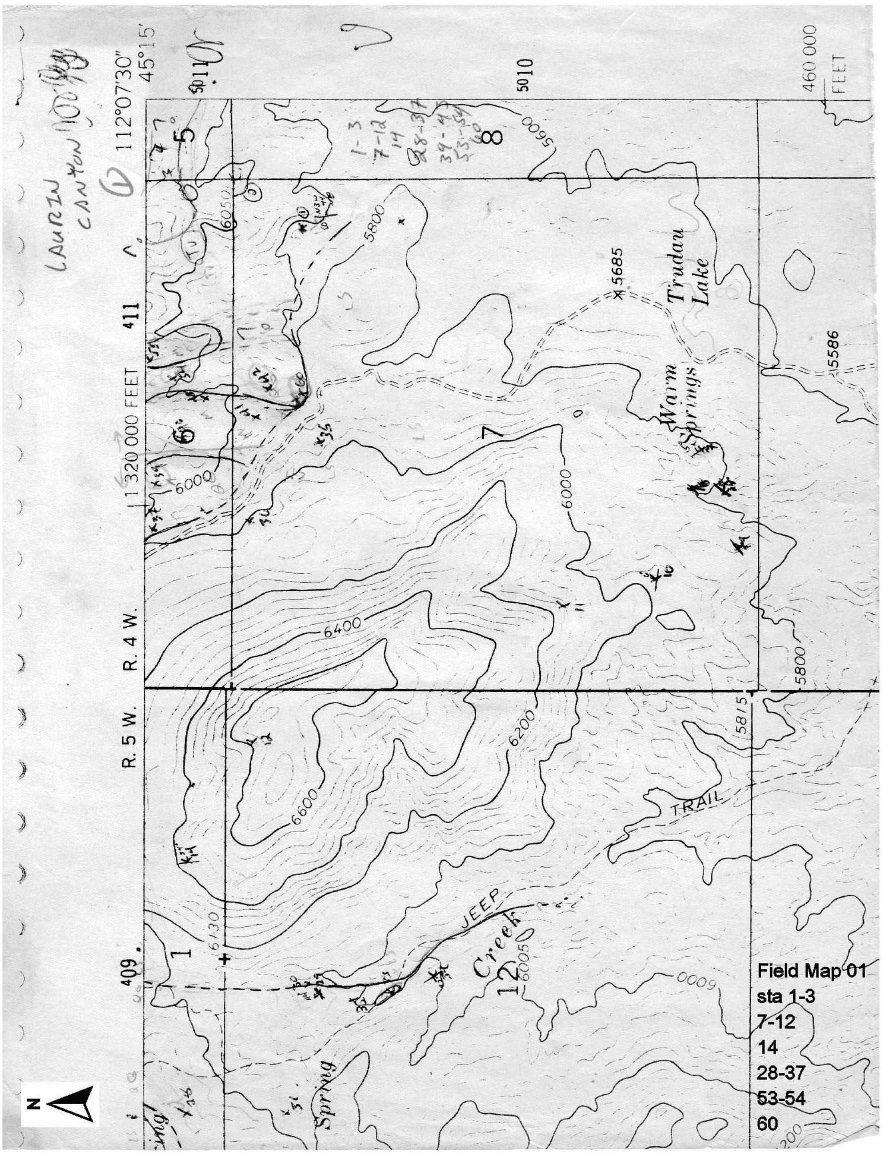
Num	Trend	Plunge	a95	a99	kappa	mean length
342	274.6	35.3	--	--	1.9	0.4721

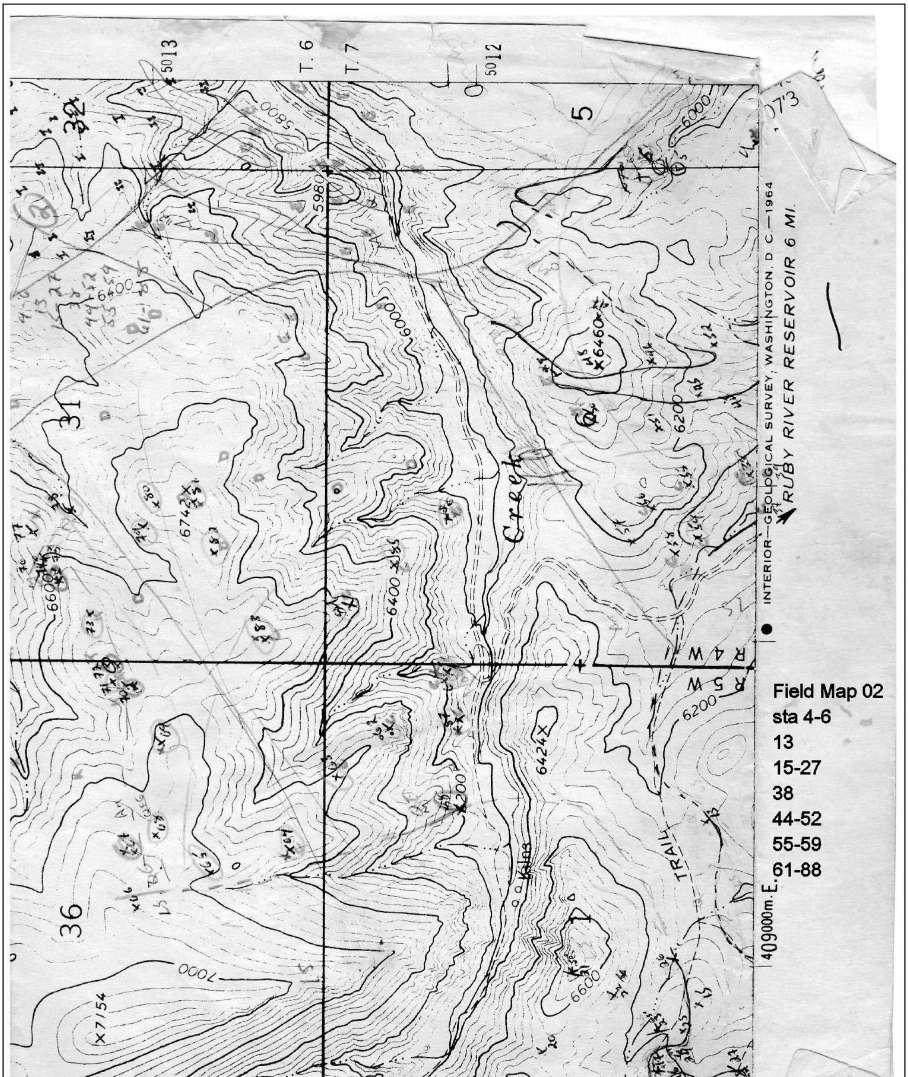
----- Bingham Analysis | 3/30/2021 at 9:02 PM-----
Data set: Poles to Imported Planes (lower hemisphere)

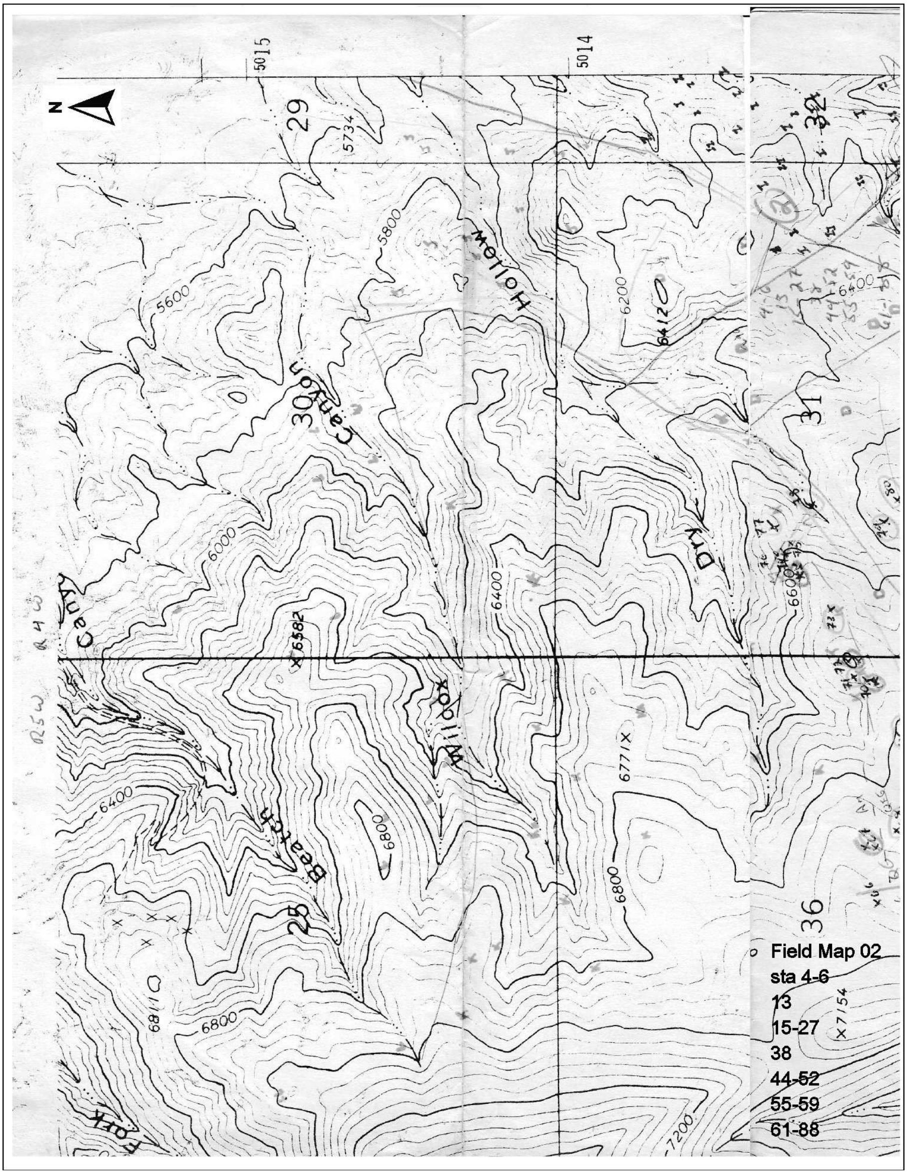
Axis	Eigenvalue	Trend	Plunge	a95 min	a95 max
1.	0.5382	312.6,	05.3	2.7	16.7
2.	0.3831	220.5,	21.3		
3.	0.0786	055.8,	68.0	2.7	4.2

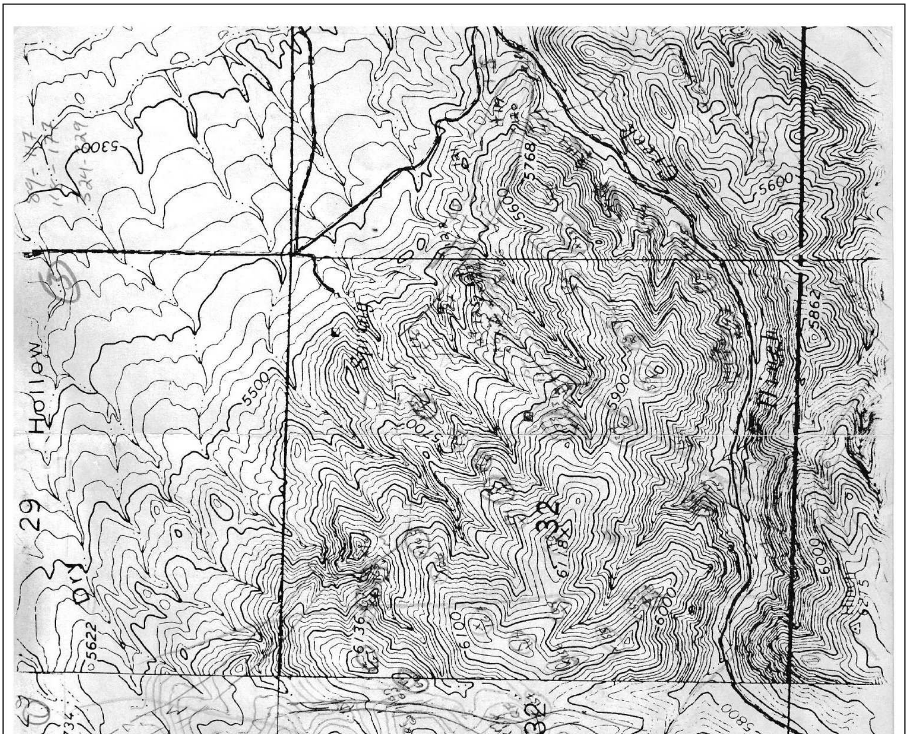
Best fit great circle (strike, dip RHR) = 145.8, 22.0

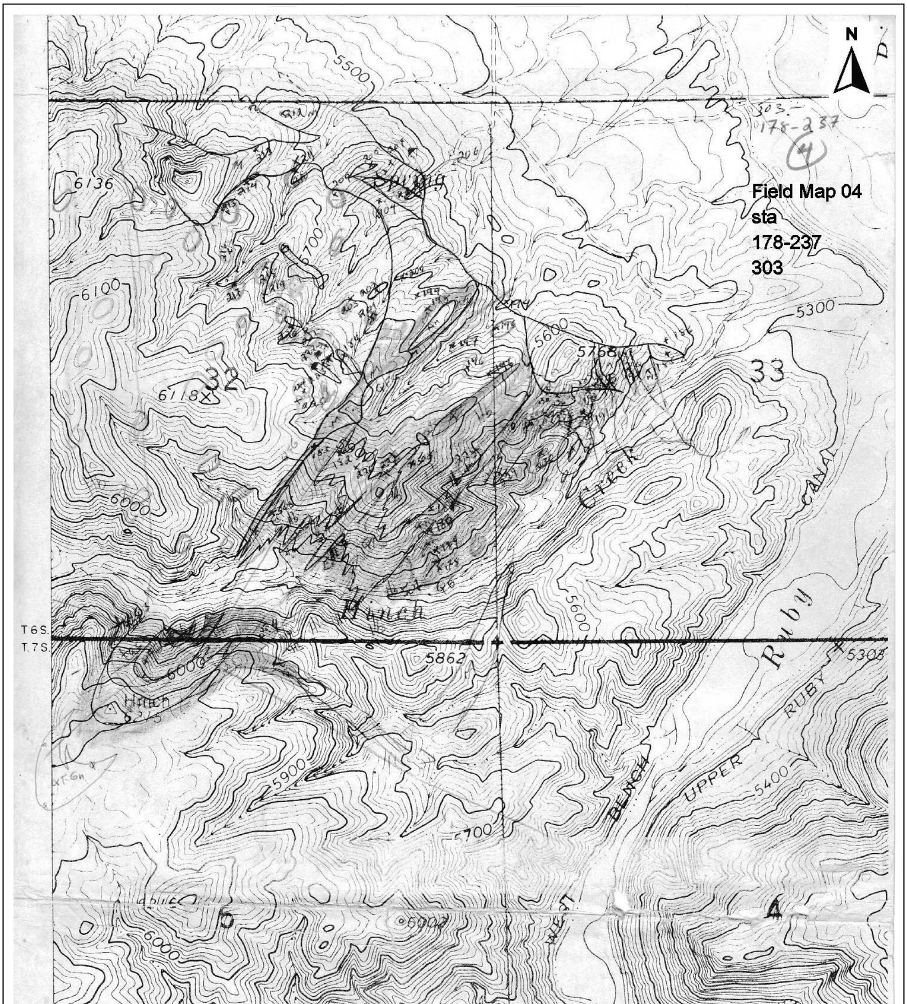
Appendix 9: Field Work Maps with stations

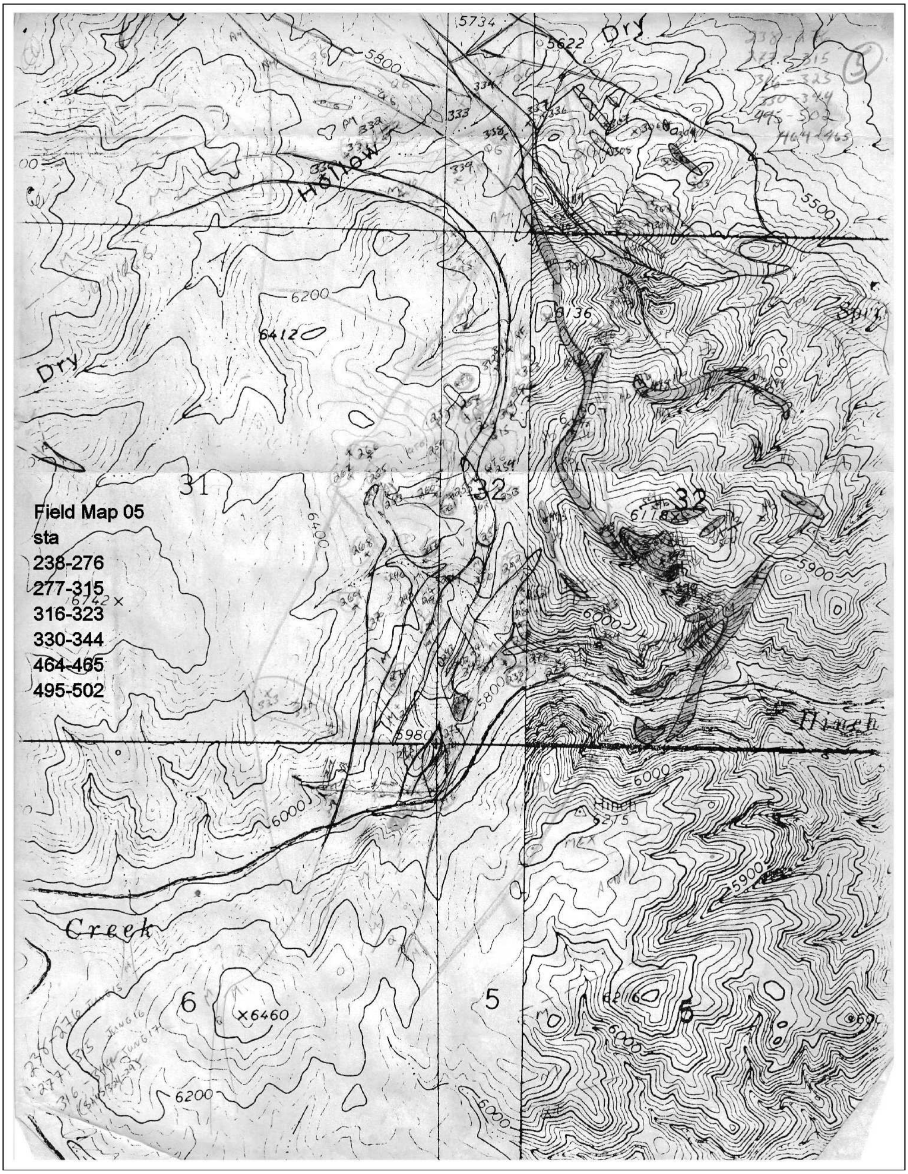



Field Map 02
sta 4-6
13
15-27
38
44-52
55-59
61-88
INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.—1964
RUBY RIVER RESERVOIR 6 MI.
T. 6
T. 7
R 4 W
R 5 W
Creek
JEEP TRAIL
409000m. E.

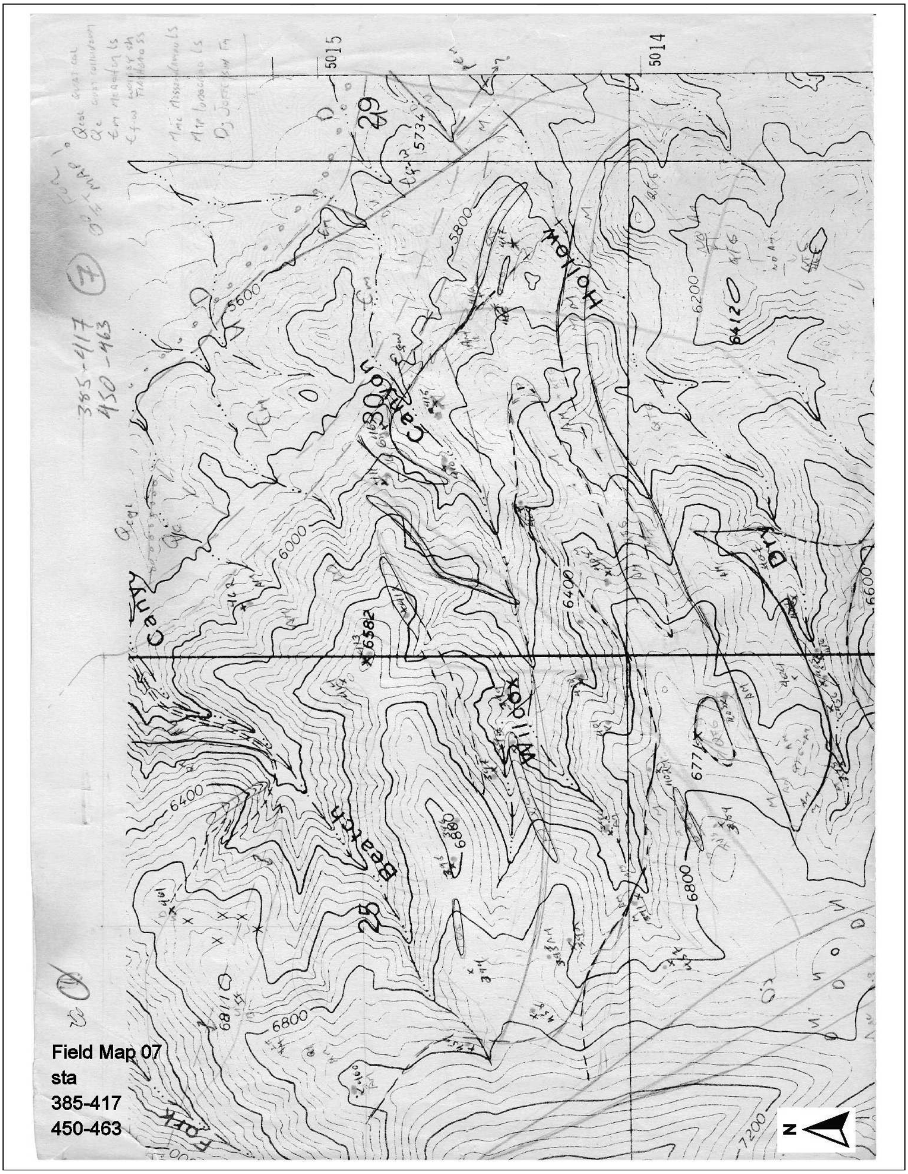

Field Map 02
sta 4-6
13
15-27
38
44-52
55-59
61-88

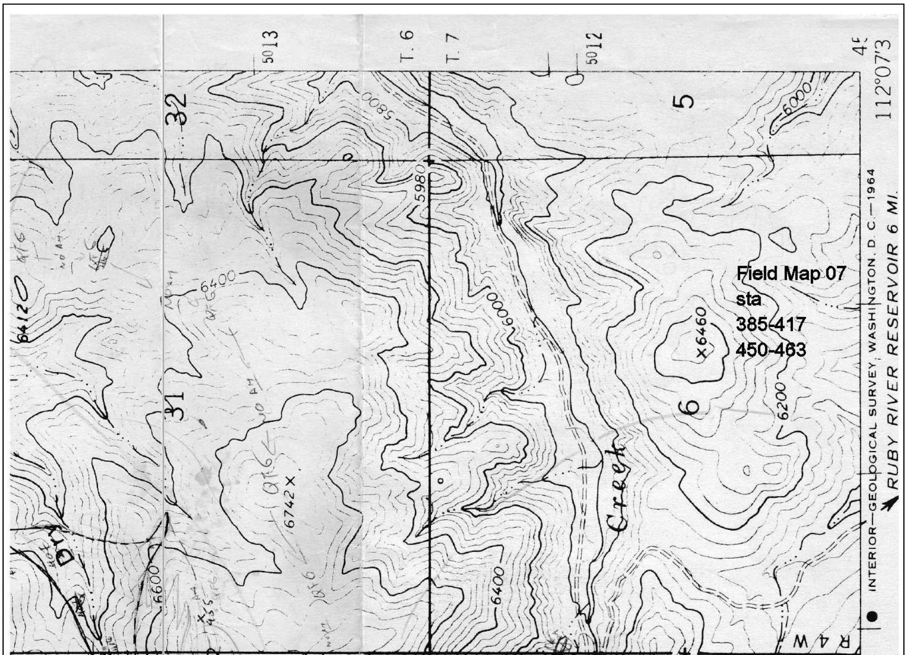

Field Map 03
sta
89-117
118-177
324-329
N

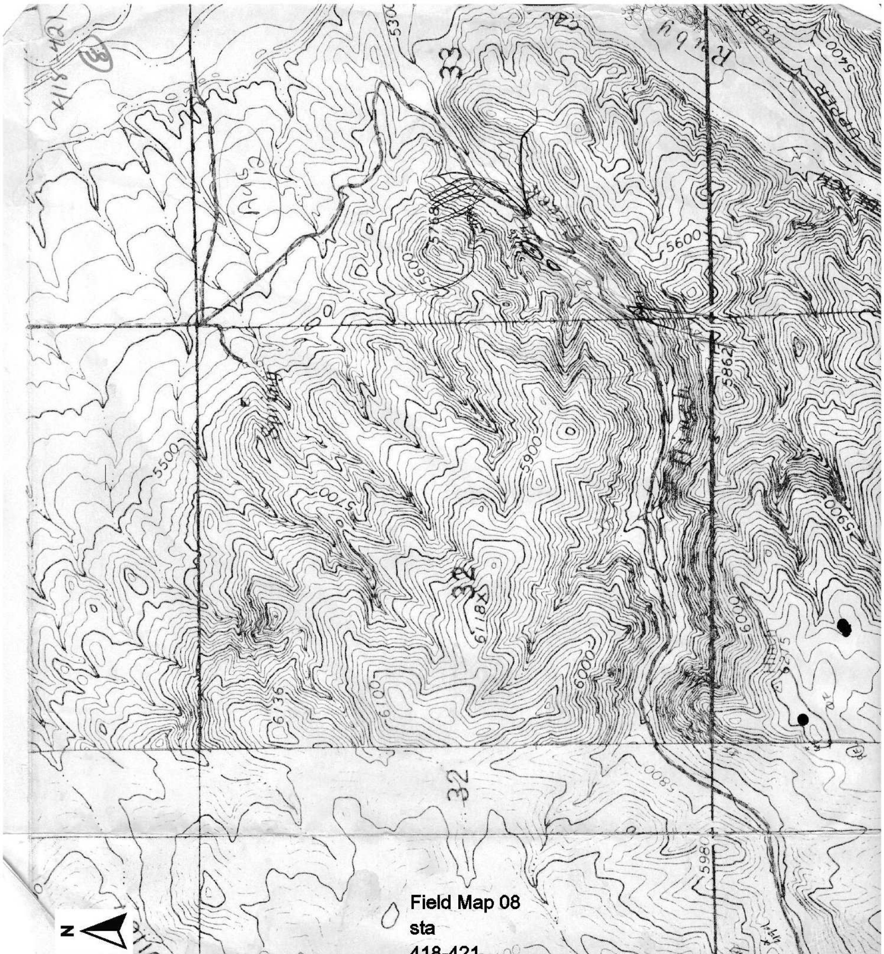

N
Field Map 04
sta
178-237
303
303
178-237
4
5500
6136
6100
5700
32
6178
5300
5600
5768
33
Creek
6000
Hinch
T.6S.
T.7S.
5862
5600
Ruby
5308
RUBY
UPPER
5400
BENCH
5900
5700
WEST
5
6908
6000
4
5600
5700
RUBY RIVER RESERVOIR 1 MI.
MONIDA 67 MI.
R.4 W.

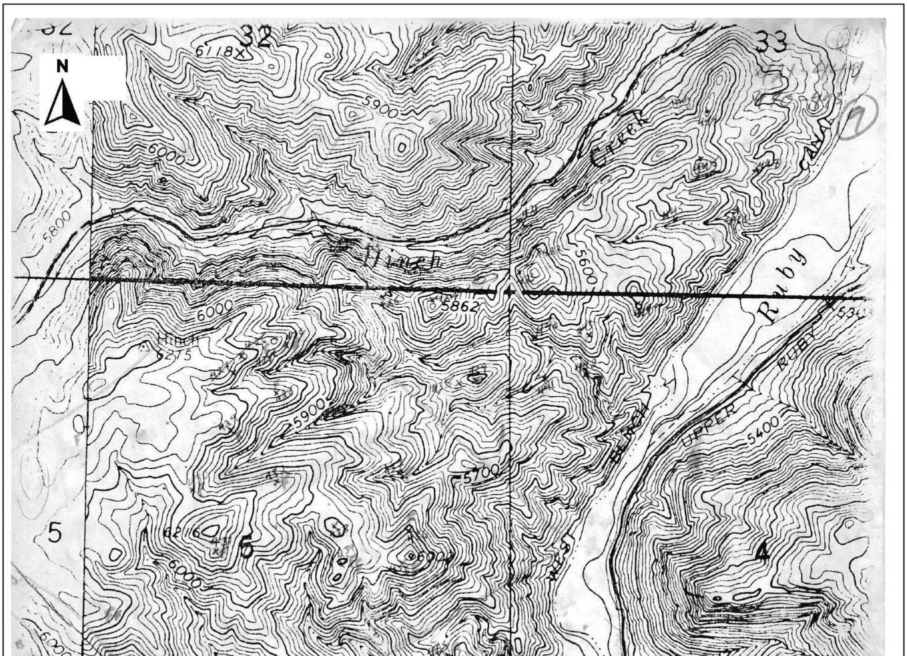

Field Map 05
sta
238-276
277-315
316-323
330-344
464-465
495-502
Dry
Hollow
Dry
Creek
Hinch
31
32
6
5
6412
6742
6460
6200
6400
6000
5800
5734
5622
5500
5900
6136
5980


Field Map 06
sta
345-375
376-384
N


Field Map 07
sta
385-417
450-463
N


Field Map 07
sta
385-417
450-463
INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.—1964
RUBY RIVER RESERVOIR 6 MI.
112°07'30"
409000m. E.
10'
Hinch
Creek
JEEP
TRAIL
R 4 W
R 5 W
T. 6
T. 7
5013
5012
N


Field Map 08
sta
418-421


N
Hinch
Creek
Ruby
Ruby River
Footbridge
Ruby Dam
SPILLWAY
ELEVATION
Field Map 09
sta
421-449
470-493

NOTES:

NOTES:

NOTES:

NOTES:

NOTES:

NOTES: