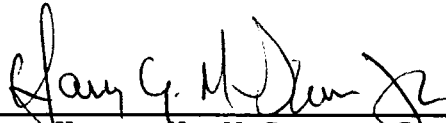


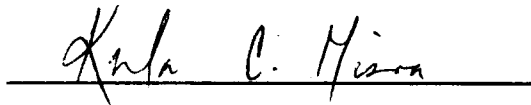
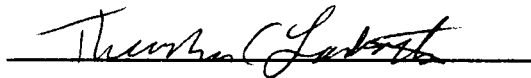
To the Graduate Council:

I am submitting herewith a thesis written by Roger C. Kittelson entitled "The Amphibolite-to-Granulite Facies Transition in the Franklin and Corbin Knob Quadrangles, North Carolina Blue Ridge." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geology.



Harry Y. McSween, Jr.,
Major Professor

We have read this thesis
and recommend its acceptance:



Accepted for the Council:



Vice Provost and Dean
of The Graduate School

THE AMPHIBOLITE-TO-GRANULITE FACIES TRANSITION IN THE
FRANKLIN AND CORBIN KNOB QUADRANGLES, NORTH CAROLINA BLUE
RIDGE

A Thesis
Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Roger Kittelson

August 1988

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ABSTRACT

Metamorphism in the southern Appalachians reached the granulite facies in the vicinity of Franklin, NC. Rocks from within the field area have been correlated with the Otto Formation, Coweeta Group, and Tallulah Falls Formation. The deformational history is similar within the amphibolite and granulite facies terranes suggesting that the metamorphism that affected this area was associated with the Mid-Paleozoic regional event.

The amphibolite-granulite facies transition in the Blue Ridge of North Carolina is characterized by a series of prograde zones: $ky + ms$, $sil + ms$, $sil + kfs$ in rocks of pelitic composition, and $grt + hbl$, $grt + hbl + opx + cpx$ in amphibolites. The transition from amphibolite to granulite facies has been placed at the boundary between the $sil + ms$ and $sil + kfs$ zones. The close spatial association of the second sil isograd and partial melting suggests that the breakdown of muscovite was the driving force behind anatexis. The most likely reaction for producing melts is $ms + ab + qtz = kfs + als + melt$. This suggests that metamorphism occurred in the absence of a free aqueous fluid phase.

Estimated conditions of metamorphism are 580-680 deg C, 5.5-6.8 kbar, $a_{H_2O} = 0.8$ in the amphibolite facies, and 680-780 deg C, 6.5-8.0 kbar, $a_{H_2O} = 0.25$ in the granulite

facies. The drop in a_{H_2O} can be attributed to the breakdown of ms and the development of in-situ partial melts, which scavenged water.

The increase in temperature with pressure indicates that increasing depth of burial was an important part of the development of this terrane. The presence of ky in what are interpreted to be in-situ melts suggests that the granulite terrane underwent nearly isobaric cooling. A model employing both crustal thickening and regional magmatic activity appears necessary to explain both a prograde path of increasing pressure, and an isobaric cooling path.

TABLE OF CONTENTS

CHAPTER	PAGE
I. INTRODUCTION.....	1
Purpose of study	1
Methods	5
II. GEOLOGIC SETTING	8
General Overview	8
Structure and Stratigraphy of the Field Area .	9
Evidence for Paleozoic Granulite Metamorphism .	11
III. PETROGRAPHY AND MINERAL CHEMISTRY	14
Metasedimentary Rocks	14
Metaigneous Rocks	29
IV. REACTIONS AND CONDITIONS OF METAMORPHISM	35
Isograds and Metamorphic Reactions	35
P-T from Mineral Exchange Equilibria	
Calculations	46
Fluid Composition	59
V. DISCUSSION OF THE AMPHIBOLITE-TO-GRANULITE FACIES	
TRANSITION	63
Single versus Polymetamorphism in the Granulite	
Terrane	63
The Development of Granulite Facies Conditions.	64
VI. CONCLUSIONS	70
REFERENCES	72

CHAPTER	PAGE
APPENDIXES	82
APPENDIX A. MINERAL ABBREVIATIONS	83
APPENDIX B. PETROGRAPHIC DESCRIPTIONS	84
APPENDIX C. REPRESENTATIVE MINERAL ANALYSIS	98
APPENDIX D. FLUID INCLUSION PROCEDURES AND RESULTS..	108
VITA	111

LIST OF TABLES

TABLE	PAGE
1. Grt-bi temperature estimates.....	51
2. Temperature and pressure estimates from the assemblage grt-opx-cpx.....	53
3. Grt-pl-als pressure estimates.....	54
4. Grt-pl-ms pressure estimates.....	56

LIST OF FIGURES

FIGURE	PAGE
1. Regional geology of the field area	2
2. Outcrop photographs of amphibolite and granulite facies rocks	15
3. Photomicrographs of representative thin sections....	18
4. AFM projections of rocks of pelitic compositions .	20
5. Plot of Ti versus Al_{VI} in biotite	23
6. Garnet compositions	27
7. Composition tetrahedron for rocks of mafic composition	31
8. Isograd map of the field area	36
9. Possible melt reactions	39
10. Pressure and temperature constraints from experimental reaction relationships	43
11. Mg/Fe in garnet versus Mg/Fe in biotite	48
12. Map of temperature and pressure calculations	57
13. Pressure and temperature diagram	60

LIST OF PLATES

Plate 1 In Pocket

CHAPTER I

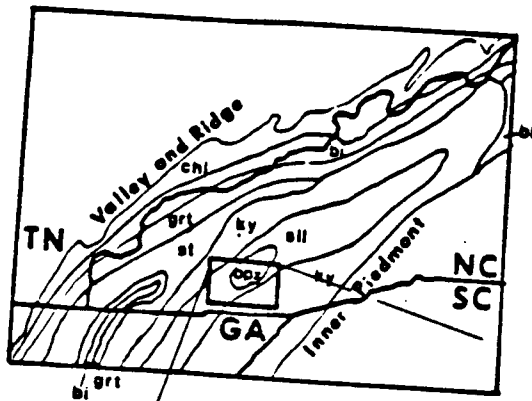
INTRODUCTION

PURPOSE OF STUDY

Metamorphism in the Blue Ridge of the southern Appalachians has been recognized as a progressive Barrovian metamorphic sequence (Carpenter, 1970; Hadley and Nelson, 1971; Hatcher, 1972; Hurst, 1973). The highest grade of metamorphism occurs in the core of the terrane with progressively lower grades occurring along the flanks (Fig. 1); however, the outcrop pattern of isograds is more complicated than the simple progressive sequence shown (Hatcher, 1985). The major metamorphic event in the Blue Ridge occurred during the Taconic orogeny (Butler, 1972; Glover et al., 1983).

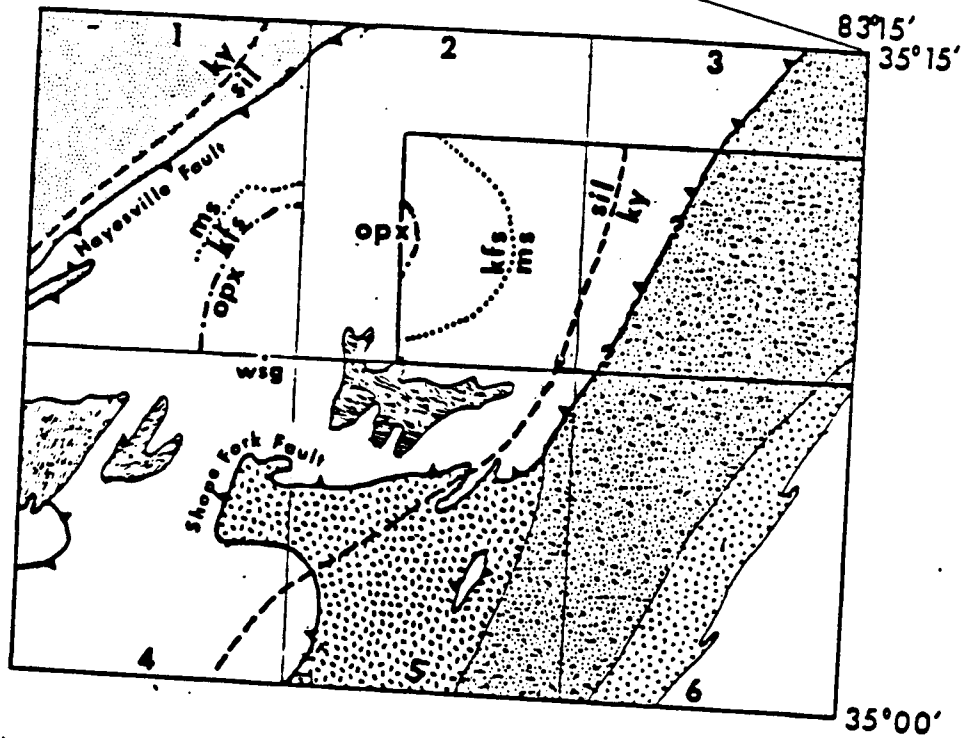
Delineation of metamorphic isograds has generally been limited to the first appearance of index minerals, with little or no regard for the bulk chemistry of the rocks or to reactions that produced the observed mineral assemblages. Those studies that have attempted to constrain the conditions under which metamorphism occurred (Allen and Ragland, 1972; Nesbit and Essene, 1982, McElhaney and McSween, 1983; and Absher and McSween, 1985) have generally dealt with single localities rather than attempting to

Figure 1. Regional geology of the field area. Isograds from McSween and Hatcher (1985) and Grant et al. (1986). Box shows area expanded in (b). General geology of the field area and surrounding vicinity, from Lesure (1966), McSween and Hatcher (1985), Eckert (1985), Hatcher et al. (1986, 1987) and Yurkovich (pers. comm., 1987). Isograds on geologic map from McSween and Hatcher (1985) and Eckert (1985). Quadrangles are: 1. Wayah Bald, 2. Franklin, 3. Corbin Knob, 4. Rainbow Springs, 5. Prentis, 6. Alarka. WSG represents the location of Winding Stair Gap described by Absher and McSween (1985).



- Great Smoky Gp.
- Coweeta Gp.
- Otto Fm.
- Coweeta Gp./Tallulah Falls Fm.
- Rabun Granite
- Mafic Complexes

83°37'30"



establish trends across a terrane.

The study area is located in the Franklin and Corbin Knob quadrangles in Macon County, North Carolina (Fig. 1). The area includes the eastern boundary of the opx zone (mineral abbreviations are in appendix A) originally delineated by Force (1976). Granulite facies assemblages were found by Hatcher and Butler (1979) in rocks at Winding Stair Gap close to the area defined by Force. They tentatively correlated the rocks there with either the Tallulah Falls Formation or the Coweeta Group. A more detailed study of structure and stratigraphy at Winding Stair Gap (Absher, 1984; Absher and McSween, 1985) affirmed that the metamorphism at Winding Stair Gap was Paleozoic, differentiating those rocks from Precambrian granulites that occur to the northeast in the vicinity of Roan Mountain, and in Virginia (Morgan, 1972; Hatcher et al., 1980; Gully and Monrad, 1983; and Gully, 1985). Absher and McSween (1985) determined peak metamorphic conditions at Winding Stair Gap to be approximately 750 deg C and 6.8 kbar.

Eckert (1985) correlated the rocks that reached the granulite facies in the Wayah Bald quadrangle to the west of the study area (Fig. 1) with the Coweeta Group and Tallulah Falls Formation. He delineated a series of prograde metamorphic zones from northwest to southeast: ky + ms, sil + ms, sil + kfs, coexistence of opx and cpx in mafic rocks.

Exposed granulite terranes are generally limited to

Precambrian shield areas (Bohlen, 1983) which have complex thermal and deformational histories. As a result, determining the metamorphic conditions in these areas is problematical due to the widespread presence of disequilibrium assemblages and retrograde effects. The presence of a relatively pristine, presumably Paleozoic, granulite terrane in the Blue Ridge offers a rare opportunity to determine more accurately the cause(s) for granulite facies metamorphism. Quantification of changing metamorphic conditions at the amphibolite-granulite transition provides a greater understanding of the thermal history of the Blue Ridge and gives important constraints on the tectonic development of this area.

For purposes of this study the boundary between the amphibolite and the granulite facies has been placed at the second sil isograd. In the text, "low-grade" refers to those rocks that contain ms or are in the area of ms-bearing assemblages, and "high-grade" to those rocks that contain kfs or are in the vicinity of kfs-bearing assemblages.

METHODS

Field work in the Corbin Knob and Franklin quadrangles was done on a scale of 1:24,000 utilizing 7 1/2 minute topographic sheets. Outcrops were selected for sampling on the basis of rock type, mineralogy, and freshness.

Orientations of foliations, lineations and fold axes were measured. Approximately 100 thin sections were made, cut perpendicular to foliation, for study in transmitted light. 21 polished thin sections were made for study in reflected and transmitted light. Sample locations are shown on plate 1 and brief petrographic descriptions are given in appendix B.

Mineral compositions were determined using a MAC 400S automated electron microprobe with natural and synthetic standards. Data reduction utilized the correction scheme of Bence and Albee (1968) with the data of Albee and Ray (1970). A beam current of 0.05 A with a beam diameter of 1 micron was used for analyzing grt and px. A current of 0.03 A with a defocused beam was used for analyzing bi, fld, ms, and hbl. Multiple analysis of grain cores and rims were used to assess instrument precision and to document grain zonation in most samples. Those mineral analysis used in temperature, pressure and fluid composition calculations are given in appendix C.

Samples for fluid inclusion study were doubly polished and left slightly thick, 50 to 75 microns. Heating and freezing measurements were made using a Fluid Incorporated heating/freezing stage. Heating runs were made at an approximate rate of 1 deg C/min, with most measurements reproducible to +/- 2 deg C. Isochores were calculated using the computer programs of Nichols and Crawford (1985).

Further discussion on fluid inclusion procedures is given in appendix D.

CHAPTER II

GEOLOGIC SETTING

GENERAL OVERVIEW

The Blue Ridge is composed of metasedimentary and metaigneous rocks, separated from the Valley and Ridge thrust belt by the Great Smoky thrust in the west and from the Inner Piedmont by the Brevard fault system in the east. The Blue Ridge is divisible into two lithotectonic belts separated by the Hayesville fault (Hatcher et al. 1979). Structural windows in which low-grade rocks are exposed under higher-grade rocks indicate that the Blue Ridge is allochthonous. COCORP seismic data indicate a master decollement extending under the Blue Ridge, possibly to the Coastal Plain, on which a minimum estimate of movement is 260 km (Cook et al., 1979).

The field area is located to the east of the Hayesville fault. The eastern Blue Ridge contains metasedimentary, volcanic, and ultramafic rocks, whereas the western Blue Ridge contains Grenville basement with no mafic or ultramafic rocks (Rankin, 1975; Hatcher, 1978). These differences have been interpreted as a break between continental shelf deposits of the western Blue Ridge and deeper-water, rift-related sediments of the eastern Blue

Ridge, with the mafic and ultramafic rocks representing possible dismembered ophiolites (Hatcher et al., 1984; and McSween and Hatcher, 1985). South of the field area, the premetamorphic Shope Fork Fault separates rocks of the Coweeta Group, in the southeast, from the Tallulah Falls Formation, in the northwest. The Tallulah Falls Formation is composed of metamorphosed pelitic and mafic volcanic rocks (Hatcher, 1973). The Coweeta Group is a generally cleaner sequence of felsic gneisses, with schists and layers of amphibolite (Hatcher, 1979).

STRUCTURE AND STRATIGRAPHY OF THE FIELD AREA

Detailed mapping of the Corbin Knob and Franklin quadrangles by S. Yurkovich (pers. comm., 1987) and the Franklin quadrangle by Lesure (1966) delineated several mafic, ultramafic and granitic bodies and some stratigraphic contacts. Plate 1 is a compilation of field work from previous workers and of this study. Recent mapping by Hatcher et al. (1979, 1986, 1987) located a contact between the Coweeta Group and Otto Formation in the Prentiss quadrangle. The Otto Formation is composed dominantly of ms-bi schist. This contact and the Shope Fork fault are shown intersecting just south of the field area (Fig. 1).

The contact shown on plate 1 may be the northern extension of the Shope Fork Fault and/or this stratigraphic

contact. It separates rocks on the east that contain outcrops of felsic gneiss with layers of schist from rocks to the west which are dominantly felsic gneiss. It also separates amphibolites containing hbl + bi from those containing hbl + grt. This difference appears to be controlled by bulk chemistry (see discussion in chapter 3). Also, small dunite bodies occur only to the east of this contact.

The rocks to the east of this contact are tentatively correlated with the Otto Formation, and rocks to the west are identified as Coweeta Group/Tallulah Falls Formation undifferentiated. The significance of this contact and its exact location is debatable. Many outcrops that occur to the east are similar to those in the west, in that they contain little or no schistose members. This may indicate that the contact is complexly folded and transposed, as are many of the premetamorphic contacts in the Blue Ridge.

Eckert (1985) correlated rocks of the lower part of the Wayah Bald quadrangle with the Coleman River Formation, part of the Coweeta Group. If a projection of his contact is made into the Franklin quadrangle, this would include those rocks defined as Coweeta Group/Tallulah Falls Formation undifferentiated in this study. However, such a projection is probably not valid due to the complex nature of the deformation that affected this terrane.

F₁ fold hinges were observed in only one outcrop. F₁

was recognized as refolded folds. These early folds have been destroyed by later deformational events. The dominant foliation, S_2 , which is defined by parallel alignment of ms and bi, formed as the result of an isoclinal folding event, F_2 , which transposes S_1 . A later F_3 event is also observed as upright isoclinal to open folds that deform S_2 .

Crenulations produce a distinct lineation in the schistose rocks. These may be related to F_3 or be related to another deformational event as suggested by Hatcher and Butler (1979). Within the granulite facies terrane F_3 and F_4 are rarely observed, and no evidence for F_1 was seen. This may have been due to the development of in-situ partial melts which disrupted the foliation. The foliation in the granulite facies terrane is also considered to be S_2 due to its similar style and orientation.

Small ductile shear zones and later brecciated zones were also observed. Movement on these zones is considered to have been minor, as nowhere were rocks of different stratigraphic character juxtaposed.

EVIDENCE FOR PALEOZOIC GRANULITE METAMORPHISM

The deformational sequence described here is similar to the regional deformation scheme of Hatcher and Butler (1979) and Glover et al. (1983). It also correlates with the structural sequence of Absher (1984) for Winding Stair Gap

and that of Eckert (1985) for the western edge of the granulite terrane. This indicates that the foliation in the study area formed as a result of the regional metamorphic event.

Age dating (Rb-Sr, K-Ar) has placed the main metamorphic event at 480-430 m.y., early Ordovician to early Silurian (Butler, 1972; Dallmeyer, 1975). This has been correlated with the Taconic deformational event (Glover et al., 1983). Later regional deformational events were at 380-340 m.y., Devonian to early Mississippian, and 330-230 m.y., late Mississippian to Pennsylvanian, which have been related to the Acadian and Alleghanian deformational events, respectively (Glover et al., 1983). A sample from Franklin, NC from which K-Ar date was taken gave an age of 307 m.y. (Kulp and Eckelmann, 1961). A sample to the north in Gay, NC, gave an age of 440 m.y. using Rb-Sr (Long, Kulp and Eckelmann, 1959). This sample would lie in the rocks delineated as Coweeta Group/Tallulah Falls Formation in this study if a projection is made along strike. These samples may have been metamorphosed during the Precambrian, and then reset by later metamorphic events.

The prograde metamorphic sequence observed along the eastern edge of the granulite facies terrane is the same as the sequence described by Eckert (1985) for the western edge of the terrane. The progression of zones is reasonable for regional metamorphic conditions. Lack of disequilibrium

assemblages and of any evidence for cross-cutting isograds, phenomena common in Precambrian granulite facies terranes, suggest that the granulite facies terrane in this area represents the peak prograde conditions recorded during the Paleozoic.

CHAPTER III

PETROGRAPHY AND MINERAL CHEMISTRY

A wide variety of rock types are present in the field area: schists, gneisses, calc-silicates, quartzite, amphibolites, and dunites. For purposes of discussion, rock types will be divided into two broad categories, metasedimentary and metaigneous rocks.

METASEDIMENTARY ROCKS

General Description

The low-grade outcrops are commonly interlayered schist and gneiss with gradational contacts. Gneissic rocks are generally light gray to dark gray, weathering to a reddish brown saprolite. As mica content increases the rocks become much darker and weather to a brighter red. The gneisses commonly exhibit a pinstripe appearance due to interlayering of qtz-fld and micas on the scale of 0.2 to 0.5 cm (Fig. 2a). These rocks have well developed foliations and are commonly lineated. The more felsic gneisses are commonly massive with poorly developed foliations.

At higher grades, layering is disrupted by fld-qtz segregations and is generally not as well defined (Fig. 2b). Rocks are generally more felsic with schistose layers more

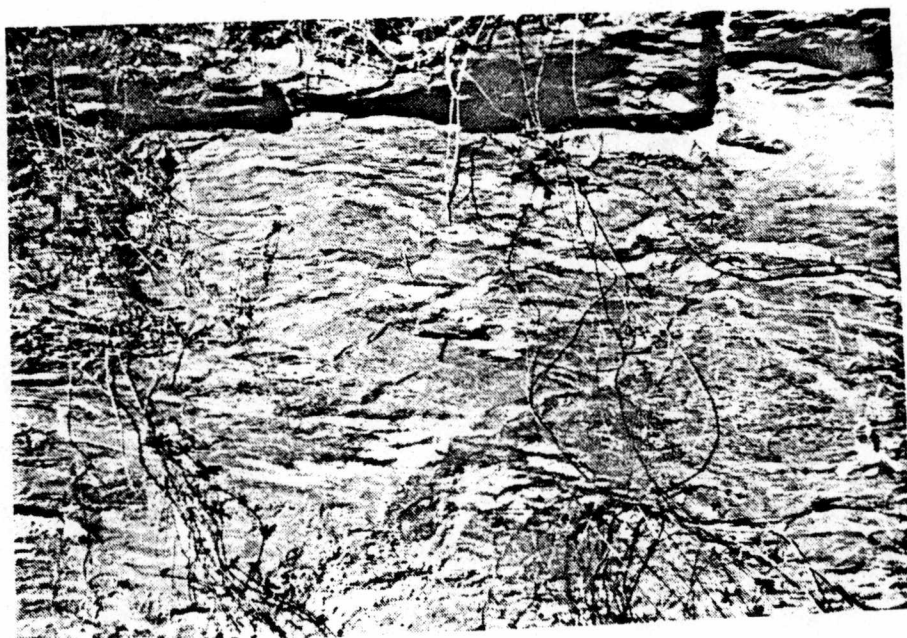
Figure 2. Outcrop photographs of amphibolite and granulite facies rocks.

a. Outcrop photograph of low grade mu-bi-grt gneiss and schist.

b. Outcrop photograph of high grade grt-bi-sil gneiss with qtz-fld segregation.



a.



b.

prominent. Qtz-fld segregations commonly have grt-bi rich rims and are non-foliated. The qtz-fld segregations are interpreted to represent in-situ partial melts (leucosome) and the grt-bi rims are thought to be restites (melanosome) (Mehnert, 1968; Ashworth, 1986). The qtz-fld segregations occur as pods and lenses discordant to the foliation and as discontinuous layers parallel to the foliation.

Assemblages

The common assemblage in rocks of pelitic composition in the amphibolite facies is grt + bi + ms + pl + qtz +/- ky (Fig. 3a). The more felsic rocks contain bi + pl + qtz +/- grt. Ky was only observed in the more schistose rocks. St was not observed in this study but has been recognized by S. Yurkovich (pers. comm., 1987) in the southeastern corner of the field area as small anhedral grains in thin section. The common high-grade assemblage is grt + bi + pl + qtz + sil +/- kfs (Fig. 3b). Assemblages are shown on a standard Thompson AFM projection from ms (Fig. 4). For those samples containing kfs, a modified Thompson projection is used (Fig. 4). A regular partitioning of Fe and Mg is observed except for two samples which cross-cut the other tie-lines.

Textures

Texturally the rocks contain porphyroblasts of grt, bi, ky and ms with straight to gently curved grain boundaries at

Figure 3. Photomicrographs of representative thin sections. Scale is the same for all pictures and is shown in the bottom right.

- a. Low-grade grt + bi + mu + ky + pl + qtz schist.
- b. High-grade grt + bi + sil + pl + kfs gniess.
- c. Retrograde reaction $\text{grt} + \text{il} = \text{bi} + \text{ru}$.
- d. Hbl + bi amphibolite.
- e. Hbl + grt amphibolite.
- f. Hbl + grt + opx + cpx amphibolite.



a.



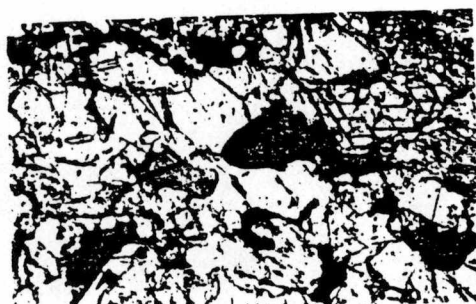
b.



c.



d.



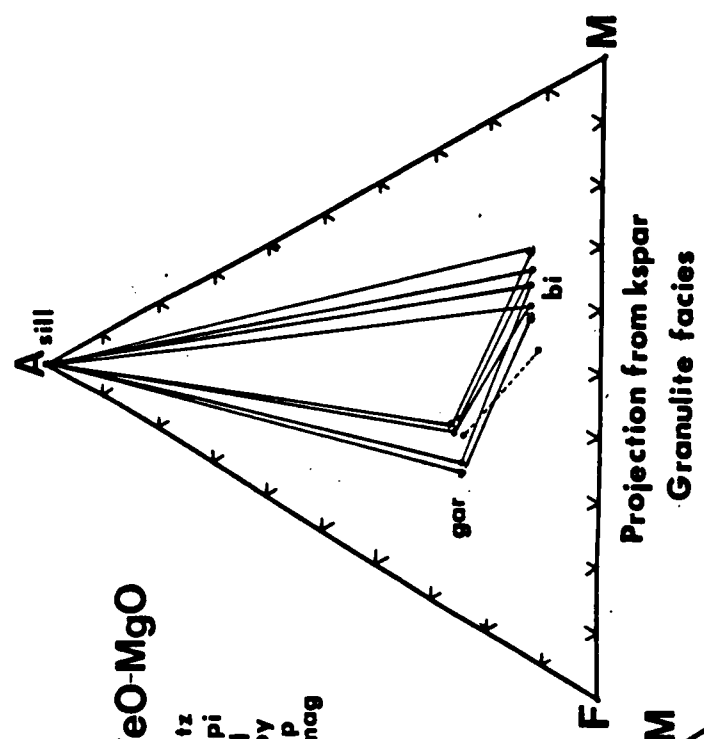
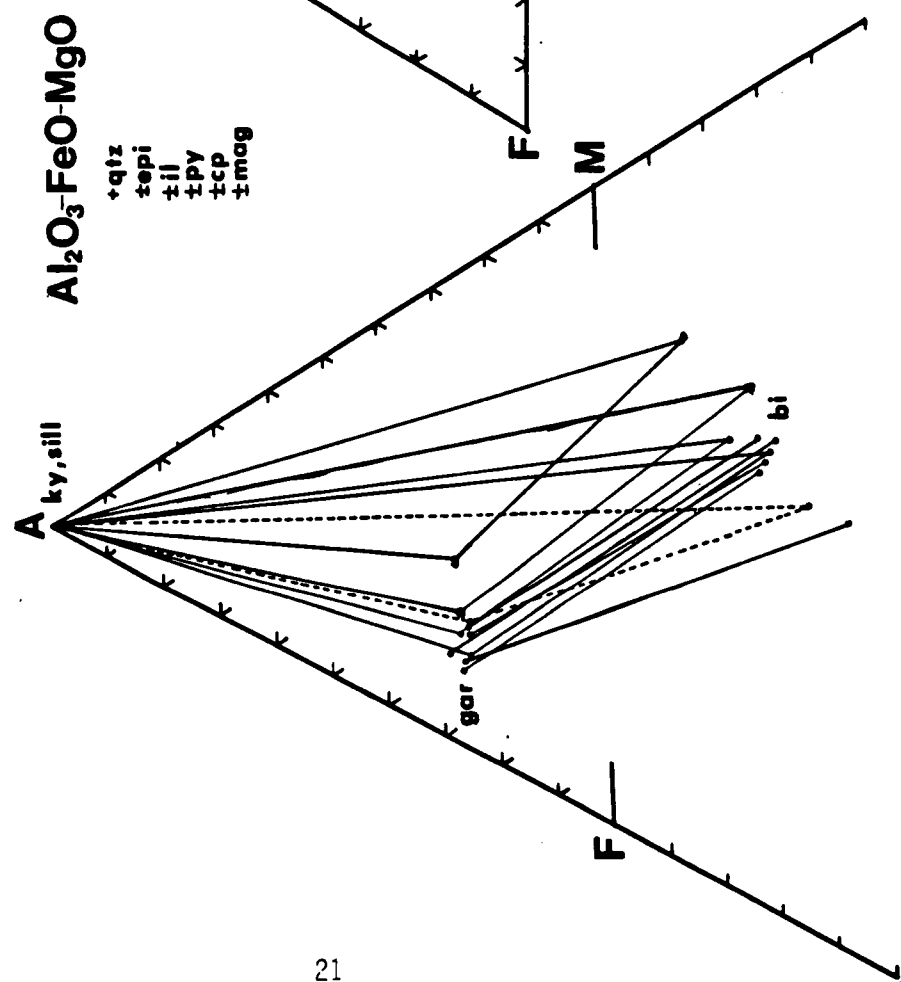
e.



f.

Figure 4. AFM projections for rocks of pelitic composition. Dashed lines indicate those assemblages that cross-cut the other tie-lines and are presumed to be disequilibrium assemblages.

Projection from muscovite
Amphibolite facies



the lower grades. In the kfs zone, rocks are more equigranular, with triple junctions common at grain boundaries. Retrograde effects are generally limited to sericitization of flds and als. Fracture filling of grt by chl was also observed. Most retrograde alteration was associated with shear zones or other deformation fabrics. In some samples ribbon qtz and fracturing of grt and fld were observed.

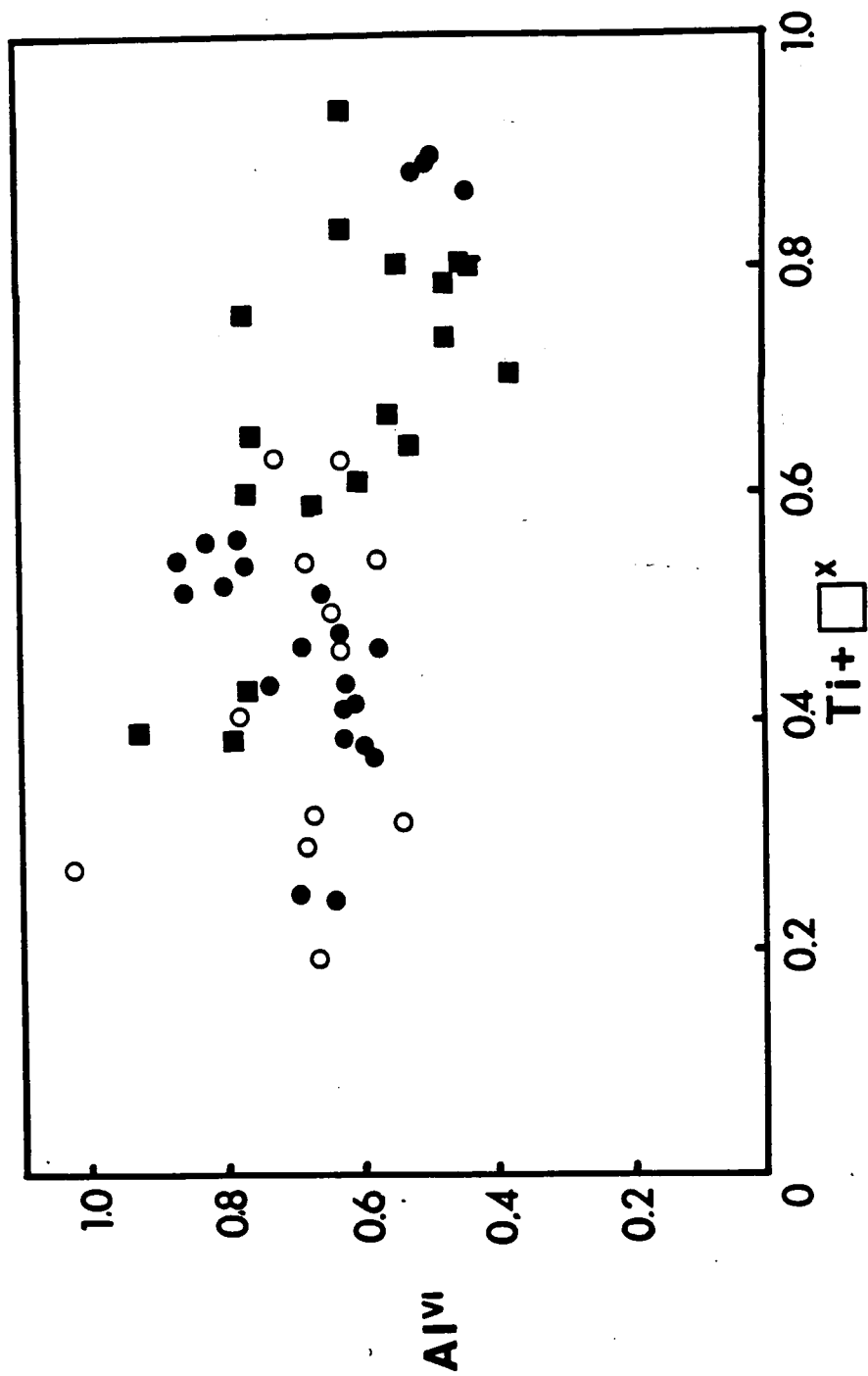
Some samples in the amphibolite facies show rounded to elliptical pods of ms + bi + pl + qtz. These may represent pseudomorphic replacement of grt or possibly st.

In the granulite terrane, a retrograde reaction involving grt and il breaking down to ru and bi was observed in some samples (Fig. 3c). Bi grains are reddish brown and radiate away from the ru and grt. This texture indicates that a late, wet, relatively hot, retrograde event affected certain parts of the high-grade terrane.

Mineral chemistry

Bi is generally euhedral, up to 1 mm in length. In the low-grade rocks pleochroism is generally light green or light brown to dark green, whereas in the high-grade rocks the pleochroism is light brown to yellow or dark brown. This may be a reflection of increasing Ti content in the bi with increasing grade (Fig. 5). At higher grades bi becomes subhedral to anhedral with irregular grain boundaries.

Figure 5. Plot of Ti versus Al_{VI} in biotite. Filled circles represent those samples from the ms-ky zone, open circles sil-ms zone, and squares from the kfs-sil zone.



Inclusions of qtz and fld are common at low grades with inclusions of opaque minerals common throughout the field area. Modal abundances of bi in the schists reach 60 %, and in the felsic gneisses 10%. No compositional zoning was observed in any of the samples, with grains containing minor amounts of Ca, Mn, and Na (see data, appendix C).

Ms is euhedral, up to 1.5 mm in length. It is commonly absent in the felsic gneiss. In schists it composes up to 30% of the rock. Inclusions of qtz and opaque minerals (il ?) are common. Compositionally ms contains small quantities of phengitic and paragonite components, and a surprisingly high celadonite component (see data, appendix C).

Pl is present as subhedral grains 0.3-1.0 mm in diameter. Albite and complex twinning are common. Grains are commonly bent with undulatory extinction. Pl composition ranges from An₂₁ to An₃₇ (see data, appendix C). No trend with increasing grade was observed, suggesting that Ca/(Ca + Na) is controlled by bulk composition rather than metamorphic grade in these rocks. Myrmekitic pl is common above and close to the second sil isograd. This type of texture has been interpreted as part of the prograde sequence (Ashworth, 1986) and also a retrograde replacement of kfs by myrmekite (Ashworth and McLellan, 1986).

Grt is generally subhedral to euhedral, though some samples contain anhedral grains. Crystal size and abundance increase with metamorphic grade. At low grade grt is most

common in schists and rare in felsic gneiss. At higher grades, grt is common in all rock types. Within the sil + kfs zone hundreds of pinhead grts are occasionally concentrated in an area of a few cm². Inclusions of qtz, pl, opaque minerals, and bi are common. Grts are almandine-pyrope solid solutions with minor amounts of spessartine and grossular (appendix C, see data). Zoning from core to rim shows an increase in Fe in all but one sample. Enrichment in Mn and Ca from core to rim is also seen in some samples (Fig. 6).

Ky occurs only in the schistose rocks. It forms euhedral grains 0.4-0.6 mm., aligned parallel to the foliation. In rocks containing sil, ky has irregular grain boundaries, indicating that ky is the unstable phase. Ky also occurs in qtz + fld segregations as euhedral grains up to 1.5 cm in length.

Near the ky-sil transition sil occurs as fibrolite along pl and ms grain boundaries. Within the sil zone, grains of sil become euhedral 0.3-0.75 cm., and are aligned parallel to the foliation. Sil was only observed in the more schistose rocks below the kfs + sil zone. Within the kfs + sil zone, sil was present in both gneiss and schist.

Kfs occurs as large 0.50-1.75 cm euhedral grains. Perthitic texture is common. Kfs composition is K⁺ with Na⁺ with minor Ca⁺ (see data, appendix C)

Common accessory minerals are ep, ap, il, and py. Ru

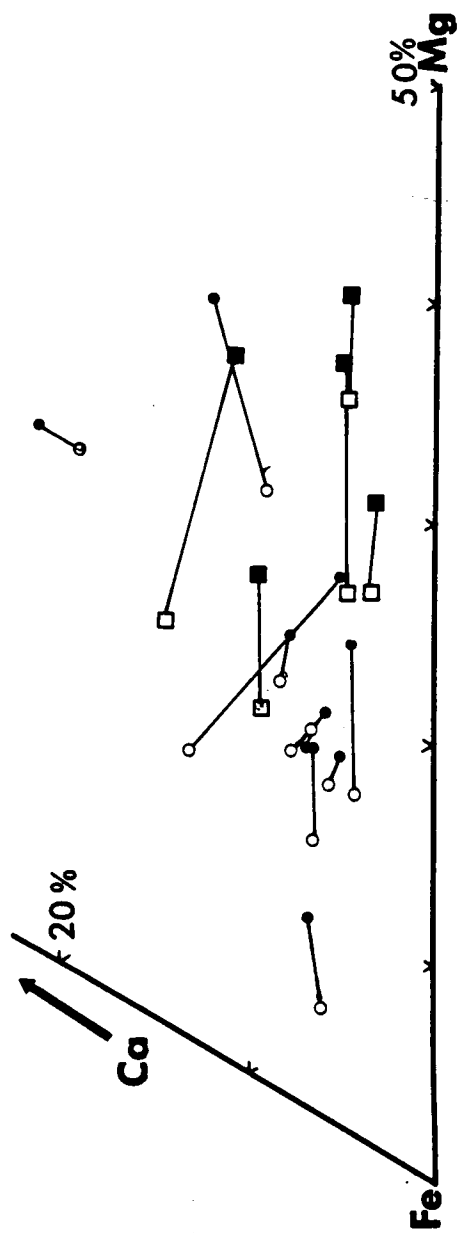
Figure 6. Grt compositions. Ternary diagrams of Mn-Fe-Mg and Ca-Fe-Mg. Closed symbols represent core compositions, open symbols represent rim compositions, and tie-lines connect coexisting cores and rims. Circles represent amphibolite facies samples squares represent granulite facies samples.

Garnet

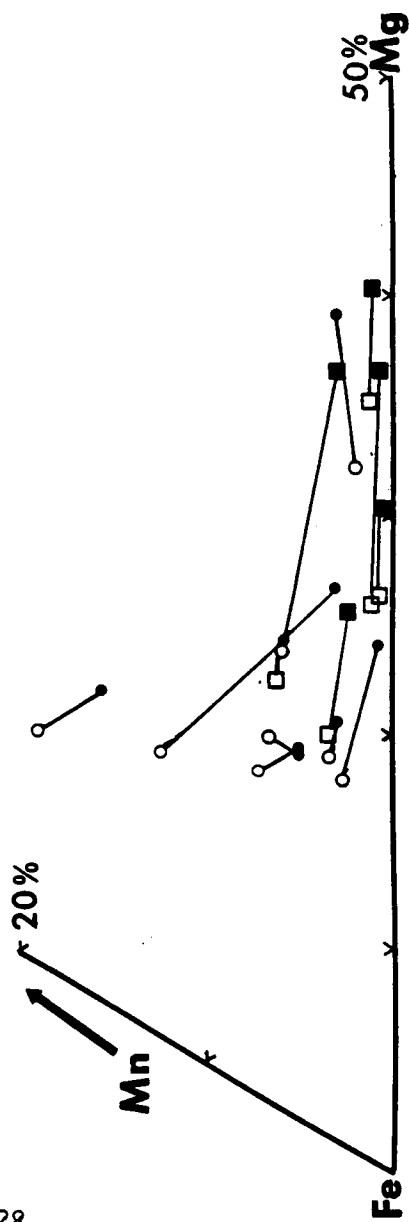
Compositions

■ cores

□ rims



28



is present in granulite facies rocks, and mag is occasionally observed in the amphibolite facies rocks.

METAIgneous Rocks

General Description

A variety of quartz-feldspathic igneous bodies are present in the field area. A large granitic body is located in the south east corner of the Corbin Knob quadrangle. This body has been correlated with the premetamorphic Rabun granite complex (Yurkovich, 1984). A smaller granodioritic body, which may be pre- to synmetamorphic, is located just to the east of the Rabun granite (Yurkovich, 1984; and Grant et al., 1986). This body is not foliated and is predominately qtz + pl with kfs, bi, and rare grt.

Pegmatite dikes are common within the field area and are a late feature, as they crosscut all previous foliations and structures. These dikes contain pl + qtz + bi + ms + kfs.

Several ultramafic bodies occur in the eastern portion of the field area. Two have been studied in detail, the Corundum Hill (Yurkovich, 1984) and Mincey Mine (Hahn and Hiemlich, 1984). Both of these bodies are dominantly dunite with rare harzburgite and olivine orthopyroxenite. Alteration of the dunite along fractures to serpentine, chlorite, and talc is common.

Amphibolites occur as lenses and boudins within the

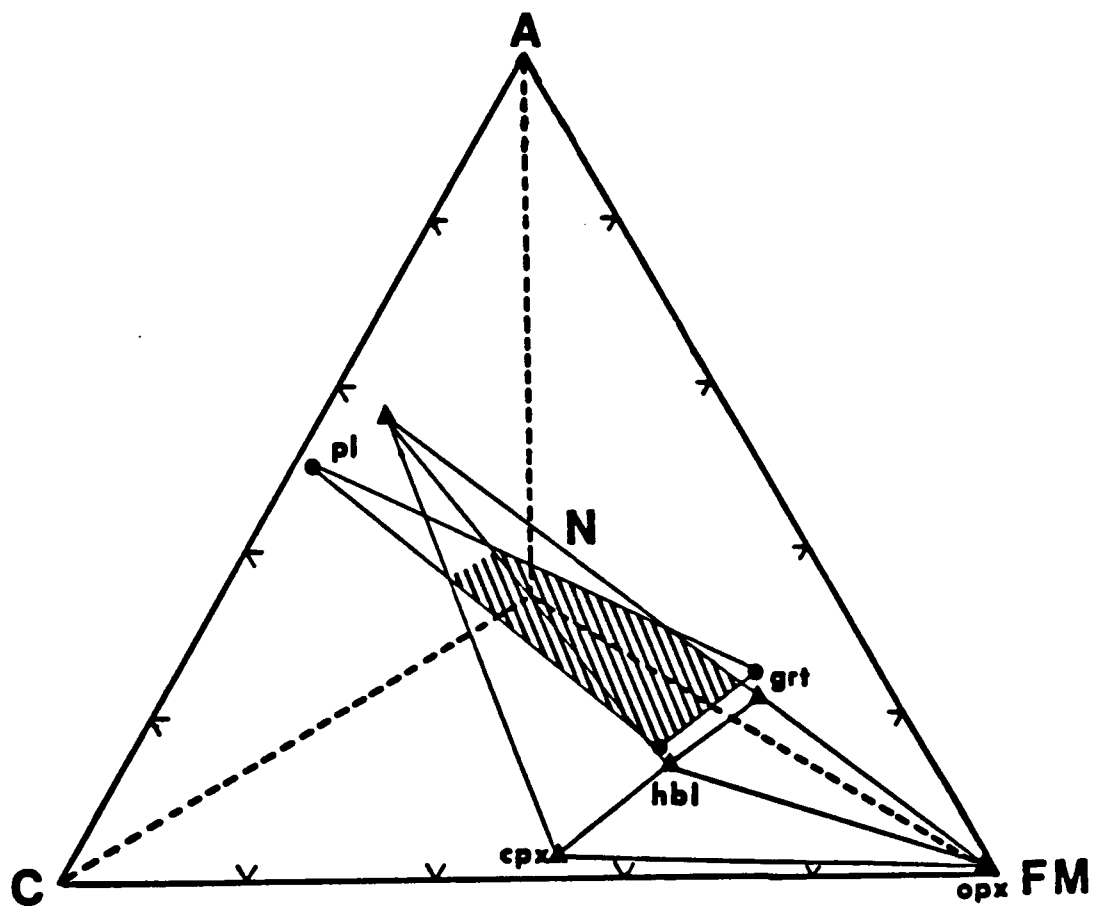
pelites and semipelites and as discrete mappable bodies. Generally these units are well foliated and occasionally folded by F3. Texturally, amphibolites are granoblastic with hbl defining the foliation. In some samples grains have serrated edges.

The amphibolites contain three main assemblages all with pl and qtz: hbl + bi, hbl + grt, hbl + grt + opx + cpx (Fig. 3d,e,f). The assemblages hbl + grt and hbl + grt + opx + cpx are shown on an Al_2O_3 -NaO-CaO-(FeO+MgO) tetrahedron (Fig. 7). The hbl + bi assemblage is the result of a difference in bulk chemistry, an excess amount of K_2O . Other observed assemblages are hbl + grt + bi and hbl + cu + grt.

Amphibolite Mineral Chemistry

Hbl occurs as euhedral grains, 0.4-2.0 cm., and commonly makes up greater than 50% of the rock. Grains have a light green to dark green pleochroism at low-grade. As metamorphic grade increases pleochroism changes to light green to light brown as Ti content increases. At higher grades a rim of light green hbl surrounds a light brown core. This type of rimming has been attributed to retrograde effects (Sen and Oliver, 1981). Site assignments were made following the criteria of Robbins (1982): Si and Al in the IV site; remaining Al, Mg, Fe, Mn, and Ti in the M1, M2, M3, sites; Ca and remaining Fe in the M4 site; and K and Na in the A site. Hbl shows an increase in the pargasite component

Figure 7. Composition tetrahedron for rocks of mafic composition. $\text{Na}_2\text{O}(\text{N})$ - $\text{Al}_2\text{O}_3(\text{A})$ - $\text{CaO}(\text{C})$ - $\text{FeO} + \text{MgO}(\text{FM})$ are the corners of the composition tetrahedron. Diagonal ruling indicates the area that is common to both the low-grade (grt + hbl + pl) and the high-grade (grt + opx + cpx + hbl + pl) assemblages. Circles represent sample from the ms-ky zone, triangles represent grt-opx-cpx zone.



and in Ti content with increasing grade (see data, appendix C).

Bi is usually euhedral, less commonly subhedral, with a light brown to dark brown pleochroism. Inclusions of opaque minerals are common. Ti and Na/Na+K contents are high, (see data, appendix C), probably as a result of bulk chemistry.

Pl occurs as anhedral to subhedral 0.3-1.0 cm. grains. Albite twinning is common. Ca content is high, An₈₈₋₈₇, in the non-px-bearing assemblages and drops to An₄₂ (see data, appendix C) in the px-bearing rocks.

Grt occurs as subhedral to euhedral grains 0.4-1.0 cm in size. Commonly grts poikilitically enclose pl, qtz, opaque minerals, and cpx. Grts are almandine-pyrope-grossular solid solutions, with a minor spessartine component (see data, appendix C).

Cpx occurs as anhedral, 0.3-0.7 cm grains with a faint pleochroism from green to light green. The Mg/Fe ratio is 2:1, with minor amounts of Mn and Na (see data, appendix C). Cpx is poikilitically enclosed by grt or is associated with opx.

Opx is subhedral 0.3-.5 cm with a light green to pink pleochroism. Opx has slightly more Mg than Fe (see data, appendix C). On a plot of Fe/Fe+Mg versus 100 Ca/Ca+Mg+Fe, opx plots within the field of metamorphic px delineated by Rietmeitser (1983).

Quartz grains are anhedral with undulatory extinction.

Sphene is commonly present as rims around il grains. Whether this reaction is prograde or retrograde is unclear from textural relationships.

Ep occurs as anhedral, 0.1-0.2 cm grains in hbl-bi rocks or as a symplectic intergrowth with qtz at hbl-pl boundaries. This symplectite has been interpreted as a retrograde reaction of hbl and pl breaking down to ep and qtz. Ep was also observed filling late fractures.

Py, cp, and il are common opaque phases in the mafic rocks.

CHAPTER IV

REACTIONS AND CONDITIONS OF METAMORPHISM

ISOGRADS AND METAMORPHIC REACTIONS

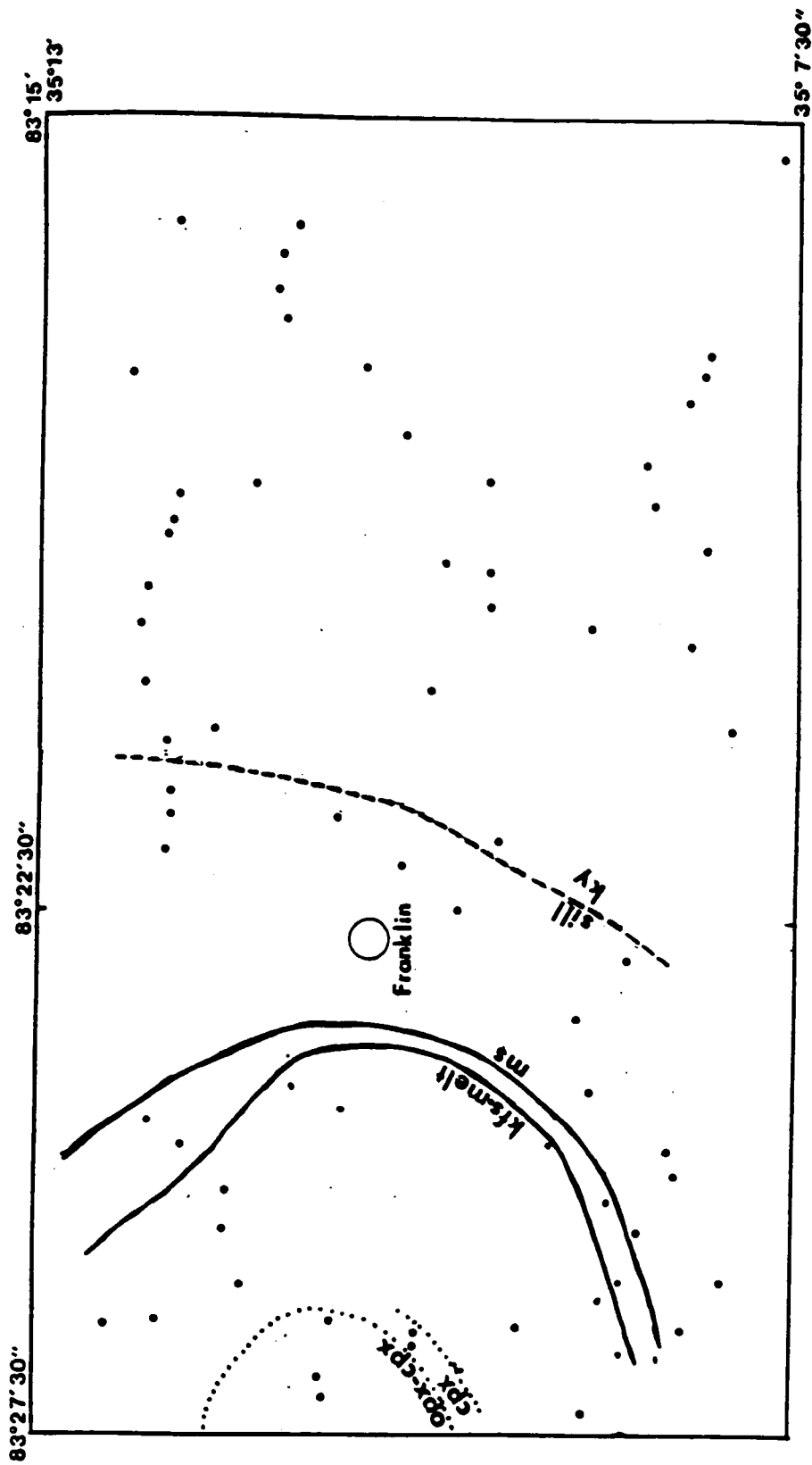
The observed sequence of isograds in the field is as follows, the transition from ky to sil, the transition from ms + qtz assemblages to kfs + sil assemblages, the development of in-situ partial melts, all in the pelites, and the transition from grt + hbl assemblages to grt + opx + cpx + hbl assemblages in mafic schists.

Reactions in the Pelitic Rocks

The sil isograd is located approximately 1 mile east of Franklin running southwest to northeast (Fig. 8). The isograd marks the first appearance of fibrolitic sil in thin section. Sil occurs along ms-pl grain boundaries, commonly with anhedral poikiloblastic ky. Further west the sil grains become euhedral and occur rarely with ky in the same thin section. These textural relationships indicate that coupled reaction(s), rather than polymorphic conversion, was the mechanism by which transformation took place. Carmichael (1969) has suggested a variety of coupled reactions, involving ms as a catalyst.

The transition from ms + sil assemblages to kfs + sil assemblages in rocks of pelitic to felsic composition occurs

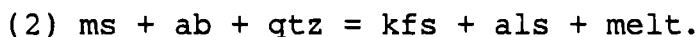
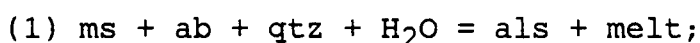
Figure 8. Isograd map of the field area. Locations of the $ky = sil$ transition, ms dehydration to kfs and appearance of migmatites, and the hbl dehydration to opx , cpx , and grt are shown. Dots indicate locations of outcrops studied.



2-3 miles west of Franklin. Spatially associated with this transition is the first appearance of migmatites, interpreted to be in-situ partial melts.

The transition from ms-bearing assemblages to kfs-bearing assemblages is relatively sharp. This may be due to a paucity of outcrops in the transition zone or to the presence of an unseen fault. Outcrop locations to the south give enough control to indicate that the sequence is relatively continuous and that the transition is abrupt.

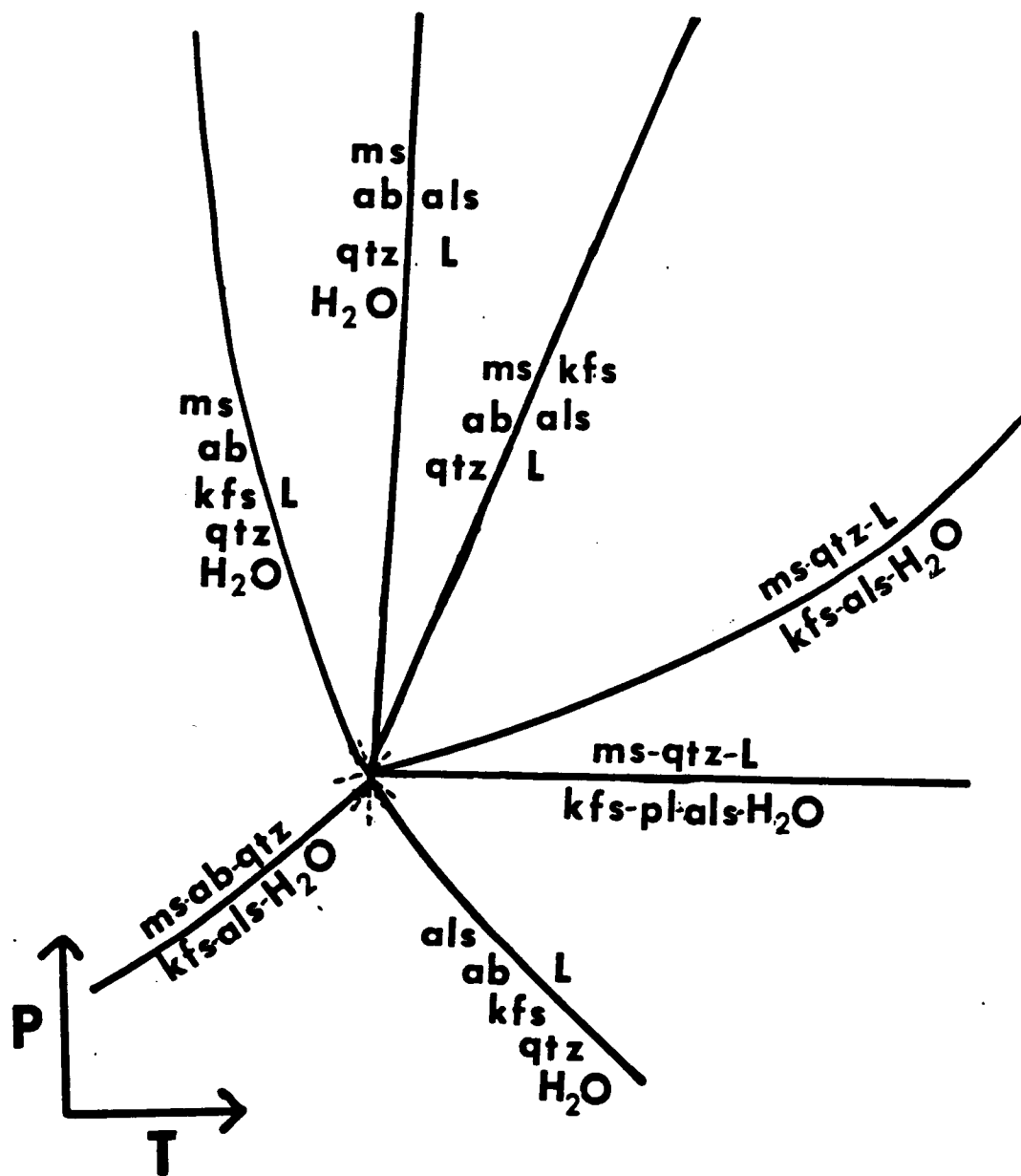
The close spatial association of ms breakdown and the first appearance of migmatites suggest these reactions may be coupled. Thompson and Algor (1977) determined the system of univariant reactions by which melts could be produced in the system $\text{NaAlO}_2\text{-KAlO}_2\text{-Al}_2\text{O}_3\text{-SiO}_2\text{-H}_2\text{O}$, and later Thompson and Tracy (1979) added CaO as a component. A schematic pressure-temperature diagram (Fig. 9) shows the univariant equilibria in this system. Two reactions may produce melts:



All other reactions involve kfs as a reactant, or do not produce melts with the dehydration of ms. If water is present as a free fluid phase then reaction (1) would produce melts. If no free water is present, reaction (2) would be the melt producing reaction. Three lines of evidence suggest that reaction (2) may have been the melting reaction in this terrane:

1. If in-situ melts were produced by reaction (1) upon

Figure 9. Possible melt reactions. Schematic pressure-temperature grid showing possible melt reactions (from Thompson and Tracy, 1979).



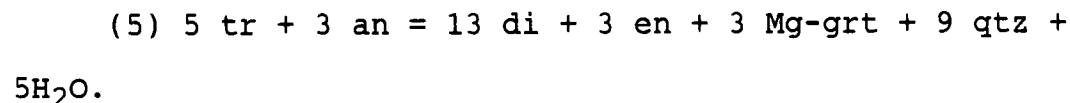
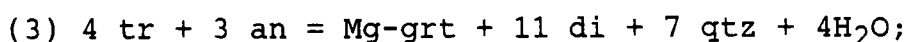
crystalizing they would have expelled water. This would presumably cause retrograde metamorphism in the surrounding rocks, but very little retrograde effects were observed.

2. Kfs is present in the neosome of the rock, indicating it was a product of the reaction involving the breakdown of ms in addition to being produced as the result of the crystallization of in-situ melts.

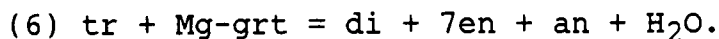
3. No H₂O-rich inclusions were observed. The absence of fluid inclusions usually is explained by the fluids never being trapped or their subsequent destruction. An equally consistent explanation would be that there was never any fluid (except CO₂) present to be trapped.

Reactions in the Amphibolites

Reactions in the amphibolites involve the dehydration of hbl to form grt, opx, and cpx. The presumed reactions are:



These reactions are based on the textural evidence of grt poikilitically enclosing cpx for reaction (3), and cpx-opx clusters for reactions (4) and (5). Another possible opx-forming reaction is:



However, texturally grt does not appear to be a reactant. As

metamorphic grade increases, cpx occurs before opx (Fig. 8), suggesting that cpx formed at slightly lower temperatures than opx.

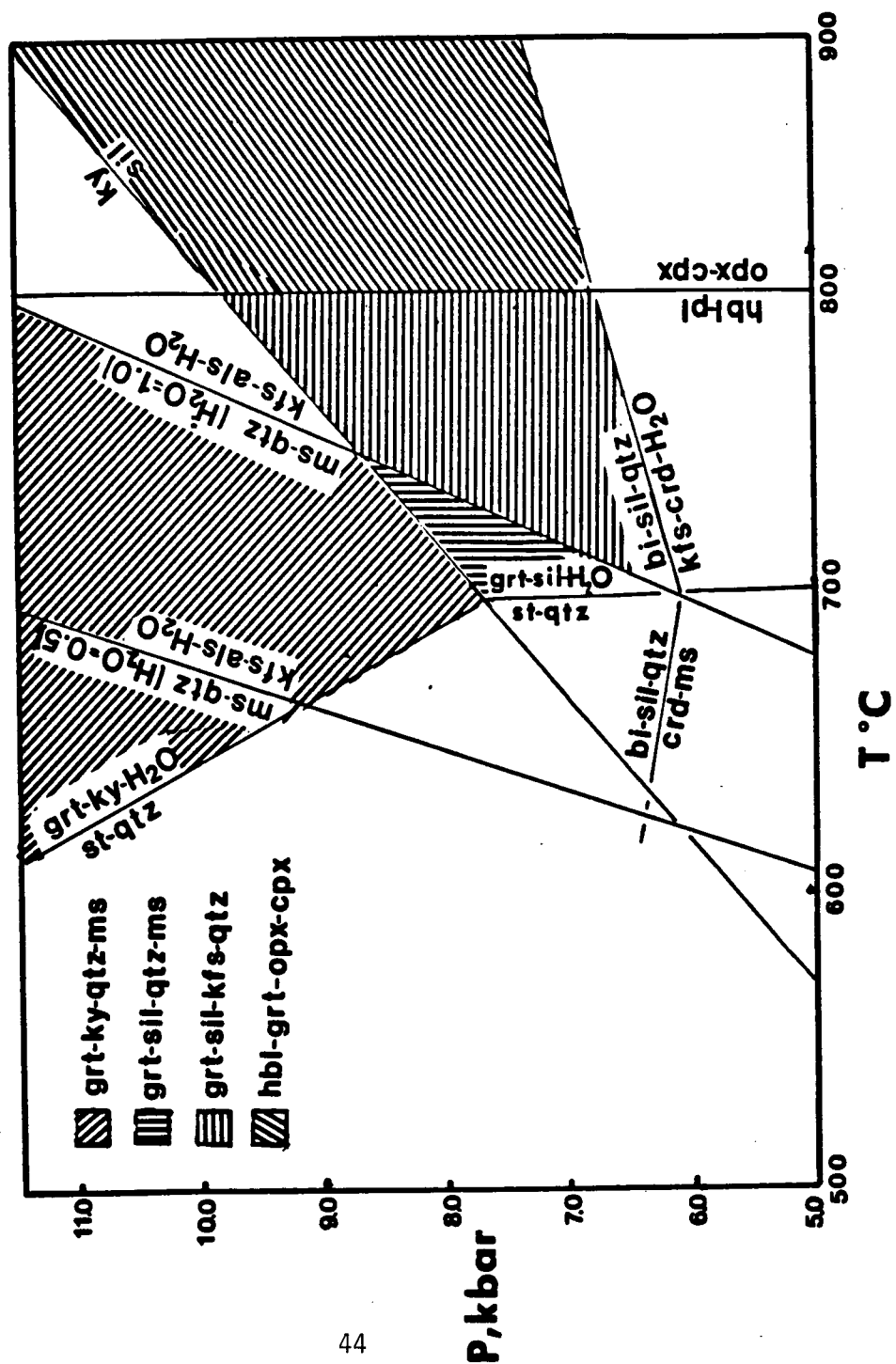
That opx and cpx in amphibolites formed as a result of reactions and not a difference in bulk chemistry can be demonstrated by the composition tetrahedron $\text{NaO-CaO-Al}_2\text{O}_3\text{-(FeO+MgO)}$ (Fig. 7). The low-grade assemblage grt + hbl + pl defines a surface within the tetrahedron. The high-grade assemblage grt + opx + cpx + pl + hbl defines a volume that contains a large portion of the surface of the low-grade assemblage, including the hbl composition of the low-grade assemblage. Both low- and high-grade assemblages can be generated, with the approximate modes, from the same bulk chemistry. Spear (1981), in an experimental study of hbl stability, observed an increase in the pargasite and Ti contents of hbl when involved in the production of px, features which are also observed here.

Pressure and Temperature from Reaction Relationships

Constraints on the pressure and temperature of each zone can be made based on reactions that have been studied experimentally. The assemblage grt + bi + ky + ms + qtz is constrained in pressure-temperature space by the maximum temperature stability limits of the minerals ky, st, and ms in the presence of qtz (Fig. 10). The intersection of the ky-to-sil transition (Holdaway, 1971) with the maximum

Figure 10. Pressure and temperature constraints from experimental reaction relationships. Reactions and references are:

ky = sil (Holdaway, 1971),
st + qtz = grt + als + H₂O (Ganguly, 1972),
ms + qtz = kfs + als + H₂O (Kerrick, 1972),
bi + sil + qtz = crd + ms(kfs + H₂O) (Thompson, 1976).



stability of st (Ganguly, 1972) places a lower pressure limit of 7.5 kbar.

The assemblage grt + bi + sil + ms + qtz is constrained by the lower temperature limit of sil, and the maximum temperature limits of st and ms stability in the presence of qtz (Kerrick, 1972) (Fig. 10). The intersection of st and ms stability curves place lower temperature and pressure limits of 700 deg C and 6.5 kbar on this assemblage. The intersection of sil and ms stability places upper temperature and pressure limits of 7.5 kbar and 750 deg C.

The assemblage grt + sil + kfs + qtz with interlayers of mafic schist containing the assemblage grt + hbl with no px, is constrained by sil, ms, crd (Thompson, 1976), and hbl stability (Spear, 1981) (Fig. 10). The intersection of crd and ms stability places lower pressure and temperature limits of 6.0 kbar and 700 deg C. A maximum temperature of 800 deg C, between 6.5 and 10.75 kbar, is obtained by the intersection of hbl, crd, and sil stability. The assemblage hbl + grt + opx + cpx in mafic schists is constrained to temperatures above 800 deg C, by the beginning breakdown reaction of hbl.

The constraints of pressure and temperature on these assemblages would suggest that the transition for amphibolite to granulite facies, as represented by the breakdown of ms, occurred between 700 and 750 deg C at pressures of 7.5 to 8.5 kbars.

P-T FROM MINERAL EXCHANGE EQUILIBRIA CALCULATIONS

A variety of cation exchange reactions were used in this study. Two-fld, two-px, grt-px, and grt-bi continuous reactions were employed as geothermometers.

The most widely applicable was Fe-Mg exchange between coexisting grt and bi. The K_d ($\text{Fe/Mg}_{\text{grt}}/\text{Fe/Mg}_{\text{bi}}$) has been shown to be controlled primarily by temperature, with pressure having very little effect on the reaction (Ferry and Spear, 1978). Samples were chosen for study based on the following criteria:

1. freshness of sample: no obvious retrograde effects such as grt altering to chl.
2. location.
3. usefulness of mineral assemblage in also determining pressure.
4. relative modal abundance of grt versus bi.

The assemblage of interest was grt + bi + ky(sil) + pl + qtz. This assemblage is widespread in the granulite facies terrane, but relatively rare in the amphibolite facies terrane. Within the amphibolite facies terrane the assemblage grt + bi + ms + pl + qtz was the second assemblage of choice.

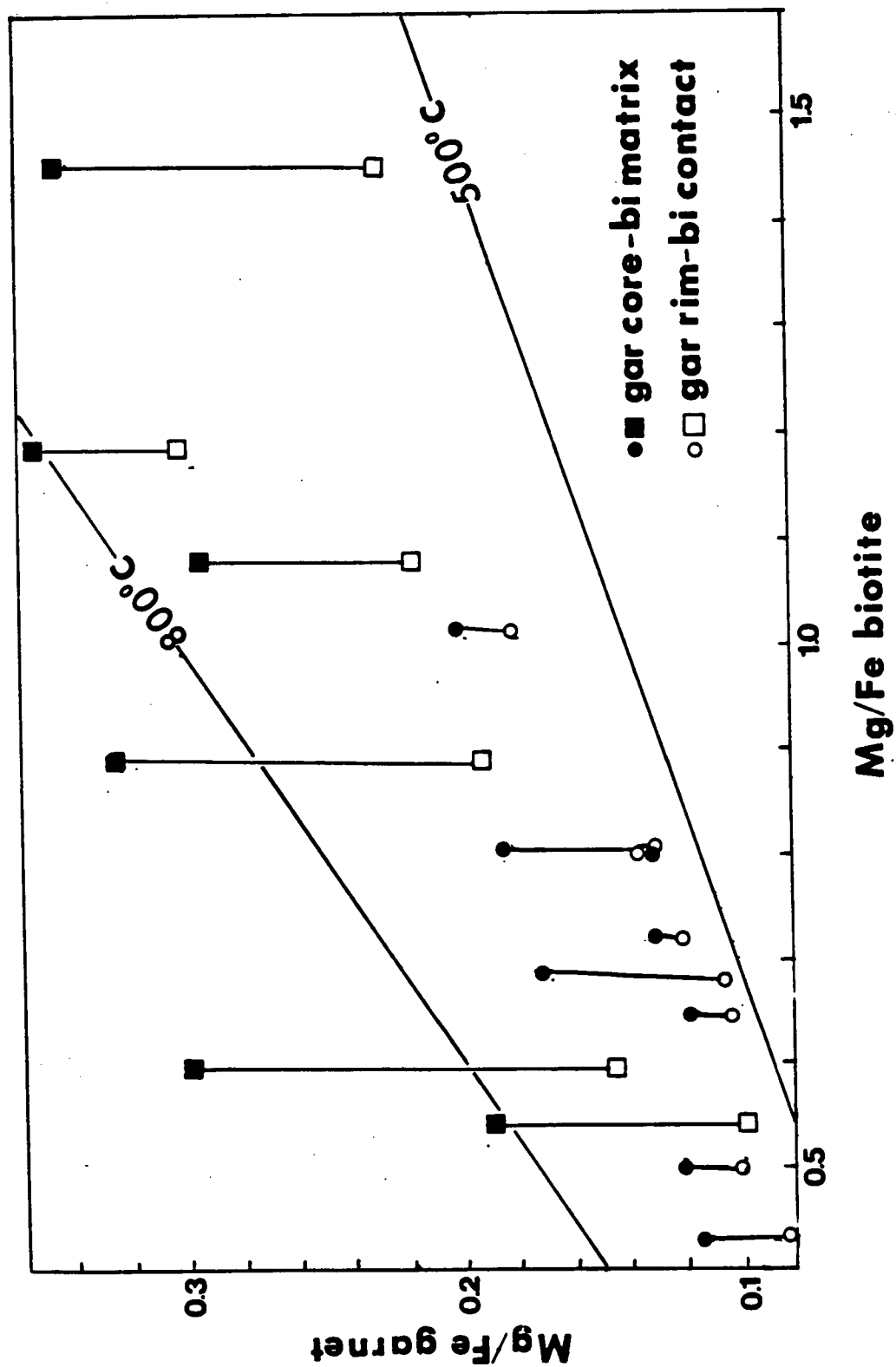
Reequilibration of grt and bi at high grades has been recognized as a problem in other granulites (Bohlen and

Essene, 1980; Indares and Martignole, 1985). The intracrystalline diffusion rate of Fe and Mg in bi is considered to be faster than grt, i.e. grt is the rate-controlling phase in the reaction. By using samples with a high ratio of modal bi to grt, the effect of reequilibration may be minimized.

Grt core with bi matrix (biotite not in contact with a grt), and grt rim with bi in contact with a grt were used to calculate temperature. Rim grt and bi contact gave consistently lower estimates than grt core and bi matrix. This is shown in Fig. 11, a plot of Fe/Mg in grt versus Fe/Mg in bi, in which any point would represent a K_d for any grt-bi pair. Two lines of equal K_d are illustrated, representing temperatures of 500 and 800 deg C, at 6 kbar. In 13 of the 14 samples, grt rim-bi contact gives a lower temperature estimate than grt core-bi matrix. The one sample (CN3-C) that gives a higher rim temperature is located near the quartz diorite pluton and may have been reset by its intrusion. The lower temperature estimates from rim compositions can best be explained by retrograde reequilibration as the rocks cooled. This interpretation is consistent with the core-rim zoning patterns in the grts (Loomis, 1975; Tracy, 1982). Therefore, grt core-bi matrix analyses were used as the best estimate of peak metamorphic conditions.

A variety of calibrations for the grt-bi geothermometer

Figure 11. Mg/Fe in garnet versus Mg/Fe biotite. Closed symbols are grt core-bi matrix pairs, open symbols represent grt rim-bi contact pairs, with tie-lines connecting coexisting grt cores and rims. Diagonal lines represent equal Kd's which when used in the Ferry and Spear (1978) calibration, would give calculated values of 500 deg C and 800 deg C at 7 kbar. Circles represent amphibolite facies samples and squares represent granulite facies samples.



have been proposed (Thompson, 1976; Goldman and Albee, 1977; Ferry and Spear, 1978; Indares and Martingole, 1986). Essene (1982) considered Ferry and Spear (FS) to be the calibration of choice, as it gives consistent results in a variety of rock types over a wide range of temperature and pressure conditions. The FS calibration has two screens, $\text{Ca} + \text{Mn in grt} < 0.2$ and $\text{Ti} + \text{Al}_{\text{VI}} \text{ in bi} < 0.15$. Using FS as a base, the Indares and Martingole (IM) formulation attempts to take into account the effect of these dilutents. Within the amphibolite facies terrane both calibrations give essentially the same result within the error of the calculation (± 50 deg C). In the granulite facies terrane FS gives much higher temperature estimates than IM. The results of these calculations are summarized in Table 1. These higher values are often geologically unreasonable. Bi in samples from the granulite terrane have $\text{Ti} + \text{Al}_{\text{VI}} > 0.15$, indicating that the FS calculated value may be in error. The IM calculation seems to give more consistent results in this terrane. Temperature in the amphibolite facies terrane is estimated to be approximately 620-700 deg C and in the granulite terrane 700-780 deg C. Those samples which give unreasonably high temperatures are the same samples that showed crossing tie-lines in Fig. 4, indicating that these samples are probably not in equilibrium.

Two-fld thermometry in the granulite facies terrane gave a much lower temperature estimate (600-620 deg C) using

Table 1: Grt-bi temperature estimates. Top number represents temperature estimated from grt core-bi matrix pairs, bottom number represents grt rim-bi contact pairs. (* No rim compositions were collected on this sample, F72.)

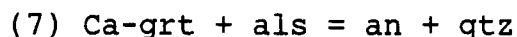
	grt (Ca + Mn)	bi (Ti + Al)	K	FS	IM
CN3	.21	.16	.2339	683	716
	.24	.16	.2518	715	770
CN10	.16	.12	.1917	607	639
	.12	.15	.1829	592	575
CN13	.11	.17	.2592	731	639
	.12	.16	.2032	630	571
CN21	.14	.13	.2267	672	671
	.13	.15	.1782	583	577
CN25	.08	.14	.3693	931	876
	.07	.14	.1769	580	634
CN56	.09	.18	.1986	621	568
	.09	.18	.1590	546	492
CN73	.15	.13	.2532	722	749
	.11	.14	.1545	541	540
CN85	.06	.16	.2520	720	655
	.07	.19	.1459	523	465
F1	.12	.17	.2364	696	639
	.12	.18	.1711	573	528
F11	.12	.18	.3670	935	774
	.06	.20	.1816	593	493
F29	.14	.16	.5524	1294	1187
	.13	.16	.2454	712	643
F36	.04	.16	.2730	763	610
	.11	.16	.1742	579	464
F38	.05	.17	.3276	862	712
	.06	.16	.1962	621	547
F72	.13	.16	.3551	913	858
*					
F77	.07	.14	.1981	625	590
	.09	.16	.1830	596	573

the formulation of Powell and Powell (1977). The perthitic nature of the Kfs suggests that this is a reequilibration temperature.

Two-px thermometry (Lindsley, 1983) was used for sample F41, which presumably represents the maximum thermal conditions in the area. Both px compositions plot on the 800 deg C partition line, with the tie-line paralleling those of Lindsley (1983).

Fe-Mg exchange between grt-cpx (Ellis and Green, 1979) was used to estimate temperature in the same sample. The temperature estimate for this reaction is 780 deg C (Table 2). Both two-px and grt-cpx estimates are in good agreement with the peak temperature conditions estimated from grt-bi equilibria.

The reaction



can be used to estimate pressure (Ghent, 1976). The calibration used (Newton and Haselton, 1981) has a reported error of +/- 0.5 kbar. In the amphibolite facies terrane this calculation gives a value of 5.3 kbar, and within the granulite facies terrane values ranged from 6.5 to 8.1 kbar (Table 3). The value of 10 kbar calculated from sample CN73 appears to be too high, but no explanation for this value is evident.

Below the ms dehydration reaction the assemblage grt + ms + pl + qtz can also be used to calculate pressure. Two

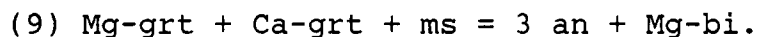
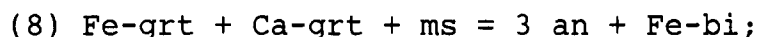
Table 2: Temperature and pressure estimates from the assemblage grt-opx-cpx. Temperature was calculated using the calibration of Ellis and Green (1979). Pressures were calculated using the relationships of Perkins and Newton (1981). K_1 is calculated from the assemblage grt-opx-pl, K_2 is calculated the from assemblage grt-cpx-pl.

	F41
X_{Fe}^{grt}	.5643
X_{Mg}^{grt}	.2115
X_{Ca}^{grt}	.1963
X_{Fe}^{cpx}	.1711
X_{Mg}^{cpx}	.4104
X_{Ca}^{cpx}	.4185
K	5.066
T deg C	784
K_1	.1174
K_2	.0478
P_1 kbar	10.0
P_2 kbar	7.5

Table 3: Grt-pl-als pressure estimates. Calculations from the calibration of Newton and Haselton (1981).

	CN56	CN73	F11	F36	F38	F77
a_{Ca}^{grt}	.0651	.1461	.0631	.0426	.0604	.0659
a_{Ca}^{pl}	.7388	.5205	.4299	.3647	.4233	.5543
P^O	12.2	15.1	17.6	17.3	16.2	13.3
P kbar	5.3	10.1	6.9	6.7	8.2	5.3

continuous reactions can be written:



The thermodynamic relationships for these two reactions were empirically derived by Ghent (1981), and reaction (9) was recalculated by Hodges and Crowley (1985) using a larger data base. The values from the Hodges and Crowley calibration range from 5.0 to 6.9 kbar in the amphibolite facies (Table 4), with an estimated error of ± 0.8 kbar.

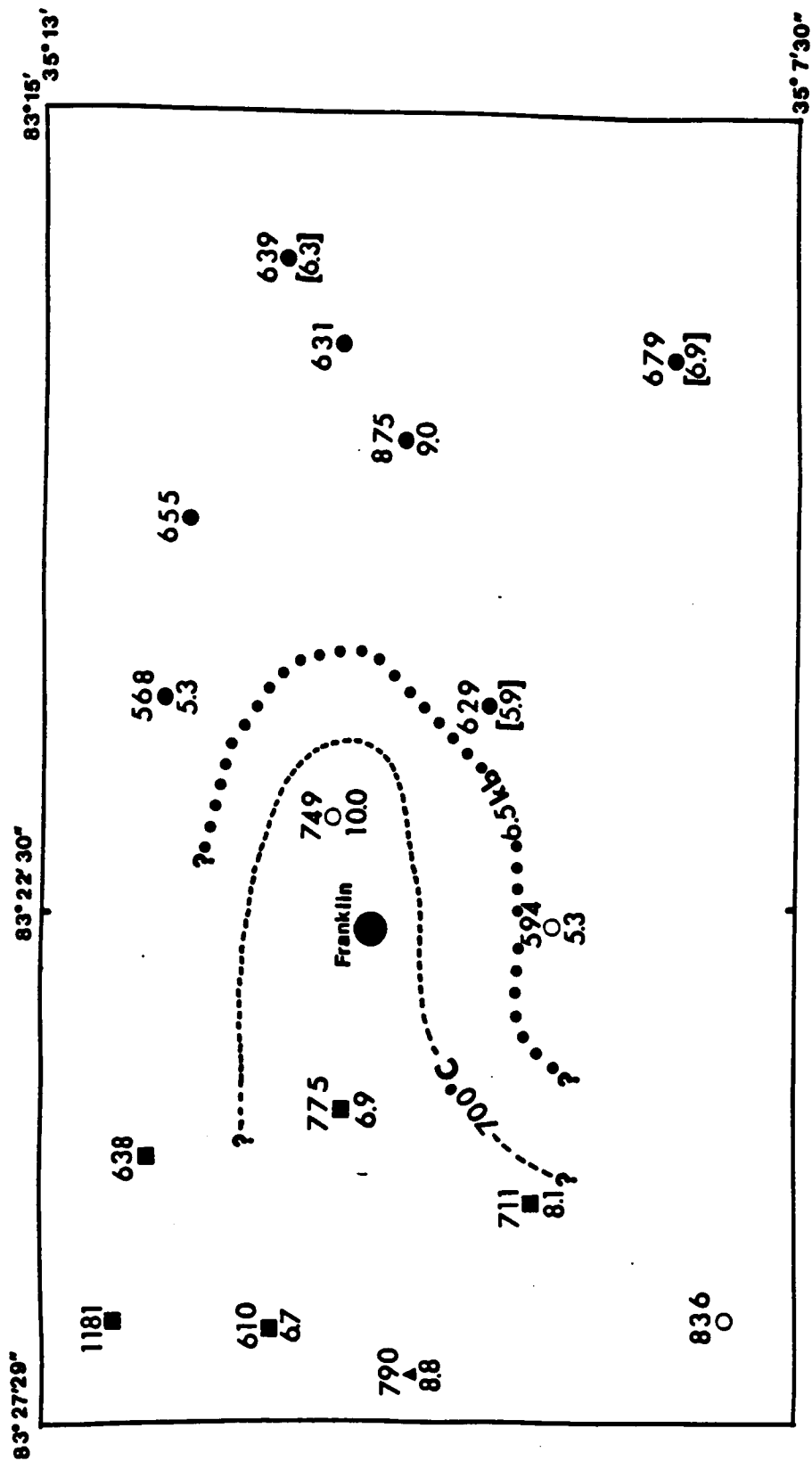
In sample F41 pressure was calculated from Ca exchange between $\text{grt} + \text{cpx} + \text{pl}$ and $\text{grt} + \text{opx} + \text{pl}$, using the calibration of Perkins and Newton (1981). These authors suggested that $\text{grt} + \text{opx}$ gives a high pressure estimate while $\text{grt} + \text{cpx}$ gives a low pressure estimate. An average of these two estimates gives a value of 8.8 kbar (Table 2).

The results of the grt-bi thermometry and grt-pl-als , grt-pl-ms barometry and calculations from the grt-opx-cpx assemblage are summarized in Fig. 12. A 700 deg C contour can be drawn that approximately separates the amphibolite facies from the granulite facies terrane. A 6.5 kbar contour can also be drawn that separates the two terranes. This indicates that the granulite terrane was at a higher temperature and pressure than the amphibolite terrane. A gradual transition from amphibolite to granulite facies conditions is not apparent from the calculations made. This may be the result of the effects of retrograde

Table 4: Grt-pl-ms pressure estimates. Pressure estimates are calculated from Hodges and Crowley (1985)

	CN3	CN10	CN13	CN25	CN56
X_{Ca}^{pl}	.2344	.3086	.2971	.3390	.2737
X_{Mg}^{bi}	.4000	.4351	.3931	.4252	.4647
X_{Fe}^{bi}	.4745	.4273	.4396	.4421	.3601
X_K^{ms}	.8741	.8600	.9746	.8825	.8835
X_{Al}^{ms}	.8382	.8479	.8491	.8424	.9081
X_{Mg}^{grt}	.1324	.1585	.1554	.2329	.1741
X_{Fe}^{grt}	.6670	.7439	.7340	.6934	.7427
X_{Ca}^{grt}	.0560	.0491	.0626	.0469	.0545
Mg K ₁	3198	8307	2473	3669	7997
Fe K ₂	47.6	76.1	32.3	36.2	77.1
P kbar	6.9	5.9	6.3	6.2	5.9

Figure 12. Map of temperature and pressure calculations. The number above the sample location is its temperature (by deg C) and the number below is its pressure. The pressure calculation in brackets was calculated from the assemblage grt-ms-pl, all others are from the assemblage grt-als-pl. A 700 deg C contour was drawn for both the Ferry and Spear (1978) (FS) calibration and the Indares and Martinogle (1985) (IM) calibration. A 6.5 kbar contour was drawn between all of the pressure calculations. Compare with Fig. 8 for location of isograds. Filled in circles represent ms-ky zone samples, open circles sil-ms zone, and squares kfs-sil zone.



reequilibration, the error involved in the calculations, and/or the effect of post-metamorphic deformation.

A compatibility diagram in which the pressure and temperature of each sample is shown in relationship to the assemblages present in the rock illustrates which calculations may be correct (Fig. 13). Also shown is the area in pressure-temperature space determined by experimental reaction relationships and the approximate placement of the reactions determined to have occurred in the field area. With the exception of the sample which is out of equilibrium (CN21) and the sample which records an anomalously high pressure (CN73), the samples fall, within error of the calculations, in the stability fields of the observed mineral assemblages. A group of samples fall outside of the range in pressures and temperatures determined by reaction relationships. This may indicate that these samples are giving anomalously low temperature and pressure estimates or, at least in the case of the al₂SiO₅-free assemblages, reached only the st-ky grade of metamorphism and provide a good approximation of the peak metamorphic conditions.

FLUID COMPOSITION

The activity of water can be estimated in the amphibolite facies from the equilibrium reaction

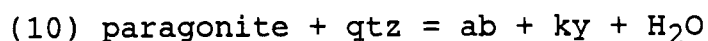
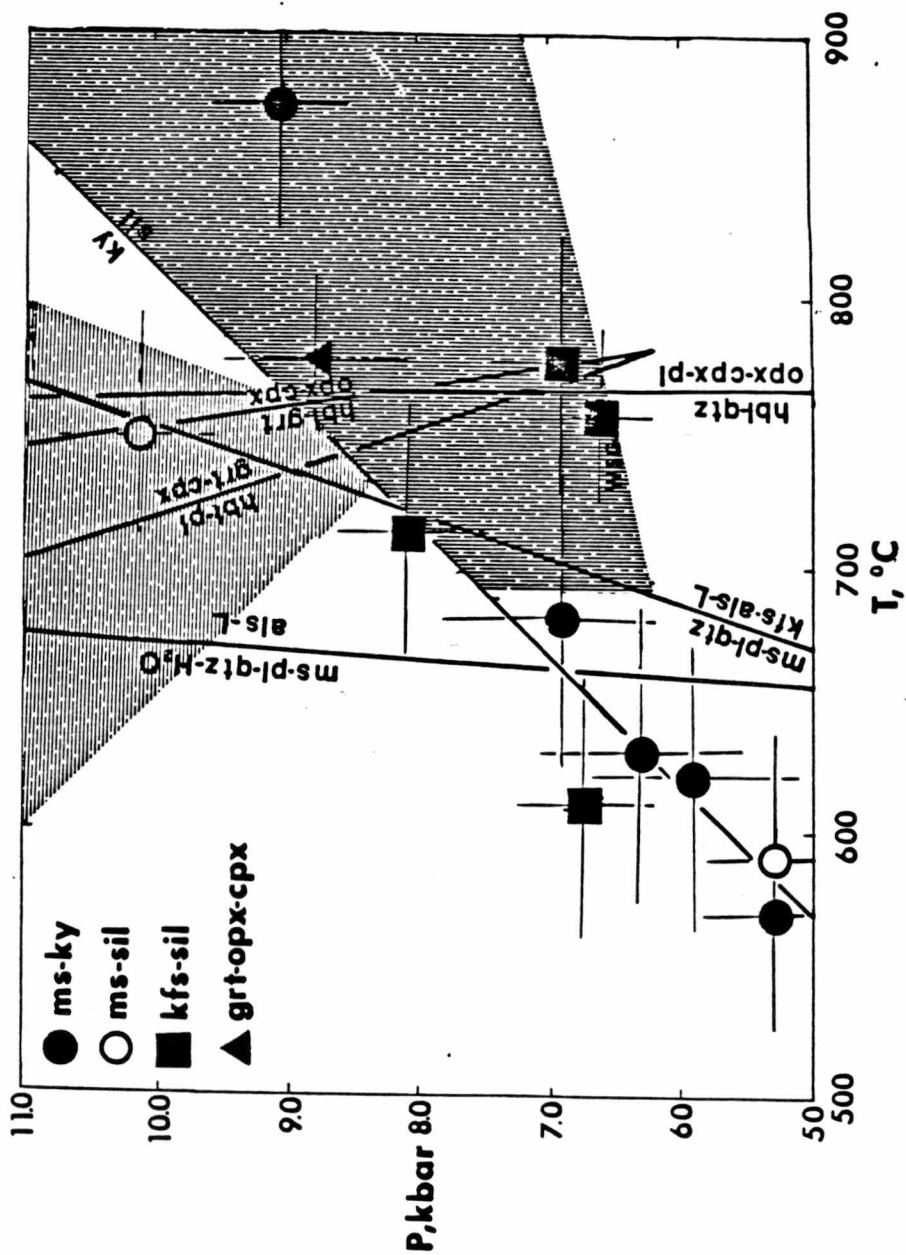
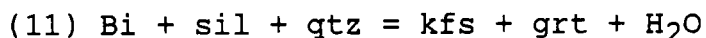


Figure 13. Pressure and temperature diagram. Plot showing the reactions that occur or possibly occur in the field area. Ky = sil transition from Holdaway (1971), melting reactions from Thompson and Tracy (1979). Hbl dehydration reactions from Percival (1984) and Spear (1981). Data for Winding Stair Gap (wsg) from Absher and McSween (1985). Shaded area represents range in pressure-temperature conditions estimated by experimental reactions.



using the method of Ghent (1979). This calculation gives a value of $a_{H_2O} = 0.8$.

Within the granulite terrane, the reaction



can be used to estimate water activity using the relationships of Phillips (1980). The calculated value is $a_{H_2O} = 0.25$. This is similar to the value calculated by Absher and McSween (1986), 0.2, at Winding Stair Gap.

Fluid inclusion data indicate that the dilutant fluid phase was CO_2 with minor amounts of methane. Isochores calculated from these fluid inclusions do pass through the temperature and pressure space delineated above; however, the small data set and secondary nature of the fluid inclusions suggest that any interpretations made from them are suspect (appendix D).

CHAPTER IV

DISCUSSION OF THE AMPHIBOLITE-TO-GRANULITE FACIES TRANSITION

SINGLE VERSUS POLYMETAMORPHISM

IN THE GRANULITE TERRANE

The presence of granulite terranes of Grenville age in other parts of the Blue Ridge (Bartholew, 1984; Gully, 1985) might suggest that this granulite terrane is also Precambrian. The boundary between the amphibolite and granulite facies would then represent a contact between Paleozoic cover rocks metamorphosed to the upper amphibolite facies and Grenville-age granulite rocks that have been remetamorphosed to the upper amphibolite facies. As the older rocks would have already been dehydrated by the first metamorphism, the second metamorphism would have had limited effects, mainly forming grt rims re-equilibrating with bi to the temperature conditions of the second event.

The continuous metamorphic sequence observed here and by Eckert (1985) would suggest one progressive event. The alternative would require that the granulite terrane outcrops in such a way that the metamorphic sequence is preserved from both the west and the east. While assigning the rocks in the granulite terrane to specific sections of the known cover sequence has been difficult (Absher, 1984;

Eckert, 1985; Absher and McSween, 1985; McSween and Hatcher, 1985; and this study), there has been general agreement that the structural history of the granulite terrane is similar to the lower grade Paleozoic rocks and not to Grenville basement, exposed elsewhere.

The presence of spinel and corundum as inclusions in grt at Winding Stair Gap implies that, at some point in their history, those rocks were at a higher temperature and pressure than previously determined (E. McLellan, pers. comm., 1987). McLellan has proposed two discrete granulite events to explain the presence of these phases: an early, high-pressure, high-temperature event, followed by a later granulite event that did not reach the same extreme conditions, and which overprints the early event. At present it would appear that one single progressive event best describes the development of this terrane; however, more study, especially the determination of isotopic age dates, will help constrain the evolution of this terrane.

THE DEVELOPMENT OF GRANULITE FACIES CONDITIONS

Two methods for developing the temperatures and pressures appropriate for granulite terranes have been proposed (Bohlen, 1983):

1. Increase in temperature alone caused by a nearby magmatic intrusion; or

2. Increasing depth of burial with a corresponding increase in temperature and pressure.

It is also clear that the production of granulites requires a change in the fluid phase accompanying metamorphism. This may be accomplished by:

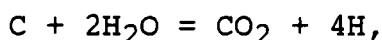
1. dilution of the fluid by non-hydrous components mainly CO_2 : or

2. physical removal of the fluid from the system.

A change in the fluid phase is suggested by the different calculated water activities in the amphibolite facies and granulite facies terranes. Fluid inclusion evidence (appendix D) suggests that the other phases present are CO_2 with a minor amount of CH_4 . CO_2 is a common fluid phase observed in almost every granulite terrane (Touret, 1971; Newton et al, 1980. Influx of CO_2 from an outside source, e.g. by degassing of the mantle, has been observed in some other terranes, such as in India (Janardhen et al., 1982). This influx of CO_2 has been proposed as the main controlling factor in granulite facies metamorphism (Newton, 1985, and 1986). No obvious passageways for fluid movement or fluid fronts, such as those in India, have been observed in this terrane.

Local sources for the carbon are enigmatic. The closest carbonates occur in the Murphy Syncline, which is at a lower metamorphic grade and was presumably at a higher structural level during metamorphism. Calc-silicates are present but do

not appear to be a volumetrically significant enough portion of the stratigraphic section to control the fluid phase throughout the terrane. Mohr and Eckert (1986) suggested a possible source to be the devolatilization of limestones present below a major reflector on seismic sections (the Great Smoky Fault). A major timing problem remains as the Great Smoky Fault is believed to be Alleghanian in age (Hatcher and Odem, 1978), whereas peak metamorphism is believed to be Taconic. This would mean the CO₂ influx from this source would have had to have been part of a major retrograde metamorphic event that is not observed. Another possible source may have been graphitic rocks in the Coweeta Group and Tallulah Falls Formation described by Hatcher (1976) in the Prentiss quadrangle and Eckert (1985) in the Wayah Bald quadrangle. The reaction



is considered to proceed with increasing temperature (Ohmoto and Kerrick, 1977). The effect of this reaction would be to lower the XH₂O while increasing XCO₂. This reaction would be a continuous reaction; however it appears that the drop in aH₂O is related to the dehydration of ms.

Experimental studies have shown that water is preferentially included in melts over CO₂ (Grant, 1973; Phillips, 1980; Wells, 1980) at modest pressures. Thus, partial melting may have lowered the water activity in the restite and paleosome. Migration of these melts to higher

structural levels would have effectively removed H_2O from the system. Of the two probable melt reactions, one has water as a reactant and the other requires that no water be present in a free fluid phase. If H_2O was a reactant in the melting reaction, the effect would have been to lower the a_{H_2O} in the remaining rock. If there was no free H_2O present, then the breakdown of ms would lower the a_{H_2O} for the whole system. As the melting reaction (2) appears to be the most probable of the two, this would indicate that the calculated values for the a_{H_2O} may not be related to the X_{H_2O} . This would also suggest that $P_{fluid} < P_{total}$.

A variety of mechanisms may have been responsible for lowering water activity. The most likely are an effect of the increasing temperature of metamorphism and the development of in-situ partial melts, in which water was included, effectively lowering the amount of H_2O present in the rocks.

Pressure and temperature calculations in this study indicate that the granulite facies terrane was at both a higher temperature and pressure than the amphibolite terrane. An increase in depth of burial with a corresponding increase in temperature appears to have been the primary mechanism by which this terrane was formed.

Metamorphism due to continental thickening is considered to be the result of overthrusting (Thompson and England, 1984). Such a mechanism would result in a cooling

path that would involve a gradual decrease in temperature with pressure. Absher and McSween (1986) postulated a nearly isobaric cooling path at Winding Stair Gap, based on the presence of ky in non-foliated fld-qtz segregations interpreted to be partial melts that crystallized upon post-peak cooling. This same relationship was observed within the field area. This shows that crystallization of the melts occurred within the ky stability field. Lowering temperature with constant pressure from the presumed peak conditions is the easiest way to develop this relationship. Isobaric cooling paths in metamorphic terranes are generally considered to be the result of cooling of nearby magmas (England and Richardson, 1977; Thompson and England, 1984). Postmetamorphic plutons are present within the Hayesville thrust sheet (Miller et al., 1983), and a quartz diorite pluton is located within the study area (Yurkovich, 1983; this study). However, none of these plutons are spatially associated with the granulite terrane.

A possible mechanism that incorporates both an increase in depth of burial with an isobaric cooling path would be to raise the geothermal gradient by increased tectonic activity, resulting in continental overthrusting. This increased tectonic activity would correspond with the Taconic orogeny, supposedly a time of plate collision (Hatcher, 1978). Magmatic activity on a regional scale during such an event would be expected. As tectonic activity waned and magmas

cooled, the effect would be an isobaric cooling path if cooling of these plutons was faster than uplift and erosion.

CHAPTER VI

CONCLUSIONS

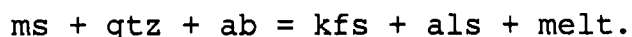
1. A contact between the Otto Formation and the Coweeta Group/Talullah Falls Formation can be delineated in the Corbin Knob quadrangle. This contact may be a continuation of the Shope Fork Fault.

2. Structural history and style are similar in the amphibolite and granulite terranes: an early F1 isoclinal folding event that transposes original bedding; an F2 isoclinal folding event that forms the dominant foliation; late open to isoclinal folds, F3, that fold this foliation. This sequence is similar to the regional deformation schemes of Hatcher and Butler (1979) and Glover, et al. (1980)., suggesting that granulite facies metamorphism was a part of the regional Paleozoic metamorphic event.

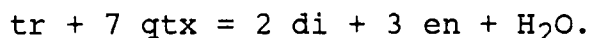
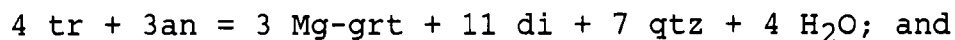
3. A series of prograde zones, $ky + ms$, $sil + ms$, $sil + kfs$ in the pelitic rocks, and $grt + hbl$, $grt + opx + cpx + hbl$ in the amphibolites, document a reasonable continuous metamorphic sequence. The transition from amphibolite to granulite facies has been placed at the boundary between the $sil + ms$ and $sil + kfs$ zones.

4. The $ky + ms$, $sil + ms$ zones can be related by a coupled reaction probably involving ms as a catalyst. The close spatial association of the second sil isograd and the

appearance of migmatites indicate these reactions are related. Based on several criteria, the presumed melting reaction was:



5. Bulk rock chemistry, mineral chemistry, and phase relations show that opx and cpx formed as the result of the continuous breakdown of hbl by the reactions:



6. A change in $a\text{H}_2\text{O}$, from 0.8 to 0.2, was determined based on calculated values in the amphibolite and granulite facies terranes. This drop in the activity of water has been related to the development of in-situ partial melts. Based on the presumed melting reaction and the absence of any H_2O rich fluid inclusions, it is possible metamorphism occurred in the absence of a free aqueous fluid phase.

7. Temperatures and pressures are estimated to have been 580-680 deg C, 5.5-6.8 kbar in the amphibolite facies terrane, and 680-780 deg C, 6.5-8.5 kbar in the granulite facies terrane. This shows that an increase in the depth of burial with a corresponding increase in the temperature played an important role in the development of this metamorphic sequence. The postulated isobaric cooling path would indicate that crustal thickening with concurrent magmatic activity would produce the calculated conditions under which metamorphism occurred.

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APPENDIXES

APPENDIX A

Mineral Abbreviations, from Kretz (1983)

ab = albite	hbl = hornblende
als = almino silicate	il = ilmenite
an = annorthite	kfs = k-feldspar
ap = apatite	ky = kyanite
bi = biotite	mag = magnetite
chl = chlorite	ms = muscovite
cp = chalcopyrite	opx = orthopyroxene
cpx = clinopyroxene	pl = plagioclase
crd = cordierite	px = pyroxene
cu = cumingtonite	py = pyrite
di = diopside	ru = rutile
en = enstatite	sil = sillimenite
ep = epidote	st = staurolite
fld = feldspar	tr = tremolite
grt = garnet	

APPENDIX B

PETROGRAPHIC DESCRIPTIONS

Sample localities are shown in Plate 1. CN refers to those outcrops in Corbin Knob quadrangle, F to those outcrops in the Franklin quadrangle.

Meta-sedimentary rocks

CN3 Well foliated ms-bi schist. Bi has yellow to dark green pleochroism, defines foliation with ms. Grts are generally euhedral with grains anhedral and subhedral grains. Pl grains are anhedral with both twinned and untwinned grains present. Qtz grains have undulatory extinction. Two types of opaque grains are present, small anhedral grains and larger needle like grains aligned with the foliation. Apatite grains are also present.

CN5 Foliated ms-bi-pl gneiss to semi-schist. Euhedral ms and bi define the foliation. Ms ranges in size from 0.2 to 1.0 mm and contains inclusions of opaques. Bi has a light yellow to dark green pleochroism. Pl grains are anhedral to subhedral with both twinned and untwinned grains. Pl grains which have twins are commonly deformed, with some sericitization along twinning planes. Qtz grains are anhedral with undulatory extinction. Opaque grains are needle to blocky in appearance aligned with the foliation.

CN10 Foliated ms-bi schist. Euhedral ms and bi defines the foliation. Bi has a light yellow to dark green pleochroism, with minor chl alteration. Pl porphyroblasts (1.0 mm) are present. Other pl grains (0.1-0.4 mm) with albite twinning are present. Qtz grains have undulatory extinction. Elongate opaque grains are aligned with the foliation. Apatite and epidote are present as small < 0.1 mm grains.

CN11 Foliation is not well developed. Bi and ms defines the foliation. Very little ms is present (< 2 %) in the sample. Bi grains are subhedral to euhedral, with light yellow to light brown pleochroism. Alteration of bi to chlorite is common. Grt grains are subhedral with chl alteration rims. Inclusions of pl grains in grt common. Large porphyroblasts (up to 4.0 mm) of pl are common. These porphyroblasts are commonly twinned and occasionally show zoning in crossed-polars. Some sericitization of pl along grain boundaries is present. Quartz grains have undulatory extinction. Small (0.1 mm) grains of epidote and opaques are common.

CN12 Foliated bi-ms gneiss. Euhedral ms and bi define the foliation. Bi has a light green to dark green pleochroism. Pl grains are generally untwinned with albite twinning rare. Quartz grains are anhedral and have undulatory extinction. Opaque grains are elongated parallel to the foliation.

CN13 Foliated bi-ms semi-schist. Euhedral to subhedral grains of ms and bi define the foliation. Bi has a yellow to green pleochroism with inclusions of opaques. Grt is subhedral up to 1 mm in diameter with inclusions of opaque minerals. Pl grains have albite twinning, with some grains containing a complex twinning pattern. Pl and qtz grain-to-grain contacts are uneven to curved. Quartz grains have undulatory extinction. Epidote is present as very small grains.

CN14 Foliated bi-ms schist. Bi grains are subhedral to euhedral with brown to dark green pleochroism. Ms occurs as porphyroblasts defining the foliation and has very fine fine grained white mica. Pl grains are anhedral with exsolution textures common. Albite twinning is rare. Opaque grains are blocky in appearance. Apatite was also observed.

CN16 Crenulated bi-sil gneiss. Bi grains are subhedral to euhedral with a yellow to dark brown pleochroism. Grts are subhedral with inclusions of opaques. Bi fills fractures in the grt. Sil occurs as a fibrolitic grains aligned parallel to the foliation and has anhedral to subhedral crystals. Pl grains are anhedral with albite twinning and also untwinned. Quartz grains are anhedral with undulatory extinction. Opaques occur as anhedral blocky grains with the long axis aligned with the foliation.

CN22 Foliated bi-ms schist. Bi grains are euhedral with a light yellow to green pleochroism. Ms grains are euhedral and with bi define the foliation. Grts are euhedral to subhedral, pink in color with inclusions of opaques, bi, and pl. Foliation appears to wrap around the grts. Ky occurs as euhedral grains aligned with the foliation. Pl is present as anhedral untwinned grains. Opaques and quartz are also present.

CN25 Foliated bi-ms semi-schist. Bi is euhedral with light green to dark green pleochroism. Ms is euhedral with inclusions of pl. Ms and bi define the foliation. Grt is anhedral with qtz and pl inclusions. Pl grains are anhedral with albite twinning. Quartz grains are also anhedral with undulatory extinction. Epidote is present as fairly large

grains (0.2-0.4 mm) and these grains are commonly zoned. Il grains appear as blocky grains with the long axis aligned with the foliation. Spene is present as anhedral grains.

CN30 Foliated bi-ms gneiss. Biotite is euhedral with yellow to dark brown pleochroism. Ms is euhedral with rare inclusions of opaques defines foliation with bi. Grt is anhedral with poikilitic and irregular grain boundaries. Pl grains are anhedral with untwinned and albite twinned grains. Quartz grains are anhedral with undulatory extinction. Opaque grains are anhedral with the long axes parallel to the foliation.

CN31 Foliated bi-ms schist. Bi is euhedral with light yellow to dark green pleochroism and defines foliation with euhedral ms. Pl grains anhedral with untwinned and albite twinning common. Grt grains are euhedral to subhedral with inclusions of opaques. Alteration of grt and bi to chl common. Quartz grains are anhedral with undulatory extinction. Spene, epidote and opaques are also present.

CN54 Foliated bi-grt semi-schist. Bi grains are anhedral to subhedral with light yellow to dark brown pleochroism, defines the foliation. Grts are anhedral to subhedral, commonly rimmed by pl, qtz, mu and rutile. Pl grains are anhedral with twinned, untwinned and mymerkitic grains present.. Epidote and opaques are also present.

CN56 Foliated bi-ms schist. Bi grains are euhedral with a light yellow to dark brown pleochroism, defines foliation with euhedral ms. Grt is anhedral to subhedral. Ky is anhedral to subhedral with irregular grain boundaries. Pl grains are twinned and untwinned generally anhedral with some subhedral grains. Ilmenite and rutile are present. Apatite was also observed.

CN57 Foliated grt-bi gneiss. Bi grains are subhedral to euhedral with light yellow to dark brown pleochroism, defines foliation. Grt contains inclusions of quartz, grains are subhedral up to 1 mm in size. Pl grains are twinned and untwinned containing mymerkitic and exsolution textures. Quartz is anhedral. Spene and opaque minerals are also present.

CN58 Foliated grt-bi gneiss. Bi is subhedral to euhedral with a yellow to brown pleochroism with some grains having a yellow to reddish brown pleochroism. Grt grains are subhedral to euhedral with inclusions of pl and qtz. Pl grains are twinned with mymerkitic and exsolution texture common. Quartz grains are anhedral with undulatory extinction. Opaque grains are also anhedral with the long

axes to the grain generally aligned parallel to the foliation.

CN59 Foliated bi-ms semi-schist. Bi is anhedral to euhedral with yellow to dark brown pleochroism. Sil needles occur along bi-pl grain boundaries generally in masses that are aligned with the foliation. Ms is present as subhedral grains that define the foliation with bi. Grt grains are anhedral and rimmed by fine grained ms and bi. Pl grains are anhedral with twinned and untwinned grains. Qtz grains are anhedral with undulatory extinction. Anhedral opaque grains are also present.

CN63 Foliated ms-bi gneiss. Bi occurs as anhedral to euhedral grains, light yellow to dark brown pleochroism, defining foliation with ms and sil. Ms occurs as euhedral grains. Sil occurs as fibrolite generally along bi-pl grain boundaries. Pl grains are generally untwinned with some grains having albite twinning or myrmekitic textures. Grt is anhedral with much retrograde alteration to bi and chl. Opaque grains are anhedral with the long axes parallel to the foliation. Rutile is present, associated with the retrograde alteration of grt to bi and chl.

CN73 Poorly foliated grt-bi gneiss. Bi anhedral to euhedral with yellow to brown pleochroism. Bi roughly defines foliation. Grt is inclusion rich with bi, pl, qtz and opaques. Grt may be up to 4mm in size. Ky grains are anhedral, parallel to the foliation and poikilitic with inclusions of pl and qtz. Sil occurs as fibrolitic needles usually aligned with the foliation. Pl grains are anhedral with albite twins or untwinned. Qtz grains are anhedral with undulatory extinction. Il occurs as anhedral grains with the long axes parallel to the foliation. Spene and apatite are also present.

CN81 Foliated bi-ms schist. Bi grains are euhedral to subhedral with light green to dark green pleochroism, defines foliation with ms. Ms is euhedral with inclusions of opaques. Grt is anhedral with inclusions of bi, qtz, and opaques. Pl is present as anhedral grains which may be twinned or untwinned. Qtz is anhedral with some grains having undulatory extinction. Opaques are anhedral with the long axes of the grain aligned parallel to the foliation. Epidote and spene are also present. The foliation wraps around the grt grains.

CN82 Foliated bi semi-schist. Bi grains are subhedral to euhedral with light yellow to dark brown pleochroism, defines the foliation. Ky is present as anhedral and subhedral grains, aligned parallel to the foliation. Ms is

anhedral to subhedral defining the foliation with bi. Pl grains are untwinned. Qtz and pl grains both have a ribbon texture which is parallel to the foliation defined the mica minerals. Opaques, epidote and sphene are also present.

CN85 Foliated bi-grt gneiss. Bi is anhedral to euhedral, with light yellow to dark brown pleochroism, defines foliation. Grt grains are anhedral to subhedral with inclusions of Qtz and pl. Pl is anhedral with both twinned and untwinned grains. Qtz is anhedral with undulatory extinction. Sphene is also present.

CN86 Foliated bi-ms semi-schist. Bi is euhedral with light green to dark green pleochroism. Ms is euhedral and defines the foliation with bi. Pl grains are both twinned and untwinned with some sericitization common. Qtz is anhedral. Epidote and opaques are also present.

CN94 Poorly foliated bi-ms gneiss. Bi is subhedral to euhedral with light yellow to dark brown pleochroism. Ms is euhedral and defines the foliation with bi. Pl is anhedral and occurs as twinned and untwinned grains. Sphene, opaques, and epidote are also present.

CN100 Foliated bi-ms gneiss. Bi grains are anhedral to euhedral with yellow to dark brown pleochroism. Ms is euhedral and defines the foliation with bi. Grt grains are anhedral with inclusions of Qtz and pl. Opaques are anhedral with the long axes aligned parallel to the foliation.

F1 Poorly foliated grt-bi gneiss. Bi euhedral to subhedral with yellow to brown pleochroism, roughly defines the foliation. Grt grains are euhedral to subhedral with rare inclusions of pl, and Qtz. Pl grains are twinned and untwinned, ksp grains are perthitic and rarely have microcline twinning. Ms grains are euhedral to anhedral, with some grains poikilitic in appearance. Anhedral grains of chalcopyrite, pyrite, and ilmenite are present. Grain to grain contacts between feld and Qtz very irregular.

F4 Foliated grt-bi gneiss. Bi is anhedral to euhedral with yellow to brown pleochroism and contains inclusions of opaque minerals. Ms is euhedral and defines the foliation with bi. Grt is anhedral with inclusions of Qtz, feld, and opaques. Pl grains are anhedral with twinned and untwinned grains. Some alteration of pl to sericite is present. Ksp is present as perthitic grains. Sphene is also present.

F11 Poorly foliated sil-kfs gneiss. Bi grains are anhedral to euhedral with a light brown to dark brown pleochroism

and contain inclusions of quartz and opaques. Grts are subhedral up to 1 mm in size, and contain inclusions of quartz, bi, and opaques. Ms grains are anhedral and occur associated with Qtz-pl-kfs "clusters". Sil grains are euhedral and are not aligned with the foliation. Pl and kfs grains are anhedral with pl grains twinned and kfs grains with perthitic. Myrmekitic pl is also present. Ky is present as anhedral grains with a poikilitic texture. Opaque phases present are subhedral to euhedral il and anhedral cp. Ru is present as anhedral grains surrounded by a very dark red anhedral bi which radiate away from the ru grain..

F29 Foliated grt-bi gneiss. Bi is subhedral to euhedral with light yellow to dark green pleochroism, defines the foliation. Grt grains are anhedral up to 3.0 mm in size with inclusions of bi and Qtz. Pl is present as twinned, untwinned and myrmekitic grains. Qtz grains are anhedral with undulatory extinction. Ms grains are anhedral and are associated with the myrmekitic pl. Chl fills in fractures in grt. Il grains are subhedral to euhedral and are aligned with the foliation. Ep is present in minor amounts. All grain to grain contacts are irregular.

F30 Poorly foliated bi-fld gneiss. Bi grains are anhedral to euhedral with light brown to dark brown, defines the foliation. Grt grains are subhedral to euhedral occurring in clusters with bi. Sil is euhedral and is parallel to the foliation. Kfs occurs as perthitic grains, and pl occurs as untwinned or myrmekitic grains. Ms occurs as small (<0.1 mm) anhedral grains associated with kfs grains. Spinel is also present.

F31 Foliated grt-bi gneiss. Bi is subhedral with light yellow to reddish brown pleochroism. Grt grains are anhedral with some grains elliptical with the long axis parallel to the foliation. Rare inclusions of Qtz and sil. Sil is present as euhedral grains aligned with the foliation and as fibrolite grains. Pl is present as twinned, untwinned and myrmekitic grains. Spinel and opaques are also present.

F33 Very poorly foliated bi-ms semi-schist. Bi grains are anhedral to euhedral with light green to dark green pleochroism, and roughly defines a foliation. Ms occurs as small anhedral to subhedral grains that are generally not aligned with the foliation. Ms commonly occurs in what may be porphyroblasts. Pl grains are anhedral with twinning common. Kfs is present as microcline twinned grains and as perthitic grains. Flds have been altered to fine grained white micas. Spinel, epidote, and opaques are also present.

F36 Poorly foliated fld-grt gneiss. Bi grains are anhedral to subhedral with a light yellow to dark brown pleochlorism, roughly defines the foliation. Grts are subhedral with inclusions of bi, opaques, fld, and qtz. Sil occurs as euhedral grains and as fibrolite. Pl is present as twinned and untwinned grains. Kfs is present as anhedral perthitic grains. Il, cp, and py are also present.

F38 Foliated to poorly foliated grt-bi gneiss. Bi grains are anhedral to euhedral with yellow to dark brown pleochlorism, defines foliation. Bi commonly contains inclusions of opaque minerals. Grts are subhedral to euhedral with inclusions of opaques, bi, pl, qtz, and fibrolitic sil. Pl grains are present as untwinned, twinned, and myrmekitic grains. Kfs is present as microcline twinned grains and less commonly as perthitic grains. Sil grains are euhedral and are aligned with the foliation. Quartz grains are anhedral and commonly have undulatory extinction. Il, cp, and py are also present. Ru is present as anhedral grains surrounded by anhedral reddish brown bi.

F41 Grt-fld quartzite. Pl is present as anhedral untwinned grains. Qtz is present as undulatory anhedral grains. Grts are anhedral with very irregular grain boundaries. In general the sample appears to be very highly strained.

F67 Foliated ms-bi schist. Bi is present as subhedral to euhedral grains which define the foliation. Ms is present as subhedral grains that are aligned with the foliation, and as small anhedral grains which occur in small non-foliated clumps with bi and fld. Grt occurs as anhedral grains within those non-foliated clumps. Opaques and epidote are also present. Small shear zones also appear to present.

F68 Well foliated ms-bi-als schist. Bi grains are anhedral to subhedral with a light yellow to dark brown pleochlorism, defines the foliation. Ms occurs as fine needles, rarely occurs as large well formed crystals. Grt grains are subhedral with inclusions of bi, and opaque needles. Center of grain has a dusty appearance with clear rims, rims contain clear needle like mineral, fibrolitic sil (?). Ky is present as subhedral to euhedral grains generally aligned with the foliation. Sil is present as euhedral grains aligned with the foliation. Pl grains are anhedral and untwinned. Qtz grains are anhedral with undulatory.

F70 Foliated fld-bi gneiss. Bi grains are subhedral to

euohedral which define the foliation and have a light brown to green pleochlorism. Ms defines the foliation. Pl grains are anhedral with rare twinning. Qtz grains are undulatory and are anhedral.

F71 Foliated bi-ms schist. Bi grains are anhedral to subhedral which are deformed around large pl and qtz grains. Ms grains are subhedral to euohedral aligned with the foliation. Pl and qtz grains occur as large grains in a matrix of very fine grained pl and qtz.

F72 Foliated grt-bi gneiss. Bi grains are subhedral, defines the foliation, with light yellow to dark brown pleochlorism. Grt grains are subhedral with inclusions of bi, qtz, pl, and opaques, alteration to chl is common. Pl grains are anhedral with twinning. Qtz grains are anhedral with undulatory extinction. Il is also present.

F73 Foliated grt-bi gneiss. Grt grains are anhedral poikiloblastic with inclusions of bi, pl, qtz, these inclusions are slightly offset from the main foliation. Bi grains are subhedral to euohedral with light yellow to dark green pleochlorism, defines the foliation. Pl grains are anhedral to subhedral with twinning common.

F76 Well foliated bi-sil schist. Bi grains are subhedral to euohedral with light yellow to dark green pleochlorism, defines the foliation. Grt grains are anhedral to euohedral. Sil grains are subhedral to euohedral and is present with as both fibrolite and well formed crystals. Pl grains are present as twinned and untwinned grains. Qtz and opaques grains are also present.

F77 Poorly foliated bi-fld gneiss. Bi grains are euohedral with a yellow to brown pleochlorism, defines the foliation. Grt grains are anhedral to subhedral with inclusions of fld, qtz, with chl filling in fractures and along rim of grains. Sil grains are euohedral and are aligned with the foliation. Pl grains are both twinned and untwinned. Ru and other opaques are present.

Amphibolites

CN4 Hbl is anhedral to subhedral with dark green to light green pleochroism, defines the foliation. Bi grains have a yellow to dark brown pleochroism aligned with the foliation. Pl grains are anhedral to subhedral with both twinned and untwinned grains present. Qtz grains are anhedral with undulatory extinction. Opaque grains are present with the long axis aligned parallel to the foliation.

CN5 Hbl grains define the foliation, with a yellow-green to dark green pleochroism. Hbl grains contain inclusions of Qtz, bi, and opaques. Bi grains are aligned parallel with the foliation, are subhedral to euhedral with a light brown to dark brown pleochroism. Pl grains are anhedral commonly twinned with rare inclusions of bi, and ep. Ep and opaque grains are also present with the long axis parallel to the foliation. Sample is layered with Qtz+fld and hbl+bi+ep.

CN6 Hbl grains are anhedral with very irregular grain boundaries. Hbl defines the foliation and has a light green to dark green pleochroism. Bi grains are euhedral are commonly aligned with the foliation, and have a light yellow to dark brown pleochroism. Pl grains are anhedral and are present as both twinned and untwinned grains. Ep grains are anhedral with very irregular grain boundaries. Sp and opaques are also present. Sample is layered with Qtz+fld and hbl+bi+ep.

CN9 Hbl grains have a light green to dark green pleochroism, subhedral and defines the foliation. Grt grains are anhedral with inclusions of pl and Qtz. Pl grains are anhedral with both twinned and untwinned grains present. Ep, and opaques are also present. Some alteration of hbl to chl and pl to sericite is present. Sp and ru are present as an intergrowth.

CN16 Hbl grains are anhedral with an irregular grain boundary, define the foliation and have a light green to dark green pleochroism. Bi grains are euhedral with a light yellow to brown pleochroism, are generally aligned parallel to the foliation. Pl grains are anhedral with both twinned and untwinned grains present. Grt grains are subhedral with inclusions of pl and Qtz. Opaques are present as small inclusions in hbl and as larger grains with the long axis parallel to the foliation. Ep is present as a symplectic intergrowth with hbl, Qtz, and pl.

CN19 Hbl grains are anhedral with a light green to dark

green pleochroism, defines the foliation. Bi grains are euhedral with a brown to yellow pleochroism, aligned with the foliation. Pl grains are anhedral with both twinned and untwinned grains. Qtz is present as anhedral grains with undulatory extinction. Ep is anhedral with inclusions of opaques, qtz and pl, and is commonly zoned.

CN43 Hbl grains are anhedral to euhedral with a brown to light brown pleochroism, generally altered to ep+qtz symplectite. Grt grains are anhedral and inclusion free. Pl is subhedral, twinned and untwinned, some x-hatched twinning present. Sp occurs as rims around opaque grains, which are anhedral. Due the extensive alteration of hbl to ep+qtz difficult to tell original texture but appears to non-foliated.

CN44 Hbl grains are subhedral to anhedral with a light brown to dark brown pleochroism, roughly defines a foliation. Grt grains anhedral poikiloblastic with inclusions of pl and qtz. Cu is present as anhedral grains with the long axis parallel to the foliation. Pl grains are anhedral rarely twinned. Ep is present around hbl grain boundaries..

CN45 Hbl grains are subhedral to euhedral with brown to green pleochroism in the cores while the rims have a light green to dark green pleochroism. Hbl grains have opaque inclusions and defines the foliation. Grt grains are subhedral to euhedral with inclusions of qtz and pl. Pl grains are anhedral untwinned, and highly altered to sericite. Qtz grains are anhedral with undulatory extinction. Symplectic intergrowth of ep and qtz is common.

CN48 Hbl grains are anhedral to euhedral with a light green to dark green pleochroism, symplectitic intergrowth of ep+qtz common. Alteration of chl, calcite and hematite also observed. Grt grains are anhedral with inclusions of opaques and pl. Pl grains are anhedral rarely twinned.

CN55 Hbl grains are anhedral to subhedral with a light brown to dark brown pleochroism, locally retrograded to ep. Grt grains are anhedral poikiloblastic with inclusions of hbl, pl, and qtz. Pl grains are anhedral albite and X-hatched twinning common. Sp occurs as rims around opaque grains. Ep occurs as a symplectic intergrowth of qtz and hbl. Opaque grains are anhedral, generally rimmed by sp.

CN62 Hbl grains are anhedral to euhedral, define the foliation, and has a light brown to dark brown pleochroism. Grt grains are anhedral with inclusions of pl, hbl, and opaques. Ep occurs as a symplectic intergrowth at pl-hbl

boundaries. Pl grains are anhedral with both twinned and x-hatched twinning common. Opaque grains are anhedral with ru present near symplectic intergrowths.

CN68 Hbl is anhedral to subhedral with a light green to light brown pleochroism defines the foliation. Grt grains are anhedral with inclusions of opaques, sp, qtz, and fld. Cores are more inclusion rich then the rims. Pl is anhedral with rare albite twinning, with some myrmekitic and exsolution textures present. Sp is present as discrete grains and as rims around opaque grains. Qtz is present as anhedral grains with undulatory extinction.

CN69 Hbl grains are anhedral to euhedral with a light brown to dark brown pleochoric core and light green to brown pleochoric rim. Grains commonly have inclusions of qtz and pl, and rarely grt. Grt grains are anhedral and inclusion free. Pl grains are untwinned anhedral, rare albite twinning is present. Ep is present as a symplectic intergrowth at pl-hbl grain boundries. Sp is present as a rim around opaque grains.

CN72 Hbl grains are subhedral to euhedral with light green to dark green pleochroism. Bi grains are euhedral with a brown to clear pleochroism. Pl is present as anhedral grains, both twinned and untwinned. Qtz grains are anhedral with undulatory extinction. Opaque grains are anhedral. This rock has a granular texture with no observed preferred orientation.

CN80 Hbl is anhedral to subhedral defines the foliation, and has a dark green to light green pleochroism. Bi grains are euhedral, parallel to the foliation, and have a yellow to brown pleochroism. Ep is present as anhedral grains, rarely zoned. Pl grains twinned and untwinned with some alteration to sericite along grain boundries common. Some alteration of bi to chl is also present.

CN82 Hbl grains are anhedral to subhedral with a yellow green to dark green pleochroism, defines the foliation. Grt grains are anhedral poikiloblastic with inclusions of hbl, and pl. Pl grains are anhedral to subhedral, both twinned and untwinned. Qtz grains are anhedral. Sp is anhedral and occurs as rims around opaque grains. Opaque grains are anhedral with the long axis parallel to the foliation.

CN88 Hbl grains are subhedral to euhedral with light green to dark green pleochroism. Grains have an hour-glass pattern of opaque inclusions. Pl grains are anhedral to euhedral with rare albite twinning present. Cu is present

as subhedral grains aligned with the foliation. Pl and qtz are concentrated in discrete layers.

F3 Hbl is anhedral to subhedral with light green to dark green pleochroism, defines foliation, inclusion rich with qtz. Grt grains are inclusion rich with qtz, pl, sph and opaques, and are anhedral. Pl grains are anhedral, albite twinning rare with some grains myrmekitic. Qtz grains are anhedral with undulatory extinction. Sp grains are anhedral and commonly found rimming opaque grains. Opaques are anhedral with the long axis aligned with the foliation.

F6 Hbl grains are anhedral with light green to dark green pleochroism. Grt grains are anhedral with inclusions of qtz. Bi grains are anhedral with a light brown to dark brown pleochroism. Pl grains are anhedral with grains having albite twinning, X-hatched twinning, and untwinned grains. Sp, ep, and opaques grains are also present.

F19 This outcrop is north of the field area and is not shown on plate 1. Hbl is anhedral to subhedral, defines the foliation and has a light green to dark brown pleochroism. Grt grains are anhedral inclusion rich with qtz, pl, and opaques. Sp is present as anhedral grains rimming opaques. Pl grains are anhedral with twinned and untwinned grains being present. Myrmekitic pl is also present. Opaque grains are anhedral with the long axis parallel to the foliation.

F28 Hbl grains are anhedral to subhedral with a light yellow to dark green pleochroism, defines the foliation. Bi grains are subhedral to euhedral with a light brown to dark brown pleochroism, aligned with the foliation. Grt grains are anhedral with inclusions of bi, hbl, pl, and opaques. Ep grains are anhedral to euhedral with the larger grains (up to 1 mm) being euhedral. Where hbl and ep are in contact commonly symplectic intergrowth. Opaque grains are anhedral with the long axis aligned parallel to the foliation.

F29 Hbl is subhedral with light brown to dark brown pleochroism, defines the foliation with inclusions of dusty opaques (graphite?). Grt grains are anhedral to euhedral with inclusions of pl and hbl. Pl grains are anhedral with rare albite twinning. Opaques, ep, and ap are also present.

F32 Hbl is subhedral to euhedral light green to dark green pleochroism, defines the foliation. Bi grains are euhedral, with a light brown to dark brown pleochroism, and aligned parallel to the foliation. Pl grains are anhedral with albite twinning rare. Sp, ru, and opaques are also present.

F38 Hbl grains are anhedral to subhedral with inclusions of opaque grains. The cores of hbl grains have a light green to dark brown pleochroism, while the rims have a light green to dark green pleochroism. Grt grains are anhedral with inclusions of hbl. Bi grains are anhedral to euhedral with a light yellow to dark brown pleochroism. Pl grains are anhedral, with both twinned and untwinned grains being present. Qtz grains are anhedral with undulatory extinction. Opaque grains are anhedral, with some dusty appearance, graphite (?).

F39 Hbl grains are anhedral with a yellow to brown pleochroism. Grt grains are anhedral with inclusions of hbl and pl. Pl grains are anhedral with albite twinning rare. Cpx is present as a clear, anhedral grains, around hbl grain boundaries. Opaque grains are anhedral.

F40 Hbl grains are anhedral to subhedral, with a light brown to dark brown pleochroism, long axis roughly defines a foliation. Grt grains are anhedral to subhedral with inclusions of pl, and cpx. Cpx grains are anhedral with the long axis parallel to the foliation, occurs as inclusions in grt and out in the matrix of the rock. Cu is present as subhedral to euhedral grains with the long axis parallel to the foliation. Pl grains are anhedral with albite twinning very common. Qtz and opaques are also present.

F41 Hbl grains are anhedral to subhedral with a green to dark green/brown pleochroism, roughly defines a foliation. Grts are anhedral to subhedral, red in color, and have inclusions of opaques, pl, cpx, and rarely opx. Cpx grains are light green, anhedral and occur as inclusions in grt and in the matrix. Opx grains are anhedral and have pink to green pleochroism. Pl grains are anhedral with twinning very common. Qtz grains are anhedral with grains having undulatory extinction. Ep and opaques are also present.

F49 Hbl grains are subhedral to euhedral with a light brown to dark brown pleochroism, defines the foliation. Pl grains are anhedral with both twinned and untwinned grains being present. Ep, Qtz and opaques are also present in the thin section.

F50 Hbl grains are anhedral to subhedral with inclusions of opaques. Hbl grains have a light brown to dark brown pleochroism, and roughly define a foliation. Grt grains are subhedral, red, and have inclusions of pl, hbl, and cpx. Cpx grains are anhedral light green, and occur in the matrix of the rock and as inclusions in grts. Pl grains are anhedral with both twinned and untwinned grains being present. Qtz and opaques are also present.

F51 Hbl grains are anhedral with a light green to green pleochroism, roughly defines a foliation. Grt grains are anhedral with inclusions of cpx. Cpx grains are anhedral to subhedral and light green. Pl grains are anhedral to subhedral with both albite twinned and untwinned grains present. Qtz, opaques, and ep also present.

F52 Hbl grains are subhedral to euhedral with a light green to dark brown pleochroism, defines the foliation. Grt grains are subhedral to euhedral with inclusions of opaques and hbl. Pl grains are present as anhedral grains with albite and x-hatched twinning common. Symplectite intergrowth of ep and qtz is present at pl-hbl boundaries. Sp is present as a rim around opaques. Opaques and qtz are also present.

F62 Hbl grains are anhedral to subhedral with a light brown to dark brown pleochroism, defines the foliation. Grt grains are subhedral with inclusions of pl and hbl. Pl grains are anhedral with rare albite twinning. Qtz and ep also present.

F75 Hbl grains are subhedral to euhedral with a light green to dark green pleochroism, defines the foliation. Opx is present as anhedral grains with a pink to green pleochroism. Cpx is anhedral with a light green color. Pl grains are anhedral with albite twinning very common. Qtz and opaques are also present.

APPENDIX C

REPRESENTATIVE MINERAL ANALYSIS

- 1: bi
- 2: ms
- 3: grt
- 4: pl and kfs
- 5: bi, hbl, grt, opx, and cpx for amphibolites

11 Representative bi analyses; m = matrix r = contact

sample #	[CN-3]		[F72]		[F29-A]		[CN73]	
	m	r	m	r	m	r	m	r
SiO2	34.69	36.83	35.85	36.08	36.51	39.32		
TiO2	1.89	0.47	2.74	3.77	1.09	1.05		
Al2O3	18.21	20.29	17.77	16.49	17.45	17.02		
FeO	21.18	14.3	17.8	18.26	11.69	11.34		
MnO	0.18	0	0.05	0.04	*	*		
MgO	9.14	13.24	11.16	11.64	16.97	16.86		
CaO	0	0.24	0.05	0	0	0.07		
Na2O	0.16	0.04	0.03	0.03	0.37	0.47		
K2O	9.59	9.07	9.58	9.56	7.9	7.66		
Total	95.04	94.48	95.03	95.87	91.93	93.79		

Formula Moles

Si	5.367	5.471	5.433	5.442	5.648	5.755
AlIV	0.633	2.529	2.567	2.553	2.352	2.345
AlVI	0.686	1.024	0.805	0.373	0.682	0.639
Ti	0.218	0.352	0.311	0.425	0.113	0.111
Fe	2.738	1.774	2.250	2.302	1.434	1.387
Mn	0.022	0	0.004	0.004		
Mg	2.106	2.93	2.523	2.617	3.711	3.676
Ca	0	0.035	0.004	0	0	0.008
Na	0.045	0.008	0.009	0.004	0.100	0.128
K	1.889	1.718	1.851	1.837	1.477	1.40
Total	15.704	15.541	15.563	15.562	15.503	15.429

sample #	[CN85]		[F77]		[CN13]	
	m	r	r	m	r	m
SiO2	36.55	36.38	37.6	37.83	34.43	34.91
TiO2	1.73	1.98	1.31	1.15	3.8	3.83
Al2O3	18.51	18.61	17.52	18.06	17.33	17.68
FeO	16.5	16.68	12.88	13.82	19.42	19.14
MnO	*	*	*	*	*	*
MgO	11.25	11.14	14.22	14.04	9.11	9.56
CaO	0	0	0	0	0.06	0.02
Na2O	0.17	0.2	0.32	0.24	0.09	0.02
K2O	9.02	9.24	8.8	9.02	10.71	11.1
Total	93.73	94.23	92.65	94.21	94.95	96.26

Formula Moles

Si	5.546	5.504	5.659	5.629	5.33	5.322
AlIV	2.454	2.496	2.341	2.371	2.67	2.678
AlVI	0.856	0.822	0.764	0.79	0.492	0.5
Ti	0.196	0.222	0.146	0.126	0.44	0.436
Fe	2.094	2.11	1.621	1.713	2.512	2.439
Mn						
Mg	2.535	2.51	3.189	3.109	2.099	2.171
Ca	0	0	0	0	0.009	0
Na	0.049	0.058	0.092	0.069	0.022	0.004
K	1.746	1.781	1.688	1.709	2.112	2.157
Total	15.476	15.503	15.5	15.516	15.686	15.709

1 continued

sample #	CN56		CN25		CN21	
	r	m	r	m	r	m
SiO2	33.91	35.88	35.68	35.66	34.67	36.52
TiO2	2.2	2.02	2.27	1.85	1.6	1.67
Al2O3	18.72	18.73	17.11	17.47	18.39	17.01
FeO	16.27	16.2	17.77	19.8	17.65	18.32
MnO	*	*	*	*	0	0
MgO	11.84	11.71	10.29	10.71	11.95	13.04
CaO	0.02	0.02	0	0	0.11	0.25
Na2O	0.25	0.23	0.25	0.27	0.31	0.37
K2O	10.1	9.55	9.65	9.97	8.75	8.50
Total	93.31	94.34	93.02	95.69	90.41	90.70

Formula Moles

Si	5.243	5.431	5.477	5.441	5.036	5.348
AlIV	2.757	2.569	2.523	2.559	2.164	2.402
AlVI	0.657	0.77	0.571	0.576	0.67	0.694
Ti	0.254	0.226	0.261	0.21	0.135	0.107
Fe	2.102	2.047	2.536	2.526	2.266	2.374
Mn	0	0	0	0	0	0
Mg	2.718	2.642	2.351	2.402	2.742	2.950
Ca	0	0	0	0	0.017	0.04
Na	0.072	0.063	0.072	0.081	0.09	0.107
K	1.993	1.643	1.887	1.939	1.717	1.65
Total	15.896	15.594	15.678	15.764	15.685	15.604

sample #	CN10		F1		F38	
	r	m	m	r	r	m
SiO2	35.83	36.68	36.61	35.93	37.45	36.92
TiO2	1.92	1.64	2.91	2.57	2.49	3.96
Al2O3	17.18	17.12	17.82	18.98	18.56	17.63
FeO	19.1	19.06	15.61	15.65	9.5	12.08
MnO	0	*	*	*	*	*
MgO	10.69	12.33	12.54	11.89	17.07	14.35
CaO	0.04	0.2	0	0.02	0.02	0.11
Na2O	0.22	0.27	0.24	0.42	0.15	0.09
K2O	9.02	8.7	9.18	9.1	9.38	9.3
Total	94	96	94.91	94.56	94.62	94.44

Formula Moles

Si	5.516	5.509	5.478	5.401	5.455	5.404
AlIV	2.484	2.491	2.522	2.599	2.545	2.536
AlVI	0.633	0.536	0.623	0.764	0.64	0.539
Ti	0.221	0.185	0.325	0.267	0.269	0.438
Fe	2.457	2.393	1.95	1.963	1.134	1.494
Mn	0	0	0	0	0	0
Mg	2.448	2.759	2.798	2.666	3.707	3.150
Ca	0.004	0.031	0	0	0	0.013
Na	0.063	0.075	0.07	0.119	0.042	0.026
K	1.771	1.666	1.752	1.743	1.74	1.754
Total	15.597	15.645	15.518	15.547	15.552	15.43

1 continued				
sample # 1	F11	F12	F36	1
	r	m	r	m
SiO2	36.91	36.69	36.31	37.01
TiO2	2	3.75	3.55	4.24
Al2O3	18.97	17.77	16.95	17.43
FeO	10.39	14.1	12.88	12.91
MnO	*	*	*	*
MgO	13.75	12.55	14.13	13.92
CaO	0.01	0	0.05	0.04
Na2O	0.07	0.09	0.13	0.12
K2O	9.42	8.38	9.48	9.41
Total	94.52	94.57	93.46	95.03
Formula Moles				
Si	5.476	5.484	5.437	5.363
AlIV	2.524	2.516	2.513	2.637
AlVI	0.793	0.812	0.471	0.483
Ti	0.222	0.421	0.402	0.477
Fe	1.86	1.739	1.622	1.624
Mn				
Mg	3.041	2.795	3.168	3.121
Ca	0	0	0.004	0.004
Na	0.017	0.021	0.035	0.031
K	1.782	1.625	1.616	1.801
Total	15.517	15.433	15.519	15.511

2: Representative ms analyses					
Sample #	CN25	CN56	CN10	CN21	CN3
SiO2	44.95	44.71	45.68	45.89	45.35
TiO2	0.65	0.63	0.53	0.63	0.73
Al2O3	31.05	33.93	29.42	29.68	31.93
FeO	3.36	1.27	3.13	2.88	3.58
MgO	0.91	0.86	0.88	0.83	0.91
CaO	0	0	0	0	0
NaO	0.85	0.89	1.02	1.07	0.85
K2O	10.54	10.16	9.45	9.12	9.33
Total	92.31	92.45	90.11	90.1	92.68
Formula moles					
Si	6.28	6.14	6.474	6.488	6.259
AlIV	1.72	1.86	1.526	1.514	1.741
AlVI	3.391	3.625	3.384	3.429	3.457
Ti	0.085	0.084	0.054	0.086	0.093
Fe	0.389	0.145	0.37	0.34	0.413
Mg	0.188	0.173	0.183	0.174	0.186
Ca	0	0	0	0	0
Na	0.129	0.238	0.278	0.29	0.227
K	1.677	1.778	1.708	1.642	1.641
Total	14.139	14.023	13.977	13.941	13.993

3: Representative grt analyses; c = core, r = rim
 sample # [CN21] [CN10] [F1]

	c	r	c	r	c	r
SiO2	37	36.27	37.63	36.95	38.66	39.35
Al2O3	21.4	21.47	20.75	20.41	21.38	20.93
FeO	32.54	32.86	33.44	33.32	30.97	32.23
MnO	2.51	2.58	2.16	3.2	1.01	1.43
MgO	4.27	3.97	4	3.41	5.74	4.19
CaO	2.51	2.54	1.73	1.89	3.39	3.23
Total	100.23	99.79	99.71	99.18	101.15	100.36

Formula moles

	c	r	c	r	c	r
Si	2.954	2.923	3.017	3.001	3.009	3.036
Al	2.012	2.039	1.96	1.955	1.96	1.951
Fe	2.171	2.214	2.243	2.262	2.015	2.132
Mn	0.168	0.182	0.146	0.219	0.066	0.095
Mg	0.506	0.475	0.478	0.412	0.665	0.492
Ca	0.213	0.217	0.148	0.162	0.281	0.274
Total	8.024	8.05	7.992	8.011	7.996	7.98

sample # [	CN13	]	CN56	]	CN25	]
	c	r	c	r	c	r
SiO2	36.95	37.91	37.13	36.71	37.12	37.48
Al2O3	20.8	21.04	20.83	20.77	20.77	20.87
FeO	33.65	33.51	34.43	34.27	32.53	30.38
MnO	2.2	2.94	1.32	1.45	1.28	4.99
MgO	4	3.41	4.53	4.06	6.16	2.96
CaO	2.25	2.22	1.97	2.28	1.74	4.11
Total	99.85	101.03	100.21	99.54	99.65	100.69

Formula moles

	c	r	c	r	c	r
Si	2.971	3.011	2.972	2.965	2.963	2.992
Al	1.971	1.969	1.964	1.977	1.953	1.963
Fe	2.263	2.226	2.304	2.313	2.173	2.029
Mn	0.148	0.195	0.089	0.097	0.084	0.33
Mg	0.479	0.403	0.54	0.488	0.73	0.351
Ca	0.193	0.188	0.169	0.196	0.147	0.349
Total	8.025	7.992	8.038	8.036	8.05	8.014

3 continued						
sample # [	CN73		[]	CN95		[]
	c	r		c	r	
SiO2	38.61	38.61		38.44	36.74	38.42
Al2O3	20.93	21.12		20.86	21.42	20.41
FeO	24.11	29.4		32.92	35.58	31.41
MnO	3.12	0.93		0.78	1.18	0.7
MgO	6.21	6.19		5.63	3.74	6.32
CaO	6.46	3.68		1.59	1.48	1.88
Total	99.44	99.93		100.22	100.12	99.14
Formula moles						
Si	3.021	3.025		3.034	2.954	3.046
Al	1.93	1.951		1.939	2.029	1.906
Fe	1.579	1.928		2.172	2.372	2.083
Mn	0.207	0.06		0.051	0.078	0.046
Mg	0.724	0.722		0.662	0.446	0.747
Ca	0.54	0.368		0.122	0.127	0.158
Total	3.001	7.994		7.989	8.026	7.986

sample # [	CN3		[]	F29		[] F72-A]
	c	r		c	r	c
SiO2	36.82	36.39		38.41	37.14	37.83
Al2O3	21.2	21.09		21.89	20.91	21.36
FeO	30.57	30.71		26.8	29.84	29.9
MnO	6.54	7.93		1.39	2.61	1.36
MgO	3.41	2.54		8.03	4.35	6.36
CaO	2.03	1.81		3.85	4.77	3.17
Total	100.57	100.47		100.37	99.62	99.98
Formula moles						
Si	2.954	2.945		2.968	2.966	2.975
Al	2.003	2.012		1.993	1.969	1.978
Fe	2.05	2.078		1.73	1.793	1.966
Mn	0.442	0.542		0.09	0.176	0.09
Mg	0.407	0.306		0.923	0.518	0.745
Ca	0.174	0.157		0.317	0.408	0.265
Total	8.03	8.04		8.021	8.03	8.019

. 3 continued						
sample # [	F38		F11		F36	
	c	r	c	r	c	r
SiO2	38.34	37.88	39.59	38.41	38.8	38.68
Al2O3	21.79	22.02	21.24	21.53	21.59	21.19
FeO	27.4	29.07	27.94	32.1	31.01	32.09
MnO	0.52	0.58	0.37	0.65	0.32	0.38
MgO	9.73	8.78	9.13	6.19	7.55	6.43
CaO	1.83	1.88	1.77	1.89	1.09	
Total	99.41	100.01	100.04	100.57	100.36	98.77
Formula moles						
Si	2.969	2.944	3.045	3.007	3.014	3.036
Al	1.789	2.016	1.926	1.934	1.976	1.96
Fe	1.775	1.888	1.797	2.059	2.013	2.105
Mn	0.034	0.036	0.022	0.041	0.021	0.023
Mg	1.123	1.015	1.045	0.721	0.873	0.75
Ca	0.134	0.139	0.144	0.14	0.089	0.105
Total	8.024	8.038	7.979	7.992	7.986	7.979

4: Representative pl and kfs compositions

Sample #	F36	F11	F38	CN3	F72	F29
SiO2	62.54	61.58	62.2	61.38	58.61	59.2
Al2O3	23.09	24.15	23.97	23.88	25.49	25.37
CaO	4.58	5.71	5.32	5.25	7.26	7
Na2O	8.67	7.92	8.44	8.66	7.46	7.65
K2O	0.22	0.16	0.25	0.13	0.17	0.29
Total	99.1	99.52	100.18	99.3	98.99	99.51

Formula moles

Si	2.787	2.74	2.752	2.741	2.641	2.653
Al	1.212	1.267	1.249	1.256	1.334	1.34
Ca	0.218	0.271	0.251	0.25	0.35	0.335
Na	0.749	0.663	0.723	0.75	0.652	0.664
K	0.012	0.008	0.013	0.006	0.009	0.016
Total	4.978	4.969	4.988	5.003	5.006	5.008

Sample #	F1	CN10	CN73	CN25	CN13	CN56
SiO2	59.88	59.88	60.13	60.44	61.64	61.94
Al2O3	25.36	25.19	24.54	24.47	23.84	23.88
CaO	6.22	6.36	6.61	6.54	5.71	5.61
Na2O	7.66	7.9	7.62	7.89	8.02	8.42
K2O	0.13	0.1	0	0.08	0.37	0.11
Total	99.25	99.45	98.9	99.42	99.6	99.96

Formula moles

Si	2.679	2.678	2.699	2.704	2.744	2.747
Al	1.337	1.327	1.297	1.289	1.25	1.248
Ca	0.298	0.304	0.317	0.312	0.271	0.265
Na	0.663	0.685	0.663	0.684	0.691	0.723
K	0.006	0.005	0	0.004	0.021	0.005
Total	4.983	4.999	4.976	4.993	4.977	4.988

5: Representative hbl, bi, grt, cpx and opx analyses

Hbl	Bi					
sample #	Cn4	F41	CN68	Cn4	Cpx	F41
SiO2	42.75	41	45.55	36.95	SiO2	50.43
TiO2	0.69	1.99	1.23	2.41	TiO2	0.23
Al2O3	14.59	12.69	10.69	17.27	Al2O3	3.48
FeO	14.31	17.16	13.05	14.6	FeO	11.25
MnO	0.16	0.15	0.04	0	MnO	0.3
MgO	10.3	10.47	13	13.71	MgO	11.27
CaO	12.16	11.46	12.59	0.04	CaO	22.29
Na2O	2.05	2.07	0.82	0.36	NaO	1.01
K2O	1.17	1.26	0.96	9.95		
Total	98.18	98.25	97.93	95.29	Total	100.26
Formula moles					Formula Moles	
Si	6.318	6.179	6.666	5.51	Si	1.907
Al	2.541	2.251	1.842	3.033	Al	0.154
Ti	0.073	0.221	0.133	0.267	Ti	0.005
Fe	1.765	2.163	1.593	1.82	Fe	0.354
Mn	0.017	0.018	0.004	0	Mn	0.009
Mg	2.268	2.349	2.934	3.046	Mg	0.634
Ca	1.921	1.849	1.971	0.004	Ca	0.901
Na	0.585	0.601	0.228	0.105	Na	0.073
K	0.217	0.239	0.176	1.89		
Total	15.705	15.87	15.447	15.675	Total	4.037

grt	F41	Cn68
SiO2	38.36	38.94
Al2O3	20.98	22.38
FeO	27.18	25.91
MnO	1.29	0.84
MgO	5.47	6.6
CaO	7.08	6.4
Total	100.36	101.07
Formula Moles		
Si	2.998	2.979
Al	1.931	2.018
Fe	1.775	1.656
Mn	0.084	0.054
Mg	0.638	0.752
Ca	0.592	0.532
Total	8.018	7.991

opx	F41
SiO2	50.11
Al2O3	1.73
FeO	29.29
MnO	0.84
CaO	0.64
MgO	17.61
NaO	0.06
Total	100.28
Formula Moles	
Si	1.932
Al	0.085
Fe	0.936
Mn	0.027
Mg	1.007
Ca	0.025
Na	0.004
Total	4.016

APPENDIX D

FLUID INCLUSION PROCEDURES AND RESULTS

Samples for fluid inclusion study were selected from those outcrops that were chosen for electron microprobe study. Investigation of thin sections from those outcrops showed that the more schistose rocks contained more fluid inclusions than the gneissic rocks.

Rock chips were polished using 1 micron paste. The polished side was then cemented to a thin section blank using super glue. The chip was then cut to a size of 40 to 60 microns using a slow speed saw. The sample was then polished using 1 micron paste. The sample was studied under transmitted light and appropriate inclusions were examined and their locations mapped for study in the heating/freezing stage. The thin section was then immersed in acetone to remove the super glue. At this point it was common for the polished rock chip to fall apart due to the lack of cohesiveness of the schist samples. Once the sample fell apart it was extremely difficult to locate the inclusions found in the petrographic study due to the small grain size of the sample.

Two samples were studied in the heating/freezing stage, one from the ky-ms zone (CN-3) and one from the sil-ksp zone (F-38). Only those inclusions that were

determined to be primary fluid inclusions were examined. Freezing runs were conducted by freezing the stage to a temperature of -150 deg C. The stage was then warmed at a rate of 5 to 10 deg C per minute to get an approximation of temperatures at which phase changes occurred. Phase changes were then studied by gradual warming and cooling (at rates of 1-2 deg C per minute) across the temperature range until repeatability to +/- 0.2 deg C was obtained. If repeatability was not obtained it was concluded that the fluid inclusion had been damaged and was the inclusion data that was obtained was not used.

The results are shown on the following page. The inclusions examined are interpreted to dominantly CO₂, based on the location of the melting temperature. The slight depression of the freezing point seen in some of the samples indicates that a small amount of a diluent fluid phase is present. This phase is presumed to be methane. The small data set makes it impossible to relate this inclusions to the metamorphic event with any certainty. It is interesting that CO₂ was the only phase observed in both the granulite and the amphibolite terranes. More study is needed to see if this is a real relationship or is simply the result of the small data set.

Fluid inclusion results.

F-38

	T_m	T_h
1.	-57.0	-22.1
2.	-56.8	-25.5
3.	-57.1	-23.5
4.	-56.9	-19.1
5.	-58.1	-23.5
6.	-58.8	-22.7
7.	-57.2	-20.2
8.	-56.9	-21.0

CN-3

	T_m	T_h
1.	-56.6	-26.5
2.	-56.5	-26.1
3.	-56.5	+ 6.7
4.	-58.1	-12.2
5.	-58.0	-19.8
6.	-57.5	-20.1
7.	-57.3	-24.3
8.	-56.8	-14.4
9.	-56.6	-21.1

VITA

Roger was raised on a small Iowa farm near the town of Clermont. Roger graduated from the University of Iowa with a BS in geology with honors. He entered the University of Tennessee in September of 1984. Roger graduated with a MS in geology in June of 1988. He is currently employed by Goodwill Industries as the coordinator of a project that finds jobs for young disabled people.

Legend

Gd granodiorite
Ot Otto Formation
Co/Tf Coweeta Group/
Tallulah Falls Formation
Ra Rabun Granite

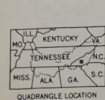
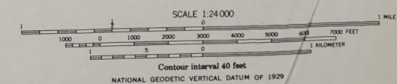
amp amphibolite
um ultramafic
• 14 sample locality
h₈₇ strike & dip [S₂]
h₃₁ plunge & bearing [F₃]

83°27' 30"
35°13'



35°7'30"
Franklin

Corbin Knob

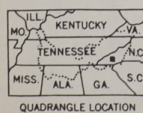


ROAD CLASSIFICATION
Heavy-duty Floor motor road
Medium-duty Wagon and pack trail
Light-duty Foot trail
U.S. Route U.S. Route
State Route State Route
In developed areas, only through roads are shown



UTM GRID AND 1976 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET

SCALE 1:24,000
1 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 5 10 15 20 KILOMETER
Contour interval 40 feet
NATIONAL GEODETIC VERTICAL DATUM OF 1929



ROAD CLASSIFICATION
Heavy-duty Poor motor road
Medium-duty Wagon and jeep track
Light-duty Foot trail
U. S. Route State Route
In developed areas, only through roads are classified

83°15'