To the Graduate Council:

I am submitting herewith a thesis written by Stephen Rex Clark entitled "Petrology of the Bear Poplar and Barber Mafic Intrusions, North Carolina." I 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.

Harry Y. McSween, Jr., Major Professor

We have read this thesis
and recommend its acceptance:

Lawrence A. Taylor

John B. Higgins

Accepted for the Council:

L. Evans Roth

Vice Chancellor
Graduate Studies and Research

PETROLOGY OF THE BEAR POPLAR AND BARBER MAFIC INTRUSIONS, NORTH CAROLINA

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Stephen Rex Clark

December 1980

ACKNOWLEDGEMENTS

I would like to express my appreciation to those people who lent their support to this thesis: to Dr. J. Higgins, who assisted me in obtaining information for the study area and helped me in the revision of the text; to Dr. L. A. Taylor, who helped me in the use of the electron microprobe, in the compilation of the data acquired from the electron microprobe, and in the revision of the text; and especially to Dr. H. Y. McSween, Jr., my major advisor, who brought the study area to my attention, provided both financial and moral support throughout the entire project, and assisted me in the revision of the text.

Financial assistance for field work was supported by a grant from the College of Liberal Arts through Dr. H. Y. McSween, Jr. Without the support of these people and the College of Liberal Arts grant, this project would not have been possible.

ABSTRACT

The Bear Poplar and Barber mafic plutons are located in the Charlotte belt of North Carolina. The Bear Poplar pluton is a post-metamorphic intrusion consisting primarily of plagioclase, orthopyroxene, clinopyroxene, hornblende, biotite, and quartz. Magnetite, ilmenite, pyrite, pyrrhotite, and hematite are present in lesser amounts. The pluton is composed of four rock types that exhibit systematic areal trends within the intrusion. Cores of norite and gabbronorite are surrounded by hornblende norite and hornblende gabbronorite. Progressive differentiation trends characterized by Fe and SiO_2 enrichment exist in the pluton. Rocks of the Bear Poplar pluton are rich in both components compared to the Barber pluton. Textures are generally hypidiomorphic granular to inequigranular with some cumulates present.

The Barber pluton is a pre-metamorphic intrusion composed of three rock types that reflect the increasing metamorphic alteration of the pluton. Relict olivine-hornblende gabbronorites show the least amount of alteration and consist of plagioclase, orthopyroxene, clinopyroxene, hornblende, and olivine. Type I metagabbros contain some relict igneous features and are composed mainly of plagioclase, hornblende, orthopyroxene, and clinopyroxene. Type II metagabbros are the most altered samples and contain primarily plagioclase, hornblende, and epidote. Magnetite, ilmenite, pyrite, pyrrhotite, and hematite are present in lesser amounts. Textures range from relict hypidiomorphic granular to granoblastic.

Samples from both intrustions are generally medium-to-coarse grained, but finer-grained gabbroic rocks crosscut both plutons. These rocks are of similar mineralogy to the gabbroic rocks they intrude and denote multiple periods of intrusive activity for each unit. Unusual glomeroporphyritic samples are associated with the border of the Bear Poplar pluton and may reflect an early chilled phase of the magma.

The Bear Poplar pluton crystallized from an aluminous magma of basaltic andesite composition, contrasted to the high-alumina to tholeiitic basalt parental magma of the Barber pluton. Increased fractionation of a basaltic magma could produce a basaltic andesite magma, similar to the Bear Poplar samples. Such magmas may be formed in an island arc or continental margin setting. Using major element discrimination diagrams, the composition of the Bear Polar pluton can be distinguished as a calc-alkaline basalt and that of the Barber pluton can be classified as a less differentiated island arc tholeiite. The calc-alkaline basalt is typically associated with intrusions within continental crust at converging plate boundaries and lends support to the idea that this complex is related to tectonic activity at a continental margin.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

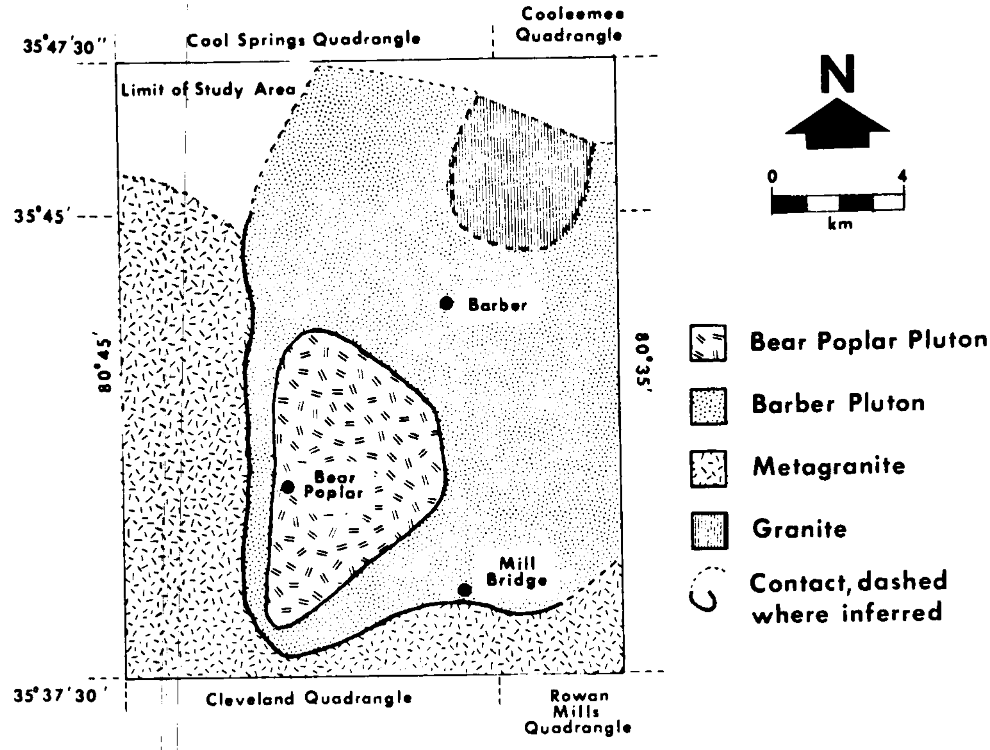
I. INTRODUCTION

Numerous gabbroic intrusions are exposed in a linear chain that stretches from North Carolina to Georgia in the Southern Appalachian Piedmont. Limited descriptive studies have been done on several of the intrusions (Butler, 1966; Cabaup, 1969; Constantino-Herrera, 1971; Glover and Sinha, 1973; Hadley, 1973; Mathews, 1969; McCauley, 1961; McSween, 1970; Medlin, 1969; Morgan, 1963; Myers, 1968; Waskom and Butler, 1971). More complete studies have been published for only a few of the intrusions (Chalcraft, 1970; Hermes, 1968; McSween and Nystrom, 1979; Medlin et al., 1972). The present study is a detailed examination of two gabbroic intrusions, the Bear Poplar and Barber plutons, in Rowan County, North Carolina (Figure 1).

The Barber pluton is a pre-metamorphic intrusion with textures ranging from relict igneous to granoblastic. The igneous precursor contained olivine and very calcic plagioclase. Metamorphism and alteration within the body have produced plagioclase- and hornblende-rich lithologies that dominate the pluton.

The Bear Poplar intrusion is an unmetamorphosed unit with distinct igneous textures and well-defined crystallization and differentiation trends. This body was emplaced within the Barber intrusion after metamorphism had occurred. The Bear Poplar pluton is compositionally distinct in that it is silica saturated.

These two intrusions form a mafic complex that differs from others in the Piedmont. These rocks may provide additional constraints on the petrogenesis of this chain of gabbro bodies.



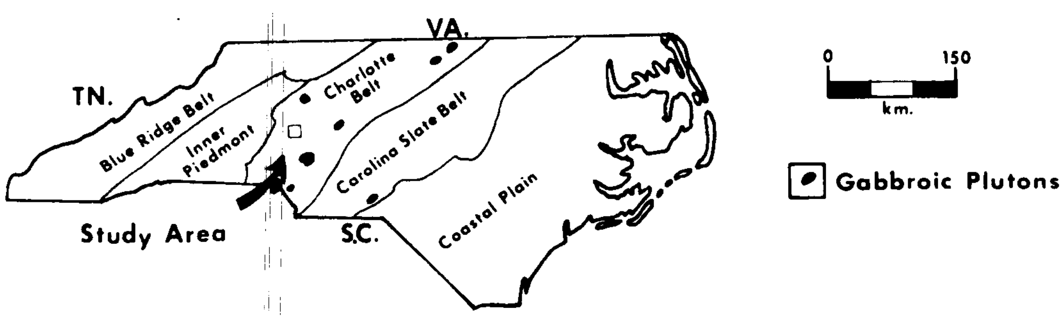


Figure 1. Location Maps of the Study Area.

The study area (open square) is located in the Charlotte Regional Geologic belt in North Carolina (bottom). The area mapped contains parts of four 7.5 minute quadrangles (top).

II. METHODS

Field mapping was done using U.S.G.S. 1:24000 scale topographic maps as base maps (see Geologic Map in pocket). Aerial photographs were used for additional information. Field sampling was conducted by foot and car traverses on north-south and east-west lines through the study area. The area contains numerous paved and unpaved county roads allowing easy access to most locations. Samples were obtained in fields, along streams, and in wooded areas from outcrops and residual boulders that were judged in place based on their size. Five abandoned quarries also occur in the Bear Poplar area. Four hundred and forty six samples were collected, yielding an average sampling density of three samples/ km^2. In areas where outcrops were not present, the saprolite was used as an index to the rock type. The gabbroic rocks weather to brown Mecklenburg and Iredell soil series in contrast to the reddish-pink, sandy soils associated with the country rocks. The two gabbroic plutons, however, cannot be distinguished in saprolite.

Precise contacts between the two intrusions and the country rocks are not readily visible in the field. The contacts were estimated by sampling every available outcrop near a supposed contact area and then distinguishing between the two intrusions in thin sections, because they cannot always be distinguished in hand specimen. Contacts between the Barber intrusion and the country rocks were more readily determined in saprolite.

Seventy-three samples from various parts of the study area were chosen for thin section preparation. Fifty-two thin sections were point counted utilizing one thousand to fifteen hundred points per thin section to determine the modal percentages of minerals in each sample. (Locations of these samples are shown on the Geologic map in pocket and modes are presented in Tables A-1 and A-2, Appendix.) The results are reproducible within a lower limit of plus or minus 2-3% absolute (Van Der Plas and Tobi, 1965). Analytical errors associated with point counting cannot always be estimated realistically due to the many variances (Neilson and Brockman, 1977). The grid distance used, relationship of adjacent grains, and layering in the samples all contribute to increased variances in point counting, and these may have affected the modal determinations in this study.

Electron microprobe analyses of individual minerals were performed using a MAC 400 S electron microprobe coupled to a Krisel Control Model 2003 Microprobe Logic Control Automation System. Appropriate synthetic and natural standards were chosen. Matrix corrections were made using the method of Bence and Albee (1968) and the data of Albee and Ray (1970). Operating conditions were set at 15 kv and .05 μa beam current. Analyses were performed on ten polished thin sections from the complex using a partially defocussed electron beam of approximately 15 μm diameter. Precision of the analyses of major elements is generally within 2% of the total. Representative microprobe analyses are presented in Tables 1 through 6. The average values for all analyses and standard deviations are listed by mineral in Tables A-3 through A-8, Appendix.

Bulk chemical analyses for two samples from the Bear Poplar pluton and three samples from the Barber pluton were obtained from J. R. Butler

Table 1. Representative Microprobe Analyses: Amphibole

	BP231	BP46	B408	B306	B329	B350	B388	B324
SiO_2	44.50	45.40	45.20	43.60	45.90	51.80	41.80	44.00
TiO_2	1.61	1.26	1.23	1.73	1.54	0.19	3.97	1.54
Al_2O_3	9.96	8.58	8.96	9.72	10.00	5.57	12.20	12.50
*FeO	16.10	13.80	14.80	14.40	11.60	8.91	11.30	9.98
MnO	0.19	0.44	0.35	0.24	0.20	0.26	0.24	0.11
MgO	11.50	13.70	12.10	12.70	14.80	17.60	13.90	15.90
CaO	11.60	11.60	11.80	12.00	12.10	12.60	11.70	12.30
Na_2O	1.16	1.07	0.95	1.40	1.61	0.54	2.14	1.98
K_2O	1.18	0.93	0.45	0.38	0.40	0.06	0.34	0.28
Total	97.80	96.78	95.84	96.17	98.15	97.53	97.59	98.59
			Atoms/23 (O, OH, F)					
Si	6.64	6.77	6.81	6.57	6.66	7.37	6.15	6.40
Ti	0.18	0.14	0.14	0.19	0.17	0.02	0.44	0.06
Al	1.75	1.50	1.59	1.72	1.71	0.93	2.12	2.14
Fe	2.01	1.72	1.86	1.82	1.40	1.06	1.39	1.21
Mn	0.02	0.05	0.04	0.03	0.02	0.03	0.03	0.01
Mg	2.55	3.04	2.72	2.85	3.19	3.74	3.04	3.44
Ca	1.85	1.84	1.90	1.93	1.89	1.92	1.84	1.91
Na	0.33	0.31	0.27	0.41	0.45	0.15	0.61	0.55
K	0.22	0.18	0.08	0.07	0.07	0.01	0.06	0.05
Total	15.55	15.55	15.41	15.59	15.56	15.23	15.68	15.77

*FeO = total Fe.

Table 2. Representative Microprobe Analyses: Biotite

	BP118	BP208	BP231	BP46
SiO_2	35.50	36.30	36.80	35.80
TiO_2	4.35	3.94	4.53	3.12
Al_2O_3	14.40	14.40	14.30	16.30
*FeO	18.20	18.80	18.60	16.50
MnO	0.11	0.17	0.11	0.21
MgO	12.00	11.80	12.30	13.00
CaO	0.00	0.00	0.01	0.00
Na_2O	0.00	0.06	0.08	0.24
K_2O	9.45	9.49	9.41	9.19
Total	94.01	94.96	96.14	94.36
		Atoms/12 (O, OH, F)		
Si	2.99	3.04	3.03	2.97
Ti	0.27	0.24	0.28	0.19
Al	1.43	1.41	1.39	1.59
Fe	1.29	1.31	1.28	1.14
Mn	0.01	0.01	0.01	0.01
Mg	1.50	1.48	1.51	1.61
Ca	0.00	0.00	0.00	0.00
Na	0.00	0.01	0.01	0.04
K	1.01	1.01	0.99	0.97
Total	8.50	8.51	8.50	8.52

*FeO = total Fe.

Table 3. Representative Microprobe Analyses: Orthopyroxene

	BP118	BP208	BP231	BP46	B329	B388	B324
SiO_2	51.30	50.80	49.90	55.50	54.00	52.60	53.40
TiO_2	0.13	0.17	0.15	0.07	0.16	0.43	0.02
Al_2O_3	0.85	0.73	0.82	0.93	1.09	3.24	2.63
*FeO	26.30	26.30	26.30	20.30	19.90	15.10	13.90
MnO	1.04	1.09	0.74	1.32	0.60	0.44	0.37
MgO	19.50	19.80	20.70	20.20	24.60	27.80	28.80
CaO	0.82	1.27	1.20	1.07	0.51	1.32	0.95
Total	99.94	100.16	99.81	99.39	100.86	100.93	100.07
			Atoms/6 Oxygens				
Si	1.96	1.94	1.92	2.05	1.97	1.88	1.91
Ti	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Al	0.04	0.03	0.04	0.04	0.05	0.14	0.11
Fe	0.84	0.84	0.84	0.63	0.61	0.45	0.42
Mn	0.03	0.03	0.02	0.04	0.02	0.01	0.01
Mg	1.11	1.13	1.18	1.11	1.34	1.48	1.54
Ca	0.03	0.05	0.05	0.04	0.02	0.05	0.04
Total	4.01	4.02	4.05	3.91	4.01	4.02	4.03

*FeO = total Fe.

Table 4. Representative Microprobe Analyses: Clinopyroxene

	BP118	BP208	BP231	BP46	B306	B329	B388	B324
SiO_2	52.00	52.40	52.20	53.20	52.20	53.00	50.80	52.50
TiO_2	0.28	0.11	0.27	0.14	0.25	0.18	0.87	0.07
Al_2O_3	1.55	1.15	1.56	1.32	1.52	1.50	4.21	2.22
*FeO	11.60	11.20	11.00	8.32	7.41	7.01	7.81	5.98
MnO	0.42	0.34	0.41	0.52	0.36	0.37	0.32	0.23
MgO	13.30	13.20	13.80	14.20	14.30	15.60	15.60	16.10
CaO	20.40	21.10	20.80	22.60	23.60	23.00	21.00	22.70
Total	99.55	99.50	100.04	100.30	99.64	100.66	100.61	99.80
			Atoms/6 Oxygens					
Si	1.96	1.98	1.96	1.97	1.95	1.95	1.87	1.93
Ti	0.01	0.00	0.01	0.00	0.01	0.00	0.02	0.00
Al	0.07	0.05	0.07	0.06	0.07	0.06	0.18	0.10
Fe	0.37	0.35	0.34	0.26	0.23	0.21	0.24	0.18
Mn	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01
Mg	0.75	0.74	0.77	0.78	0.80	0.86	0.85	0.88
Ca	0.83	0.85	0.83	0.90	0.94	0.91	0.83	0.90
Total	4.00	3.98	3.99	3.99	4.01	4.00	4.00	4.00

*FeO = total Fe.

Table 5. Representative Microprobe Analyses: Plagioclase

	BP118	BP208	BP231	BP46	B408	B366	B329	B350	B388	B324
SiO_2	55.50	53.90	54.20	53.80	48.00	48.20	46.70	45.70	50.40	43.20
Al_2O_3	28.00	29.50	30.10	30.00	33.10	33.60	34.20	34.90	32.30	37.20
CaO	10.00	11.40	10.80	11.30	15.60	15.90	17.70	17.50	13.60	18.80
Na_2O	5.66	5.19	5.54	4.85	2.70	2.32	1.71	1.52	3.72	0.77
K_2O	0.53	0.23	0.21	0.10	0.02	0.03	0.02	0.01	0.02	0.01
Total	99.69	100.22	100.85	100.05	99.42	100.05	100.33	99.63	100.04	99.98
				Atoms/8 Oxygens						
Si	2.51	2.43	2.42	2.42	2.21	2.20	2.14	2.11	2.29	2.00
Al	1.49	1.57	1.59	1.59	1.80	1.80	1.85	1.90	1.73	2.03
Ca	0.49	0.55	0.52	0.54	0.77	0.78	0.87	0.86	0.66	0.93
Na	0.49	0.45	0.48	0.42	0.24	0.20	0.15	0.14	0.33	0.07
K	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	5.01	5.01	5.02	4.97	5.02	4.98	5.01	5.01	5.01	5.03

Table 6. Representative Microprobe Analyses: Olivine

	B388	B324
SiO_2	39.10	45.20
*FeO	16.90	18.60
MgO	44.40	36.30
Total	100.40	100.10
Atoms/4 Oxygens		
Si	0.99	1.13
Fe	0.36	0.39
Mg	1.67	1.35
Total	3.02	2.87

*FeO = total Fe.

(personal communication). Additional data were estimated from a synthesis of modal mineral contents and mineral compositions analyzed by the electron microprobe (Table A-9, Appendix). Weight percent oxides were allotted to each mineral based on its volume proportion of the rock. Where mineral analyses were not available (e.g., quartz), weight percent oxides were distributed to the minerals based on idealized formulas.

III. FIELD RELATIONS

The study area lies in the western part of Rowan County, North Carolina within the Charlotte Regional Geologic belt (Figure 1, page 2). This belt is the main location of igneous intrusions in the Southern Appalachians (Butler and Ragland, 1969). Although most of the intrusions are of granite or metagranite, adamellites, syenites, diorites, and gabbros are present. Regional metamorphism in the area is generally of greenschist to amphibolite facies grade (Butler and Ragland, 1969). Chlorite, sericite, and epidote commonly replace the original minerals in some metamorphosed samples. The metamorphic grade is not easily established in the study area due to the lack of diagnostic reactions in the granitic country rocks.

The Bear Poplar and Barber intrusions are bounded on the western side by a medium-grained metagranite (Figure 1). This unit consists of quartz, microcline, plagioclase, and lesser amounts of biotite and muscovite. Zircon and epidote are present in minor amounts. Several of the samples show relict zoning in the plagioclase. Quartz-rich pegmatite dikes crosscut the unit at various locations. Textures of the metagranite are generally hypidiomorphic granular to hypidiomorphic inequigranular, although a few samples are porphyritic with large microcline phenocrysts. Myrmekitic intergrowths of quartz and feldspar are common in this unit. Gneissic textures are less common. A weak foliation often visible in thin section and hand specimen suggests that this unit has undergone metamorphism.

Two post-metamorphic granites occur near the study area. The Churchland pluton lies to the northeast of the area and the Landis pluton is located to the south (Butler and Fullagar, 1978; Butler and Ragland, 1969; Fullagar, 1971).

The Bear Poplar intrusion is an unmetamorphosed, gabbroic pluton exposed in an elongated outcrop pattern that trends roughly northeast-southwest. The pluton is exposed over 33 km^2 and covers the central portion of the Cleveland Quadrangle, North Carolina (Figure 1, page 2). It consists of gabbroic rocks composed primarily of plagioclase, orthopyroxene, clinopyroxene, hornblende, biotite and quartz. Exposure within the intrusion is very good. Outcrops in the pluton are for the most part large, spheroidal boulders, although some quarries are present. Individual samples are remarkably "fresh," although the bluish-gray boulders produce exfoliation sheets upon weathering.

The Barber intrusion is a metamorphosed, gabbroic pluton that is intruded by the Bear Poplar pluton. It is exposed over 120 km^2 in the study area and extends outside of this area to the north and east. The altered, gabbroic rocks consist mainly of plagioclase, hornblende, orthopyroxene, and clinopyroxene. A few outcrops of relict, olivine-bearing rock occur at isolated locations within the body. The intrusion is poorly exposed in most areas and consists of small boulders that are often highly weathered.

Samples from both intrusions are generally medium-to-coarse grained. Fine-grained gabbroic rocks crosscut the coarser, more dominant phases of both plutons. These fine-grained samples are of similar mineralogy to the rocks they crosscut and contain xenoliths of the coarser phases. This relationship denotes multiple periods of magma injection within each intrusion.

Gabbroic samples composed of plagioclase glomerocrysts within fine-grained matrices of plagioclase, pyroxene, and hornblende grains were found near the southern and western boundaries of the Bear Poplar intrusion. These samples, which occur as small boulders and may not be in place, may represent a border zone of the magma chamber that was chilled upon emplacement. Their glomeroporphyritic textures suggests that plagioclase was the first liquidus phase and that the magma had already begun to crystallize before emplacement.

Mesozoic diabase dikes (Ragland et al., 1968) crosscut the metagranite and the two gabbroic intrusions at numerous locations. Isolated boulders of diabase occur at random throughout the study area. These fine-to-medium grained, subophitic diabases consist primarily of olivine, clinopyroxene, and plagioclase. The variations in grain size probably reflect the different thicknesses of the dikes and their different cooling rates.

The topographic relief in the study area is relatively low (maximum relief approximately 100 feet), and there is no correlation between the mafic intrusions and topographic relief. This contrasts with other gabbroic plutons in the Piedmont which display striking correlations between outcrop and topography (e.g., Chalcraft, 1970; McSween and Nystrom, 1979).

Gravity data for the western half of Rowan County, North Carolina (Hatcher and Zietz, 1980) denote a large positive Bouger anomaly associated with the study area (Figure 2). This is similar to

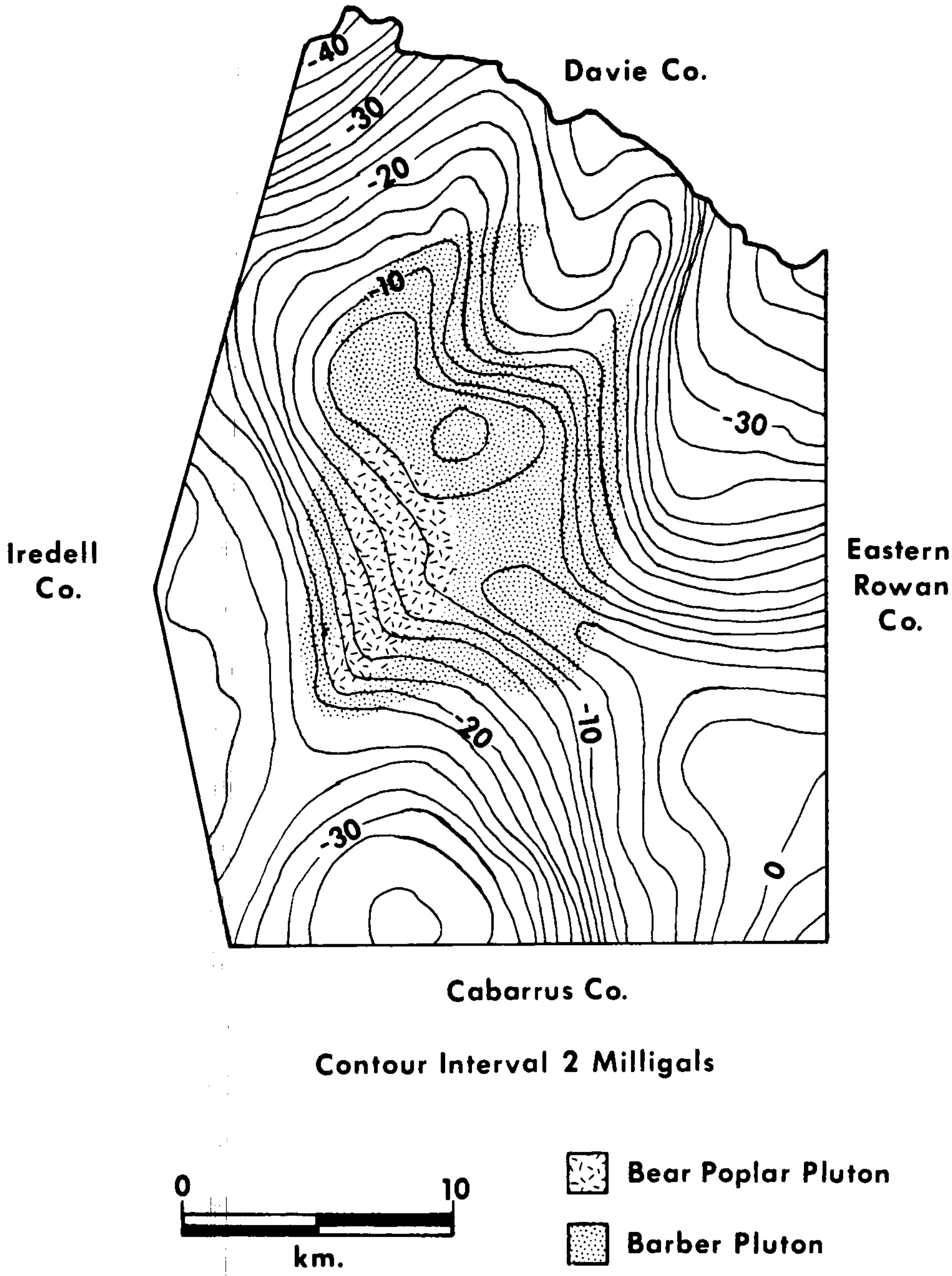


Figure 2. Gravity Data for the Western Half of Rowan County, North Carolina.

Source: Hatcher and Zietz, 1980.

The two intrusions occupy most of the area covered by the positive Bouger anomaly in the area. The Churchland granite is the large negative anomaly to the northeast of the area, and the Landis granite forms a similar anomaly to the south.

gravity anomalies associated with other gabbroic intrusions (e.g., Chalcraft, 1970; Hermes, 1968). The outcrops of the Bear Poplar and Barber intrusions occupy most of the area covered by the anomaly. Lack of exposure northwest of the study area suggests that a small part of the complex has not been exposed by erosion.

IV. MINERALOGY AND PETROGRAPHY

Bear Poplar Mineralogy and Petrography

Rocks of the Bear Poplar intrusion consist of plagioclase, orthopyroxene, clinopyroxene, hornblende, biotite, and quartz. Opaque minerals (magnetite, ilmenite, and subordinate amounts of pyrite, pyrrhotite, and hematite) are present in lesser amounts. Apatite, sericite, and chlorite are present in minor amounts. Representative analyses of major minerals are presented in Tables 1-6 (pages 5-9).

Plagioclase (44-63.8 volume percent) forms medium-to-coarse grained, distinctly zoned crystals (Figure 3a). Electron microprobe traverses across several grains revealed normal zoning, with calcic cores (An_{60}) and sodic rims (An_{48}). The subhedral grains are clouded with minute inclusions or contain pyroxene and opaque minerals as inclusions within their cores. Carlsbad, albite, and pericline twinning are common. The average anorthite content of the samples analyzed by the electron microprobe ranges from An_{43} to An_{58}. All but one of the samples have average anorthite contents greater than 50%.

Orthopyroxene (hypersthene) is present in amounts from 5.7-32%. It is the most abundant pyroxene in the intrusion, forming elongated, prismatic grains pleochroic from pale pink to pale green. The grains are commonly interstitial to plagioclase. Their composition ranges from $Wo_2En_{56}Fs_{42}$ to $Wo_2En_{62}Fs_{36}$ (Figure 4).

Clinopyroxene (1-10.2%) forms more equant-shaped grains that are also interstitial to plagioclase. Its composition ranges from $Wo_{43}En_{38}Fs_{19}$ to $Wo_{45}En_{41}Fs_{14}$ (Figure 4).

Figure 3. Photomicrographs of Samples from the Bear Poplar Pluton.

Scale shown at bottom.

a. Strongly zoned plagioclase grain in norite.

b. Hypidiomorphic granular texture with subhedral plagioclase and prismatic pyroxene grains in gabbronorite.

c. Pronounced igneous foliation displaying alignment of plagioclase, pyroxene, and hornblende grains in norite.

d. Glomeroporphyritic border sample with clumps of plagioclase phenocrysts and fine-grained matrix of plagioclase, pyroxene, and hornblende grains.

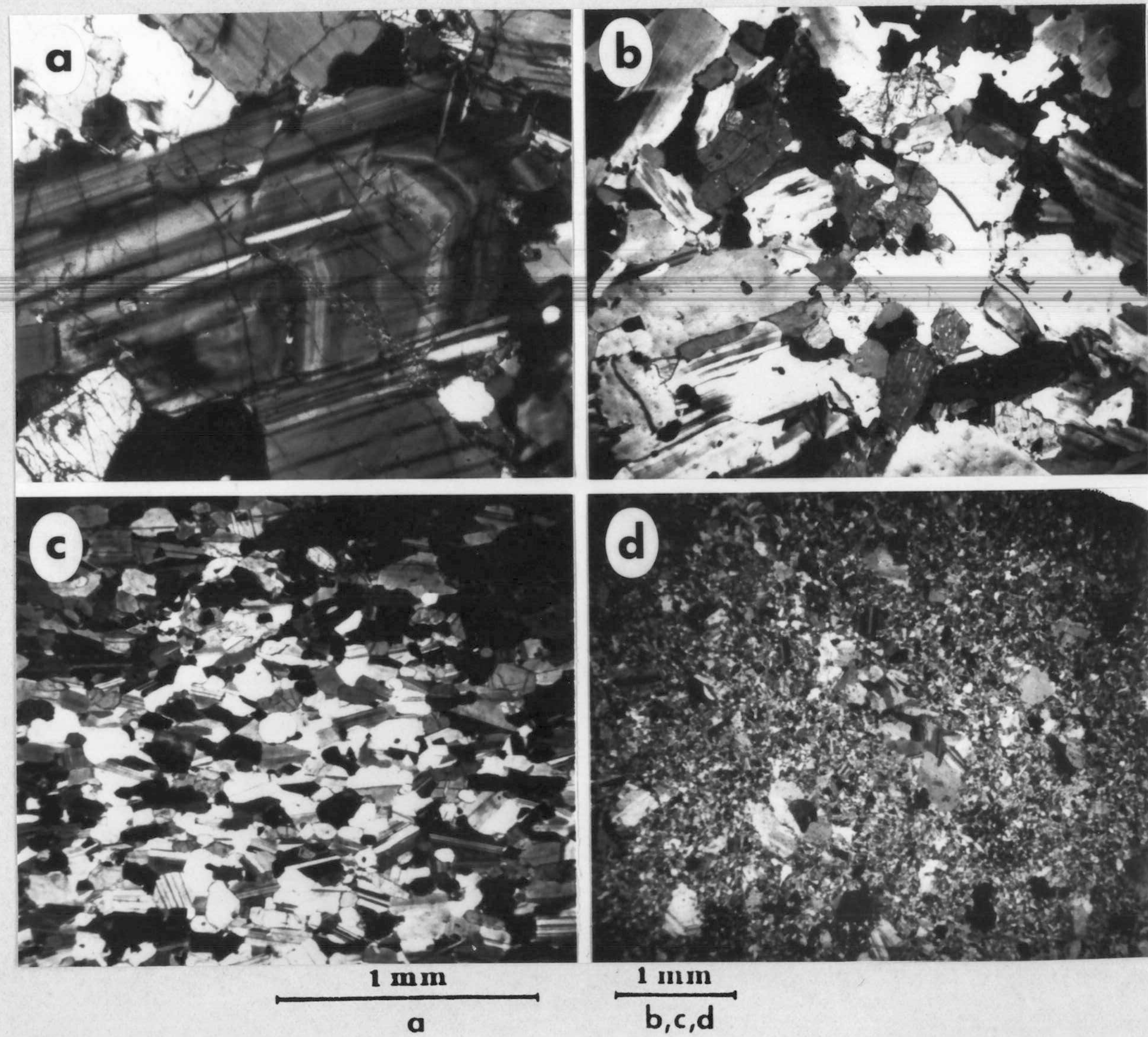


Figure 3.

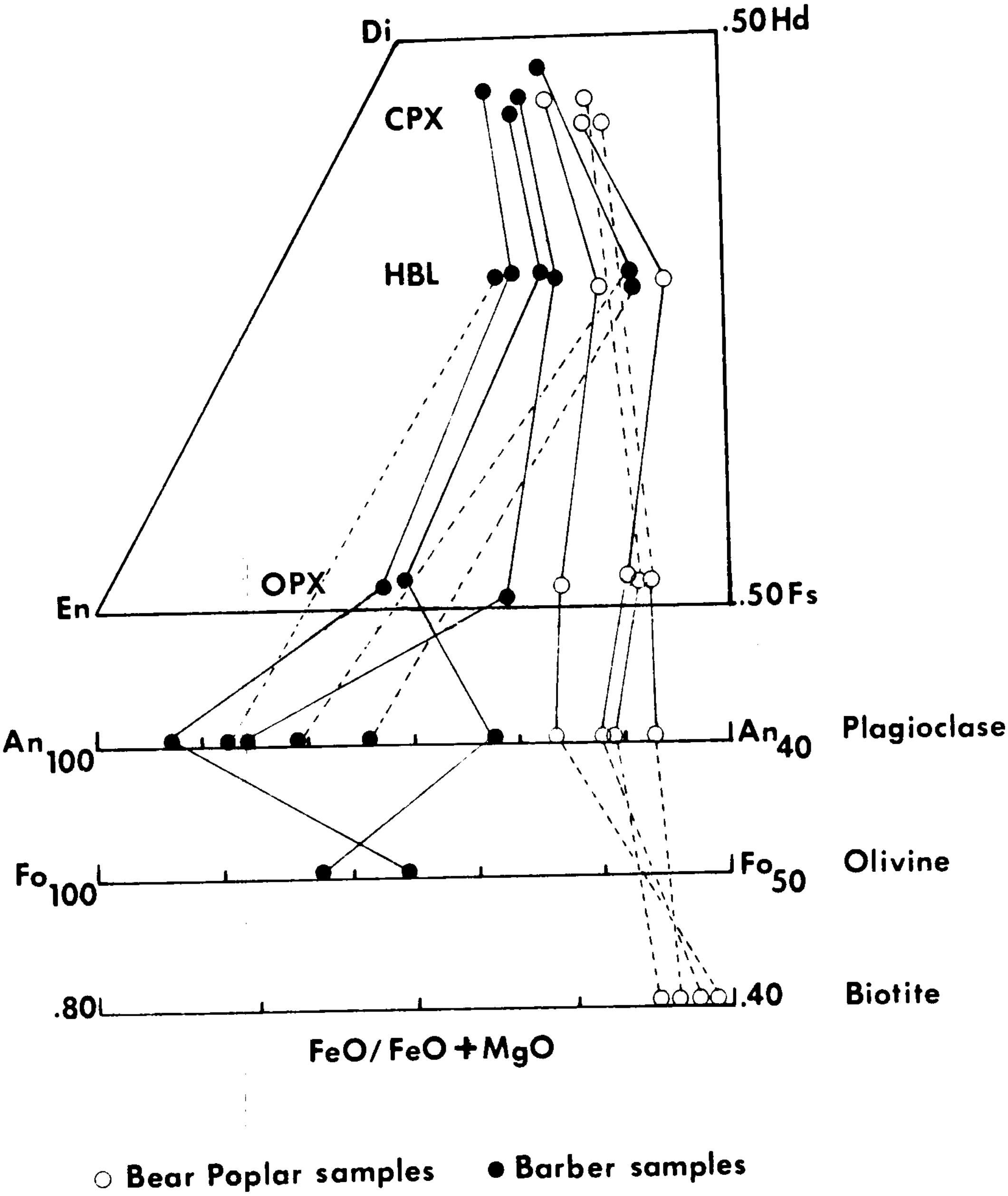


Figure 4. Compositions (mole %) of Coexisting Silicates in the Bear Poplar and Barber Intrusions.

All coexisting phases are joined by tie-lines. Bear Poplar ferromagnesian silicates (open symbols) are more Fe-rich and plagioclases have lower average anorthite contents than Barber samples (filled symbols). Hornblende compositions are projected into the pyroxene quadrilateral in terms of Mg, Fe, and Ca.

Both pyroxenes commonly contain inclusions of acicular or rounded opaque minerals and hornblende oriented parallel to cleavage lamellae. Rarely, schiller structures are formed. Pyroxene grains are often rimmed by hornblende and uralitic amphiboles.

Hornblende (0-18.4%) forms large, anhedral grains that poikiliticly enclose the primary grains. It is also found as reaction rims around pyroxene and opaque minerals and more rarely forms pseudomorphs of pyroxene. The grains are pleochroic from light tan or light green to dark green and often have concentrations of minute opaque minerals in their cores. Hornblende compositions in terms of Mg, Fe, and Ca contents may be plotted on the pyroxene quadrilateral in the same way that pyroxene compositions are represented (Figure 4). Hornblende compositions plot within a narrow range in the "hornblende" field (Figure 5, after Deer et al., 1962), although this phase would be classified as edenitic hornblende by Leake (1978).

Biotite (0.2-13.2%) forms anhedral-to-subhedral, tabular grains that are pleochroic from light tan to reddish brown. Minute opaque minerals are often included in the grains. Biotite is found rimming pyroxenes and opaque minerals. Its FeO/FeO+MgO content ranges from 0.38 to 0.49 (Figure 4). Complete analyses are presented in Table A-6 (Appendix).

Quartz (0.1-16.6%) forms anhedral grains that are interstitial to plagioclase, pyroxene, and biotite. The grains have fewer acicular inclusions than plagioclase and are thus optically clearer.

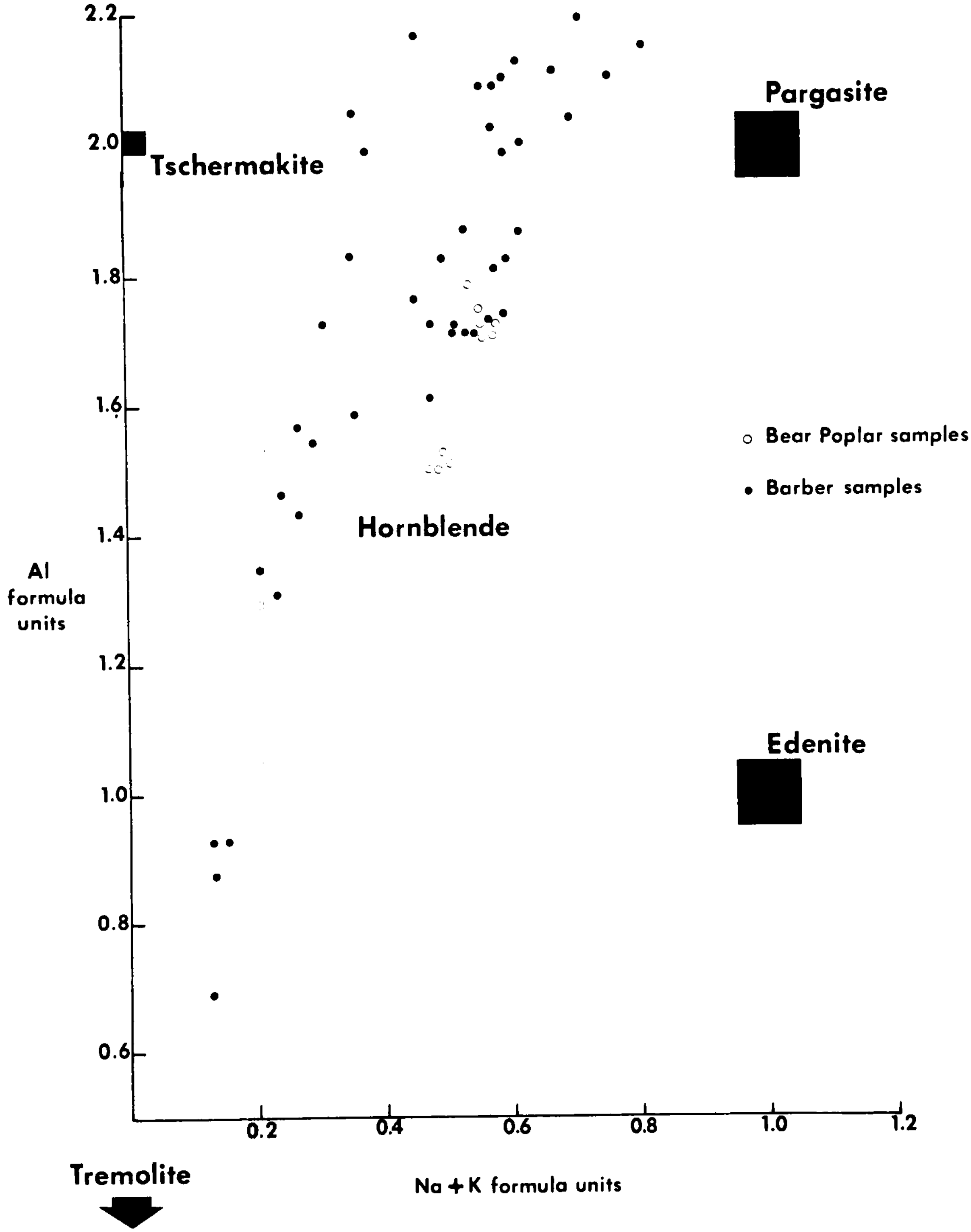


Figure 5. Amphibole Classification.

Source: Deer et al., 1962.

Bear Poplar samples (open symbols) plot in a narrow zone in the "hornblende" field. Barber samples (filled symbols) plot in a wide range across the hornblende-tschermakite-pargasite series fields.

Opaque minerals (1.2-7.8%) consist of magnetite and ilmenite, with subordinate amounts of pyrite, pyrrhotite, and hematite. They occur as primary phases and also as subsolidus reaction phases in pyroxene and hornblende. The primary opaque minerals are often rimmed by hornblende or biotite.

Apatite, sericite, and chlorite are present in minor amounts. Apatite forms small, subhedral grains in pyroxene and hornblende. Sericite is found as fibrous masses or veinlets that crisscross plagioclase grains. Chlorite, along with hornblende, forms fibrous pseudomorphs of pyroxene.

Textures in the Bear Poplar samples are generally hypidiomorphic granular to hypidiomorphic inequigranular (Figure 3b, page 17). Cumulate textures are formed in samples with large plagioclase grains and interstitial pyroxene, hornblende, and biotite. Poikilitic textures are present in most rocks with abundant hornblende. Igneous layering, present in most samples, ranges from the slight alignment of plagioclase grains to strong foliation of the entire sample (Figure 3c, page 17). Layering, however, is not observed in the field. Segregation of plagioclase-rich and pyroxene-rich layers in some samples is probably due to crystal settling. Symplectic textures occur in interstitial areas. Dactylitic intergrowths of hornblende plus quartz and biotite plus quartz are present, along with myrmekitic intergrowths of plagioclase plus quartz.

The unusual glomerporphyritic samples (Figure 3d, page 17) may reflect textures produced upon early crystallization of the magma at the pluton border. Large, subhedral plagioclase-grain aggregates are surrounded by minute plagioclase, pyroxene, and hornblende grains.

Barber Mineralogy and Petrography

The Barber intrusion is a metamorphosed pluton containing some rocks that display its relict igneous character. Rocks containing olivine are virtually unmetamorphosed and retain their igneous mineralogy (olivine and pyroxene) and igneous texture (hypidiomorphic granular) as in Figure 6a. Type I metagabbros contain orthopyroxene, clinopyroxene, and pseudomorphs of olivine, but show increased amounts of metamorphic alteration (Figure 6b). Type II metagabbros, displaying the most advanced stages of metamorphic alteration, contain abundant hornblende and significant amounts of epidote, but generally lack pyroxenes (Figure 6c). The metagabbro units of the Barber intrusion are similar to the metagabbro units in the Mecklenburg gabbro-metagabbro complex, North Carolina (Hermes, 1968). The major difference is that metagabbro in the Barber intrusion have recognizable olivine pseudomorphs present. Olivine is only present in the gabbroic rocks of the Mecklenburg complex, and no evidence for it was noted in the metagabbro units (Hermes, 1968).

The rocks of the Barber intrusion are composed of plagioclase, hornblende, orthopyroxene, clinopyroxene, olivine, epidote, and biotite. Opaque minerals (magnetite, ilmenite, pyrite, pyrrhotite, and hematite) and quartz are present in lesser amounts. Apatite, chlorite, sericite, zircon, hercynitic spinel, iddingsite, serpentine, and calcite are found in minor amounts.

Plagioclase (0-71.5%) forms medium-to-coarse grained, subhedral crystals that are rarely zoned. The grains contain minute inclusions of opaque minerals, hornblende, and pyroxene, although they are not as

Figure 6. Photomicrographs of Samples from the Barber Pluton.

Scale shown at bottom.

a. Olivine-hornblende gabbronorite with relict hypidiomorphic granular texture. Note large anhedral olivine crystals.

b. Type I metagabbro with subhedral plagioclase, altered pyroxene, and granular texture.

c. Type II metagabbro with subhedral plagioclase, abundant hornblende, and increased amounts of epidote.

d. Double coronas formed around olivine in olivine-hornblende gabbronorite. Inner rims against olivine are orthopyroxene. Outer rims abutting plagioclase consist of amphibole + spinel.

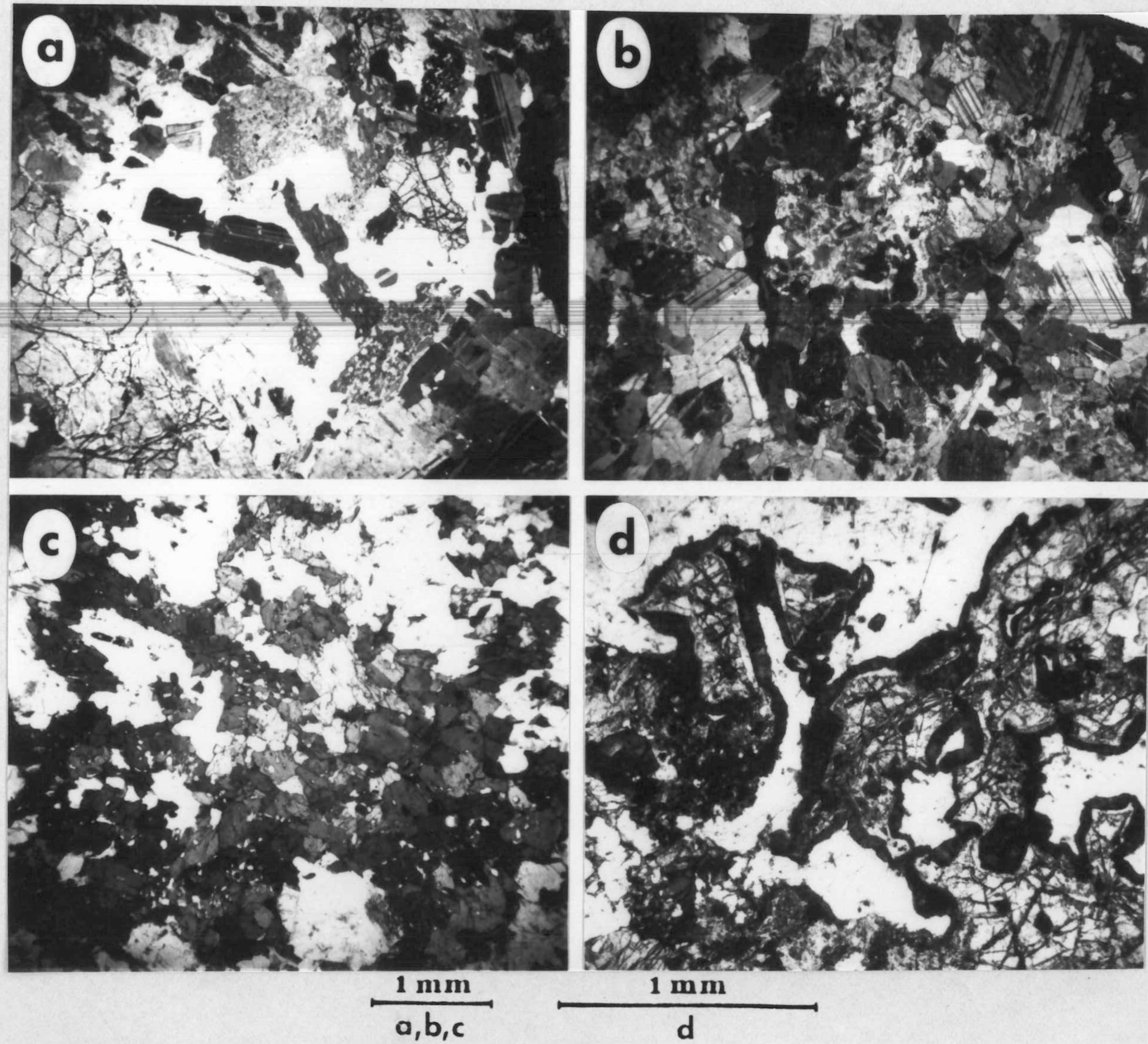


Figure 6.

clouded as plagioclase from the Bear Poplar intrusion. The opaque inclusions are either minute, rounded grains or acicular rods. The average anorthite contents of the samples analyzed by the electron microprobe range from An_{74} to An_{93} (Figure 4, page 19). The most calcic plagioclase generally occurs with olivine in the samples showing the least amount of metamorphic alteration.

Hornblende (10.8-79.8%) occurs as medium-to-coarse grained, anhedral crystals that are strongly pleochroic from light green or light brown to dark green or dark brown. The grains often have concentrations of minute acicular-to-rounded opaque inclusions parallel to cleavage. Hornblende poikiliticly encloses plagioclase, pyroxene, or olivine and forms reaction rims around pyroxene and opaque minerals. Hornblende pseudomorphs of pyroxene are common. The Mg, Fe, and Ca contents of hornblende can be represented on the pyroxene quadrilateral (Figure 4). Hornblende analyses plot within the "hornblende-tschermakite-edenite series" fields (Figure 5, after Deer et al., 1962). More specifically, the compositions range from pargasitic hornblende for the olivine-bearing samples to magnesio-hornblende for the most altered metagabbro samples (Leake, 1978).

Orthopyroxene (hypersthene) occurs in amounts from 0-31.4%. It forms medium-to-coarse grained, elongated prisms pleochroic from pale pink to pale green. The subhedral grains occur as both interstitial and poikilitic grains that range in composition from $Wo_1En_{67}Fs_{32}$ to $Wo_2En_{76}Fs_{22}$ (Figure 4). Clinopyroxene (0-6%) forms more equant-shaped grains that are interstitial to plagioclase. Its composition ranges from $Wo_{43}En_{44}Fs_{13}$ to $Wo_{46}En_{45}Fs_9$ (Figure 4).

Pyroxene grains often have inclusions of hornblende and opaque minerals in their cores. Hornblende lamellae are normally parallel to pyroxene cleavage traces and appear to replace the grains. Minute rounded or acicular opaque inclusions are present along cleavage lamellae. Pyroxenes are rimmed by hornblende, biotite, and more rarely acicular opaque minerals that form opaque "beards" around the grains.

Olivine (0-13.5%) has only been found in three samples in the Barber intrusion. It forms anhedral grains usually rimmed by orthopyroxene or hornblende, or partially altered to iddingsite, serpentine, and opaque minerals. Distinctive coronas are formed around olivine grains that are in contact with plagioclase (discussed later). Olivine pseudomorphs composed of orthopyroxene plus opaque minerals, orthopyroxene plus serpentine, or only serpentine are present in all petrologic types. Olivine ranges in composition from Fo_{70} to Fo_{83} (Figure 4, page 19), although individual grains are homogeneous and little variation occurs with any one section.

Epidote (0-35.8%) is restricted to Type I and Type II metagabbros. It forms anhedral-to-subhedral veinlets, prismatic grains, and rounded "rosettes" that are produced as an alteration product of plagioclase. Saussuritization of plagioclase is complete in some samples.

Biotite (0-15.6%) occurs as tabular grains that are pleochroic from light brown to reddish brown. The subhedral grains often have inclusions of apatite, zircon, or acicular opaques parallel to cleavage. Biotite forms reaction rims around pyroxene and is usually interstitial to plagioclase.

Opaque minerals (magnetite, ilmenite, pyrite, pyrrhotite, and hematite) are present in amounts from 0-10%. They occur as primary grains, products of late-stage magmatic reactions, and as precipitates produced by subsolidus reactions. The primary grains are often rimmed by hornblende or biotite and are commonly associated with hercynitic spinel. Late-stage magmatic oxide minerals form symplectites with orthopyroxene at olivine grain boundaries. Precipitates of oxide minerals are present in pyroxene and hornblende.

Quartz (0-13.4%) is only present in the Type II metagabbros and usually in small amounts (less than 3%). It forms anhedral, interstitial grains that are less clouded with inclusions than plagioclase.

Minor amounts of apatite, chlorite, sericite, zircon, hercynitic spinel, iddingsite, serpentine, and calcite are present. Apatite occurs as small prismatic grains in pyroxene, hornblende, and biotite. Chlorite forms fibrous pseudomorphs of pyroxene. Localized patches of chlorite occur in the Type II metagabbros. Sericite is found as felty masses and irregular veinlets that crisscross plagioclase grains. Zircon is present as subhedral-to-euhedral inclusions that produce pleochroic haloes in biotite. Hercynitic spinel is found in the Type I and Type II metagabbros as greenish, anhedral-to-subhedral grains. It is often associated with other opaque minerals, orthopyroxene and hornblende, and serpentinized olivine grains. In the Type II metagabbros, it is intergrown with hornblende. Its occurrences in the Barber intrusion are more numerous than in similar gabbroic intrustions, such as the Dutchman's Creek gabbro (McSween and Nystrom, 1979). Iddingsite, found only in the olivine-bearing samples, forms yellowish-brown veinlets and patches in olivine grains. Serpentine forms greenish-yellow masses replacing olivine grains. Serpentine and orthopyroxene form pseudomorphs of olivine in all three lithologic types. Calcite occurs as minute, irregularly-shaped masses or veinlets in plagioclase.

The Barber intrusion displays a wide variety of metamorphic textures superimposed on relict igneous textures. The igneous textures occur in the olivine-bearing gabbroic rocks and Type I metagabbros. Hypidiomorphic granular to hypidiomorphic inequigranular textures predominate, with poikilitic textures less common. Relict igneous layering displayed by aligned plagioclase grains is rarely present. Symplectic textures are common in the Barber intrusion. Opaque minerals are often vermicularly intergrown with orthopyroxene and olivine.

Metamorphic textures are best developed in the Type II metagabbros. Granoblastic textures in plagioclase are present in some samples. Foliation of hornblende and plagioclase grains produced some samples resembling amphibolites.

Coronas in various stages of development are present in this pluton. Double coronas form around olivine grains that are in contact with plagioclase in relict olivine-bearing rocks (Figure 6d). These coronas consist of an outer rim in contact with plagioclase composed of radially-oriented, fibrous amphibole plus vermicular spinel intergrowths. An inner rim in contact with olivine consists of radial, prismatic orthopyroxene crystals. Double coronas are present around orthopyroxene pseudomorphs of olivine in the Type I metagabbros.

Advanced corona development in the Type II metagabbros has produced fibrous amphibole masses rimmed by spinel. Serpentine and orthopyroxene pseudomorphs of olivine are often associated with these altered coronas. Coronas of hornblende plus hercynitic spinel also rim relict orthopyroxene grains. Single coronas composed of a rim of radially-oriented, fibrous amphibole plus vermicular spinel intergrowths are present around some opaque minerals and around hornblende grains that rim olivine.

Petrologic Classification

Petrologic classification is based on the International Union of Geological Sciences (IUGS) recommended system of classification and nomenclature (Streckeisen, 1973). The relative proportions of the major minerals (plagioclase, orthopyroxene, clinopyroxene, hornblende, and olivine in the Barber pluton) were used for classification.

Figure 7a is a plagioclase-orthopyroxene-clinopyroxene diagram of pyroxene-rich samples showing the distinction between norites (open circles) and gabbronorites (open squares). All the samples in Figure 7a are from the Bear Poplar pluton. Open circles and squares transferred from Figure 7a to Figure 7b, a plagioclase-total pyroxene-hornblende diagram, show that Bear Poplar norites generally have higher hornblende contents than gabbronorites of the same pluton. Barber intrusion metagabbro samples have much higher hornblende contents and are plotted as filled symbols in Figure 7b. Figure 7c is an olivine-total pyroxene-hornblende diagram for relict olivine-bearing samples from the Barber intrusion that exhibit less metamorphic alteration. These samples are relatively rich in pyroxene and hornblende, with lesser amounts of olivine.

Figure 7. Petrologic Classification of Samples.

Source: Streckeisen, 1973.

a. Plagioclase-orthopyroxene-clinopyroxene diagram showing distinction between norites (open circles) and gabbronorites (open squares). All plotted samples are from the Bear Poplar intrusion.

b. Plagioclase-total pyroxene-hornblende diagram showing the hornblende-rich character of the Bear Poplar norites relative to gabbronorites (open circles and squares transferred from "a." Relict olivine-hornblende gabbronorites (filled stars). Type I metagabbros (filled circles), and Type II metagabbros (filled squares) from the Barber pluton are also represented.

c. Total pyroxene-hornblende-olivine diagram for the olivine-hornblende gabbronorites of the Barber intrusion. These relict igneous samples are the only olivine-bearing rocks in the area.

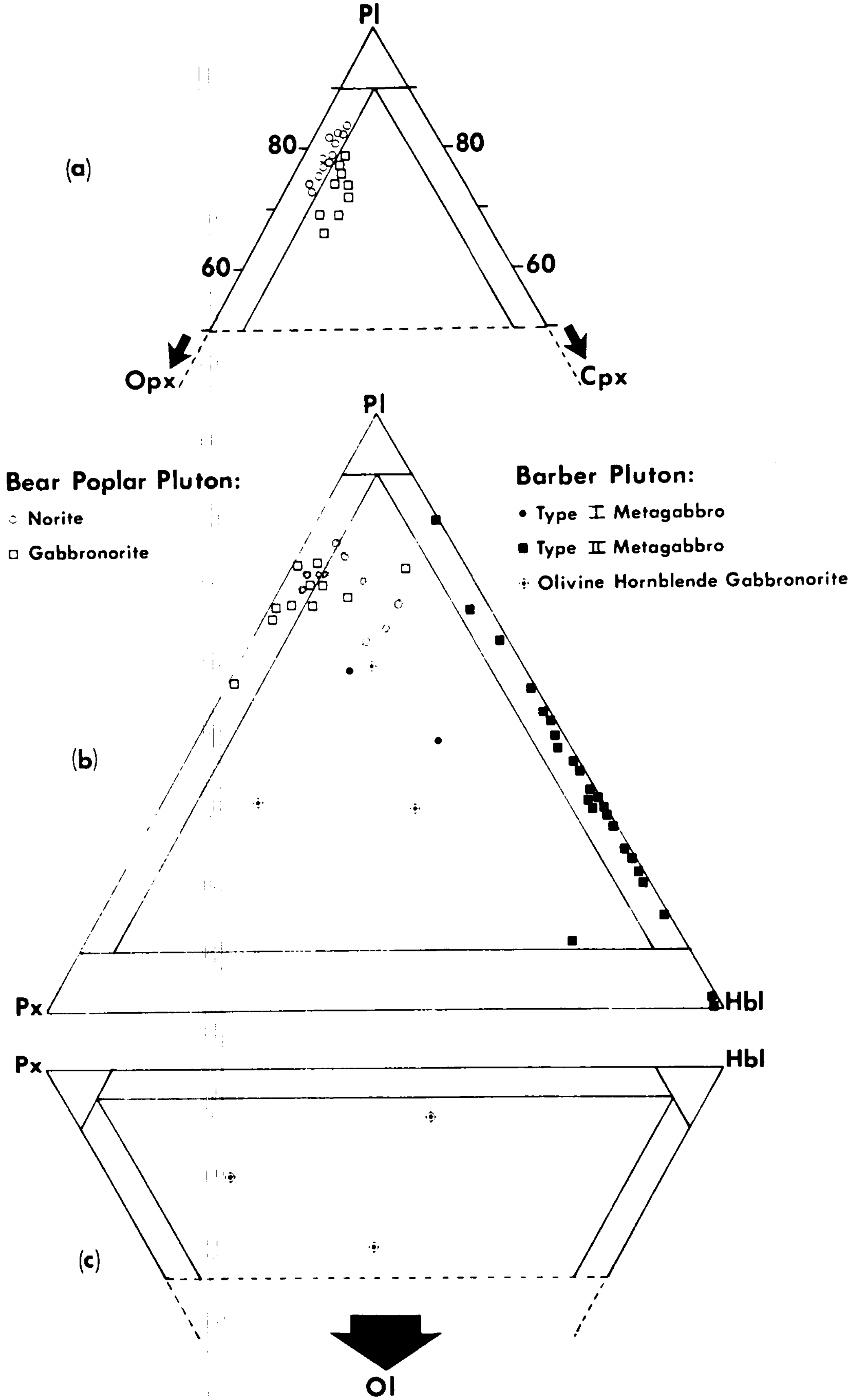

Pl
80
80
60
60
Opx
Cpx
(a)
Pl
Bear Poplar Pluton:
Norite
Gabbronorite
Barber Pluton:
Type I Metagabbro
Type II Metagabbro
Olivine Hornblende Gabbronorite
(b)
Px
Hbl
Px
Hbl
(c)
Ol

Figure 7.

Combining Figures 7a, 7b, and 7c, four petrologic types can be distinguished for the Bear Poplar intrusion (norite, hornblende norite, gabbronorite, and hornblende gabbronorite) and three for the Barber intrusion (olivine-hornblende gabbronorite and two types of metagabbro, designated Types I and II). Each of the petrologic types is characterized by a specific mineral assemblage. Norites are composed of plagioclase and orthopyroxene, with lesser amounts of clinopyroxene. Hornblende norites are similar, with the addition of hornblende. Gabbronorites are composed of plagioclase and subequal amounts of orthopyroxene and clinopyroxene. Hornblende gabbronorites have similar mineralogy, except for more hornblende. Olivine-hornblende gabbronorites are made of plagioclase, subequal amounts of orthopyroxene and clinopyroxene, hornblende, and olivine. Type I metaggabros consist of plagioclase, hornblende, and subordinate amounts of orthopyroxene and clinopyroxene. Type II metagabbros consist mainly of plagioclase and hornblende, but usually contain epidote. Hermes (1968) also recognized several types of metagabbro in the Mecklenburg complex, North Carolina. The usage adopted here differs from that of Hermes in that his distinction between the metagabbro units was based primarily on texture.

Areal Variations

The Bear Poplar and Barber intrusions display distinctive petrologic variations (presented in Geologic Map in pocket and summarized in Figure 8). The Bear Poplar pluton has two central cores of lithologic types that contain only small amounts of hydrous phases (hornblende, biotite, or chlorite). The upper core is predominantly norite and the

Figure 8. Areal Variations in Petrologic Types.

The Bear Poplar pluton is composed of two cores of norite and gabbronorite, surrounded by hornblende norite and hornblende gabbronorite. The Barber intrusion consists mainly of Type II metagabbro with subordinate amounts of Type I metagabbro and olivine-hornblende gabbronorite.

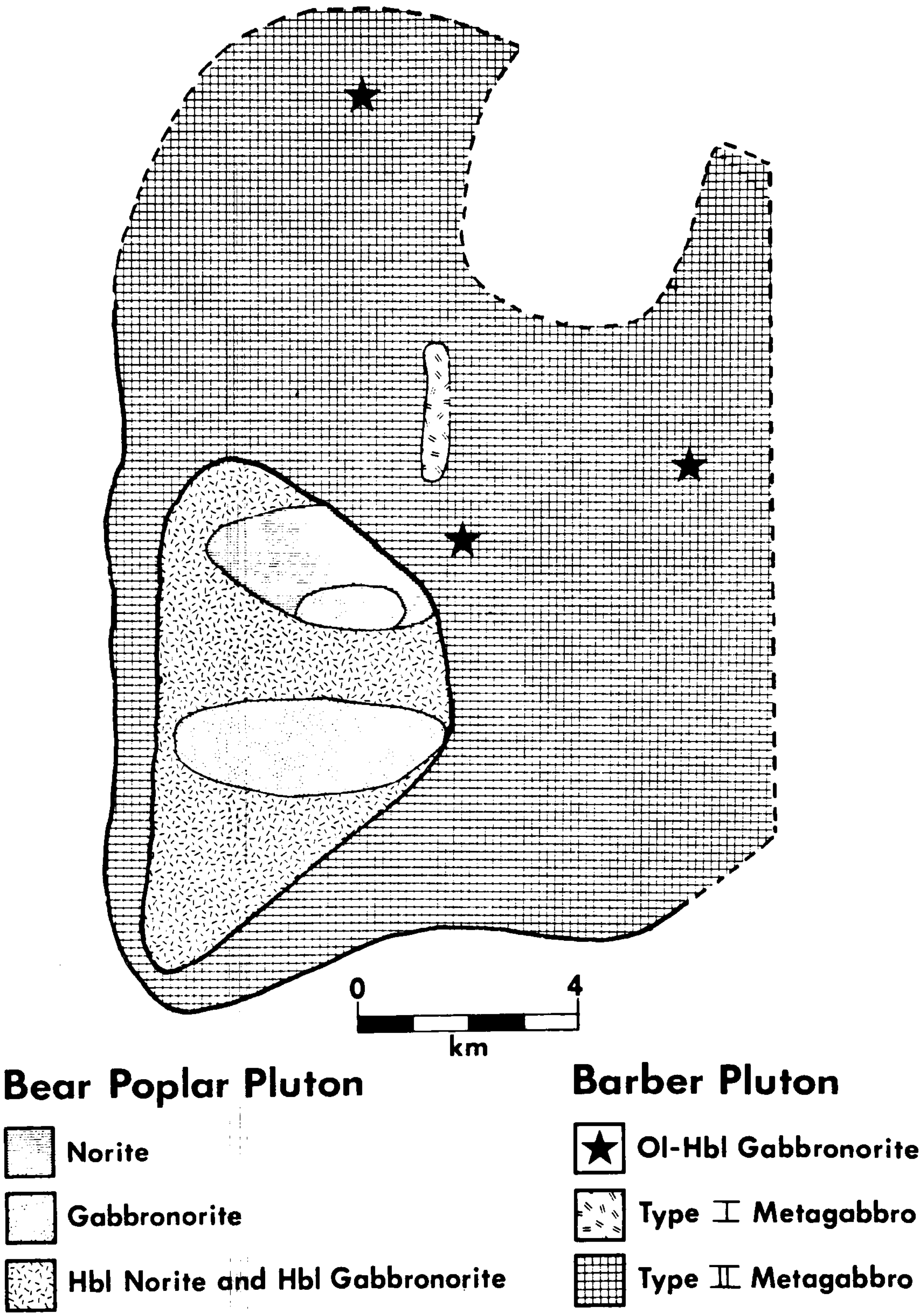

0
4
km
Bear Poplar Pluton
Norite
Gabbronorite
Hbl Norite and Hbl Gabbronorite
Barber Pluton
Ol-Hbl Gabbronorite
Type I Metagabbro
Type II Metagabbro

Figure 8.

lower core is composed exclusively of gabbronorite. Hornblende norite and hornblende gabbronorite surrounded these two areas, with hornblende gabbronorite generally grading outward into hornblende norite at the margins.

The Barber intrusion consists mainly of Type II metagabbro with localized occurrences of less altered Type I metagabbro and relict olivine-hornblende gabbronorite (Figure 8). Type II metagabbro surrounds the entire Bear Poplar intrusion and is the most abundant lithologic type of this mafic complex. Sampling to the north and east of the study area reveals that the Type II metagabbro is also present, although outcrops are scarce.

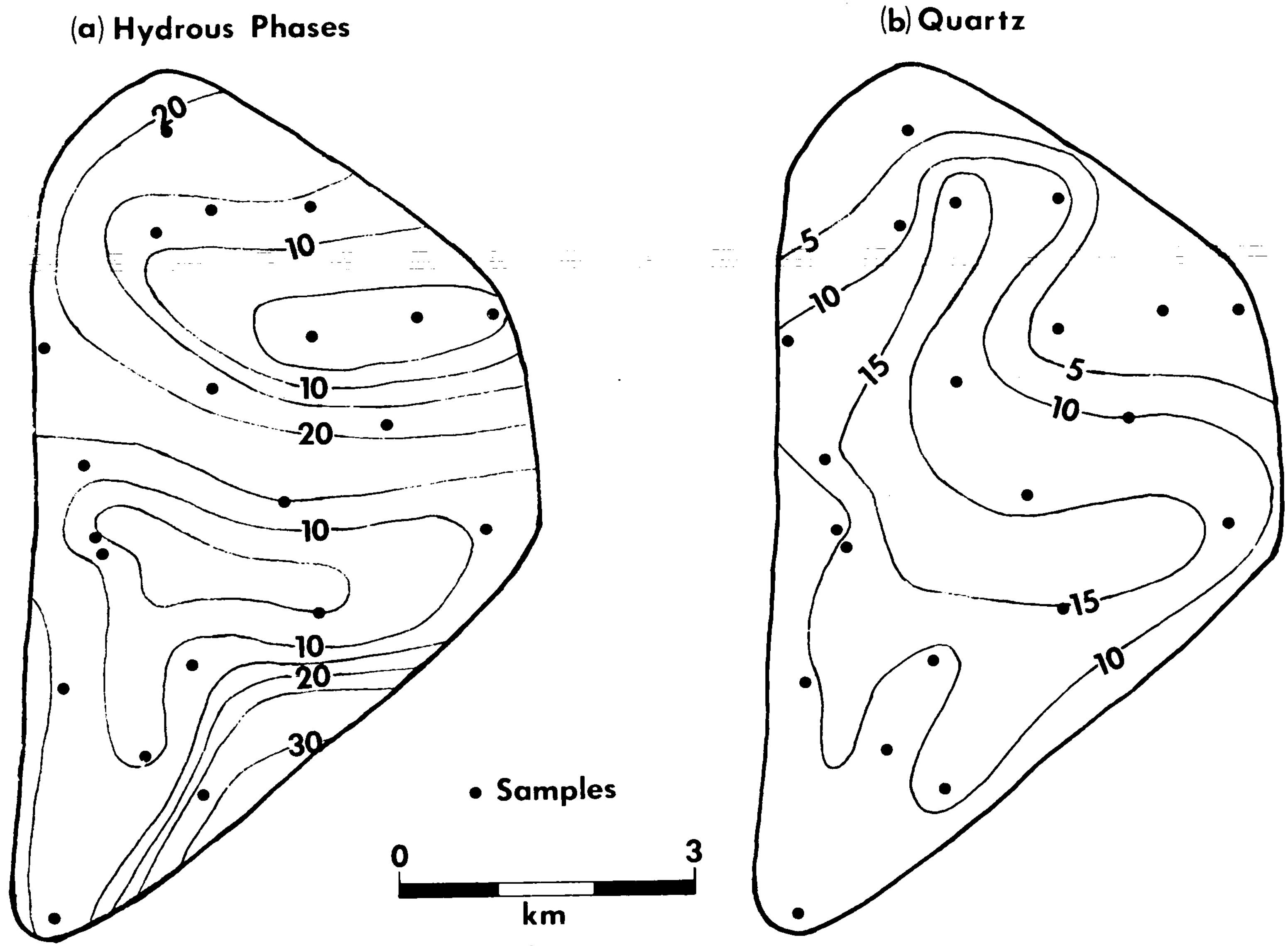
The complete list of modal analyses is given in Tables A-1 and A-2, Appendix. Systematic areal variations in modal mineralogy are shown in Figure 9a and 9b for the Bear Poplar intrusion. Hydrous phases (hornblende, biotite, and very minor chlorite) increase outward from the norite and gabbronorite cores, shown by contours in Figure 9a. This increase is present in both modal hornblende and modal biotite when plotted separately or together as in Figure 9a. This trend is compared with the increase in modal quartz content of the samples toward the center of the body (Figure 9b). Most intrusions crystallize from the exterior inwards toward the center. It seems likely that the trend in modal quartz contents reflects differentiation. Water content, hence hydrous minerals, normally increase with progressive differentiation, but hydrous minerals are inversely correlated with quartz in this intrusion. The pattern shown by the hydrous phases may be due to the intake of water from the country rocks at the margins of the intrusion, and not to differentiation.

Figure 9. Modal Variations in the Bear Poplar Pluton.

Lines represent contours in volume percent.

a. Hydrous phases (hornblende + biotite + minor chlorite) increase outward from the norite and gabbronorite cores, possibly in response to the intake of water from the country rocks.

b. Quartz content increases inwards as a result of magma fractionation.



(a) Hydrous Phases
20
10
10
20
10
10
20
30
(b) Quartz
5
10
15
5
10
15
10
• Samples
0
3
km

Figure 9.

In the Barber pluton, few systematic petrologic trends exist. Pyroxenes are only abundant in three samples from an area around the town of Barber. In the Type II metagabbros that surround this area, pyroxenes are present only in a very altered state or they have been completely replaced by hornblende. Epidote-rich samples are common around the town of Barber and also northwest of the community of Mill Bridge. These variations are probably due to localized increases in the amount of water in these particular areas (Hermes, 1968). With increased metamorphism, these water-rich areas were able to react and saussuritization of plagioclase occurred to form epidote. Modal epidote and modal plagioclase appear to vary antithetically in the Type II metagabbros (Table A-2, Appendix).

V. GEOCHEMISTRY

Whole rock chemistry for 15 samples from the Bear Poplar and Barber intrusions is shown in Table A-9 (Appendix). The bulk chemistry for both plutons is also plotted on the AFM diagram in Figure 10. This plot demonstrates an increase in the alkalis and total Fe from the Barber samples to the Bear Poplar samples. Type II metagabbros from the Barber intrusion display a high Fe content due to their high hornblende contents.

A diagram of alkalis versus silica reveals that both intrusions plot approximately along the boundary between high alumina and tholeiitic basalt fields (Figure 11). The Bear Poplar pluton, with its high silica content, plots also within the basaltic andesite range, while the Barber samples are within the basalt range (Figure 11). High alumina basalt typically has Al_2O_3 contents greater than 17% and TiO_2 contents around 1% (Carmichael et al., 1974), characteristics found in both intrusions. This type of basalt is often associated with andesites. Basaltic andesites are typically found in island arcs and at Andean margins (Ewart, 1976; Fairbrothers et al., 1978; Ringwood, 1974; Whitford et al., 1979). The Bear Poplar samples are all similar in composition to island arc lavas of basaltic andesite composition (Ewart, 1976) and basaltic andesite from the tholeiitic series lavas of Java (Whitford et al., 1979). Most island arc lavas have TiO_2 contents less than 1.2% (Whitford et al., 1979), as do rocks of the Bear Poplar pluton.

Plotting the concentrations of the major element oxides using a discriminant analysis devised by Pearce (1976) enables basalts from

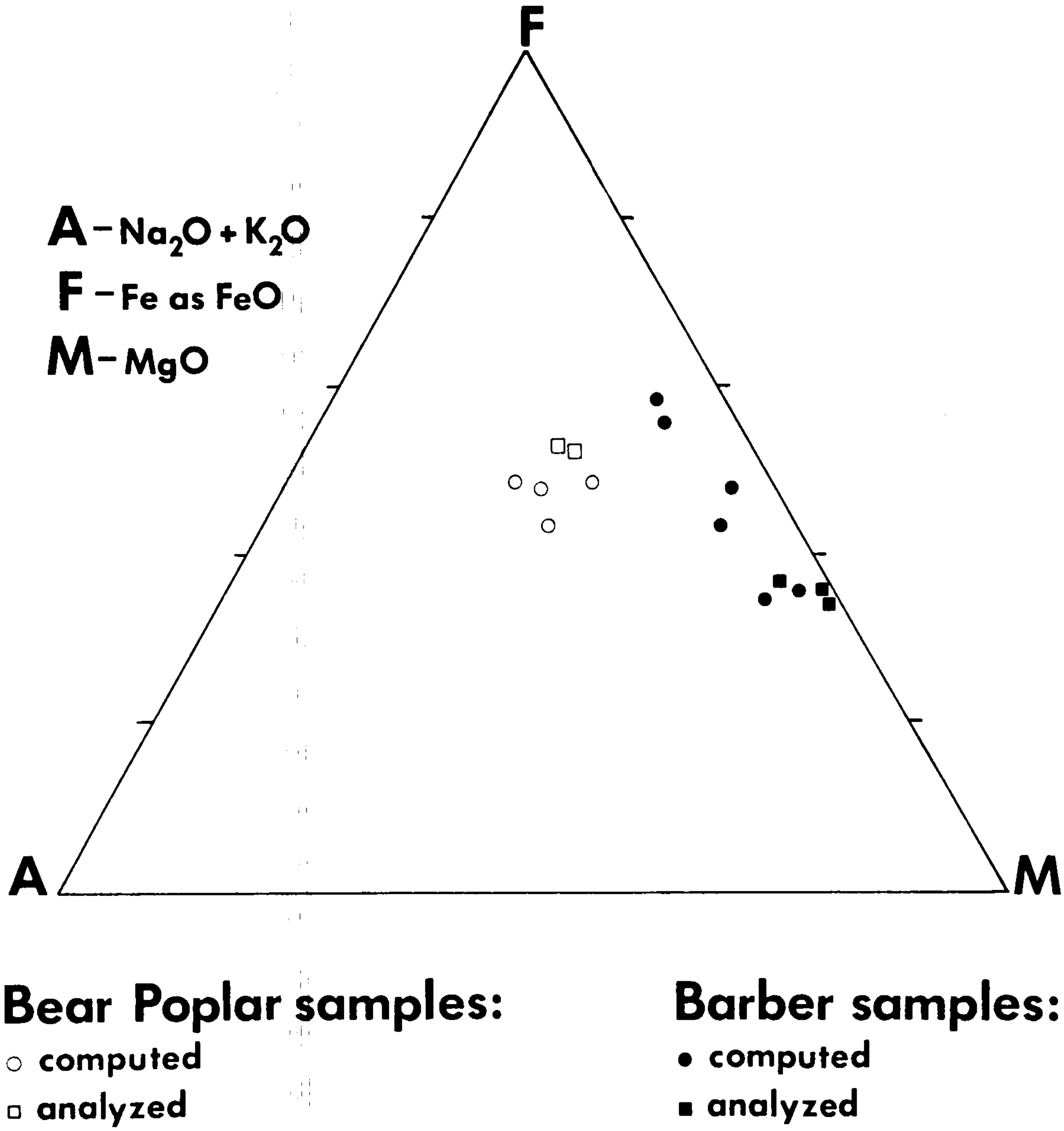


Figure 10. AFM Diagram for Bear Poplar and Barber Samples.

The Bear Poplar samples (open symbols) have higher contents of alkalis and total Fe than the Barber samples (filled symbols). Total Fe is reported as FeO.

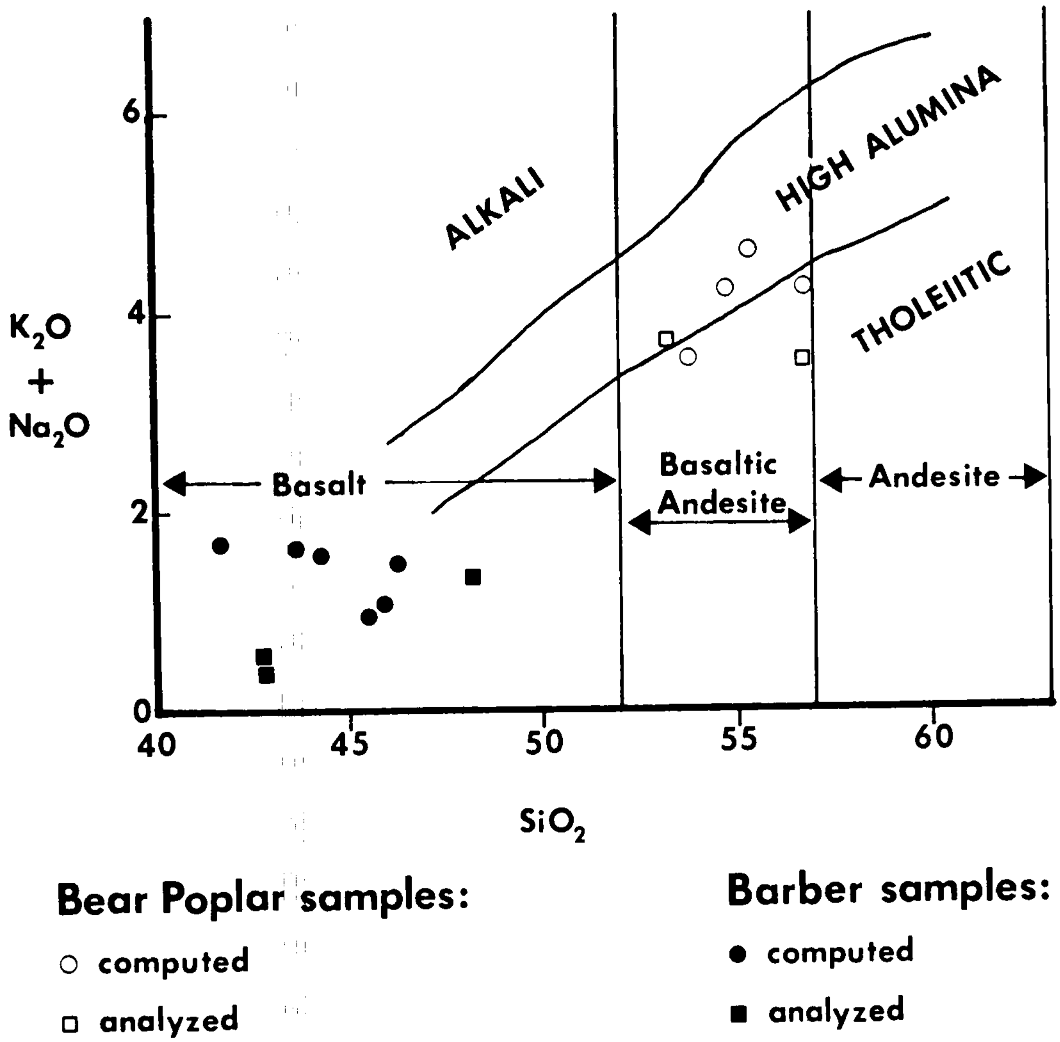


Figure 11. Alkalis and Silica Variation in Bear Poplar and Barber Samples.

Symbols as in Figure 10.

Bear Poplar samples have higher amounts of alkalis and silica than Barber samples. Basaltic andesite compositions of Bear Poplar rocks differ from the basaltic compositions of Barber samples (modified from Kuno, 1966, and Whitford et al., 1979).

different tectonic settings to be distinguished (Figure 12). Pearce considered samples of basalts with compositions of CaO + MgO between 12 and 20%. Samples that meet this screening requirement are shown with open or filled "star" symbols in Figure 12. The data show that samples from both intrusions plot within the island arc tholeiite and calc-alkali basalt field (Figure 12a). Further discrimination of the functions shows that the samples plot within the calc-alkali basalt field and near the island arc tholeiite region (Figure 12b). Both magma types are associated with converging plate margins, either with oceanic crust (low-K tholeiites) or with continental crust (low-K tholeiites and calc-alkali basalts). The data suggest that the Bear Poplar pluton may be an eroded island arc remnant associated with intrusion through continental crust. Its high Al_2O_3 and SiO_2 and low TiO_2 contents are very similar to basaltic andesite compositions. The Barber samples lie within the basaltic field and may reflect a less differentiated magma within the same tectonic framework.

Trace element data were obtained for three Barber samples and two Bear Poplar samples by Price (1969) for the following elements: Cu, Pb, Zn, Li, V, Cr, Co, Ni, Sr, Zr, and Rb (Table A-10, Appendix). The Barber pluton has significantly higher contents of Cr, Co, and Ni. The Bear Poplar intrusion is enriched in Cu, Li, V, Sr, Zr, and Rb. These trends can be explained by fractionation processes, such as those documented in the Palisades sill and the Skaergaard intrusion (Carmichael et al., 1974). Cr is removed early, probably by pyroxenes or spinel, while Co and Ni are removed by olivine in the Barber intrusion. Sr is removed by plagioclase with moderate anorthite contents, or else

Figure 12. Diagrams for Discriminating Between Rocks from Various Tectonic Settings.

Source: Pearce, 1976.

Samples meeting the screen (CaO + MgO = 12-20%) are plotted in open (Bear Poplar) or filled (Barber) stars.

a. Plot of first two discriminant functions. Samples plot within the low-K tholeiite (LKT) and calc-alkali basalt (CAB) fields.

b. Plot of second and third functions for distinguishing calc-alkali basalts from low-K tholeiites. Starred Bear Poplar samples plot in calc-alkali basalt (CAB) field; Barber samples plot in low-K tholeiite (LKT) area. Other fields are CON (continental basalts), OFB (ocean floor basalts), OIB (ocean island basalts), and SHO (shoshonites).

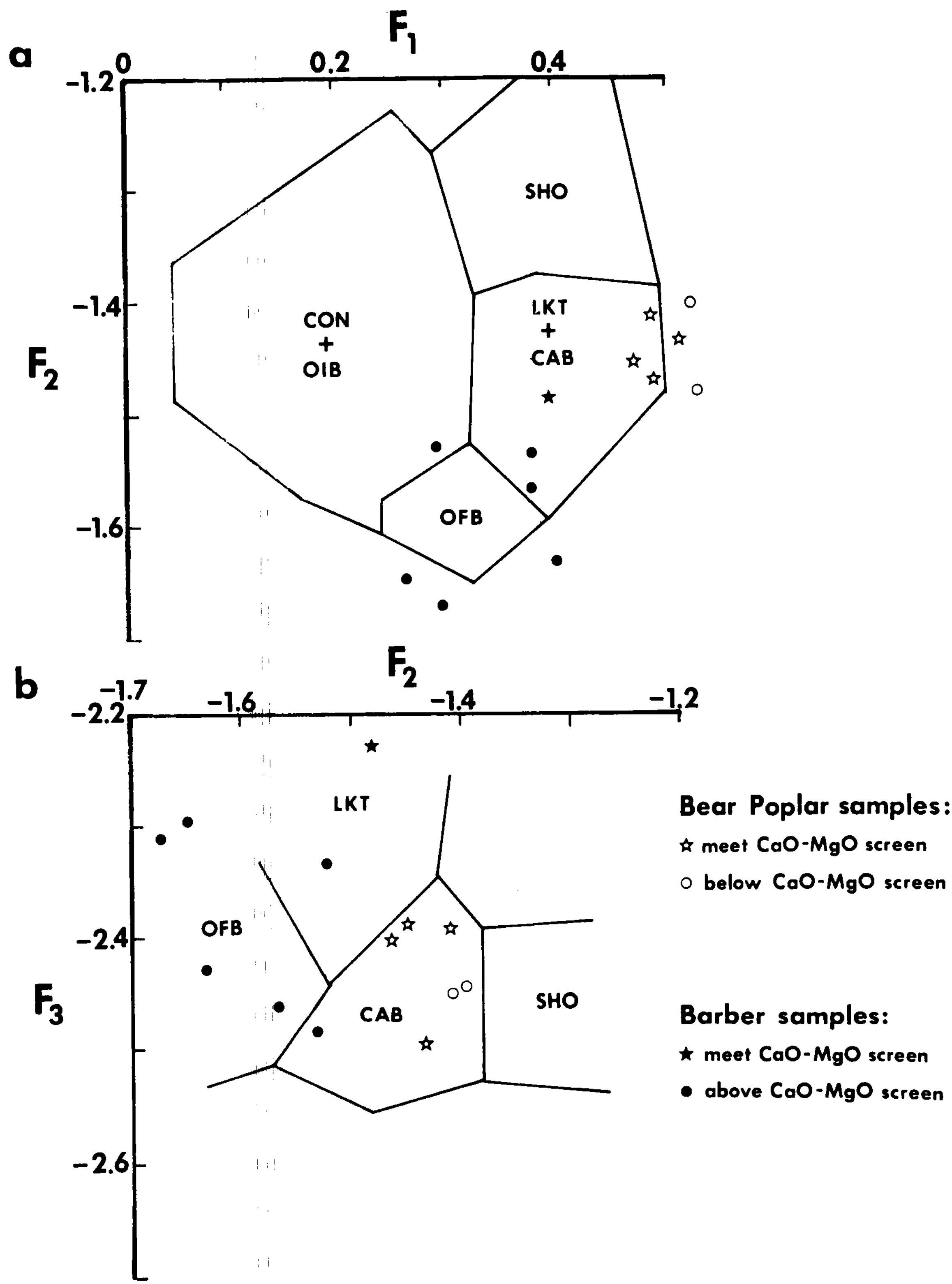

a
F_1
0
0.2
0.4
-1.2
-1.4
-1.6
F_2
SHO
CON
+
OIB
LKT
+
CAB
OFB
b
F_2
-1.7
-1.6
-1.4
-1.2
-2.2
-2.4
-2.6
F_3
LKT
OFB
CAB
SHO
Bear Poplar samples:
☆ meet CaO-MgO screen
○ below CaO-MgO screen
Barber samples:
★ meet CaO-MgO screen
● above CaO-MgO screen

Figure 12.

fractionates into residual liquids. V is commonly removed late from the melt by magnetite. The other elements are incompatible and build up in the residual liquids, especially Zr, Rb, Cu, and Li (Carmichael et al., 1974). The Barber intrusion is enriched in those elements that are removed from the melt early, often by cumulate phases such as olivine and pyroxene. The Bear Poplar intrusion has high concentrations of those incompatible elements that concentrate in residual liquids. This indicates that the parental magma for the Bear Poplar pluton was more highly differentiated than that of the Barber pluton.

VI. SUMMARY OF DIFFERENCES BETWEEN THE BEAR POPLAR AND BARBER INTRUSIONS

The two intrusions have significant differences in their mineralogy, textures, areal petrologic variations, and geochemistry.

Mineralogy

Differences in mineralogy include:

1. All the Bear Poplar samples have quartz present; some have as much as 17% modal quartz. Fewer samples in the Barber intrusion have quartz present. If present, it is usually less than 3% of the total assemblage and may have formed during metamorphism.

2. Olivine is only present in the Barber intrusion. Pseudomorphs of olivine and coronas occur in the metagabbros.

3. Plagioclase is more abundant in the Bear Poplar samples, forming distinctly zoned grains that are clouded with many minute inclusions. The anorthite contents of all analyzed grains in this pluton range from An_{42} to An_{69} (Figure 13). Most samples display wide ranges in their feldspar composition due to zonation.

Individual plagioclase grains in the Barber intrusions are more homogenous in composition, have fewer inclusions, and are thus optically clearer than the Bear Poplar samples. The measured anorthite contents of all grains range from An_{57} to An_{97} (Figure 13). This wide range of compositions occurs because metamorphism has produced more sodic plagioclase in highly altered samples. The range in Figure 13 thus includes both igneous and metamorphic plagioclase.

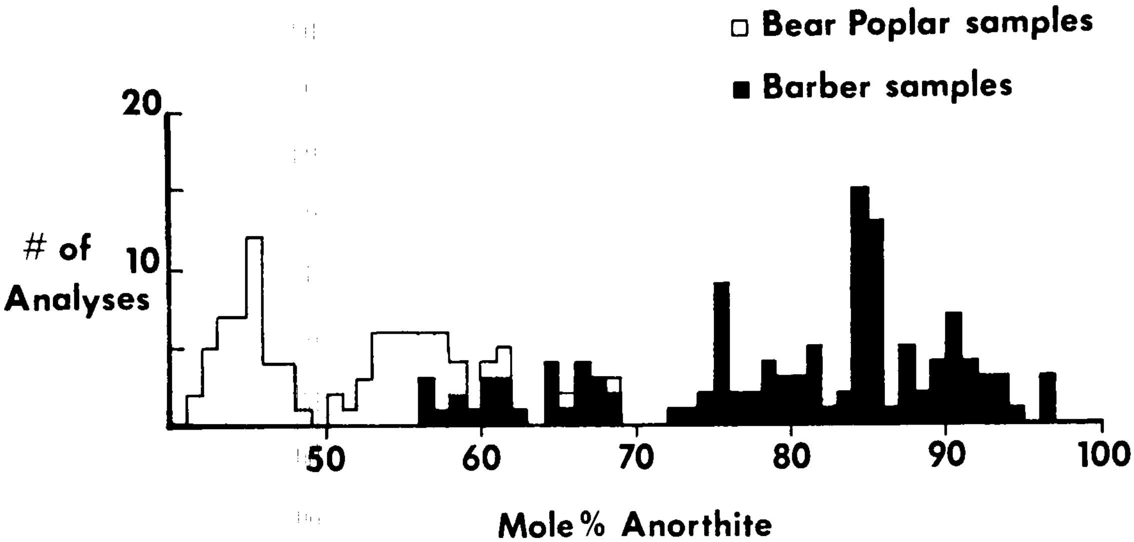


Figure 13. Histogram of Plagioclase Analyses.

Bear Poplar samples have plagioclases with lower anorthite contents but wider ranges in individual grains due to zonation. Barber samples have plagioclases that are more calcic and less zoned. Barber samples exhibit a wider range in compositions because metamorphism has produced more sodic feldspars in highly altered rocks.

4. Orthopyroxene and clinopyroxene are present in all Bear Poplar samples, but are only present in one third of the Barber samples. Pyroxenes in the Bear Poplar pluton have higher Fe contents and lower Mg contents than Barber samples (Figure 4, page 19). As the FeO/FeO+MgO contents increase in the pyroxenes, the average anorthite contents decrease, presumably reflecting differentiation (Figure 14). The Bear Poplar samples all show higher pyroxene FeO/FeO+MgO ratios relative to the Barber samples. As the FeO/FeO+Mg contents increase in orthopyroxene and clinopyroxene, the modal percents of quartz, biotite, and plagioclase in the Bear Poplar samples increase (Figure 15). The Bear Poplar pluton is enriched in all three phases. The Ca content in clinopyroxene is generally lower in Bear Poplar samples (Table A-4, Appendix). The Al contents are significantly less in the Bear Poplar orthopyroxenes than in Barber orthopyroxenes (Table A-3, Appendix). The presence of Al in the pyroxene analyses suggests that Na may be present in the formation of the jadeite molecule. Omission of Na from the analyses, however, does not allow quantitation of the jadeite molecule. The Mn contents are lower in the Barber pyroxenes (Tables A-3 and A-4, Appendix).

5. Hornblende is present in samples from both intrusions, but it is more Fe- and K-rich in the Bear Poplar rocks (Figure 4, page 19, and Table A-5, Appendix). The Bear Poplar samples generally have lower MgO contents and can be classified as edenitic hornblende, while the Barber samples have higher MgO contents and range from pargasitic hornblende in the olivine-hornblende gabbronorites to magnesic-hornblende in the Type II metagabbros (Leake, 1978).

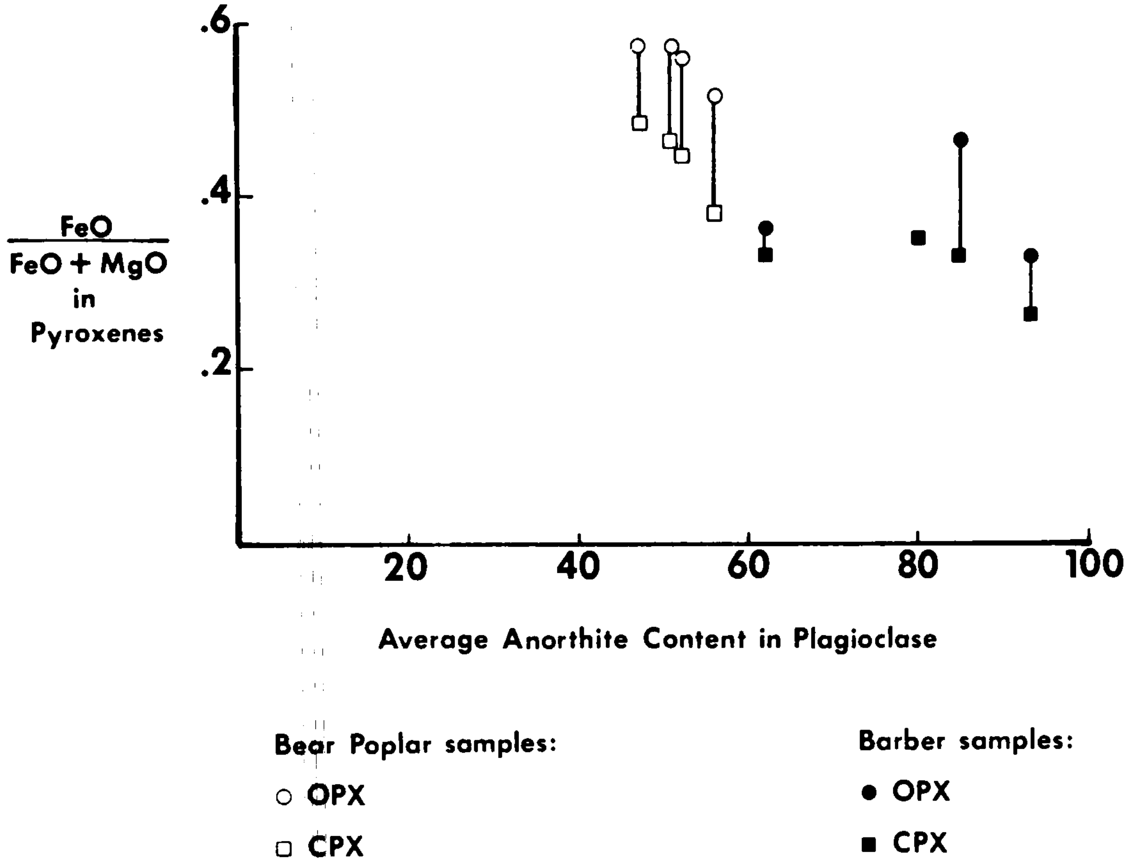


Figure 14. Variation in FeO/FeO+MgO Contents of Pyroxenes and the Average Anorthite Content of Plagioclases in Analyzed Samples.

Bear Poplar samples (open symbols) have higher FeO/FeO+MgO contents and lower average anorthite contents than Barber samples (filled symbols). Tie lines connect coexisting orthopyroxenes and clinopyroxenes.

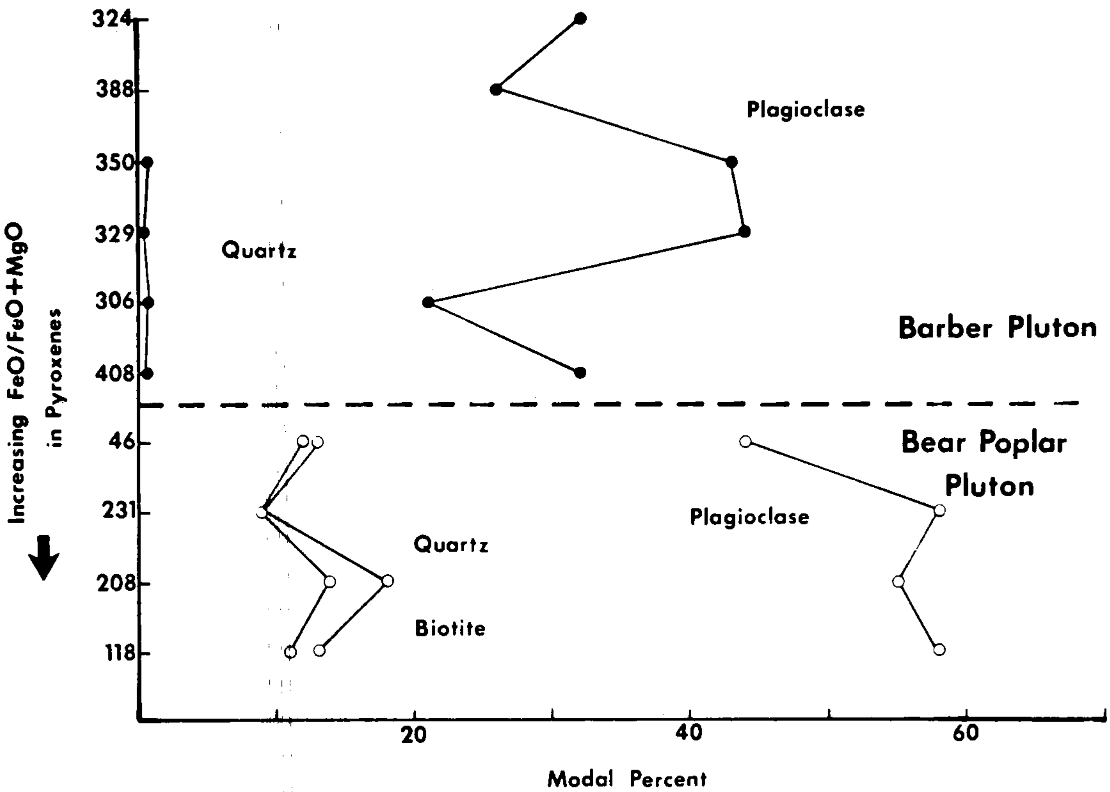


Figure 15. Rocks Plotted in Order of Increasing FeO/FeO+MgO in Pyroxenes (an Approximate Index of Differentiation) versus Modal Contents of Selected Minerals.

Bear Poplar samples (open symbols) have higher contents of plagioclase, quartz, and biotite relative to Barber samples (filled symbols). Tie lines connect samples from the same intrusion.

6. Biotite is a ubiquitous accessory in the Bear Poplar samples, but is rare in the Barber samples (Figure 15 and Tables A-1 and A-2, Appendix).

7. Chlorite and epidote are secondary minerals that are commonly found only in the Barber pluton.

Textures

Rocks of the Bear Poplar intrusion display primary igneous textures that include hypidiomorphic, cumulate, and poikilitic. Pronounced igneous layering is common. Symplectic relationships and alteration to the grains are rare.

The Barber intrusion exhibits textures that range from relict hypidiomorphic igneous textures to the more common metamorphic-related granoblastic and foliated textures. Symplectic relationships, the formation of coronas, and mineral alteration are all common in this unit. The formation of coronas in the olivine-hornblende gabbronorites is characteristic of reactions formed under metamorphic conditions (Murthy, 1958; Reynolds and Frederickson, 1962).

Areal Petrologic Variations

Distinct and systematic petrologic trends are present in the Bear Poplar intrusion that reflect magmatic crystallization. The Barber intrusion lacks any systematic trends, but shows localized variations in mineralogy based on the effects of metamorphism and the availability of water for reactions.

Geochemistry

The Bear Poplar pluton's geochemical profile features higher contents of alkalis and silica than the Barber pluton. The silica-saturated nature of the Bear Poplar intrusion distinguishes it as basaltic andesite in composition, contrasted to the basaltic composition of the Barber intrusion. Discrimination of the major elements present identifies the intrusions as being related to island arc tholeiites and calc-alkali basalts which are associated with continental margin tectonics. Trends in the trace element data show that the Barber pluton has high contents of elements removed early from basaltic melts. The Bear Poplar pluton has higher concentrations of elements that are normally present in the residual liquids and are thus more fractionated.

VII. PETROGENESIS

Parent Magmas

Based on the chemical, textural, and petrologic differences cited, the writer concluded that the two intrusions crystallized from two different magmas. The Bear Poplar pluton crystallized from magma with sufficient silica saturation to characterize it as a basaltic andesite. The formation of such a magma may be related to the fractionation of tholeiitic basalt towards basaltic andesite and andesite (Ringwood, 1974). A tholeiitic differentiation trend, characterized by Fe enrichment, is commonly displayed. The Bear Poplar intrusion features such an Fe enriched trend based on its variations in mineral chemistry and bulk chemistry. Silica enrichment in the Bear Poplar intrusion may be related to increasing fractionation. Similar noritic intrusions in the Coast Ranges batholith of California apparently formed by assimilation of granitic country rocks (Walawender et al., 1979; Walawender and Smith, 1980), but quartz in the Bear Poplar pluton increases toward the center of the intrusion, in contrast to plutons of the Coast Ranges.

The Barber intrusion formed from transitional high-alumina to tholeiitic basalt that was silica undersaturated. Its olivine-normative character distinguishes it as a less differentiated basaltic magma that was more Mg-rich than the Bear Poplar intrusion. The sporatic occurrences of olivine in this unit reflect areas of the pluton that have experienced little metamorphism. The abundance of hornblende-, plagioclase-, and epidote-rich lithologies with olivine pseudomorphs reflect the metamorphism that has occurred throughout most of the body.

The random occurrence of quartz in the Type II metagabbros is attributed to metamorphism (Winkler, 1976).

Crystallization and Differentiation

Textural criteria can aid in establishing the sequence of crystallization in the Bear Poplar pluton. Subhedral-to-euhedral plagioclase and opaque minerals crystallized early, followed by the precipitation of prismatic orthopyroxene and clinopyroxene grains from the melt. The magma probably differentiated by fractionation of some or all of these phases. Late-stage crystallization of intercumulus liquids produced poikilitic hornblende and biotite along with interstitial quartz. Progressive differentiation in the intrusion led to increased FeO/FeO+MgO contents and lower anorthite contents (Figure 14).

Early crystallization in the Barber intrusion produced subhedral plagioclase, olivine, and probably opaque minerals. Orthopyroxene and clinopyroxene crystallized from the melt next, often replacing or rimming olivine. Continued crystallization of orthopyroxene along with hornblende and biotite produced poikilitic grains that surrounded the earlier formed phases. Metamorphism of the unit produced reaction coronas around the olivine and formed epidote, chlorite, sericite, and additional amphibole.

Relative Timing of Emplacement

The geologic history and relative timing of emplacement for the two intrusions is based on field evidence, textural relations, and previous work done in the Piedmont. Plutonic activity occurred in the

Piedmont between 595 and 300 mya (Fullagar, 1971). Metamorphic events occurred through a time span that overlapped the igneous activity with the last major metamorphic event occurring between 400 and 350 mya (Tull, 1980) or around 350 mya (Butler and Ragland, 1969) to 300 mya (Fullagar, 1971).

The geologic history of the study area can be summarized as follows:

1. During the early Paleozoic, granite was intruded in the western part of the study area. Subsequent metamorphic events produced the metagranite present today (Butler and Ragland, 1969; Stuckey and Conrad, 1958).

2. At the same time or shortly after, the Barber intrusion was emplaced as an olivine-bearing gabbroic intrusion. After the coarse-grained phases were emplaced, late-stage, fine-grained gabbroic rocks crosscut the unit. A date of approximately 500 mya has been assumed for this pluton (Fullagar, 1971), although no radiometric evidence for this date is available. Middle Paleozoic metamorphic events produced foliation in some samples. Alteration stabilized the mineralogy to hornblende- and plagioclase-rich lithologies.

3. The Churchland and Landis granites were intruded to the northeast and south of the study area, respectively. They were emplaced around 300 mya (Butler and Fullagar, 1978; Fullagar, 1971). Field evidence in a quarry near the town of Woodleaf reveals xenoliths of Type II metagabbro included within a large granitic intrusion (possibly a part of the Churchland granite). This suggests that the Barber pluton may be older than the Churchland granite.

4. The Bear Poplar intrusion was emplaced within the Barber pluton after the last metamorphic event occurred. This metamorphic event probably occurred around 350 mya. After the medium-to-coarse grained phases crystallized, fine-grained gabbroic phases crosscut the pluton. Field evidence for several similar gabbroic intrusions in the Piedmont suggest that they are younger than the surrounding post-metamorphic granites (McSween, 1970; Waskom and Butler, 1971). Since the Bear Pluton does not crosscut a post-metamorphic granite directly, no conclusive evidence exists for its relative time of emplacement.

5. Mesozoic diabase dikes were emplaced throughout the study area (Ragland et al., 1968).

Comparison with Other Gabbro-Metagabbro Complexes

The mafic complex formed by the Bear Poplar and Barber intrusions differs significantly from other gabbro-metagabbro complexes in the area. Specific differences distinguish this complex from the Mecklenburg gabbro-metagabbro complex, North Carolina (Hermes, 1968) and the gabbro-metagabbro bodies in York and Chester Counties in South Carolina (McSween, 1980).

Differences between the Bear Poplar and Barber plutons and the above units include:

1. In the gabbroic bodies:

a. The Bear Poplar pluton does not contain olivine, unlike the other gabbroic bodies. Orthopyroxene is the dominant pyroxene in the Bear Poplar pluton, reflecting the high silica contents. Quartz is present in all the Bear Poplar samples, often in amounts greater than 10%. The other units have little or no quartz.

b. The Bear Poplar rocks contain high Fe contents, and ferromagnesium minerals have significantly higher FeO/FeO+MgO ratios than corresponding phases in other gabbros.

c. Plagioclase appears to be more strongly zoned in Bear Poplar samples than in samples of the other gabbros.

d. The rocks of the Bear Poplar intrusion are basaltic andesite in composition, in contrast to the basaltic compositions of the other plutons.

2. In the metagabbro bodies:

a. Relict olivine-bearing rocks and olivine pseudomorphs in more highly altered rocks are present in the Barber pluton. Although the metagabbro in the other bodies was assumed to have been derived from an olivine gabbro (Hermes, 1968; McSween, 1980), no evidence for this was noted in the other metagabbro units.

b. Plagioclase is more calcic in the Barber metagabbros than the other units.

c. The chemical composition of the Barber metagabbro is basaltic and differs from the Bear Poplar gabbro. These two plutons crystallized from different parent magmas, unlike the other metagabbro units that are chemically similar to their related gabbroic bodies.

Relation to Tectonic Setting

It has been suggested that the linear chain of gabbroic plutons that stretches from North Carolina to Georgia, which includes the Bear Poplar and Barber intrusions, may be related to subduction zone activity, possibly at a continental margin (McSween, 1980). Geochemical evidence suggests that the Bear Poplar and Barber plutons are related to a fractionation trend ranging from basalt to basaltic andesite. Basaltic andesites are typically found with island arc tholeiites (Ewart, 1976) and tholeiitic series lavas from continental margins (Whitford et al., 1979).

Using the method of Pearce (1976), it is possible to classify the Bear Poplar intrusion as a calc-alkali basalt (Figure 12b, page 44). These basalts are typically associated with magmas that intrude continental crust at converging plate margins (Pearce, 1976). The formation of such a system is consistent with current tectonic models for the eastern North American continent involving subduction and collision of the African Plate with the North American Plate. The Taconic Orogeny was characterized by the subduction of the African Plate under the North American Plate around 500 mya. The Barber intrusion may be an igneous pluton intruded in the area at that time. Collision of the plates during the Acadian Orogeny (Late Devonian) followed by more igneous activity in the Allegheny Orogeny (Late Pennsylvanian and/or Permian) may have resulted in the emplacement of the Bear Poplar pluton within the Barber intrusion. The Bear Poplar intrusion is the first recognized pluton within this chain to display several of the distinctive features for this tectonic setting (e.g., basaltic andesite composition, multiple intrusive complex, and distinctive fractionation trends) to support the idea that this chain of gabbros is related to continental margin tectonics or island arc formation.

LIST OF REFERENCES

LIST OF REFERENCES

Albee, A. L., and Ray, L., 1970, Correction of electron probe microanalysis of silicates, oxides, carbonates, phosphates, and sulfates: Analyt. Chem., v. 42, pp. 1408-1414.

Bence, A. E., and Albee, L. A., 1968, Empirical correction factors of the electron microanalysis of silicates and oxides: Jour. Geol., v. 76, pp. 382-403.

Butler, J. R., 1966, Geology and mineral resources of York County, South Carolina: S. C. State Devel. Board, Bull. 33.

Butler, J. R., and Fullagar, P. D., 1978, Petrochemical and geochronological studies of plutonic rocks in the Southern Appalachians: III. Leucocratic adamellites of the Charlotte belt near Salisbury, North Carolina: Geol. Soc. Am. Bull., v. 89, pp. 460-466.

Butler, J. R., and Ragland, P. C., 1969, A petrochemical survey of plutonic intrusions in the Piedmont, Southeastern Appalachians, U.S.A.: Contr. Mineral. Petrol., v. 24, pp. 164-190.

Cabaup, J., 1969, Origin and differentiation of the gabbro in the Concord ring dike, North Carolina Piedmont: Unpublished M.S. thesis, Univ. of North Carolina at Chapel Hill.

Carmichael, I. S. E., Turner, F. J., and Verhoogen, J., 1974, Igneous petrology: McGraw-Hill Book Co., New York, 737 p.

Chalcraft, R. G., 1970, Petrography and geophysics of the Rock Hill gabbro pluton, York County, South Carolina: Southeastern Geol., v. 11., no. 3, pp. 153-171.

Constantino-Herrera, S. E., 1971, Geology of the Cleveland gabbro, Rowan County, North Carolina: Unpublished M.S. thesis, Univ. of North Carolina at Chapel Hill.

Deer, W. A., Howie, R. A., and Zussman, J., 1962, Rock forming minerals, vol. 2 chain silicates: Longman, Green, and Co. Ltd., London, 379 p.

Ewart, A., 1976, Mineralogy and chemistry of modern orogenic lavas—some statistics and implications: Earth Planet. Sci. Lett., v. 31, pp. 417-432.

Fairbrothers, G. E., Carr, M. J., and Mayfield, D. G., 1978, Temporal magmatic variation at Boqueron volcano, El Savador: Contr. Mineral. Petrol., v. 67, pp. 1-9.

Fullagar, P. D., 1971, Age and origin of plutonic intrusions in the Piedmont of the Southeastern Appalachians: Geol. Soc. Am. Bull., v. 82, pp. 2845-2862.

Glover, L., III, and Sinha, A. K., 1973, The Virgilina deformation, a late Precambrian to early Cambrian (?) orogenic event in the central Piedmont of Virginia and North Carolina: Am. Jour. Sci., Cooper vol. 273-A, pp. 234-251.

Hadley, J. B., 1973, Igneous rocks of the Oxford area, Granville County, North Carolina: Am. Jour. Sci., v. 273-A, pp. 217-233.

Hatcher, R. D., and Zietz, I., 1980, Tectonic implications of regional aeromagnetic and gravity data from the Southern Appalachians: Proc. The Caledonides in the U.S.A., VPI and SU, Mem. 2, pp. 235-244.

Hermes, O. D., 1968, Petrology of the Mecklenburg gabbro-metagabbro complex, North Carolina: Contr. Mineral. Petrol., v. 18, pp. 270-294.

Hyndman, D. W., 1972, Petrology of igneous and metamorphic rocks: Mc-Graw-Hill Book Co., New York, 533 p.

Kuno, H., 1966, Lateral variation of basalt magma type across continental margins and island arcs: Bull. Volcanol., v. 29, pp. 195-222.

Leake, B. E., 1978, Nomenclature of amphiboles: Am. Mineral., v. 63, pp. 1023-1052.

Mathews, V., III, 1969, The Gladesville norite and its relationship to similar mafic plutons in the Georgia Piedmont (abstr.): Geol. Soc. Am. Abstracts with Programs, v. 4, no. 50.

McCauley, J. R., 1961, Relationship between the Carolina Slate belt and the Charlotte belt in Newberry County, South Carolina: S. C. State Devel. Board, Geol. Notes, v. 5, pp. 59-71.

McSween, H. Y., Jr., 1970, Petrology of Charlotte and Kings Mountain belt rocks in northern Greenwood County, South Carolina: S. C. State Devel. Board, Geol. Notes, v. 14, pp. 57-84.

McSween, H. Y., Jr., 1980, Petrogenesis of the Mecklenburg-York-Chester mafic complex, Southern Appalachian Piedmont: submitted to Am. Jour. Sci., August 1980.

McSween, H. Y., Jr., and Nystrom, P. G., Jr., 1979, Mineralogy and petrology of the Dutchman's Creek gabbroic intrusion, South Carolina: Am. Mineral., v. 64, pp. 531-545.

Medlin, J. H., 1969, Petrology of two mafic igneous complexes in the South Carolina Piedmont (abstr.): Geol. Soc. Am. Abstracts with Programs, v. 4, no. 52.

Medlin, J. H., Thornton, C. P., and Gold, D. P., 1972, Petrology of mafic igneous complexes in the Southeastern U. S. Piedmont: II. The Buffalo mafic igneous complex, Union County, South Carolina: Southeastern Geol., v. 14, pp. 73-106.

Morgan, B. A., 1963, A gravity survey of a ring-dike near Concord, North Carolina: Unpublished M.S. thesis, Univ. of North Carolina at Chapel Hill.

Murthy, M. V. N., 1958, Coronites from India and their bearing on the origin of coronas: Geol. Soc. Am. Bull., v. 69, pp. 23-38.

Myers, C. W., 1968, Geology of the Presley Mill gabbro, Putnam County, Georgia: Unpublished M.S. thesis, Univ. of Georgia.

Neilson, M. J., and Brockman, G. F., 1977, The error associated with point counting: Am. Mineral., v. 62, pp. 1238-1244.

Pearce, J. A., 1976, Statistical analysis of major element patterns in basalts: Jour. Petrol., v. 17, pt. 1, pp. 15-43.

Price, V., Jr., 1969, Distribution of trace elements in plutonic rocks of the southeastern Piedmont: Unpublished Ph.D. dissertation, Univ. of North Carolina at Chapel Hill.

Ragland, P. C., Rogers, J. J. W., and Justus, P. S., 1968, Origin and differentiation of Triassic dolerite magmas, North Carolina, U.S.A.: Contr. Mineral. Petrol., v. 20, pp. 57-80.

Reynolds, R. C., Jr., and Frederickson, A. F., 1962, Corona development in Norwegian hyperites and its bearing on the metamorphic facies concept: Geol. Soc. Am. Bull., v. 73, pp. 59-72.

Ringwood, A. E., 1974, The petrological evolution of island arc systems: Jour. Geol. Soc. London, v. 130, pp. 183-204.

Streckeisen, A. L., 1973, Plutonic rocks—classification and nomenclature: Geotimes, v. 18, pp. 43-63.

Stuckey, J. L., and Conrad, S. G., 1958, Explanatory text for the geologic map of North Carolina: N. C. Dept. of Conservation and Development, Div. of Min. Resources, Bull. no. 71, Raleigh, North Carolina.

Tull, J. F., 1980, Overview of the sequence and timing of deformational events in the Southern Appalachians: Evidence from the crystalline rocks North Carolina to Alabama: Proc. The Caledonides in the U.S.A., VPI and SU, Mem. 2, pp. 167-177.

Van Der Plas, L., and Tobi, A. C., 1965, A chart for judging the reliability of point counting results: Am. Jour. Sci., v. 263, pp. 87-90.

Walawender, M. J., Hoppler, H., Smith, T. E., and Riddle, C., 1979, Trace element evidence for contamination in a gabbronorite-quartz diorite sequence in the Peninsular Ranges batholith: Jour. Geol., v. 87, pp. 87-97.

Walawender, M. J., and Smith, T. E., 1980, Geochemical and petrologic evolution of the basic plutons of the Peninsular Ranges batholith, Southern California: Jour. Geol., v. 88, pp. 233-242.

Waskom, J. D., and Butler, J. R., 1971, Geology and gravity of the Lilesville granite batholith, North Carolina: Geol. Soc. Am. Bull., v. 82, pp. 2827-2844.

Whitford, D. J., Nicholls, I. A., and Taylor, S. R., 1979, Spatial variations in the geochemistry of Quaternary lavas across the Sundra Arc in Java and Bali: Contr. Mineral. Petrol., v. 70, pp. 341-356.

Winkler, H. G. F., 1976, Petrogenesis of metamorphic rocks, Springer-Verlag, New York, 334 p.

APPENDIX

Table A-1. Modal Variations: Bear Poplar Intrusion

	PLG	HBL	OPX	CPX	BIO	QTZ	OPA	HEM	APA	CHL
BP10	62.4	2.9	21.3	6.3	0.2	0.2	6.3	0.2	0.1	0.1
BP12	56.9	2.9	13.1	7.1	4.8	12.3	2.8		0.1	
BP45	57.5	8.4	13.3	5.2	5.5	8.5	1.6			
BP46	44.0	18.4	9.2	2.4	11.0	11.6	3.2		0.2	
BP67	54.2	9.4	12.1	4.2	3.1	14.0	3.0			
BP89	56.1	4.2	11.0	4.1	9.5	13.5	1.2		0.2	0.2
BP96	60.2	14.0	5.7	1.0	4.0	13.2	1.8		0.1	
BP103	58.5	3.7	13.1	4.2	6.9	9.2	2.9	0.1	0.1	1.3
BP106	50.2	2.2	13.2	3.3	12.1	16.6	2.0	0.1	0.1	0.2
BP118	58.6	3.8	10.2	3.0	10.4	11.0	2.9		0.1	
BP160	57.2	16.0	8.1	3.4	1.6	9.7	4.0			
BP161	58.9	1.3	22.4	8.3	0.7	0.3	7.8		0.1	0.2
BP175	53.0	1.4	32.0	10.2	0.3	0.6	2.5			
BP184	63.8	2.6	20.2	4.3	0.1	0.1	7.8	0.5	0.4	0.2
BP208	54.6		13.0	5.3	11.5	13.8	1.8			
BP213	51.7		16.2	8.1	4.4	15.3	4.3			
BP231	58.3	5.2	13.1	4.4	9.2	8.6	1.2			
BP246	59.0	5.1	15.1	8.1	4.2	6.9	1.6			
BP260	63.2	5.7	11.0	3.2	6.3	9.0	1.6			
BP293	52.0	9.1	10.1	2.3	13.2	10.9	2.4			
BP416	55.9	15.0	16.7	2.3	0.2	0.2	6.5	0.2	0.3	2.7

Table A-2. Modal Variations: Barber Intrusion

	PLG	HBL	OPX	CPX	BIO	QTZ	OL	OPA	HEM	APA	CHL	EPI	IDD & SERP.	HER	S
B128	47.3	20.6	0.9	0.4		1.7		10.0		0.1	18.8	0.2			
B191	36.6	43.5	0.3	0.1	6.7	9.3		1.7	0.1		0.7	1.0			
B197	44.2	25.5	0.6	0.2	15.6	13.4						0.5			
B249	71.5	15.4			5.3	3.3		4.2	Trace	Trace		0.3			
B274	30.5	65.9						3.6							
B308 or 3	45.9	46.5				1.2		1.3		0.2		4.9			
B306	20.8	60.7		0.3		0.5		2.7				15.0			
B314	47.7	14.2	17.2	5.0				3.9		0.1	11.4	0.5			
B315	18.5	53.6				0.9		0.5				26.5			
B317		60.2						3.8	0.2			35.8			
B318	34.0	61.5				0.8		3.6	0.1			Trace			
B324	32.3	35.2	21.0	5.0			5.6	0.7					0.2		
B329	43.3	36.0	13.1	6.0				1.3	0.2		0.1				
B331	11.2	68.9	14.9	0.4				0.4			4.2				
B346	12.8	68.8						1.4	0.4	0.1		16.5			
B348	36.9	45.5	1.8	0.1				4.4	0.6			10.7			
B350	43.2	45.8				0.2		0.1			0.6	10.1			
B357	31.8	53.6						0.8				13.8			

Table A-2 (continued)

	PLG	HBL	OPX	CPX	BIO	QTZ	OL	OPA	HEM	APA	CHL	EPI	IDD & SERP.	HER	S
B362	33.3	61.0						2.4				3.3			
B363	40.0	33.6			0.9	7.6		3.4		Trace		14.5			
B378	33.5	64.7						0.6				1.2			
B381	1.5	79.8		4.3				2.0	0.2		1.6	10.6			
B388	26.3	10.8	31.4	7.3			11.0	9.5	0.4		0.9		1.4	1.0	
B389	40.0	56.7				0.4		2.6	0.1			0.1			Trace
B390	18.7	62.5								Trace		18.8			
B393	30.5	68.1						0.6				0.8			
B404	41.1	56.4				0.3		1.2	0.6			0.4			
B408	31.6	58.6	0.7			0.8		4.4	0.1	0.8		3.0			
B435	42.8	14.6	15.4	0.9			13.5	3.4	0.5		0.6		7.7	0.6	
B439	24.2	66.3				6.5		1.3	0.3			1.4			

Table A-3. Electron Microprobe Analyses (Averaged): Orthopyroxene

	*BP118(6)	BP208(8)	BP231(5)	BP46(7)	B329(1)	B388(8)	B324(4)
SiO_2	**51.60(0.40)	51.90(0.66)	52.00(1.20)	55.00(0.49)	54.00	52.80(0.69)	53.80(0.64)
TiO_2	0.17(0.04)	0.15(0.08)	0.17(0.03)	0.10(0.07)	0.16	0.38(0.09)	0.09(0.07)
Al_2O_3	0.81(0.06)	0.82(0.08)	0.84(0.04)	0.70(0.27)	1.09	2.75(0.49)	2.38(0.19)
***FeO	26.00(0.36)	26.00(0.64)	26.60(0.31)	20.90(0.95)	19.90	15.40(0.77)	14.40(0.54)
MnO	0.99(0.04)	0.96(0.10)	0.82(0.06)	1.30(0.09)	0.60	0.48(0.05)	0.34(0.04)
MgO	19.40(0.26)	19.60(0.45)	20.70(0.22)	20.40(0.28)	24.60	27.10(0.57)	28.70(0.56)
CaO	0.93(0.14)	1.17(0.33)	1.03(0.20)	0.91(0.26)	0.51	1.48(0.16)	0.92(0.09)
Total	99.90	100.60	102.16	99.31	100.86	100.39	100.63
				Atoms/6 Oxygens			
Si	1.97	1.96	1.94	2.04	1.97	1.90	1.92
Ti	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Al	0.04	0.04	0.04	0.03	0.05	0.12	0.10
Fe	0.83	0.82	0.83	0.65	0.61	0.46	0.43
Mn	0.03	0.03	0.03	0.04	0.02	0.01	0.01
Mg	1.10	1.10	1.15	1.13	1.34	1.46	1.53
Ca	0.04	0.05	0.04	0.04	0.02	0.06	0.04
Total	4.01	4.00	4.03	3.93	4.01	4.02	4.03

*Bear Poplar sample number 118. The number in parentheses is the number of analyses averaged.

**Values in weight (%) oxides. The number in parentheses is the standard deviation from the mean value.

***FeO = total Fe.

Table A-4. Electron Microprobe Analyses (Averaged): Clinopyroxene

	*BP118(5)	BP208(4)	BP231(5)	BP46(9)	B306(8)	B329(7)	B388(6)	B324(6)
SiO_2	**50.80(1.49)	52.30(0.63)	52.20(0.26)	52.60(0.67)	52.00(0.40)	53.30(0.70)	49.60(0.99)	52.50(0.72)
TiO_2	0.32(0.05)	0.11(0.01)	0.26(0.02)	0.20(0.05)	0.24(0.02)	0.22(0.03)	0.90(0.09)	0.09(0.02)
Al_2O_3	1.57(0.09)	1.24(0.08)	1.61(0.07)	1.52(0.12)	1.65(0.22)	1.89(0.47)	4.46(0.31)	2.12(0.44)
***FeO	11.90(0.35)	10.60(0.49)	11.40(0.90)	8.73(0.46)	7.52(0.24)	7.57(0.31)	7.72(0.78)	5.71(0.60)
MnO	0.41(0.02)	0.39(0.04)	0.37(0.07)	0.51(0.06)	0.32(0.05)	0.31(0.04)	0.33(0.04)	0.22(0.04)
MgO	13.20(0.51)	13.30(0.09)	14.10(0.28)	14.40(0.34)	14.10(0.14)	15.60(0.13)	15.40(0.68)	16.00(0.32)
CaO	20.30(1.85)	21.40(0.30)	20.80(0.80)	21.60(0.96)	23.10(0.25)	22.60(0.60)	20.70(1.66)	22.60(1.23)
Total	98.50	99.34	100.74	99.56	98.93	101.49	99.11	99.24
				Atoms 6/Oxygens				
Si	1.95	1.97	1.95	1.97	1.95	1.95	1.86	1.94
Ti	0.01	0.00	0.01	0.01	0.01	0.01	0.02	0.00
Al	0.07	0.06	0.07	0.07	0.07	0.08	0.20	0.09
Fe	0.38	0.33	0.36	0.27	0.24	0.23	0.24	0.18
Mn	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01
Mg	0.75	0.75	0.78	0.80	0.79	0.85	0.86	0.88
Ca	0.83	0.87	0.83	0.86	0.93	0.88	0.83	0.90
Total	4.00	3.99	4.01	4.00	4.00	4.01	4.02	4.00

*Bear Poplar sample number 118. The number in parentheses is the number of analyses averaged.

**Values in weight (%) oxides. The number in parentheses is the standard deviation from the mean value.

***FeO = total Fe.

Table A-5. Electron Microprobe Analyses (Averaged): Amphibole

	*BP231(6)	BP46(5)	B408(8)	B306(7)	B329(7)	B350(6)	B388(5)	B324(6)
SiO_2	**44.00(0.58)	44.80(0.56)	46.30(2.48)	42.80(0.96)	45.40(0.81)	48.80(1.96)	41.40(0.89)	44.10(0.49)
TiO_2	1.66(0.09)	1.20(0.11)	0.53(0.32)	1.48(0.21)	1.68(0.13)	0.27(0.07)	3.96(0.31)	0.61(0.04)
Al_2O_3	9.80(0.14)	8.69(0.37)	8.56(2.47)	9.87(0.49)	10.20(0.38)	7.64(2.56)	12.20(0.26)	12.00(0.41)
***FeO	16.00(0.37)	13.80(0.11)	14.50(1.45)	14.60(0.29)	11.70(0.32)	9.85(1.23)	11.00(0.16)	9.67(0.18)
MnO	0.20(0.03)	0.40(0.05)	0.39(0.03)	0.25(0.02)	0.18(0.04)	0.23(0.03)	0.20(0.03)	0.12(0.01)
MgO	11.50(0.26)	13.40(0.18)	12.60(1.58)	12.40(0.33)	14.40(0.28)	16.20(1.78)	13.90(0.29)	15.70(0.17)
CaO	11.60(0.13)	11.50(0.17)	11.60(0.13)	11.80(0.24)	12.00(0.16)	12.40(0.16)	11.60(0.22)	12.20(0.19)
Na_2O	1.15(0.08)	1.10(0.06)	0.81(0.30)	1.53(0.14)	1.57(0.12)	0.75(0.29)	2.33(0.18)	1.88(0.08)
K_2O	1.19(0.04)	0.95(0.04)	0.24(0.15)	0.49(0.08)	0.42(0.03)	0.12(0.04)	0.34(0.02)	0.29(0.02)
Total	97.10	95.84	95.53	95.22	97.55	96.26	96.93	96.57
				Atoms/23 (O, OH, F)				
Si	6.62	6.75	6.95	6.53	6.63	7.09	6.13	6.46
Ti	0.19	0.14	0.06	0.17	0.18	0.03	0.44	0.07
Al	1.74	1.54	1.52	1.78	1.76	1.31	2.13	2.07
Fe	2.01	1.74	1.82	1.86	1.43	1.20	1.36	1.18
Mn	0.02	0.05	0.05	0.03	0.02	0.03	0.02	0.15
Mg	2.58	3.01	2.82	2.82	3.14	3.51	3.07	3.43
Ca	1.87	1.86	1.87	1.93	1.88	1.93	1.84	1.91
Na	0.34	0.32	0.24	0.45	0.44	0.21	0.67	0.53
K	0.23	0.18	0.05	0.10	0.08	0.22	0.06	0.05
Total	15.60	15.59	15.38	15.67	15.56	15.53	15.72	15.85

*Bear Poplar sample number 231. The number in parentheses is the number of analyses averaged.

**Values in weight (%) oxides. The number in parentheses is the standard deviation from the mean value.

***FeO = total Fe.

Table A-6. Electron Microprobe Analyses (Averaged): Biotite

	*BP118(6)	BP208(9)	BP231(6)	BP46(7)
SiO_2	**35.50(0.36)	35.80(0.46)	36.20(0.36)	35.30(0.56)
TiO_2	4.28(0.13)	3.96(0.14)	4.12(0.35)	3.17(0.14)
Al_2O_3	14.20(0.48)	14.60(0.29)	15.10(0.61)	15.40(0.54)
***FeO	18.20(0.36)	18.70(0.36)	17.50(0.85)	16.80(0.94)
MnO	0.08(0.02)	0.16(0.03)	0.11(0.03)	0.19(0.04)
MgO	11.90(0.09)	11.70(0.19)	12.30(0.17)	13.00(0.52)
CaO	0.10(0.24)	0.01(0.01)	0.05(0.04)	0.00
Na_2O	0.00	0.05(0.03)	0.06(0.03)	0.23(0.02)
K_2O	9.05(0.52)	9.34(0.19)	9.17(0.35)	9.14(0.17)
Total	93.31	94.32	94.61	93.23
	Atoms/12 (O, OH, F)			
Si	3.01	3.01	3.01	2.98
Ti	0.27	0.25	0.26	0.20
Al	1.42	1.45	1.48	1.53
Fe	1.29	1.32	1.22	1.18
Mn	0.01	0.01	0.01	0.01
Mg	1.50	1.47	1.52	1.63
Ca	0.01	0.00	0.00	0.00
Na	0.00	0.01	0.01	0.04
K	0.98	1.00	0.97	0.98
Total	8.49	8.52	8.48	8.55

*Bear Poplar sample number 118. The number in parentheses is the number of analyses averaged.

**Values in weight (%) oxides. The number in parentheses is the standard deviation from the mean value.

***FeO = total Fe.

Table A-7. Electron Microprobe Analyses (Averaged): Olivine

	*B388(8)	B324(5)
SiO_2	**38.80(0.41)	41.60(2.16)
TiO_2		
Al_2O_3		
***FeO	17.00(0.29)	20.80(3.97)
MnO		
MgO	44.30(0.38)	38.10(3.47)
CaO		
Na_2O		
K_2O		
Total	100.10	100.50
	Atoms/4 Oxygens	
Si	0.98	1.06
Ti		
Al		
Fe	0.36	0.44
Mn		
Mg	1.67	1.44
Ca		
Na		
K		
Total	3.01	2.94

*Barber sample number 388. The number in parentheses is the number of analyses averaged.

**Values in weight (%) oxides. The number in parentheses is the standard deviation from the mean value.

***FeO = total Fe.

Table A-8. Electron Microprobe Analyses (Averaged): Plagioclase

	*BP118(20)	BP208(20)	BP231(23)	BP46(20)	B408(22)	B306(20)	B329(20)	B350(21)	B388(21)	B324(19)
SiO_2	**55.90(0.92)	53.40(2.26)	54.30(1.85)	53.10(0.87)	47.80(1.50)	47.90(1.06)	46.30(1.79)	45.40(1.10)	50.90(0.96)	43.40(1.75)
Al_2O_3	27.70(0.64)	28.60(1.67)	29.20(1.16)	30.20(0.81)	32.60(0.96)	33.30(0.62)	35.80(1.13)	34.60(0.66)	30.70(0.85)	37.30(0.88)
CaO	9.63(0.71)	10.60(1.89)	10.70(1.37)	11.60(0.68)	15.10(1.14)	16.10(0.75)	17.40(0.26)	17.60(0.64)	12.80(0.71)	18.80(0.43)
Na_2O	5.86(0.41)	5.53(1.08)	5.37(0.74)	4.89(0.43)	2.97(0.66)	2.20(0.41)	1.68(0.08)	1.37(0.36)	4.27(0.46)	0.81(0.30)
K_2O	0.44(0.14)	0.25(0.08)	0.31(0.12)	0.10(0.02)	0.03(0.01)	0.02(0.01)	0.02(0.01)	0.01(0.01)	0.04(0.02)	0.01(0.01)
Total	99.53	98.38	99.88	99.89	98.50	99.52	101.20	98.98	98.71	100.32
					Atoms/8 Oxygens					
Si	2.53	2.45	2.45	2.40	2.22	2.20	2.10	2.11	2.34	2.00
Al	1.48	1.55	1.55	1.61	1.78	1.80	1.92	1.89	1.66	2.02
Ca	0.47	0.52	0.52	0.56	0.75	0.79	0.85	0.88	0.63	0.93
Na	0.51	0.49	0.47	0.43	0.27	0.20	0.15	0.12	0.38	0.07
K	0.02	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Total	5.01	5.02	5.01	5.01	5.02	4.99	5.02	5.00	5.01	5.02

*Bear Poplar sample number 118. The number in parentheses is the number of analyses averaged.

**Values in weight (%) oxides. The number in parentheses is the standard deviation from the mean value.

Table A-9. Bulk Chemical Compositions

	BP118	BP208	BP231	BP46	**10270	**10590	B408	B306	B329	B350	B388	B324	**10571	**10572	**10580
SiO_2	55.41	56.64	54.78	53.82	56.60	53.40	44.23	41.69	46.92	45.52	43.61	45.82	42.90	42.80	48.20
TiO_2	0.52	0.47	0.47	0.59	0.54	0.58	0.30	0.90	0.63	0.12	2.53	0.23	0.12	0.12	0.58
Al_2O_3	18.02	17.49	18.96	16.65	15.30	16.40	16.60	18.02	19.68	21.71	11.37	16.70	9.60	11.40	8.30
*FeO	8.35	7.99	7.28	9.48	9.58	10.00	12.62	11.88	8.45	4.63	16.93	8.63	12.70	12.10	10.90
MnO	0.13	0.17	0.14	0.23	0.17	0.16	0.22	0.15	0.16	0.11	0.19	0.12	0.18	0.17	0.19
MgO	4.02	4.51	4.95	6.10	5.15	5.20	7.28	7.56	9.32	7.44	16.65	14.68	23.35	20.90	16.83
CaO	6.67	7.03	7.76	7.90	8.56	8.92	12.63	15.58	13.42	16.59	6.44	11.60	8.90	11.22	12.99
Na_2O	3.44	3.06	3.18	2.37	2.76	2.84	1.44	1.39	1.30	0.93	1.39	0.91	0.50	0.42	1.01
K_2O	1.20	1.17	1.06	1.21	0.78	0.86	0.15	0.30	0.16	0.06	0.23	0.10	0.04	0.03	0.34
Total	97.87	98.53	98.58	98.55	99.44	98.36	96.27	97.47	100.04	97.11	99.34	98.84	98.29	99.16	99.34

*FeO = total Fe.

**Bulk analyses for major elements by Butler and Ragland (1969).
Number 10270 and number 10590 = Bear Poplar samples.
Number 10571, number 10572, and number 10580 = Barber samples.

Table A-10. Trace Element Compositions

	*NC-27	*NC-59	*NC-57A	*NC-57B	*NC-58
Co	170	58	230	287	410
Cr	56	80	361	340	785
Ni	25	42	1450	880	720
Pb	9	7	13	11	10
Rb	24	21	2	2	8
Sr	400	423	163	158	176
V	223	223	80	86	171
Zr	88	98	27	26	38
Cu	101	120	31	34	53
Zn	84	85	87	70	82
Li	11	7	2	2	2

*Analyses for trace elements by Price (1969).
NC-27 and NC-59 = Bear Poplar samples.
NC-57A, NC-57B, and NC-58 = Barber samples.
Major elements reported as weight percent oxides; trace elements as ppm.

VITA

Stephen Rex Clark was born in Dallas, Texas on September 17, 1954. After moving to Knoxville, Tennessee in 1959, he attended elementary school in Knoxville and graduated from West High School in June 1972. From September 1972 until June 1973, he attended Roane State Community College in Harriman, Tennessee. In the fall of 1973, he entered The University of Tennessee, Knoxville. He received his Bachelor of Arts degree in Geology when he graduated with honors in August 1978. In the fall of 1978, he accepted a teaching assistantship in the Department of Geological Sciences at The University of Tennessee, Knoxville and began his graduate studies. He received his Master's degree in Geology in December 1980.

He is a member of Sigma Xi, Sigma Gamma Epsilon, American Mineralogical Society, and Geological Society of America. In the fall of 1980, he accepted a position with Exxon Company, USA.

GEOLOGIC MAP OF THE BEAR POPLAR AND BARBER INTRUSIONS, NORTH CAROLINA