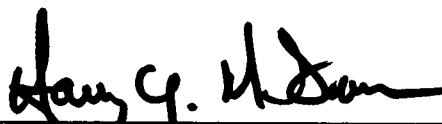


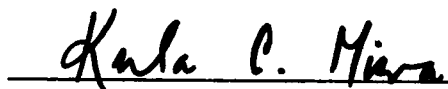
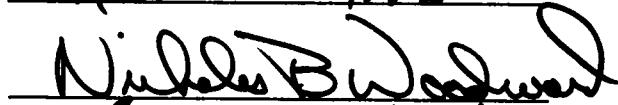
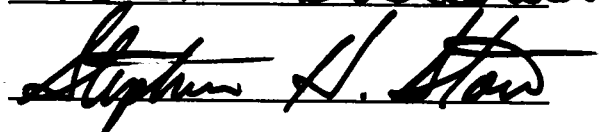
To the Graduate Council:

I am submitting herewith a thesis written by Elizabeth Allison Strange entitled "The Geochemistry of the Barber Mafic Complex, Rowan County, North Carolina." 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.

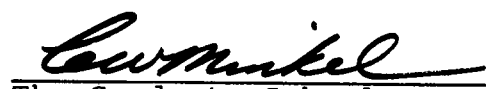


Harry Y. McSween
Major Professor

We have read this thesis and
recommend its acceptance:

Accepted for the Council:


The Graduate School

THE GEOCHEMISTRY OF THE BARBER MAFIC COMPLEX,
ROWAN COUNTY, NORTH CAROLINA

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

Elizabeth Allison Strange

December 1983

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ABSTRACT

The Barber complex is a composite gabbro-metagabbro body located in the Charlotte belt in Rowan County, North Carolina. Samples from both parts of the body were analyzed for major and minor oxides and trace elements using atomic absorption spectrophotometry. Discriminant analysis indicated that the metagabbro (B1) and gabbro (B2) sample populations are geochemically distinct, although some overlap between the two occurs. Normative mineralogy of the two units differ, with B2 samples falling in the quartz tholeiite field and B1 samples falling in the alkali basalt and olivine tholeiite field. In addition, it was found that geochemistry correlates closely with mineralogy and has been strongly influenced by crystal accumulation.

Four B1 and four B2 samples exhibited a much finer-grained texture than do the majority of samples. The fine-grained B2 samples occur near the B1/B2 contact and may be chill margin samples; their compositions have probably been affected by assimilation. The significance of the fine-grained B1 samples is unclear.

Based on geochemical and petrological characteristics of the two intrusions, it is concluded that B1 probably originated from a tholeiitic parental magma and B2 from a calc-alkaline parental magma. The complex was probably intruded at a collisional plate boundary. This complex is

petrologically and geochemically similar to one other gabbro-metagabbro complexes in the Piedmont, e.g., the Mecklenburg complex, North Carolina, and is probably genetically related to it.

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CHAPTER I

INTRODUCTION

The Barber complex is a composite gabbro-metagabbro body located within the Charlotte belt in Rowan County, North Carolina (Figure 1). Similar gabbro-metagabbro complexes form a chain of intrusions extending in the Piedmont from Georgia through North Carolina. Their arcuate distribution suggests their emplacement may have been tectonically controlled (McSween et al., 1983).

Limited geochemical data for the gabbro and metagabbro of the Barber complex have been published (Ragland and Butler, 1969; Price, 1969). Ragland and Butler (1969) analyzed three samples from the metagabbro and two samples from the gabbro for major and minor elements, and the same samples were analyzed for trace elements by Price (1969). The metagabbro contains higher concentrations of those elements, such as Mg, Cr and Ni, which are partitioned into early cumulates. The gabbro contains higher amounts of elements, such as Si, Na, K and Rb, fractionated into residual liquids. However, because of the small number of samples analyzed, it was unclear if the two units were geochemically distinct or gradational.

The metagabbro, called the Barber pluton, was intruded by the gabbro, originally called the Bear Poplar pluton

Figure 1. Location map of the Barber complex and other gabbro-metagabbro complexes in the Piedmont from McSween et al. (1983). Relative positions of the southern Appalachian belts are from Hatcher (1972).

Gabbro- Metagabbro Association

3

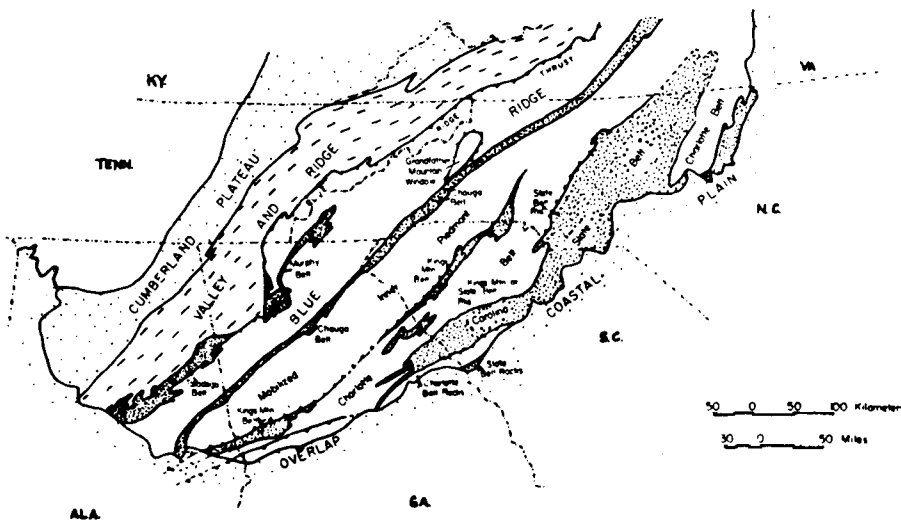
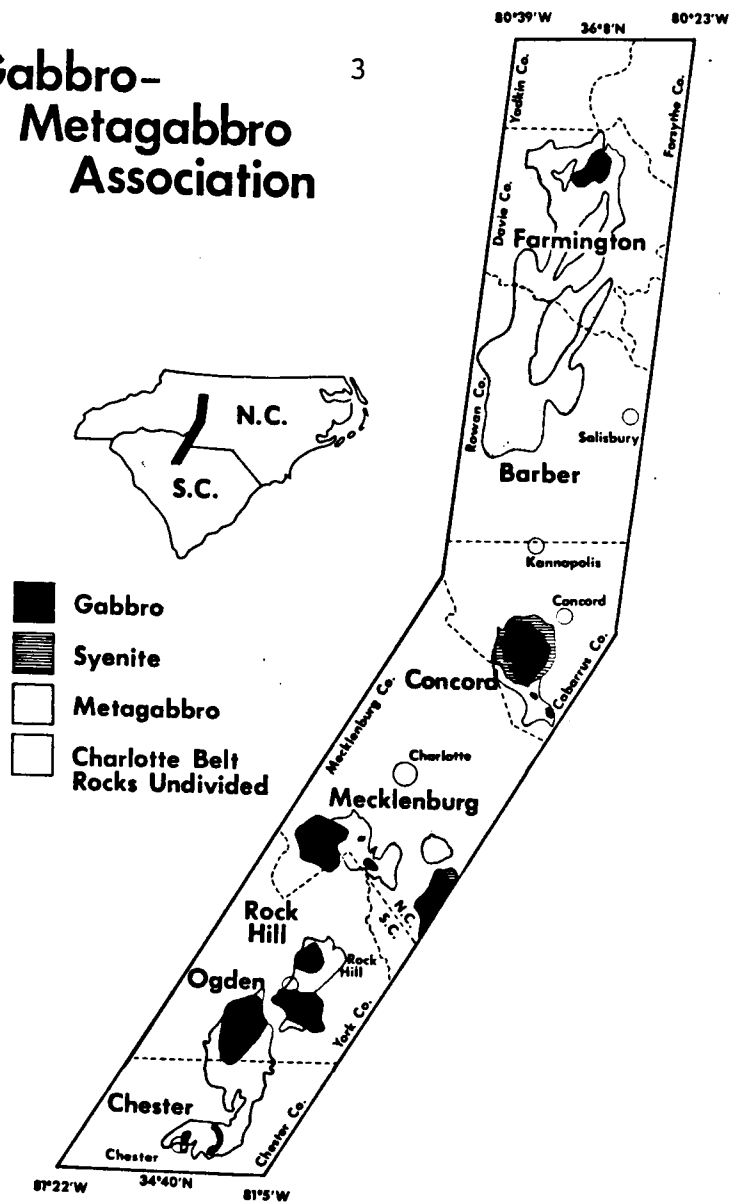


Figure 1.

(Ragland and Butler, 1969). Clark (1980) mapped and studied the petrology of the Barber and Bear Poplar plutons. He found that the Bear Poplar pluton consists of four basic rock types: norite, gabbronorite, hornblende norite and hornblende gabbronorite. Major mineral constituents are plagioclase, orthopyroxene, clinopyroxene, hornblende, biotite and quartz with magnetite, ilmenite, pyrite, pyrrhotite and hematite present as minor constituents. The pluton displays primarily hypidiomorphic granular to inequigranular textures, although cumulate and poikilitic textures are also present. Based on petrography, progressive differentiation trends are exhibited by concentric zones within the pluton, characterized by Fe and SiO_2 enrichment toward the center (Clark, 1980). This concentric zoning could result from the fractionation of a tholeiitic magma which commonly displays similar trends.

The Barber pluton consists of three rock types distinguished by their degree of alteration: olivine hornblende gabbronorite, Type I metagabbro and Type II metagabbro (Clark, 1980). The olivine hornblende gabbronorite maintains its igneous mineralogy and texture, exhibiting very little alteration. Major mineral constituents include plagioclase, orthopyroxene, clinopyroxene, hornblende and olivine. Type I metagabbro displays both metamorphic and relict igneous features and is comprised primarily of

plagioclase, orthopyroxene, clinopyroxene and hornblende. Type II metagabbro reflects the highest degree of alteration and apparant metamorphism among the three rock types displayed within the Barber intrusion. It consists of plagioclase, hornblende and epidote, and may exhibit metamorphic foliation in some cases. Minor mineral constituents are consistent throughout all three rock types of the Barber pluton and are essentially identical to those of the Bear Poplar pluton, with the presence of apatite, hercynitic spinel, iddingsite, serpentine and calcite in the Barber pluton (Clark, 1980). The Barber pluton displays a wide variety of textures with hypidiomorphic granular to hypidiomorphic inequigranular dominating. Poikilitic and granoblastic textures are present in some samples (Clark, 1980). The presence of hornblende, epidote and chlorite are ubiquitous for mafic rocks that are subjected to low- to medium-grade metamorphism (Winkler, 1979), as the Barber samples have been (McSween et al., 1983). However, only a few samples in the Barber pluton display textures characteristic of regional metamorphism.

After detailed petrographic study, Clark (1980) concluded that two different magmas had produced the two intrusions. The Barber pluton was believed by Clark to have formed from a transitional high-alumina to tholeiitic, silica-undersaturated basaltic magma. Clark theorized that the Bear Poplar pluton crystallized from a basaltic

andesitic magma. This magma may have been produced by fractionation of tholeiitic basalt (Ringwood, 1974). Basaltic andesites are typically associated with magmas that intrude continental crust at converging plate margins (Pearce, 1976). These two ideas support the suggestion that the two plutons may be related to subduction zone activity (McSween, 1980).

Previous workers (Price, 1969; Butler and Ragland, 1969; Fullagar, 1971; Clark, 1980) assumed that the gabbro and metagabbro lithologies within the Barber complex represented two separate intrusions, although no contact relations were observed. The belief that two separate intrusions were present was founded on the fact that the Bear Poplar pluton does not exhibit metamorphic features, whereas the Barber pluton does show a metamorphic overprint. However, it has been recognized that the presence or absence of metamorphism in mafic rocks may be controlled by the availability of water (Hermes, 1968). Consequently, the presence or absence of metamorphism in restricted areas of the complex may not be a valid basis on which to determine if two intrusions exist.

Because it was unproven whether the complex was comprised of two separate intrusions or was only one, large, zoned intrusion, the gabbro and metagabbro lithologies were dated using Sm-Nd mineral isochrons. Relict igneous

minerals from the least altered Barber sample were dated, so both ages probably reflect times of emplacement. These ages were found to be 479 ± 24 mya for gabbro and $567 \pm \sim 50$ mya for metagabbro (McSween et al., 1983), indicating the two lithologies represented separate intrusions.

The primary objective of this study is the characterization of the geochemical aspects of the two intrusions within the Barber complex. This information combined with age dates and petrologic data provide further constraints on the petrogenesis of the complex. In addition, a comparison is made between this complex and another similar and well-documented composite body in the Piedmont.

In this paper, the Bear Poplar and Barber plutons are referred to as the Barber gabbro and metagabbro, respectively, conforming to nomenclature for the other gabbro-metagabbro complexes of the Piedmont (McSween et al., 1983). B1 and B2 are also used as shorthand notation to refer to the metagabbro and gabbro, respectively.

CHAPTER II

METHODS OF ANALYSIS

Analytical Procedure

Rock samples were those Clark (1980) had previously collected and point counted; some were previously analyzed by electron microprobe by Clark (1980). These documented samples were used because of the availability of petrographic information that could be correlated with the geochemical data obtained in this study. Sample locations are shown in Figure 2.

The procedure for bulk rock analysis involved preparation of powdered samples using the procedure outlined by Shapiro and Brannock (1962). Rock samples and standards were dissolved by a procedure slightly modified from that of Medlin et al. (1969) for the determination of major and minor elements. For the determination of trace elements, a dissolution method using HF and HNO₃ was used. Sample crushing procedure and dissolution techniques for both major and trace elements are described in detail in the Appendix.

A Varian AA-475 atomic absorption spectrometer was used for all chemical analyses. The analytical procedure is given in the Appendix. Major and trace element analyses are given in Tables 1 and 2. These values are averages of 3 replicate analyses for major and minor elements, but trace

Figure 2. Geologic map of the Barber complex by Clark (1980), with locations of samples analyzed in this study. Quadrangles are (1) Cool Springs, N.C., (2) Cooleemee, N.C., (3) Cleveland, N.C., and (4) Rowan Mills, N.C. B1 (Barber pluton) samples are designated by squares and B2 (Bear Poplar pluton) samples by stars.

Table 1. Geochemical Analyses for 81 Samples.

	324	388	435	314	128	191	274	303	306	315	317	318	331	346	348	350	357	362	378	381	389	390	393	404	408	439	197	249	363	
Major and Minor Oxides (wt. %)																														
SiO ₂	47.3	44.5	44.6	46.1	46.4	48.0	42.8	53.7	44.6	45.7	41.0	45.2	45.1	44.1	46.1	45.5	45.6	45.7	48.0	46.8	46.2	45.5	48.9	48.6	45.4	48.2	60.6	55.9	54.9	
Al ₂ O ₃	17.1	10.6	17.7	16.6	19.8	18.7	19.7	16.3	16.2	20.4	16.9	18.0	14.8	17.3	18.3	24.6	18.9	18.6	16.0	9.1	19.2	17.6	15.3	15.3	17.1	18.3	15.8	16.1	16.8	
TiO ₂	0.21	1.52	0.09	0.77	0.98	0.82	0.95	0.77	0.93	0.55	0.99	0.97	1.06	1.45	1.02	0.29	0.68	0.95	0.89	0.74	1.16	0.66	1.13	0.73	0.75	0.54	0.49	0.62	0.86	
FeO ^a	7.32	19.5	13.0	10.7	14.5	14.1	9.25	14.4	9.08	15.0	15.7	8.40	13.6	14.9	6.62	9.60	14.5	10.5	12.4	12.3	9.52	12.0	12.3	13.7	11.5	8.47	10.1	9.88		
MgO	11.25	16.8	17.4	8.10	5.67	12.60	9.75	5.21	7.45	6.52	7.41	7.57	13.6	7.79	6.37	5.93	11.8	6.27	8.84	16.5	6.58	9.84	7.99	5.70	6.72	7.09	4.02	4.60	3.59	
CaO	15.94	6.77	8.18	14.8	10.76	9.41	11.8	9.52	14.8	16.3	11.4	12.9	12.5	11.2	15.8	12.9	11.0	10.9	12.4	10.0	15.1	9.75	10.7	12.0	10.7	7.00	9.07	7.76		
Na ₂ O	0.78	1.13	0.65	1.11	1.93	2.96	1.60	3.31	1.38	1.20	0.74	1.85	1.21	1.67	2.38	0.83	1.19	1.83	1.88	1.16	2.56	0.89	2.75	2.13	2.03	1.71	2.88	2.60	3.50	
K ₂ O	0.11	0.16	0.09	0.11	0.09	0.49	0.23	0.32	0.21	0.19	0.21	0.28	0.26	0.17	0.10	0.23	0.10	0.23	0.35	0.21	0.37	0.19	0.19	0.35	0.32	0.23	0.83	0.75	0.43	
H ₂ O	0.13	0.24	0.17	0.15	0.23	0.22	0.17	0.16	0.14	0.09	0.13	0.23	0.12	0.15	0.22	0.10	0.16	0.23	0.15	0.24	0.14	0.14	0.14	0.15	0.24	0.15	0.11	0.13	0.19	
Total	100.1	101.1	101.9	98.4	100.4	98.7	101.1	98.5	100.1	100.0	98.6	101.1	97.7	98.8	100.6	99.8	101.0	99.4	97.4	99.7	98.4	99.4	98.3	99.9	98.7	98.3	100.2	99.8	97.9	
Calculated Norms																														
qtz	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
ab	0.65	0.93	0.52	0.66	0.53	2.93	1.34	1.92	1.24	1.12	0.00	1.23	1.69	1.55	1.00	0.59	1.35	2.08	1.27	2.19	1.14	1.13	2.10	1.83	1.91	1.38	4.89	4.44	2.59	
an	6.59	9.45	5.40	9.54	16.27	25.38	8.90	28.43	8.89	8.71	0.00	15.47	10.48	14.29	20.02	7.04	9.96	15.57	16.33	9.84	22.03	7.57	23.66	18.04	17.39	14.71	24.31	22.02	30.24	
ne	42.80	33.04	39.82	40.57	44.85	36.83	45.44	38.96	37.40	49.72	43.38	39.78	34.93	39.39	38.51	63.31	45.05	41.70	35.54	18.60	40.90	43.79	28.87	42.20	37.17	42.22	27.70	30.13	49.47	
di	0.00	0.00	0.00	0.00	0.00	0.00	2.43	0.00	1.50	0.78	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
hy	28.93	8.26	0.00	27.60	6.95	8.69	10.02	15.61	29.70	25.20	29.14	13.18	24.20	19.20	13.81	12.28	14.82	11.10	16.33	35.57	7.98	25.36	16.60	9.14	19.00	9.49	5.76	12.37	8.22	
ol	6.14	23.65	22.49	9.12	18.18	9.64	0.00	15.77	0.00	0.00	5.11	1.76	0.20	3.78	7.10	3.22	12.05	21.58	4.22	8.48	3.30	14.85	22.23	4.26	26.67	16.67	16.64	16.04		
wt	11.94	35.11	35.48	7.24	6.34	10.56	25.22	0.00	14.53	10.26	16.25	18.00	21.82	17.79	15.79	6.82	21.02	10.57	3.46	24.86	12.88	14.26	7.50	3.90	14.03	0.00	0.00	0.00	0.00	
il	2.55	6.69	4.45	3.79	5.03	4.39	4.86	3.27	4.99	3.16	5.33	5.40	3.06	4.78	5.16	2.31	3.30	5.06	3.75	4.30	4.35	3.34	4.25	4.27	4.81	4.05	2.94	3.51	3.51	
il	0.40	2.85	0.17	1.49	1.85	1.58	1.78	1.48	1.76	1.04	1.92	1.82	2.06	2.79	1.93	0.55	1.28	1.87	1.73	1.41	2.24	1.26	2.18	1.39	1.44	1.04	0.93	1.18	1.67	
Normative Mineral Compositions																														
di	Wo _{15.1}	Wo _{4.3}	Wo _{0.00}	Wo _{14.1}	Wo _{3.5}	Wo _{4.4}	Wo _{5.1}	Wo _{7.9}	Wo _{15.0}	Wo _{12.9}	Wo _{17.7}	Wo _{6.7}	Wo _{12.7}	Wo _{8.8}	Wo _{6.9}	Wo _{6.3}	Wo _{7.7}	Wo _{5.6}	Wo _{8.4}	Wo _{18.0}	Wo _{4.1}	Wo _{13.1}	Wo _{8.5}	Wo _{4.6}	Wo _{9.6}	Wo _{4.8}	Wo _{2.9}	Wo _{6.2}	Wo _{9.1}	
hy	En _{10.6}	En _{2.7}	En _{0.00}	En _{16.5}	En _{16.5}	En _{16.5}	En _{16.5}	En _{16.5}	En _{16.5}	En _{16.5}	En _{16.5}	En _{16.5}	En _{16.5}	En _{16.5}	En _{16.5}	En _{16.5}	En _{16.5}	En _{16.5}	En _{16.5}	En _{16.5}	En _{16.5}	En _{16.5}	En _{16.5}	En _{16.5}	En _{16.5}	En _{16.5}	En _{16.5}	En _{16.5}		
ol	Fe _{8.9}	Fe _{16.1}	Fe _{18.2}	Fe _{4.4}	Fe _{2.8}	Fe _{5.0}	Fe _{17.8}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	
Trace Elements (ppm)																														
Co	14	47	36	23	36	33	48	21	36	16	34	36	16	34	39	14	23	32	21	24	29	16	27	24	32	26	15	21	23	
Cr	1004	130	105	167	11	12	13	62	34	246	56	37	470	83	28	115	43	35	252	519	119	218	73	48	56	38	44	41	13	
Mn	83	176	216	58	32	36	69	40	64	47	46	52	46	30	38	48	80	40	173	135	109	46	128	51	41	47	38	42	30	
Cu	25	190	37	320	115	72	208	27	250	89	155	178	82	59	136	114	89	160	117	37	87	70	59	178	168	147	98	147	28	
Zn	43	101	73	67	111	105	96	84	73	46	62	101	90	79	116	152	76	109	71	96	70	65	103	92	100	73	74	78	82	
Rb	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	2	5	1	6	1	2	3	1	1	2	3	22	3	
Sr	105	229	266	537	645	480	408	599	640	766	555	478	425	542	637	509	525	538	574	238	408	605	574	461	512	370	430	380		
V	132	244	280	243	317	310	429	276	478	210	500	427	234	159	383	176	176	400	192	71	366	202	283	440	391	325	152	241	236	

FeO^a = Total Fe.

Table 2. Geochemical Analyses for 82 Samples.

	103	106	118	12	89	208	213	46	160	231	260	293	45	67	96	246	184	10	161	175	416
	Major and Minor Oxides (wt. %)																				
SiO ₂	56.1	57.9	57.2	55.8	54.4	56.1	57.5	53.0	56.4	57.1	56.9	55.3	54.4	55.7	55.8	54.2	46.3	51.8	50.0	50.3	48.2
Al ₂ O ₃	16.8	15.8	16.6	15.2	16.4	15.5	16.4	15.5	16.6	16.2	16.6	16.8	16.9	15.5	15.5	16.0	19.5	17.2	18.0	16.8	17.2
TiO ₂	0.74	0.81	0.88	0.60	0.64	0.73	0.65	0.77	0.66	0.61	0.61	0.76	0.65	0.69	0.74	0.62	1.03	0.52	0.92	0.81	0.84
FeO*	8.73	9.83	9.33	11.1	9.15	9.55	9.83	11.6	9.28	9.82	9.67	9.63	9.88	9.23	9.07	9.67	14.2	8.73	12.1	11.2	14.6
MgO	4.84	4.42	4.08	5.30	4.86	4.67	4.47	5.39	4.81	4.82	4.75	4.29	5.41	4.51	4.08	5.69	5.81	5.92	5.10	9.33	5.18
CaO	7.89	7.08	6.87	8.06	8.55	9.24	8.70	8.86	8.05	8.97	10.1	7.54	8.64	7.43	6.72	8.41	10.9	10.9	9.46	11.4	9.44
Na ₂ O	3.18	3.12	3.32	2.84	2.90	2.50	2.78	2.43	2.92	2.83	2.83	3.14	2.78	3.06	2.97	2.54	2.50	3.15	3.23	1.76	2.85
K ₂ O	0.70	0.82	0.76	0.64	0.69	0.84	0.73	0.81	0.53	0.62	0.61	0.74	0.61	0.55	0.77	0.65	0.20	0.37	0.33	0.20	0.33
MnO	0.16	0.13	0.13	0.16	0.14	0.17	0.13	0.18	0.14	0.14	0.14	0.14	0.15	0.15	0.14	0.16	0.22	0.22	0.20	0.22	0.23
Total	99.1	99.9	99.2	99.7	97.7	99.3	101.2	98.5	99.4	101.1	102.2	98.3	99.4	96.8	95.8	98.0	100.6	98.8	99.4	101.8	98.9
	Calculated Norms																				
qtz	8.63	11.82	13.98	8.84	7.62	10.56	10.91	6.23	10.37	9.92	8.47	8.70	6.73	11.03	12.52	8.10	0.00	0.00	0.00	0.00	0.00
or	4.17	4.85	4.53	3.80	4.17	5.00	4.26	4.86	3.15	3.62	3.53	4.45	3.63	3.36	4.75	3.92	1.17	2.19	1.96	1.17	1.97
ab	27.14	26.42	28.16	24.12	25.11	21.29	23.23	20.88	24.86	23.67	23.43	27.02	23.66	26.75	26.22	21.93	21.02	26.69	27.50	14.64	24.37
an	29.67	26.70	28.53	26.85	30.33	28.81	29.85	29.31	30.78	29.41	30.18	30.01	31.94	27.68	27.91	30.99	41.08	31.80	33.90	36.57	33.63
ne	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
di	8.07	7.00	4.69	11.00	10.78	14.33	10.59	12.70	7.76	12.06	15.39	6.66	9.21	8.60	5.70	9.53	10.49	18.29	11.07	15.55	11.47
hy	17.82	18.25	11.70	20.41	17.51	15.27	16.56	20.46	18.57	16.08	14.59	18.29	20.14	17.90	18.13	20.88	4.29	15.59	16.34	25.39	15.48
ol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.09	1.07	3.23	2.01	6.34
wt	3.07	3.42	6.72	3.86	3.26	3.34	3.38	4.08	3.25	3.38	3.29	3.41	3.46	3.33	3.30	3.45	4.91	3.40	4.24	3.82	5.13
il	1.42	1.54	1.69	1.14	1.21	1.40	1.22	1.49	1.26	1.15	1.13	1.47	1.24	1.35	1.47	1.20	1.94	0.99	1.76	0.88	1.61
	Normative Mineral Compositions																				
di	Wo _{4.1}	Wo _{3.5}	Wo _{2.4}	Wo _{5.5}	Wo _{5.5}	Wo _{7.2}	Wo _{5.3}	Wo _{6.4}	Wo _{3.9}	Wo _{6.1}	Wo _{7.8}	Wo _{3.4}	Wo _{4.7}	Wo _{4.4}	Wo _{2.9}	Wo _{4.8}	Wo _{5.3}	Wo _{9.3}	Wo _{5.6}	Wo _{8.0}	Wo _{5.7}
hy	En _{2.2}	En _{1.8}	En _{1.7}	En _{2.8}	En _{2.9}	En _{3.7}	En _{2.6}	En _{3.2}	En _{2.1}	En _{3.1}	En _{4.0}	En _{1.7}	En _{2.5}	En _{2.2}	En _{1.4}	En _{2.6}	En _{2.5}	En _{5.1}	En _{2.7}	En _{4.8}	En _{2.5}
ol	En _{10.0}	En _{9.3}	En _{8.6}	En _{10.5}	En _{9.5}	En _{8.0}	En _{8.4}	En _{10.4}	En _{10.0}	En _{8.8}	En _{7.6}	En _{9.2}	En _{11.1}	En _{9.4}	En _{9.2}	En _{11.8}	En _{2.1}	En _{8.9}	En _{8.0}	En _{16.3}	En _{6.8}
ol	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.0}	Fe _{0.6}	Fe _{0.6}	Fe _{1.5}	Fe _{1.2}	Fe _{2.6}
	Trace Elements (ppm)																				
Co	23	21	21	23	23	18	23	33	18	18	21	23	23	21	21	21	11	21	30	27	34
Cr	32	28	27	55	56	53	40	48	36	50	42	28	61	44	20	52	20	57	37	96	13
Ni	41	38	37	44	44	43	38	44	45	43	39	40	49	42	37	46	40	37	33	74	32
Cu	97	157	87	112	128	116	118	125	169	95	118	112	198	96	99	103	195	115	129	126	215
Zn	87	107	89	88	98	88	80	119	108	81	81	83	106	85	131	79	131	92	81	117	107
Rb	14	23	20	14	16	24	19	32	8	18	16	17	17	8	26	16	1	2	1	3	3
Sr	529	462	507	422	434	370	390	411	467	430	402	543	443	426	565	427	609	445	505	543	508
V	239	213	235	262	230	230	235	316	200	222	240	259	241	211	205	216	345	213	298	203	410

FeO* = Total Fe.

element concentrations were determined on single samples. Normative mineralogy was calculated for all samples chemically analyzed. Fortran program "NORM" was used and norm values are given in Table 1. The computation of Fe^{2+} and Fe^{3+} in the normative calculations utilized the ratio of $0.24 = \text{Fe}^{3+}/\text{Fe}$ total for average gabbro as reported by Nockolds (1954).

Analysis of Reference Material

Five standards were utilized in the analyses: BHVO-1, BCR-1, WS-1000, AGV-1 and a high Mg silicate standard prepared by the author. BHVO-1 (a Hawaiian basalt USGS reference standard), AGV-1 (an andesite USGS reference standard) and BCR-1 (a Columbia River basalt USGS reference standard) were analyzed 10 times each by the same method used to prepare rock samples for the analysis of major elements. BHVO-1, AGV-1 and WS-1000 (an amphibolite) were prepared in triplicate by the same method followed in the preparation of rock samples for trace element analysis. The high Mg silicate standard was prepared using standard element reference materials in order to more closely match some highly magnesian samples to avoid interferences which might arise due to matrix differences between standards and samples. The composition of this standard is given in the Appendix (Table A-1).

For each element analyzed, the standard that most closely matched the concentration of that element in the samples was used. To determine if the instrument were stable and in proper working order and for a check of analytical accuracy, standards were analyzed against one another. BHVO-1, AGV-1 and BCR-1 were analyzed for major and minor elements, and BHVO-1, AGV-1 and WS-1000 were analyzed for trace elements. For each element, the standards with the highest and lowest concentration of that element were analyzed as known values and the standard with the intermediate composition was analyzed as an unknown. Comparisons of analyzed standards that were examined as unknowns with published values are given in Table 3.

Total weight percent oxides of B1 samples (Tables 1 and 2) range from 97.4% to 101.9% and B2 samples range from 95.8% to 102.2%. These totals do not include water, because this was not analyzed. Because water may be a significant phase in gabbroic rocks, it was necessary to obtain a rough estimation of the water content in order to assess the integrity of the analyses, i.e., to determine if the oxides (including water) added to approximately 100%. The water content in each sample was estimated by totalling the water content of all hydrous minerals present in the rock, such as hornblende, biotite, epidote, serpentine and chlorite. The volume percent of each hydrous mineral in each sample was

Table 3. Assessment of Accuracy.

	Standard Identification ¹	Average Value Reported ²	Values from This Study	% Error
<u>Major and Minor Oxides (wt. %)</u>				
SiO ₂	BCR-1	54.05	54.5	+0.8
Al ₂ O ₃	BCR-1	13.43	13.7	+2.0
TiO ₂	BHVO-1	2.66	2.70	+1.5
FeO*	BCR-1	12.69	13.5	+6.4
MgO	BCR-1	3.49	3.28	-6.0
CaO	BCR-1	6.97	6.95	-0.3
Na ₂ O	BCR-1	3.35	3.31	-1.5
K ₂ O	BCR-1	1.31	1.68	+28.2
MnO	BCR-1	0.16	0.17	+6.3
<u>Trace Elements (ppm)</u>				
Co	WS-1000	39.8	36	-9.6
Cu	WS-1000	121.6	126	+3.6
Cr	WS-1000	289.2	290	+0.3
Ni	WS-1000	54.5	66	+21.1
Zn	WS-1000	76.1	83	+9.1
Rb	BHVO-1	6.0	8	+33.3
Sr	BHVO-1	335.6	326	-2.9
V	WS-1000	216.7	230	+6.1

¹BCR-1--Columbia River Basalt
 BHVO-1--Hawaiian Basalt
 WS-1000--Amphibolite

²All values in BCR-1 from Flanagan (1969); BHVO-1 from Flanagan et al. (1976); WS-1000 from S. H. Stow (pers. comm., 1983).

converted to weight percent, and that number was multiplied by the weight percent of water in each mineral using water contents from Deer et al. (1965) were used. This number was the estimated percentages of water in the rock for that mineral. The percentage of water in each mineral were added together to give the total water content of each sample. The water contents were estimated to be between 0.39% and 2.80% for B1 samples and between 0.03% and 0.65% for B2 samples. This produces somewhat high totals (98.9%-103.0%) for B1 samples, but the totals for B2 samples (96.2%-102.4%) are closer to 100%.

Assessment of Precision

To assess the precision of major and minor oxide analyses, ten replications of sample 293 were analyzed for each oxide. Eight replicate analyses of sample 274 were made to assess the precision of trace element analyses. The results of this test along with the mean concentration and standard deviation of each oxide or element of the sample analyzed are in Table 4. Precision is defined in terms of the standard deviation divided by the mean (coefficient of variation). For major and minor oxides, all analyses have a coefficient of variation of less than 0.05 for the ten replicate analyses. All trace element analyses, except for Rb, have a coefficient of variation of less than 0.08 for

Table 4. Assessment of Analytical Precision.

	Mean (wt. %) ¹	Mean (ppm) ²	σ	σ/Mean
SiO ₂	55.2	-	0.2	0.00
Al ₂ O ₃	16.8	-	0.12	0.01
TiO ₂	0.76	-	0.01	0.01
FeO*	9.63	-	0.14	0.02
MgO	4.29	-	0.02	0.01
CaO	7.54	-	0.12	0.02
Na ₂ O	3.14	-	0.01	0.00
K ₂ O	0.76	-	0.01	0.01
MnO	0.16	-	0.01	0.05
Co	-	48	1	0.02
Sr	-	408	18	0.04
Ni	-	69	3	0.04
Cr	-	13	1	0.08
V	-	429	10	0.02
Rb	-	2	1	0.50
Zn	-	96	4	0.04
Cu	-	208	2	0.01

¹Ten replicate analyses of No. 293.

²Eight replicate analyses of No. 274.

the eight replicate analyses. The analysis of Rb is precise to 0.50. However, this value is misleading due to the fact that the mean concentration of Rb is extremely small (2 ppm); thus, even a minute error of 1 ppm is statistically significant.

CHAPTER III

GEOCHEMISTRY

Discriminant Analysis

A discriminant analysis was utilized to determine (1) if the two intrusions within the Barber complex were geochemically distinct from each other, and (2) how well geochemistry correlates with petrology, i.e., is the geochemical classification of samples as B1 or B2 the same as the petrological classification of Clark (1980).

The Statistical Analysis System (SAS) "PROC DISCRIM" discriminant analysis (Barr et al., 1976) was used. This program first generates a pooled within-group correlation matrix. On the basis of this matrix, the pairwise squared distance between the groups was calculated using the following equation:

$$D^2(I/J) = (\bar{X}_I - \bar{X}_J) \cdot \text{COV}^{-1} (\bar{X}_I - \bar{X}_J) - 2 \text{LN PRIOR}_J(1)$$

where

D = the pooled covariance matrix,

I, J = subscripts to distinguish the groups,

$\bar{X}_{I,J}$ = the vector of means of the variables being analyzed,

PRIOR = prior probability that a sample falls in a group.

The prior probabilities are given in Table 5. The pairwise squared distance between groups, a measure of how distinct the groups are, is given in Table 6.

A linearized discriminant function was obtained for each group using equations 2 and 3,

$$\text{CONSTANT} = -.5 \bar{X}_J \cdot \text{COV}^{-1} \bar{X}_J + \text{LN PRIOR}_J \quad (2)$$

$$\text{COEFFICIENT VECTOR} = \text{COV}^{-1} \bar{X}_J \quad (3)$$

The results are reported in Table 7. To test the effectiveness of the discriminant function, the oxide or element values were substituted into each of the two equations in Table 7. These values were subsequently normalized to unity, providing probability membership functions (Tables 8 and 9) which are illustrated in Figure 3. In this figure, samples that plot to the left of 0.5 on the horizontal axis are classified into group 1 (B1) and samples that plot to the right of 0.5 are classified as group 2 (B2). Figure 3 illustrates that the discriminant analyses of major and minor oxides and trace elements effectively subdivide the complex into discrete well-defined groups, although a few samples are transitional in composition. In addition, the geochemical classification of samples as B1 or B2 generally correlates closely with the petrological classification (Clark, 1980). According to the statistical analysis for

Table 5. Prior Probabilities for Discriminant Analysis.

Group	Frequency	Prior Probability
B1	21	0.43137
B2	29	0.56863
Total	50	1.00000

Table 6. Generalized Squared Distance to Group.

From Group	B1	B2
<u>Major and Minor Elements</u>		
1	1.68157	5.45180
2	6.00431	1.12906
<u>Trace Elements</u>		
1	1.68157	4.06716
2	4.61967	1.12906

Table 7. Linearized Discriminant Functions.

	B1	B2
<u>Major and Minor Elements</u>		
Constant	-3650.29735	-3598.54382
SiO ₂	69.65986	69.04080
Al ₂ O ₃	69.66722	69.30013
TiO ₂	188.75854	187.52972
FeO*	58.96918	58.97010
MgO	74.32080	74.10819
CaO	83.38085	83.06199
Na ₂ O	142.88584	142.35139
K ₂ O	175.49761	170.78035
MnO	-11.64944	-41.63467
<u>Trace Elements</u>		
Constant	-58.12671	-61.41526
Co	0.52339	0.60048
Cr	0.06905	0.07513
Ni	0.10513	0.12011
Cu	-0.00409	-0.00849
Zn	0.30373	0.27406
Rb	0.98403	0.90097
Sr	0.08539	0.09021
V	0.04864	0.05568

Table 8. Discriminant Analysis of Major and Minor Elements.

Sample Number	Petrological Classification (Clark, 1980)	Geochemical Classification ¹	Posterior Probability Membership Function	
			B1	B2
197	B1	X	0.9820	0.0180
249	B1	X	0.9018	0.0982
324	B1		0.0259	0.9741
388	B1		0.0149	0.9851
435	B1		0.0047	0.9953
314	B1		0.0155	0.9845
128	B1		0.1691	0.8309
191	B1	X	0.6250	0.3750
279	B1		0.0179	0.9821
303	B1	X	0.6485	0.3515
306	B1		0.0080	0.9920
315	B1		0.0110	0.9890
317	B1		0.0006	0.9994
318	B1		0.1333	0.8667
331	B1		0.0105	0.9895
346	B1		0.0168	0.9832
348	B1		0.1559	0.8441
350	B1		0.0182	0.9818
357	B1		0.0676	0.9324
362	B1		0.2488	0.7512
363	B1	X	0.9073	0.0927
378	B1		0.0384	0.9616
381	B1		0.1804	0.8196
389	B1		0.0254	0.9746
390	B1		0.0211	0.9789
393	B1		0.0865	0.9135
404	B1		0.1222	0.8778
408	B1		0.2495	0.7505
439	B1		0.0412	0.9588
103	B2		0.9670	0.0330
106	B2		0.9709	0.0291
118	B2		0.9588	0.0412
12	B2		0.8926	0.1074
89	B2		0.8141	0.1859
208	B2		0.9800	0.0200
213	B2		0.9615	0.0385
46	B2		0.8958	0.1042
160	B2		0.8701	0.1299
231	B2		0.9434	0.0566
260	B2		0.9575	0.0424
293	B2		0.9045	0.0955
45	B2		0.8419	0.1581
67	B2		0.7850	0.2150
96	B2		0.8601	0.1399
246	B2		0.8238	0.1762
184	B2	X	0.2491	0.7509
10	B2		0.8828	0.1172
161	B2		0.5780	0.4220
175	B2		0.6704	0.3252
416	B2	X	0.3824	0.6176

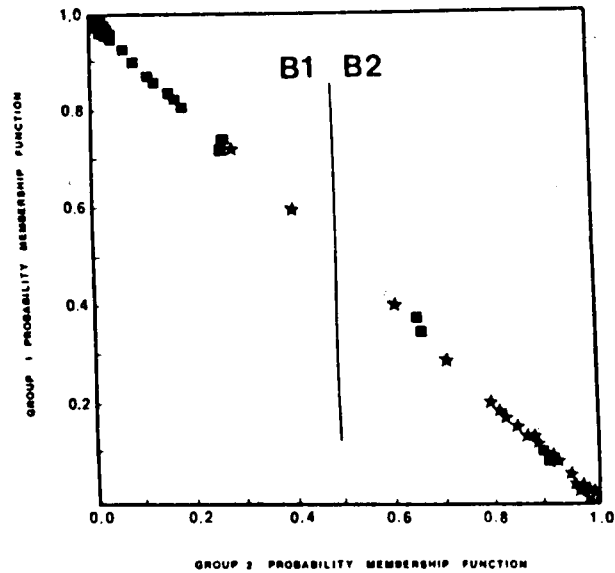
¹X indicates a different assignment from the petrological classification.

Table 9. Discriminant Analysis of Trace Elements.

Sample Number	Petrological Classification (Clark, 1980)	Geochemical Classification ¹	Posterior Probability Membership Function	
			B1	B2
197	B1	X	0.9857	0.0143
249	B1	X	0.8600	0.1400
324	B1		0.0061	0.9939
388	B1		0.0653	0.9347
435	B1		0.0161	0.9839
314	B1		0.2345	0.7655
128	B1		0.1848	0.8152
191	B1		0.3559	0.6441
279	B1		0.0683	0.9317
303	B1		0.2686	0.7314
306	B1		0.0250	0.9750
315	B1		0.0302	0.9698
317	B1		0.0205	0.9795
318	B1		0.1265	0.8735
331	B1		0.1124	0.8876
346	B1		0.0610	0.9390
348	B1		0.1145	0.8855
350	B1	X	0.9004	0.0996
357	B1		0.2899	0.7101
362	B1		0.2612	0.7388
363	B1	X	0.5754	0.4246
378	B1		0.0206	0.9794
381	B1		0.1028	0.8972
389	B1		0.0173	0.9827
390	B1		0.1314	0.8686
393	B1		0.0877	0.9123
404	B1		0.1743	0.8257
408	B1		0.1721	0.8279
439	B1		0.2186	0.7814
103	B2		0.6572	0.3428
106	B2		0.9519	0.0481
118	B2		0.8239	0.1761
12	B2		0.7141	0.2859
89	B2		0.8335	0.1665
208	B2		0.9341	0.0659
213	B2		0.8382	0.1618
46	B2		0.9116	0.0884
160	B2		0.8825	0.1175
231	B2		0.8374	0.1626
260	B2		0.8114	0.1886
293	B2		0.6634	0.3366
45	B2		0.8822	0.1178
67	B2		0.7002	0.2998
96	B2		0.9650	0.0350
246	B2		0.7715	0.2285
184	B2		0.7669	0.2331
10	B2		0.6299	0.3701
161	B2	X	0.1602	0.8398
175	B2	X	0.4381	0.5619
416	B2	X	0.2994	0.7006

¹X indicates a different assignment from the petrological classification.

a) Major and Minor Elements



b) Trace Elements

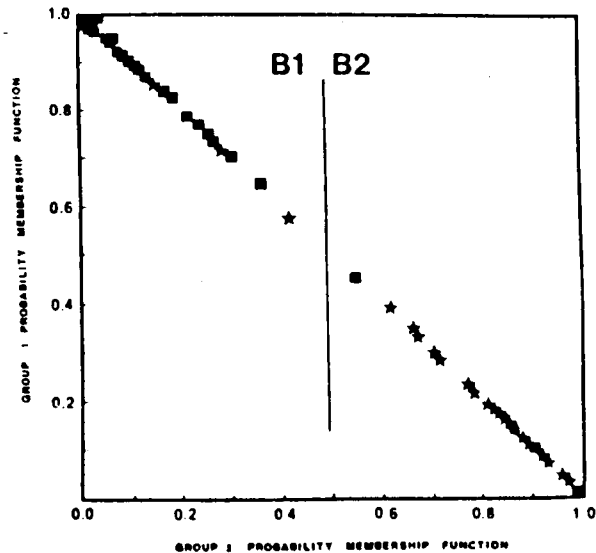


Figure 3. Group 1 and Group 2 probability membership function variations in B1 and B2 samples. Symbols as in Figure 2, p. 9.

major elements, samples 184 and 416 of the B2 unit geochemically resemble the B1 unit, and samples 191, 303, 197, 249 and 363 of the B1 unit geochemically resemble the B2 unit. B2 samples 175 and 161 appear to be borderline. For trace elements, B2 samples 161, 175 and 416 and B1 samples 197, 249, 350 and 363 are geochemically more comparable to the adjacent pluton. Samples 103, 293 and 10 of the B2 unit and 191 of the B1 unit are borderline samples. If both major and trace element probability membership functions are considered, only B2 samples 416, 161 and 175 and B1 samples 191, 197, 249 and 363 are assigned to the wrong group. The statistical analysis could not consistently discriminate B1 samples 350 and 303 and B2 sample 184 as belonging to either group.

With the exception of one sample (350), all of the 10 samples that, according to the statistical analysis, are more similar geochemically to the other pluton or could not be conclusively discriminated as resembling either group, are located at or near the B1/B2 contact set by Clark (1980) (Figure 2, p. 9). This suggests that the chemical composition of the 9 samples at the contact may be a product of assimilation or metasomatism produced during the second intrusive episode.

To test for the effect of metasomatism, mobile and immobile elements were examined in the questionable samples.

Immobile elements were considered to be Ti, Fe, Ni and Cr (Field and Elliot, 1974; Elliot, 1974; Wood et al., 1976; Dickin and Jones, 1983). All other elements were regarded as possibly mobile. It was assumed that if the immobile elements in B2 samples generally clustered with other B2 samples while the mobile elements in B2 samples consistently clustered with B1 samples, metasomatism might have occurred. The same relationship was examined in B1 samples. For all elements of the 9 samples, the trends of B1 and B2 overlapped over the FeO^*/MgO ratio examined; thus, the effect of metasomatism could not be resolved.

However, there is evidence for assimilation in anomalous samples of the B2 unit. These samples display intermediate compositions between B1 and B2 samples and contain xenoliths that mineralogically and texturally resemble the B1 lithology or large corroded plagioclase grains that may represent undigested B1 xenocrysts. However, there is no petrographic evidence that assimilation occurred in the B1 unit. Anomalous B1 samples do not contain xenoliths or xenocrysts or display intermediate compositions. In fact, sample 197 displays the highest SiO_2 content (60.0%) and 363 displays the lowest MgO content (3.59%) of any sample in either the B1 or B2 units (Table 1, p. 10).

Fine-Grained Samples

Clark (1980) noted that several samples from both units exhibit a much finer-grained texture than the large majority of samples from the complex. The grain diameter of the finer-grained samples (determined in this study) ranges from 0.10 to 0.50 mm; the more typical samples within the complex range from 0.75 to 2.5 mm. Four of the fine-grained samples are from the B1 unit (numbers 128, 274, 331 and 348) and four are from the B2 unit (numbers 10, 161, 184 and 416). Sample locations of these samples are shown in Figure 2 (p. 9).

B1 sample 274 contains plagioclase, hornblende and opaques. Hornblende and plagioclase show a strong foliation which resembles amphibolite, and the fine-grained texture in this sample may result from amphibolitization (Clark, 1980). B1 sample 348 contains plagioclase, orthopyroxene, clinopyroxene, hornblende, opaques, epidote and hematite. Texture varies from relict igneous to highly altered and is characterized by poikilitic and fibrous amphibole and rounded epidote "rosettes." B1 sample 128 is extremely fine-grained (0.1 mm) and contains plagioclase, orthopyroxene, clinopyroxene, hornblende, quartz, opaques, apatite, chlorite, epidote and hematite. Relict igneous layering is displayed by aligned plagioclase grains. Stringers or pods of larger-grained plagioclase, pyroxene

and hornblende (greater than 0.75 mm) occur. B1 sample 329 consists primarily of plagioclase, hornblende, orthopyroxene and clinopyroxene and minor amounts of opaques, hematite and chlorite. Abundant plagioclase glomerocrysts and poikilitic amphibole characterize this sample.

The fine-grained samples from the B2 unit show a close mineralogical and textural similarity to each other. All consist primarily of plagioclase, orthopyroxene and clinopyroxene and contain minor amounts (less than 3%) of biotite, quartz, opaques, hematite, apatite and chlorite. The abundance of hornblende ranges from 1.3% to 15.0%. All samples anhedral to subhedral granular to inequigranular textures. Sample 184 has a slightly smaller grain size than other fine-grained B2 samples and is the only B2 sample to show relict igneous layering displayed by aligned plagioclase grains. B2 sample 416 contains xenoliths mineralogically and texturally resembling the B1 lithology.

Clark (1980) believed that these relatively fine-grained rocks crosscut the more dominant coarser-grained rocks and represent multiple periods of magma injection. However, it is significant that six of the eight fine-grained samples (B2 samples 10, 161, 184, and 416 and B1 samples 128 and 274) are from the B1/B2 contact area, suggesting that these finer-grained rocks might denote a chill margin or contact metamorphosed rind.

Texturally, the four fine-grained samples of the B2 unit appear more to be igneous than metamorphic. Therefore, these samples may be a chilled border to the B2 unit. Sample 128 of the B1 unit is mineralogically and texturally dissimilar to the B2 samples, although it also appears to be more igneous than metamorphic in character. However, because the B1 unit was intruded before the B2 unit based on age dates, this sample could not represent a chilled contact. Therefore, this sample may have been contact metamorphosed upon intrusion of the B2 unit or may indicate the occurrence of multiple periods of magma injection in the B1 unit as suggested by Clark (1980). Sample 274 lies near the B1/B2 contact and near the contact of the Barber and a granitic pluton, inferred by Clark (1980) to be the Landis pluton. This sample is highly altered and has only metamorphic mineralogy and texture. The Churchland and Landis plutons are believed to have been emplaced at about 300 mya (Butler and Fullagar, 1978; Fullagar, 1971), after the emplacement of the Barber complex. Therefore, the fine-grained texture of this sample may result from contact metamorphism by these granites. Alternatively, it may have been metamorphosed upon intrusion of the B2 unit, resulting in the fine-grained texture.

Because of the location of samples 329 and 348 in the interior of the B1 unit, the fine-grained texture exhibited

by these samples cannot be related to the intrusion of the Churchland or Landis plutons or the B2 unit into the B1 unit. Furthermore in sample 329, metamorphism has not obscured relict igneous textures, and thus, contact metamorphism was not responsible for the finer grain size in this sample. Therefore, the fine-grained texture may have resulted from multiple intrusive activity within the B1 unit as suggested by Clark (1980). This sample was not analyzed geochemically, so its composition cannot be compared with other B1 samples to support this conclusion.

If the fine-grained samples of the B2 unit represent a chilled margin, their compositions should be an approximate reflection of the liquid composition of the magma from which they crystallized. Therefore, these samples should contribute valuable information concerning the nature of the parental magma. However, as discussed previously, the compositions of samples 161, 184 and 416 (3 of the 4 fine-grained samples found in the B2 unit) may have been altered by assimilation of B1 lithology. The fourth fine-grained sample (number 10) also contains large corroded plagioclase grains that may represent undigested xenocrysts of the B1 unit; thus, the composition of this sample may have been modified by assimilation also. If the composition of these fine-grained samples reflects assimilation of B1 lithology, no information can be obtained concerning parental liquids.

Geochemical Variations Between Units

The variations of major and minor element oxides and trace elements were plotted against FeO^*/MgO (Figure 4), commonly taken as an approximate indicator of fractionation (Miyashiro, 1973). Fine-grained samples, discussed in the previous section, are distinguished by open symbols in the figure.

In the B1 intrusion, the trends of FeO^* , Na_2O , V and Co show some variability, but they increase; TiO_2 , Sr and Zn increase slightly as FeO^*/MgO increases. MgO decreases markedly, and CaO, Ni and Cr show variability, but they also decrease markedly as FeO^*/MgO increases. Values of SiO_2 , Al_2O_3 , MnO, K_2O and Rb are approximately constant, and Cu appears random as FeO^*/MgO increases.

As FeO^*/MgO increases in B2 samples, few strong trends are evident, possibly due to the small range in FeO^*/MgO ratios in B2 samples. TiO_2 , K_2O , Na_2O , V and Sr increase slightly, and SiO_2 increases only fractionally as FeO^*/MgO increases. MgO decreases, Ni and Cr decrease very slightly and CaO displays a large degree of variance but tends to decrease also as FeO^*/MgO increases. The distributions of FeO^* , Rb, Zn and Cu are variable, and Al_2O_3 , MnO and Co show no variation as FeO^*/MgO increases. B1 samples are generally higher than are B2 samples in those elements that are concentrated in the early crystallizing fractions of a

Figure 4. Oxide and trace element variations of the Barber complex plotted against FeO^*/MgO . B1 samples (squares) generally have lower FeO^*/MgO ratios and lower amounts of incompatible elements compared with B2 samples (stars). Samples were classified by Clark (1980) based on petrology. Fine-grained samples are designated with unfilled symbols. Major and minor oxides are reported in weight percent. Trace elements are reported in ppm. Total Fe is reported as FeO^* .

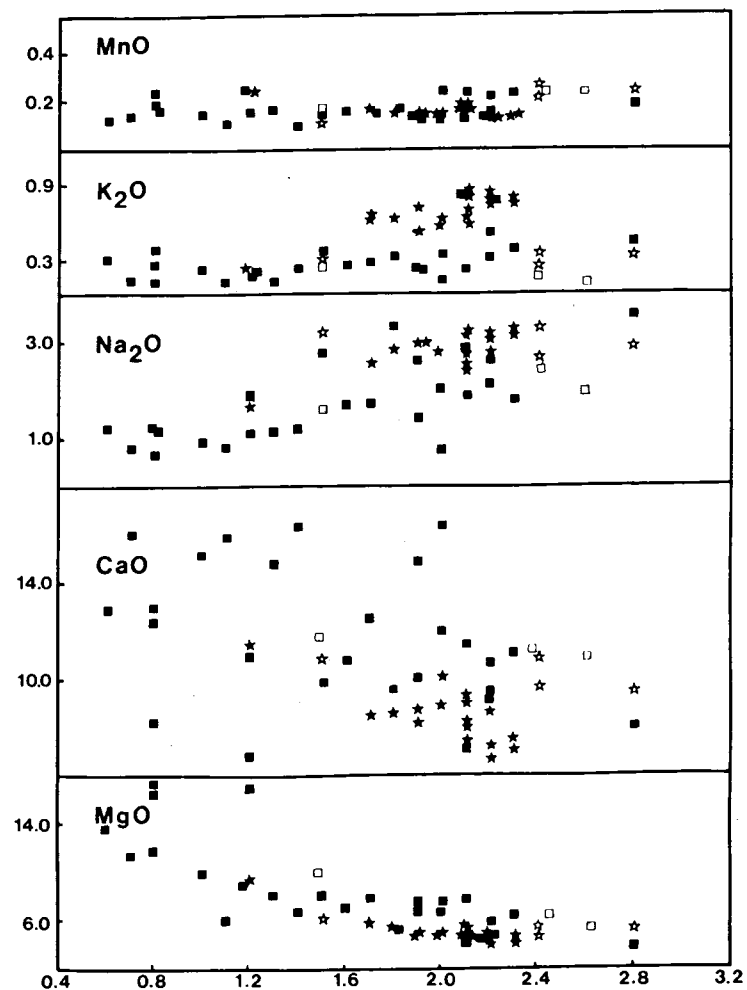
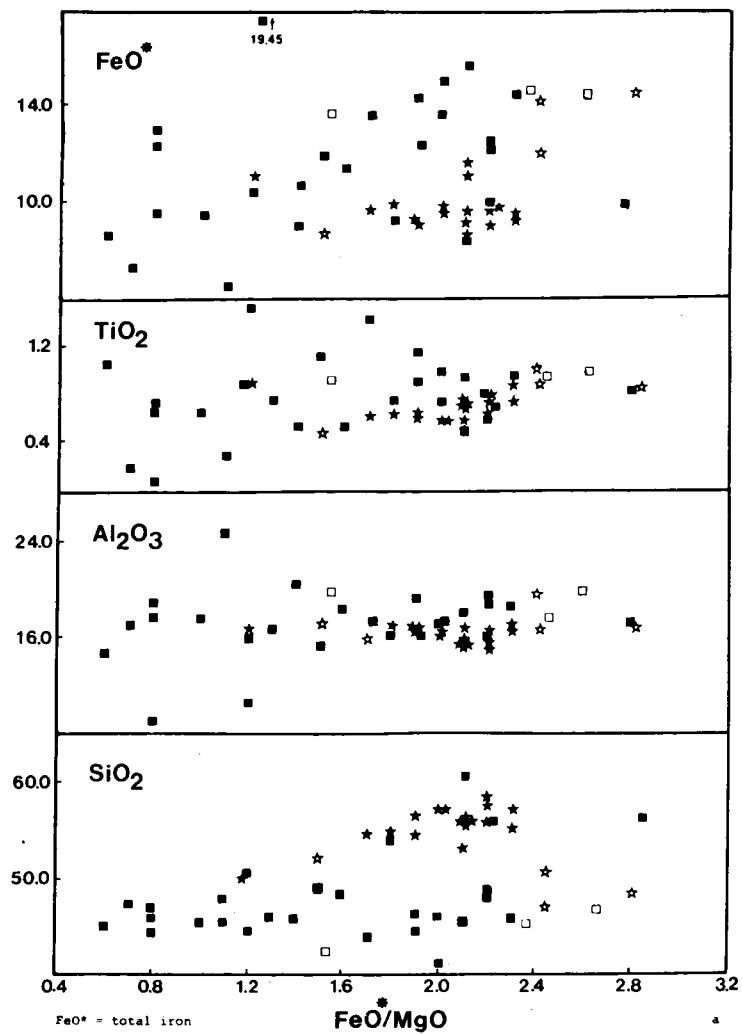


Figure 4.

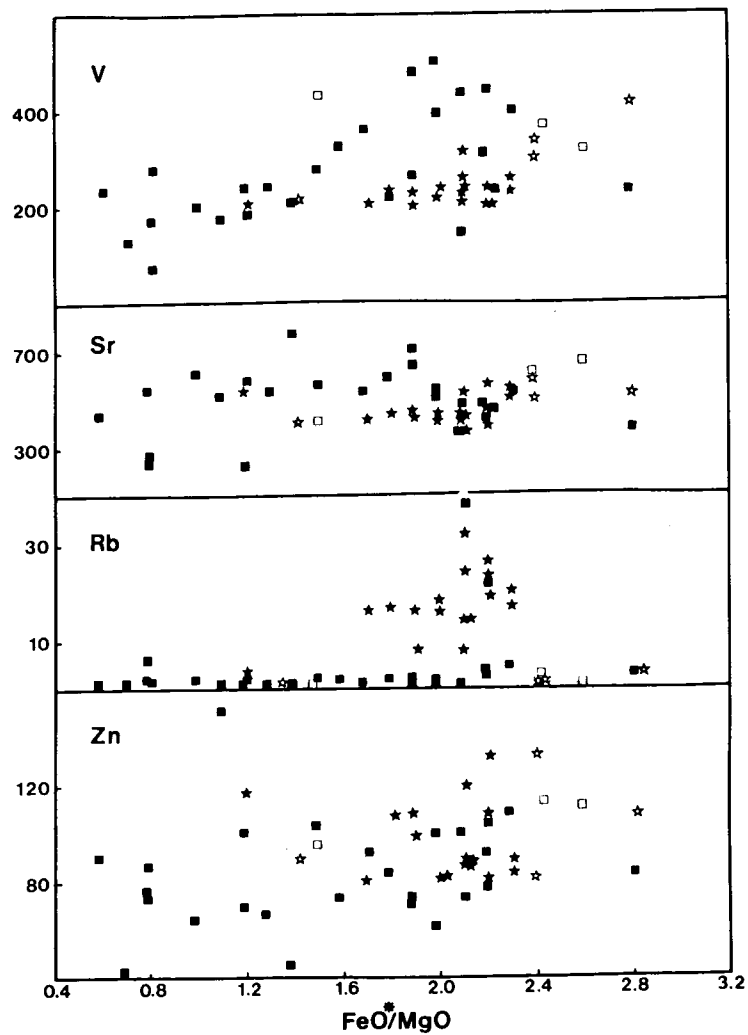
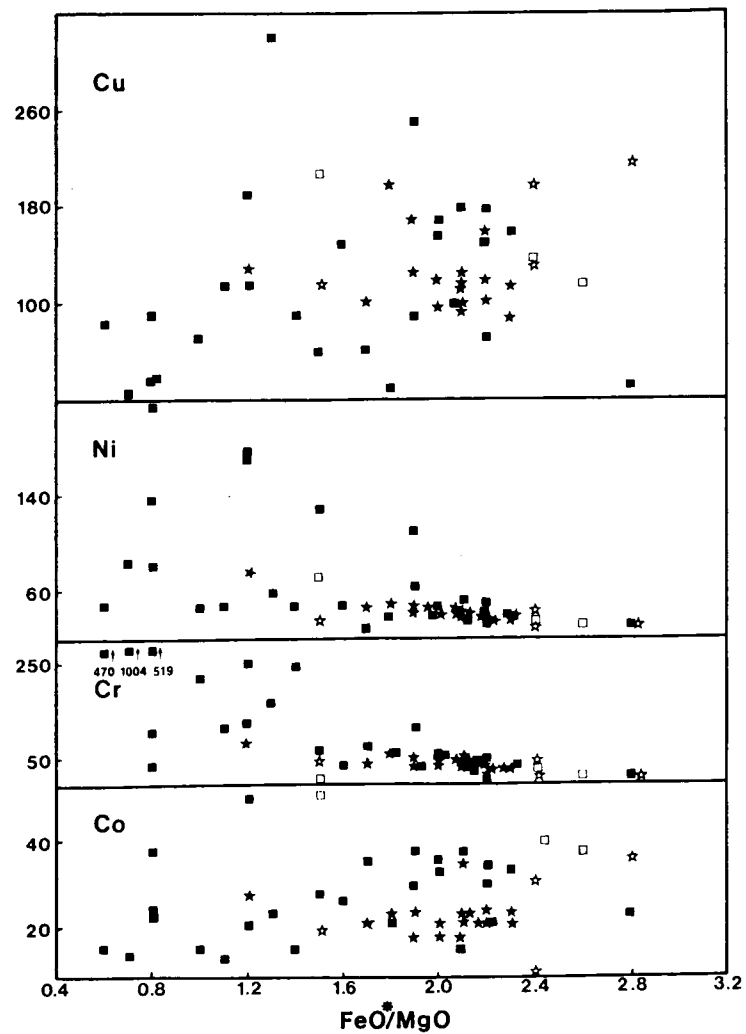


Figure 4 (continued).

melt (MgO, CaO, Cr and Ni). However, a few B1 samples contain unusually low amounts of these elements. B2 samples are generally higher than are B1 samples in those elements that are concentrated in the late fractions of a crystallizing melt (SiO_2 , Na_2O , K_2O and Rb). A few B2 samples contain unusually low amounts of these elements. In addition, for many elements and oxides the distribution of B1 and B2 samples tends to be different (SiO_2 , K_2O , Na_2O , Co and Rb), while for other elements, the distributions of B1 and B2 samples broadly overlap.

From Figure 4, it is difficult to determine if there are significant differences between B1 and B2 samples for many elements and oxides analyzed. For this reason, a Statistical Analysis System (SAS) "PROC TTEST" (Barr et al., 1976) was utilized to determine the similarity of the means of each element or oxide in the B1 and B2 sample populations. The discriminant analysis, as discussed previously, demonstrated that when all elements are considered simultaneously the two intrusions are geochemically distinct. The t-test demonstrates which elements, considered separately, are most different between the two intrusions. Table 10 lists, for each oxide or element analyzed, the mean, standard deviation and "probability > F", i.e., the probability that the means of the two groups are statistically different at the 95% confidence level. K_2O and SiO_2 show the greatest probability of difference between the two groups for major and minor

Table 10. t-Test of Major, Minor and Trace Elements between B1 and B2.

Oxide or Element ¹	Unit	N	Mean	Standard Deviation	Prob > F'
SiO ₂	B2	21	54.3	3.2	0.2533
	B1	29	47.3	4.1	
Al ₂ O ₃	B2	21	16.5	1.0	0.0001
	B1	29	17.3	2.8	
TiO ₂	B2	21	0.7	0.1	0.0001
	B1	29	0.8	0.3	
FeO*	B2	21	10.3	1.6	0.0108
	B1	29	11.9	2.9	
MgO	B2	21	5.1	1.1	0.0001
	B1	29	8.3	3.7	
CaO	B2	21	8.7	1.3	0.0011
	B1	29	11.6	2.8	
Na ₂ O	B2	21	2.8	0.4	0.0003
	B1	29	1.8	0.8	
K ₂ O	B2	21	0.6	0.2	0.5586
	B1	29	0.3	0.2	
MnO	B2	21	0.2	0.0	0.1619
	B1	29	0.2	0.1	
Co	B2	21	22.6	5.1	0.0065
	B1	29	27.6	9.5	
Cr	B2	21	42.6	18.4	0.0001
	B1	29	140.5	208.5	
Ni	B2	21	42.2	8.4	0.0001
	B1	29	70.4	49.3	
Cu	B2	21	124.3	42.6	0.0216
	B1	29	118.7	70.8	
Zn	B2	21	97.1	16.8	0.1902
	B1	29	85.5	22.4	
Rb	B2	21	14.2	8.8	0.4818
	B1	29	3.9	7.7	
Sr	B2	21	468.0	63.8	0.0003
	B1	29	489.9	148.1	
V	B2	21	248.7	52.9	0.0013
	B1	29	287.0	109.8	

¹Major and minor oxides are given in weight percent, and trace elements are given in ppm.

element oxides, and Rb and Zn show the greatest probability of difference for trace elements. MgO , TiO_2 , Al_2O_3 , Na_2O , Sr, Ni and Cr show the least probability of a difference between the two units.

Normative Mineralogy

The B1 and B2 units have distinctive normative mineralogies. Most B2 samples are quartz and hypersthene normative, whereas almost all B1 samples are olivine and/or nepheline normative (Tables 1 and 2, pp. 10 and 11, and Figure 5). Fine-grained B2 samples that may have suffered assimilation of B1 xenoliths generally plot outside the quartz tholeiite field.

The normative mineralogy agrees extremely well with the modal mineralogy of the samples. All B2 samples that have less than 1% quartz fall outside the quartz-hypersthene-diopside normative field, and all B1 samples that contain over 1% quartz (with the exception of two samples) fall within this field. No samples contain any modal nepheline, but the presence of minor (less than 6%) Ne in the norm is possibly due to a minor fluctuation of the $\text{Fe}^{2+}/\text{Fe}^{3+}$ ratio or minor Na metasomatism in these samples.

Variation of Mineralogy with Geochemistry

Mineralogy is often heavily obscured by alteration in B1 samples, and thus, correlation of relict mineralogy with

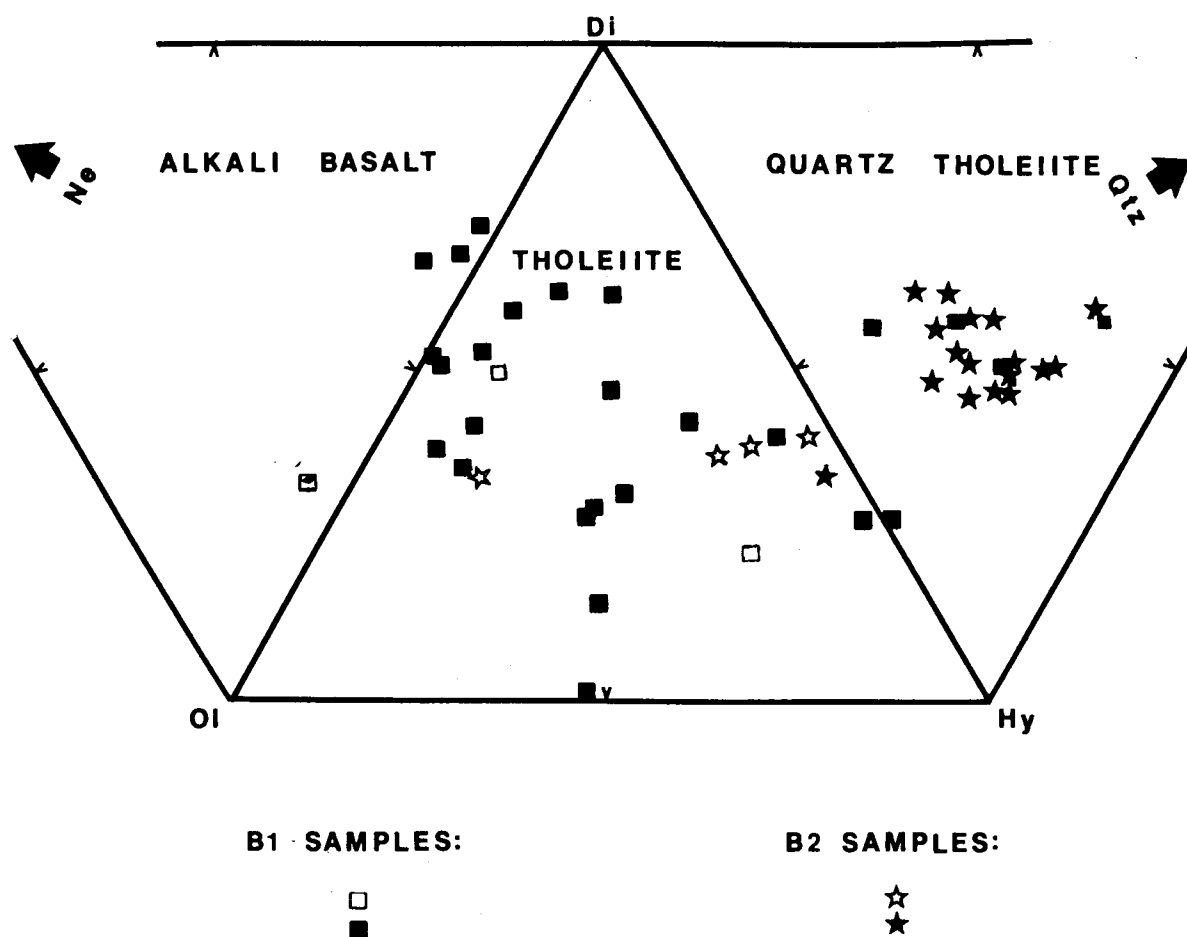
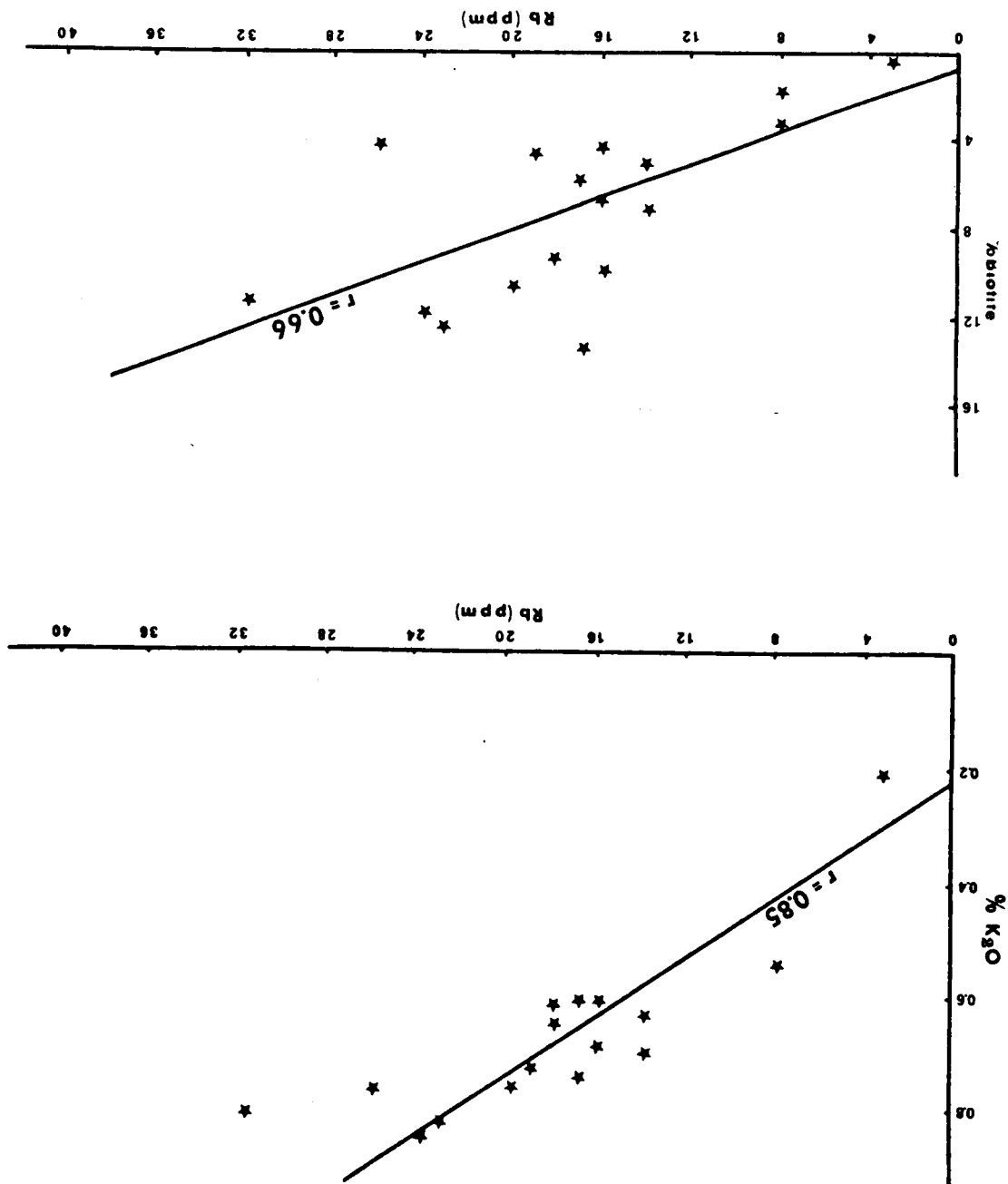


Figure 5. Normative compositions of B1 and B2 samples. Symbols as in Figure 4, p. 32. Most B1 samples fall in the alkali basalt or tholeiite region. Most B2 samples [except fine-grained rocks (open stars)] cluster tightly in the quartz tholeiite region. Fine-grained B2 samples have probably been contaminated by assimilation of B1 xenoliths.

geochemistry is difficult. However, a few relationships are evident. In the B1 unit, rocks generally contain less than 2 weight percent biotite and quartz. However, a few B1 samples contain these phases in abundance, and this is reflected in high concentrations of SiO_2 compared to other B1 samples. The presence of olivine can be correlated with extremely low CaO and Al_2O_3 and high FeO^* and MgO . The presence of olivine is also reflected in the variation of trace elements such as Ni and Cr which are exceptionally high in olivine-rich samples.

In the B2 unit, biotite plus quartz are generally abundant (greater than 10% of the rock), and quartz, biotite and hornblende exhibit the most regular variation over the unit (Clark, 1980). This mineralogy is reflected by the geochemistry in high concentrations of SiO_2 and K_2O compared with B1 samples. A few B2 samples contain only minute (less than 1%) amounts of quartz and biotite, and this is also reflected by the geochemistry in anomalously low concentrations of SiO_2 compared with other B2 samples. The trend of Rb follows that of K_2O and appears to be primarily controlled by biotite crystallization (Figure 6). CaO and Na_2O variations are probably controlled chiefly by plagioclase crystallization.

Figure 6. Variation of Rb (ppm) with K_2O (wt. %) and variation of Rb (ppm) with biotite (vol. %) from Clark, 1980) in the B2 unit.



Variation of Geochemistry with Rock Type

No geochemical correlation could be made with any of the rock types defined by Clark (1980) that occur within the B2 unit. This is probably due to the small degree of mineralogical difference between each rock type. The B1 unit was subdivided on the basis of degree of alteration.

To establish if geochemistry varied regularly with degree of alteration, a t-test was utilized. The means of each oxide or element in olivine hornblende gabbro norite (which exhibits the least degree of alteration of the three rock types within the B1 metamorphosed unit) and Type II metagabbro (which exhibit the greatest degree of alteration of the 3 B1 rock types) (Clark, 1980) were compared using the Statistical Analysis System (SAS) "PROC TTEST" (Barr et al., 1976). For major and minor oxides, MgO, MnO, SiO₂ and Al₂O₃ show a significant difference between olivine hornblende gabbro norite and Type II metagabbro (Table 11). For trace elements, Sr, V, Zn and Cu show a significant difference between the 2 groups (Table 11). High concentrations of MgO may be due to olivine crystallization in olivine hornblende gabbro norite, and high concentrations of Sr and Al₂O₃ may be due to a higher concentration of plagioclase in Type II metagabbro compared with olivine hornblende gabbro norite. However, these elements are often

Table 11. t-Test of Major, Minor and Trace Elements for Olivine Hornblende Gabbronorite and Type 2 Metagabbro.

	Olivine Hornblende Gabbronorite ¹	Type 2 Metagabbro ²	Prob > F'
SiO ₂ ³	45.5	47.5	0.25
Al ₂ O ₃	15.1	17.5	0.25
TiO ₂	0.61	0.84	0.00
FeO*	13.3	11.8	0.01
MgO	15.1	7.55	0.55
CaO	10.3	11.8	0.07
Na ₂ O	0.85	1.90	0.19
K ₂ O	0.12	0.29	0.08
MnO	0.18	0.17	0.49
Co ⁴	32	27	0.07
Cr	413	109	0.00
Ni	158	60	0.09
Cu	84	123	0.38
Zn	72	87	0.38
Rb	1	4	0.01
Sr	200	523	0.84
V	219	295	0.75

¹Mean of 3 samples.

²Mean of 26 samples.

³Major and minor oxides given in weight percent.

⁴Trace elements given in ppm.

mobile and it is possible that metamorphism may have altered the geochemistry, although this cannot be proven conclusively.

Areal Variations

Within the B1 unit, Clark (1980) found no areal variations in mineralogy. The B1 rock types were defined on the basis of degree of alteration. Therefore, because no systematic variation could be observed for the rock types of the B1 unit, no systematic variation could be observed for the degree of alteration over the unit.

Clark (1980) also examined the areal variation of rock types over the B2 unit. He found that the norite, hornblende norite, gabbro-norite and hornblende gabbro-norite of the B2 unit exhibit systematic variations. He also found that within the concentrically zoned B2 unit, there was a systematic variation in hornblende plus biotite and an increase in quartz generally toward the center of the unit.

Major element distributions were examined on an areal basis over the complex to determine if chemical trends varied regularly either over the entire complex or over each unit. MgO and SiO_2 are the only chemical species to exhibit systematic variations (Figure 7). MgO content tends to vary regularly over the entire complex, increasing toward the

Figure 7. Areal geochemical variations in the Barber complex. Lines represent contours in weight percent. (a) SiO_2 generally decreases outward from the center of the B2 unit. No regular variation is observed over the B1 unit. (b) MgO generally increases from the periphery of the complex to the center.

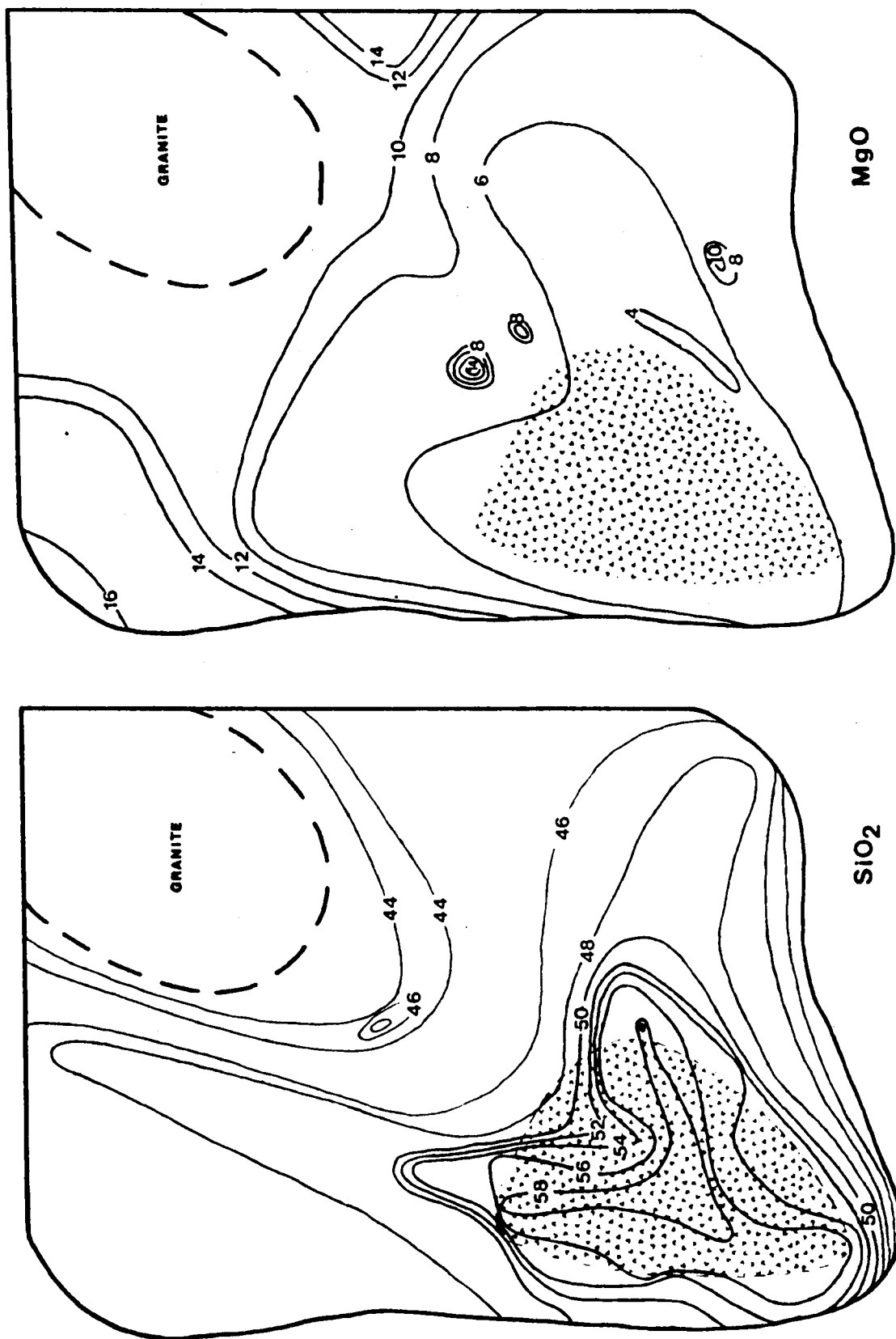


Figure 7.

periphery. SiO_2 exhibits regular variation only over the B2 unit, corresponding to the increase in quartz toward the center of the unit. These systematic variations are probably related to crystallization of the two units from the periphery to the center. The continuity of MgO variation over the complex is probably not significant in light of the differences already established for the two units.

Affects of Accumulation on Geochemistry

Variations in all major and minor oxides and trace elements were previously plotted against FeO^*/MgO (Figure 4, p. 32). However, this differentiation index may not be applicable to nonvolcanic gabbroic rocks due to the possibility of crystal accumulation. In order to test for the geochemical effects of accumulation, the FeO^*/MgO ratio of each rock was examined against the three factors that could possibly control this ratio: (1) the percentage of postcumulus minerals, (2) the FeO^*/MgO ratio in postcumulus minerals, and (3) the FeO^*/MgO ratio in cumulus minerals. The regression lines and r values for each of these variables against the FeO^*/MgO ratio for the samples were calculated and are shown in Figures 8 and 9. The amount of postcumulus minerals is controlled by the amount of interstitial liquid present in a cumulate rock. The interstitial

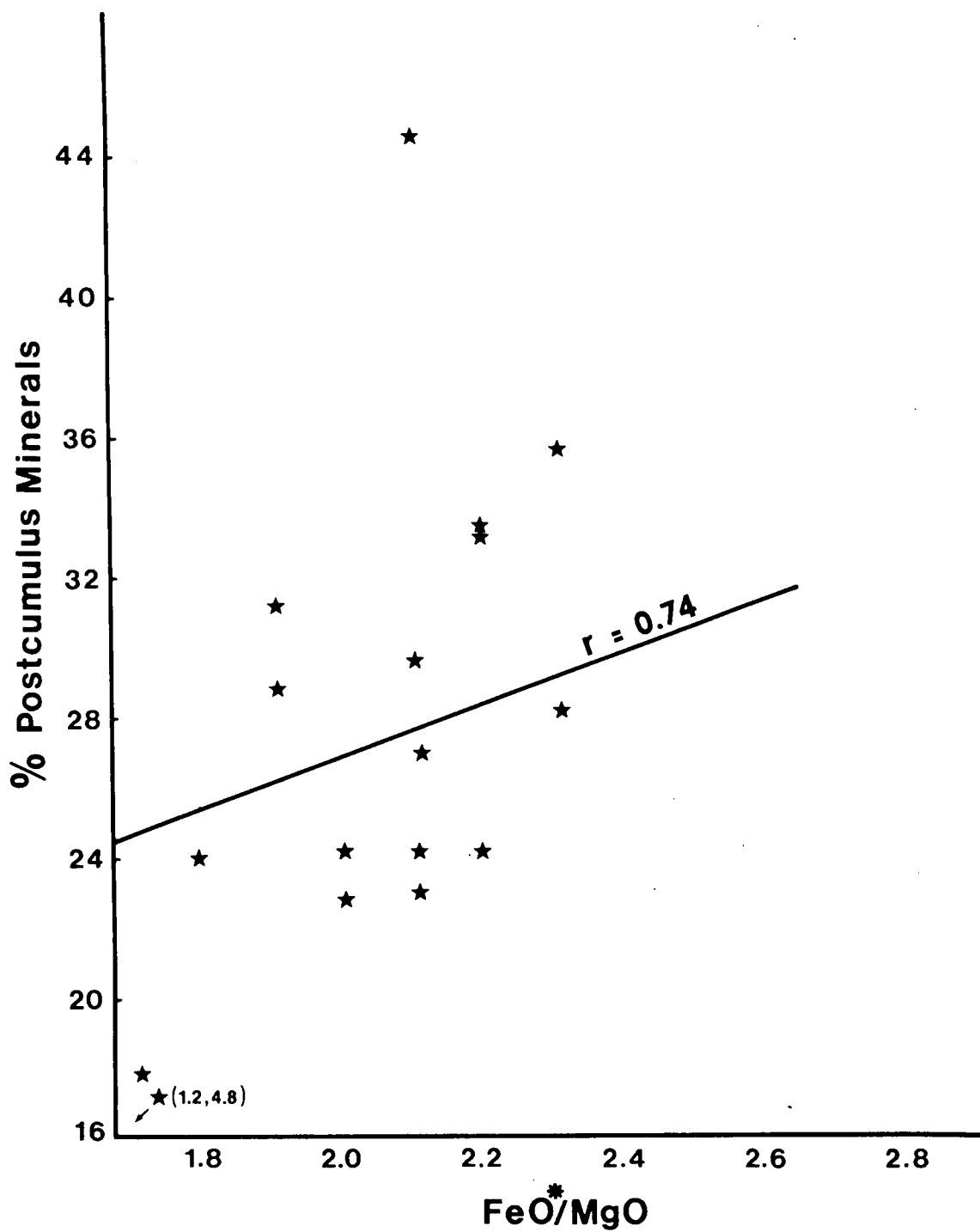


Figure 8. Variation of percent postcumulus mineral phases in unmetamorphosed B2 samples with FeO^*/MgO ratio.

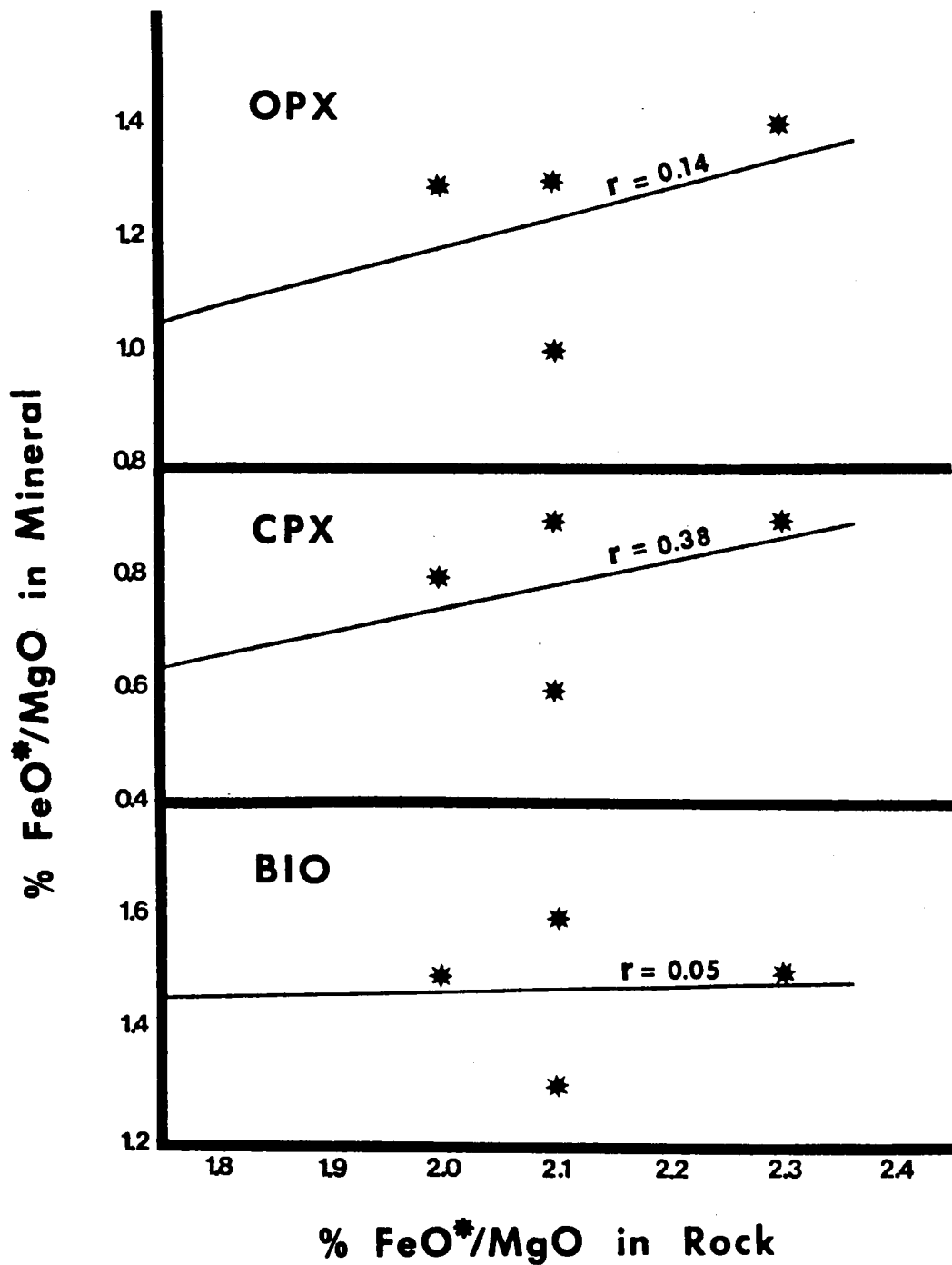


Figure 9. Variation of FeO^*/MgO in cumulus and postcumulus phases in unmetamorphosed B2 samples with FeO^*/MgO ratio in the samples.

liquid may contain a high concentration of FeO^* and thus may strongly affect the FeO^*/MgO ratio of a rock. Because the amount of postcumulus minerals is not a function of degree of fractionation, a good correlation with FeO^*/MgO ratio of the rock and percent postcumulus minerals would indicate that the FeO^*/MgO ratio is not a good differentiation index. However, the FeO^*/MgO ratio in cumulus and postcumulus minerals is controlled by the degree of fractionation. Therefore, a good correlation between FeO^*/MgO in the rock and FeO^*/MgO in either cumulus or postcumulus minerals indicates that the FeO^*/MgO ratio is a good differentiation index.

Clark (1980) presented modal analyses, but did not determine if minerals were cumulus or postcumulus. The determination in this study of minerals as cumulus was defined on textural criteria as used by Wager et al. (1960) and does not imply crystal settling. Minerals, such as plagioclase, orthopyroxene and clinopyroxene, which were not poikilitic or interstitial were considered cumulus. All other minerals were considered postcumulus. Because presumably small percentages of the minerals taken as cumulus also occur as postcumulus phases, these percentages may represent the lower limits of the abundance of postcumulus phases. Samples examined were those that had remained unmetamorphosed and were mineralogically unaltered. Fine-grained samples from the B2 unit were not examined due to

the possibility of assimilation, as discussed earlier. Most samples from the B1 unit were highly metamorphosed, and so this unit was not examined at all.

As shown in Figure 8, the r value of the regression line of the percent postcumulus minerals versus FeO^*/MgO ratio of a rock is +0.74. This is a high correlation and indicates that the FeO^*/MgO ratio is probably controlled by the percent postcumulus minerals present. This implies that accumulation may be important in controlling the FeO^*/MgO ratio, and thus, this may not be a good differentiation index for these samples.

The r values for the FeO^*/MgO ratio in both cumulus (orthopyroxene and clinopyroxene) and postcumulus (biotite) minerals (taken from microprobe analyses by Clark, 1980) versus FeO^*/MgO ratio of the rock are extremely low (Figure 9). However, the three mineral phases which contain FeO and MgO were analyzed in only four B2 samples, and any correlation would be difficult to see from these few data. The good correlation of percent postcumulus minerals with the FeO^*/MgO ratio in the rock suggests that accumulation may strongly influence this ratio.

In order to gain more information concerning the affects of accumulation versus fractionation on the composition of Barber samples, the percentage of $\text{CaO} + \text{MgO}$ was also compared with percent cumulus minerals (Figure 10). This

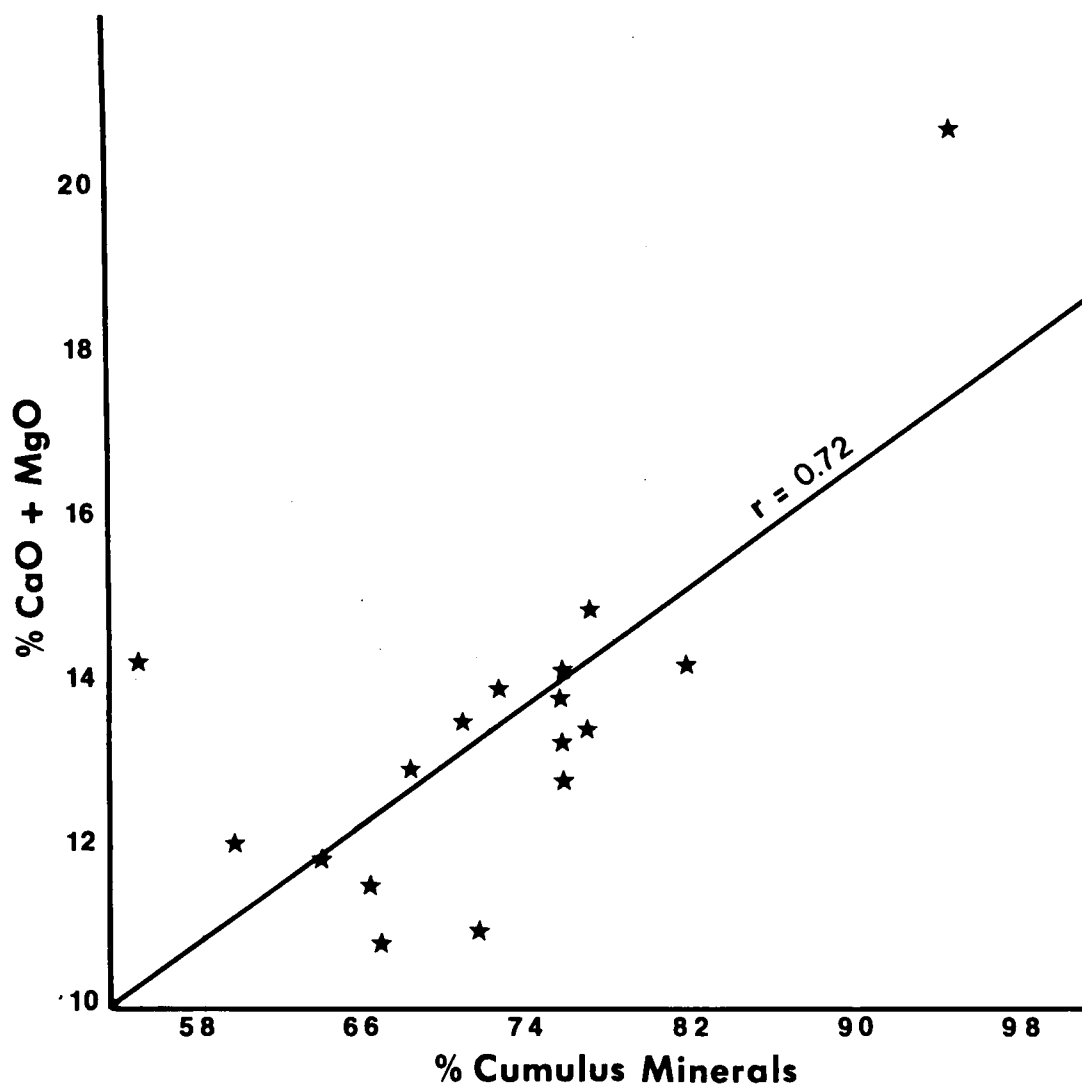


Figure 10. Variation of CaO + MgO (wt. %) with percent cumulus phases in B2 samples.

oxide sum is a commonly used screen to test for crystal accumulation (e.g., Pearce, 1976). The sum of CaO + MgO in most B2 samples falls within the limits of the screen for liquid compositions, i.e., 12-20%. However, a good correlation ($r = 0.72$) between the two factors indicates that CaO + MgO is strongly controlled by the amount of cumulus material in the rock. The graphs of FeO*/MgO versus percent postcumulus minerals and CaO + MgO versus percent cumulus minerals suggest that although fractionation may influence the composition of the Barber samples, accumulation is probably a dominant factor.

Summary of Geochemical Differences Between
the B1 and B2 Units

1. B1 samples generally contain higher amounts of those oxides and trace elements that are more abundant in the early crystallizing fractions of a melt (MgO, CaO, Ni and Cr). B2 samples generally contain higher amounts of oxides and trace elements that are more abundant in the late fractions of a crystallizing melt (SiO₂, Na₂O, K₂O, Rb and Co).
2. The composition of B1 samples is more diverse than that of B2 samples.
3. For many elements and oxides (SiO₂, K₂O, MnO, Zn and Rb) the B1 and B2 values are distinctly different.

4. B2 samples are silica-saturated and contain quartz and hypersthene in the norm, whereas most B1 samples are undersaturated and contain olivine and/or nepheline in the norm. Exceptions are fine-grained B2 samples from near the contact, that appear to have assimilated B1 material.

5. Generally, B2 samples contain no modal olivine and significant amounts of modal quartz and biotite, and B1 rocks contain modal olivine and little to no modal quartz or biotite. However, some overlap does occur in the mineralogy between B1 and B2 samples.

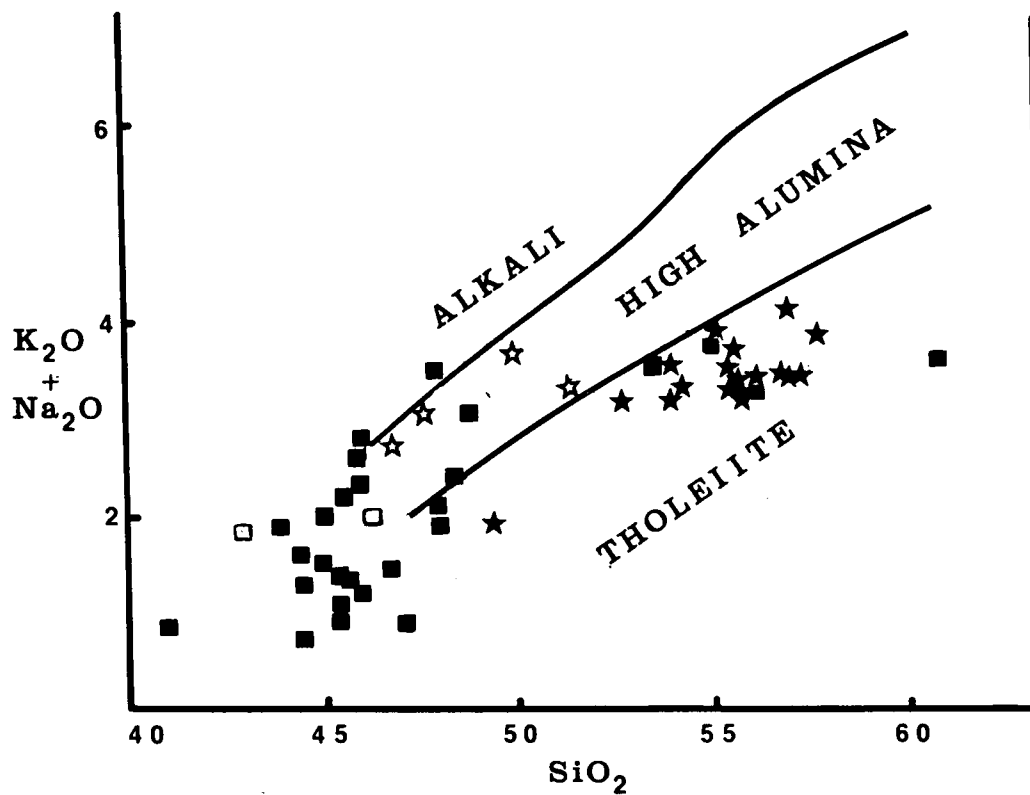
6. The B1 unit shows systematic areal variation in MgO only, whereas the B2 unit shows concentric variations in MgO and SiO_2 , following quartz and hydrous minerals (Clark, 1980).

CHAPTER IV

DISCUSSION

Parental Magmas

It is difficult to reconstruct parental magma compositions in light of the effects of accumulation already discussed. However, trends in crystallization may allow this to be done. When plotted on a diagram of $\text{Na}_2\text{O} + \text{K}_2\text{O}$ versus SiO_2 (Kuno, 1966), samples of the Barber complex range from high-Al (B1) to tholeiitic (B2) basalt (Figure 11). A plot of Barber samples on an AFM diagram (Figure 12) reveals that B1 samples exhibit a clear iron enrichment trend indicating that they are probably tholeiitic, but samples from the B2 unit show no Fe-enrichment and are probably calc-alkaline. A wide variation in the FeO^*/MgO ratio for B1 samples is probably a result of this iron enrichment trend that is characteristic of tholeiitic rocks. Miyashiro and Shido (1975) have suggested that the trends of tholeiitic rocks for FeO^* , TiO_2 and V increase first and then decrease after passing through a maximum with increasing FeO^*/MgO . FeO^* , TiO_2 and V in calc-alkaline rocks tend to decrease monotonically and rapidly as FeO^*/MgO increases. Values of B2 samples display no clear trends for these species. Values for B1 samples are generally too scattered to see clear trends, but there is a suggestion of



B1 SAMPLES:



B2 SAMPLES:



Figure 11. Alkali and silica variations (weight percent) in B1 and B2. Field boundaries are from Kuno (1966), with symbols as in Figure 4, p. 32.

Figure 12. AFM diagram for B1 and B2 samples. Symbols as in Figure 4, p. 32. B1 samples show pronounced Fe-enrichment and lower alkali contents than B2 samples. B1 and B2 samples fall within the field of compressional plate boundaries defined by Petro et al. (1979).

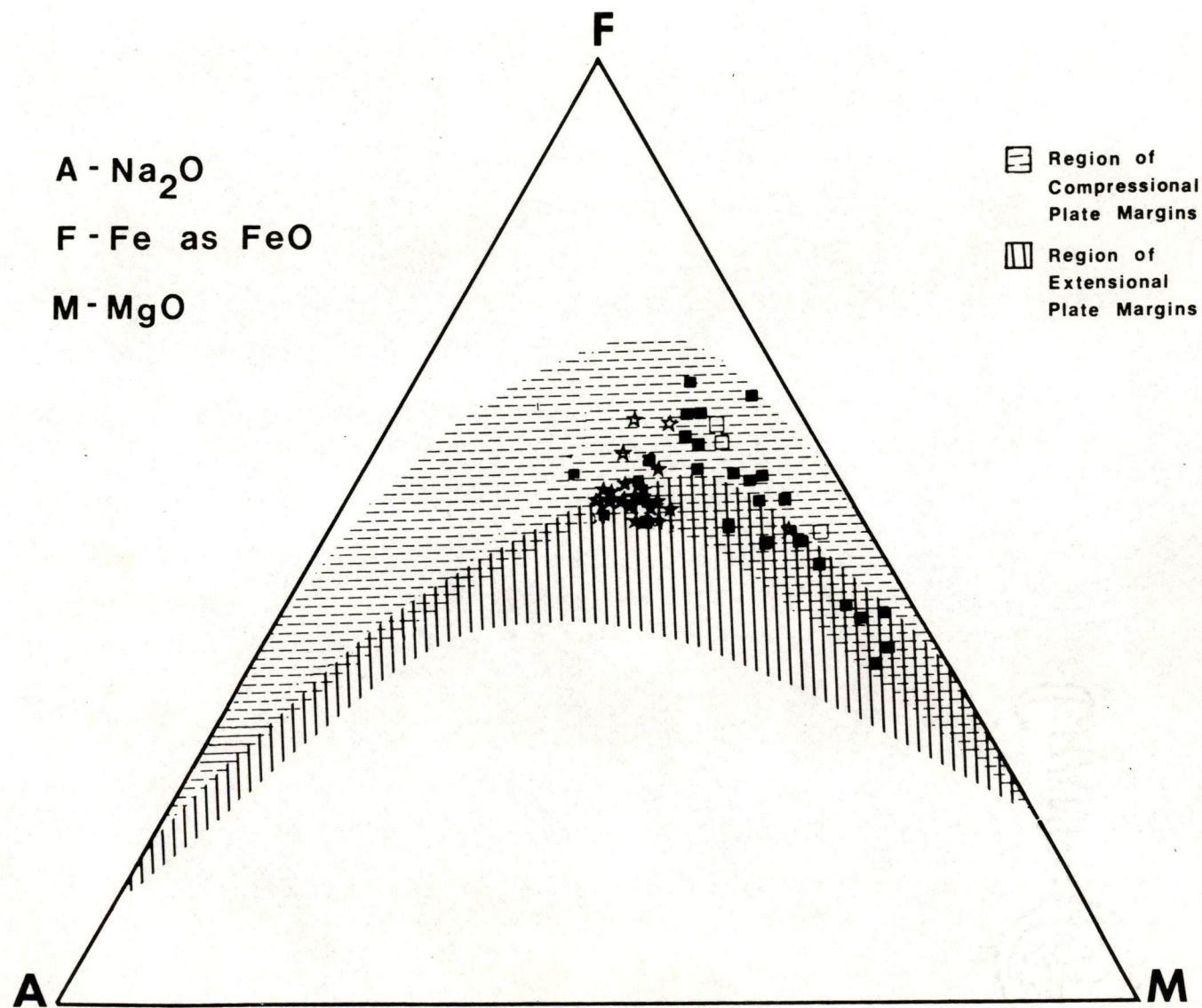


Figure 12.

increasing values. However, tholeiitic and calc-alkaline trends overlap when SiO_2 is less than 54% (Miyashiro, 1974; Kay et al., 1982), and a large portion of the B1 samples have less than 54% SiO_2 . Tholeiitic parental magmas were inferred for other gabbros in the Piedmont which are possibly genetically related to the Barber complex (McSween et al., 1983). However, none of these was silica-saturated, as in the calc-alkaline B2 unit. The compositions of the fine-grained samples in the B2 unit have probably been modified by assimilation, as discussed previously, and thus they cannot be utilized for this purpose. Clark (1980) suggested that the B2 unit crystallized from a magma of basaltic andesite composition.

Tectonic Setting

Typically, low-Ti, high-Al, low-K tholeiite grading to calc-alkaline rock types are characteristically formed in island-arcs and at Andean-type margins (Ewart, 1976; Fairbrothers et al., 1978; Ringwood, 1974, Whitford et al., 1979). This tectonic setting for the Barber complex is substantiated by age dates and regional geologic setting, tectonic discrimination diagrams of the B1 and B2 units, and isotope geochemistry of the B2 unit.

In the early Paleozoic at approximately 567 ± 50 Ma, granitic plutons and the B1 unit were intruded (Clark, 1980;

McSween et al., 1983). The B2 unit was intruded at 479 ± 24 Ma into the B1 pluton (McSween et al., 1983). Subsequently or concurrently with the intrusion of the B2 unit, the area was metamorphosed during the Taconic metamorphic event [inferred by Hatcher et al. (1980) to have peaked at about 460 ± 20 Ma in the Piedmont). This intrusive activity and the ensuing regional metamorphism are inferred to be associated with a subduction zone (Hatcher, 1972). Metamorphic grade is generally greenschist to amphibolite facies (Butler and Ragland, 1969). At about 300 Ma the Churchland and Landis granites were intruded into the study area (Butler and Fullagar, 1978; Fullagar, 1971), to the northeast and south of the B1 unit, respectively. These granites are probably not differentiates of gabbroic magmas, but instead were probably formed by anatexis of the lower crust (Wenner, 1981; Sando and Hart, 1982).

When plotted on major element discriminant diagrams (Pearce, 1976), B1 samples fall almost exclusively in the orogenic field of LKT (low-K tholeiite), and B2 samples generally fall in the orogenic field of CAB (calc-alkaline basalt) (Figure 13). All samples plotted fell within the screen (12-20% CaO + MgO) for noncumulate rocks. However, caution should be exercised when interpreting these diagrams for gabbros which may contain a cumulate component, because

Figure 13. Major element discriminant diagrams for basaltic rocks from various tectonic settings (Pearce, 1976). Only samples meeting the screen ($\text{CaO} + \text{MgO} = 12\text{-}20\%$) are plotted using symbols as in Figure 4, p. 32. (a) Plot of discriminant functions F1 and F2 showing the fields of within-plate basalts (WPB), shoshonites (SHO), calc-alkaline basalts and low-potassium tholeiites (CAB + LKT) and ocean floor basalts (OFB). Samples plot in the CAB + LKT field. (b) Plot of discriminant functions F2 and F3. B1 samples generally plot in LKT field and B2 samples in the CAB field.

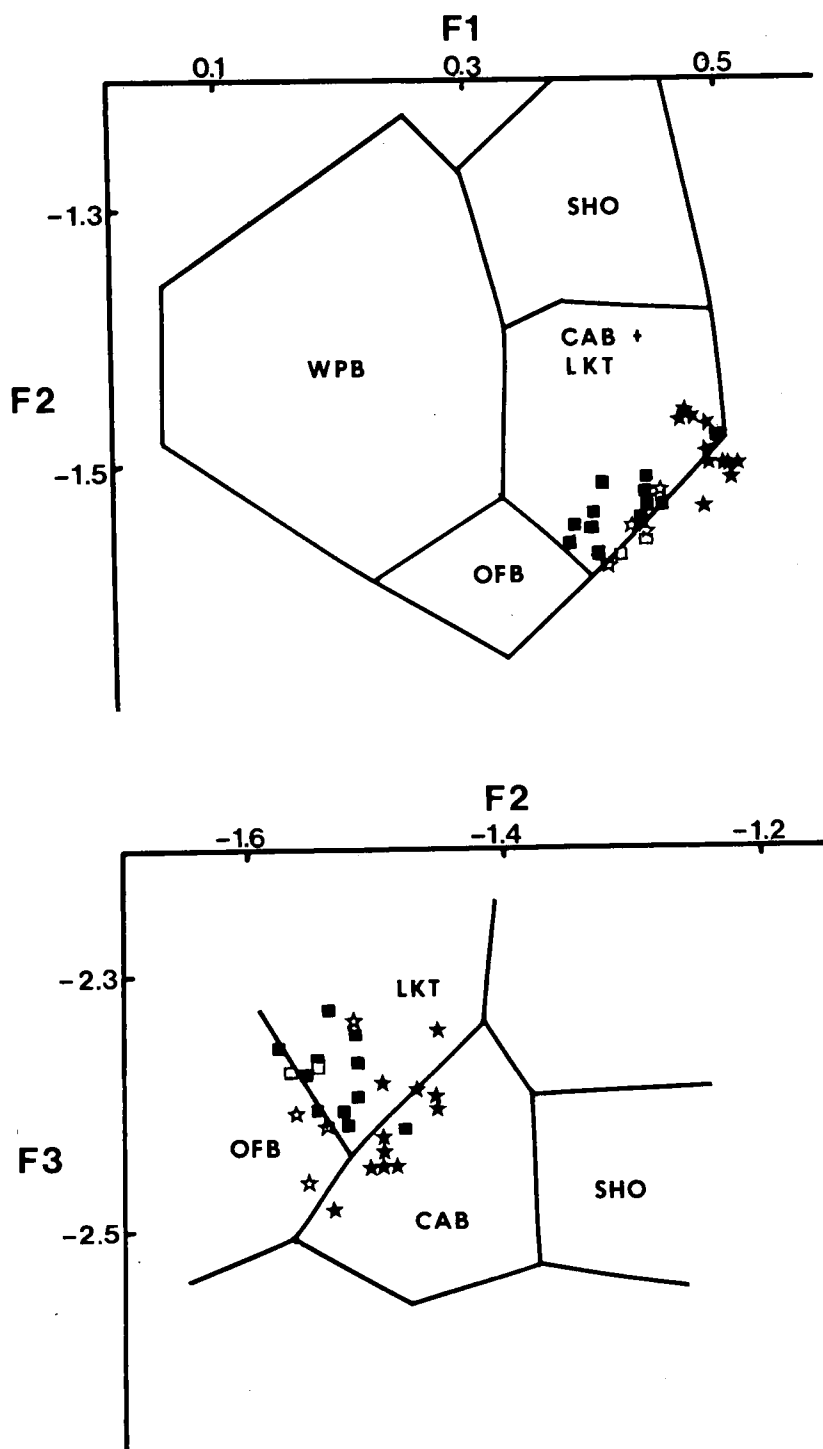


Figure 13.

the diagrams were intended to be applicable to nonaccumulative basaltic rocks only. Function F1 is primarily controlled by TiO_2 and SiO_2 , F2 by MgO and K_2O , and F3 by Al_2O_3 (Pearce, 1976). Accumulation would probably effect an increase in MgO , Al_2O_3 and TiO_2 and a decrease in SiO_2 and K_2O . In Figure 13a, accumulation would cause samples from the Barber complex to be shifted left along the F1 axis, i.e., increasing TiO_2 and decreasing SiO_2 , and down the F2 axis, i.e., increasing MgO , toward the WPB and OFB (within-plate basalt and ocean floor basalt) field. Even if the most differentiated samples were cumulates, this would not alter the interpretation of an orogenic regime for the emplacement of the Barber complex. Where olivine is a significant cumulate phase, the effects of accumulation would be to decrease the amount of Al_2O_3 and increase the amount of MgO . Thus, in Figure 13b, Barber complex samples would be shifted left along the F2 axis, i.e., increasing MgO , and up the F3 axis, i.e., decreasing Al_2O_3 , toward the LKT field. Where plagioclase is the primary cumulate phase, accumulation would result in an increase in Al_2O_3 and samples would be shifted down the F3 axis toward the CAB field. In Figure 13b, it is difficult to assess to what extent accumulation affected the composition of the samples of the Barber complex. However, as in Figure 13a, accumulation would not alter an orogenic interpretation for the emplacement of the Barber complex.

Petro et al. (1979) compared plutonic rock types characteristic of compressional and extensional plate boundaries. Figure 12, p. 56, shows the trend of each type of boundary. Rocks of the Barber complex most closely match that trend shown by the compressional plate boundary.

$\epsilon_{\text{Nd}}-\epsilon_{\text{Sr}}$ isotope geochemistry of the Barber gabbro also overlaps that of mafic rocks from compressional plate boundaries (McSween et al., 1983). The data support Clark's (1980) position that the Barber complex was formed in the tectonic setting of an island-arc or an Andean-type plate margin.

Comparison of the Barber and Mecklenburg Complexes

Other than the Barber complex, the only other related gabbro-metagabbro complex that has been studied in detail both geochemically and petrologically is the Mecklenburg complex in North Carolina (Figure 1, p. 2). The two complexes are compared below in the hope that parallels could be drawn between them which may broaden current understanding of these rocks. In the following discussion, Mecklenburg metagabbro will be referred to as M1 and Mecklenburg gabbro as M2, analogous to the Barber complex terminology.

Mineralogically, the Mecklenburg complex resembles the Barber in the major mineral phases present, such as plagio-

clase, orthopyroxene, clinopyroxene, and their relative abundances. Modal olivine is present and quartz is generally absent or scarce in B1 and M2, whereas modal quartz is abundant and olivine is absent in B2 and M1. Textural similarities occur between the two gabbro units and between the two metagabbro units of both complexes. Both gabbros are characterized by hypidiomorphic granular textures, and metagabbros exhibit a range of textures that span from relict igneous to granoblastic.

M1 is more differentiated than is M2, in contrast to the situation in the Barber complex where B2 is more differentiated than is B1. When compared on an AFM diagram, the two complexes show close similarities in geochemical composition and in the trends shown between M2 and B1 and between M1 and B2 (Figure 14). B1 and M2 display strong tendencies toward iron enrichment, and both M1 and B2 contain higher iron and alkali contents than do their respective gabbro and metagabbro lithologies. Normative mineralogy for M1 is very similar to that of B1 (Figure 15). M1 and B1 appear to make a broad sweep from the quartz tholeiite field and into the alkali basalt field, although the Barber samples are scattered over a broader region of the tholeiite field. This is in contrast to the gabbros of both complexes. M2 samples are scattered widely over the tholeiite field and B2 samples cluster tightly in the quartz

Figure 14. AFM diagram for rocks of the Mecklenburg complex. The trends of B1 and B2 samples of the Barber complex are shown for comparison. Fine-grained B2 samples were not included within the B2 field due to the probability that the compositions of these samples have been altered by assimilation of B1 lithology and thus no longer reflect B2 compositions.

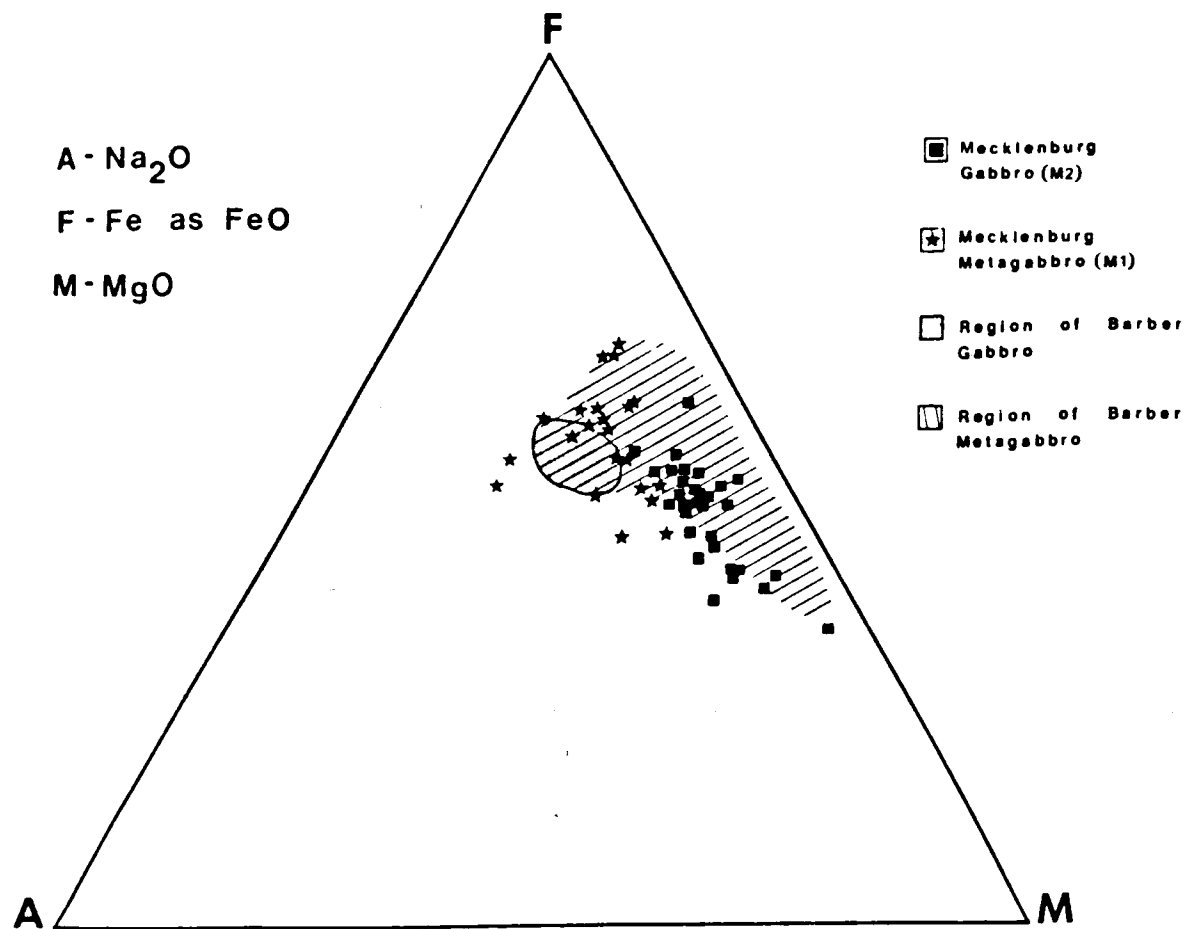


Figure 14.

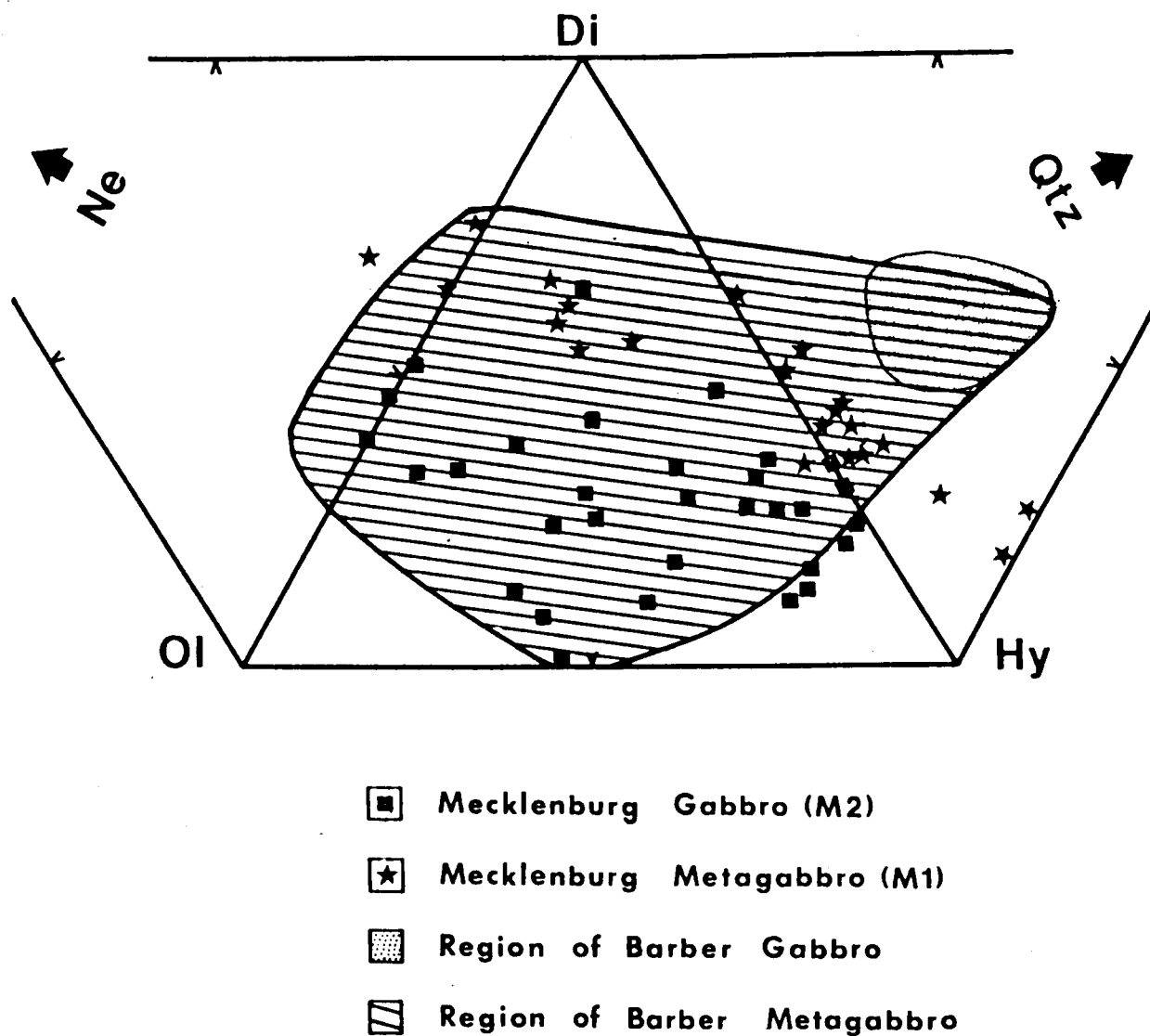


Figure 15. Normative mineralogy of rocks of the Mecklenburg complex. Gabbros (M2) plot across all three fields, whereas metagabbros (M1) fall in the tholeiite field only. The trends of B1 and B2 samples of the Barber complex are shown for comparison. Symbols as in Figure 14. Fine-grained B2 samples were not included within the B2 field due to the probability that the compositions of these samples have been altered by assimilation of B1 lithology and thus no longer reflect B2 compositions.

tholeiite field, with only a few isolated samples falling in the tholeiite field.

In summary, geochemical, mineralogical, and textural differences are recognized between the Barber and Mecklenburg complexes, but it appears that the similarities are certainly significant and are perhaps indicative of a close genetic association between the two complexes. However, the gabbro of the Mecklenburg is more similar to the metagabbro of the Barber, and vice versa.

CHAPTER V

CONCLUSIONS

The two intrusions of the Barber complex are geochemically distinct with K_2O , SiO_2 , V and Sr showing the greatest differences between the two units. However, for many oxides, the B1 and B2 trends overlap. B1 samples are generally silica-undersaturated and contain olivine and/or nepheline in the norm; modal quartz plus biotite comprise less than 2% of the rock. B2 samples are generally silica-saturated and contain normative quartz; modal quartz plus biotite comprise over 10% of the rock. Statistical analysis, normative mineralogy and petrology data indicate that although the B1 and B2 plutons are geochemically and petrologically distinct from each other, some overlap in these characteristics occurs.

Effects of crystal accumulation, and in some cases assimilation, can be observed in the geochemical patterns. B1 samples appear to have formed from a tholeiitic parental magma, and B2 are probably calc-alkaline. This complex is similar to one other in the Piedmont, suggesting a genetic relationship between them. The tectonic setting is inferred to be a Paleozoic island-arc or an Andean-type plate margin.

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APPENDIX

PROCEDURE FOR SAMPLE PREPARATION,
DISSOLUTION AND ANALYSIS

Crushing Procedure

Below is a detailed description of the crushing procedure utilized, following Shapiro and Brannock (1962).

1. A 1000 g hand specimen of each rock was wrapped in clean leather and broken with a hammer to pieces with a diameter of about 1 inch. These pieces were handled only with plastic gloves. Weathered surfaces were discarded.

2. The jaw crusher was thoroughly cleaned with a clean brush and deionized water and allowed to dry before each sample was crushed. The crusher was adjusted to crush the sample to about $\frac{1}{2}$ inch diameter.

3. The sample rock fragments and powder were quartered until an amount small enough to fit into the tungsten grinding capsule of a Pitchford vibrating mill was achieved. The sample was ground for about 5 minutes or until the material was finely powdered (-200 mesh). A portion of each powdered sample was set aside and examined by rubbing the powder over a smooth surface. If the powder contained any grit or coarse particles, the sample was ground for an additional 2 to 3 minutes. The grinding capsule was rinsed with deionized water and dried between each grinding. Powders were stored in either new plastic or new glass vials.

Dissolution Procedure for the
Analysis of Major Elements

1. A muffle furnace was preheated to 1000°C.
2. A 3% nitric acid solution was prepared by adding 60 ml concentrated nitric acid to 2 liters deionized water.
3. One half gram of lithium metaborate (anhydrous) was measured and placed into a graphite crucible while insuring that the bottom of the crucible was covered. A 0.1 ± 0.0001 g portion of sample was weighted and poured into the crucible containing the lithium metaborate. The crucible was transferred to the muffle furnace and heated for 5 minutes. The crucible was then removed from the furnace with long-handled tongs and the contents were swirled carefully to gather any uncoalesced beads of molten material. The crucible was placed back into the furnace and heated for an additional 15 minutes.
4. While the crucible was heating, 60 ml of the 3% HNO_3 solution were transferred to a flat bottomed 100 ml polypropylene beaker. A teflon covered stirring bar was added to the beaker.
5. The crucible was removed from the furnace and the molten bead was immediately poured into the beaker of HNO_3 . The beaker was covered to prevent evaporation and stirred gently over a magnetic stirring unit (without heating) until solution was complete.

6. The solution was poured into a clean 250 ml volumetric flask. The beaker and stirring rod were polished well into the flask to insure that all of the solution had been transferred. The flask was filled to the 250 ml mark with deionized water then stoppered and shaken to mix well.

7. For each sample, a polypropylene plastic screw topped bottle was rinsed several times with the sample solution. The bottle was filled with the remaining solution and any leftover was discarded.

Procedure for the Analysis of Major Elements

All geochemical analyses were performed using a Varian AA-475 atomic absorption spectrometer. Si, Al, Mg, Ca, Mn and Ti concentrations were determined by atomic absorption techniques using hollow cathode lamps and nitrous oxide-acetylene and air-acetylene flames. Na and K concentrations were determined using flame emission techniques, employing an air-acetylene flame. Burner height and flame conditions were those recommended for each element by the Varian Atomic Absorption Manual. Minor adjustments were made to further optimize the instrument. Burner position was determined by the concentration of the element in question. If the concentration exceeded that which was considered (according to the Varian operation manual) optimal for analyses, the burner was turned 90°. This served to increase precision and to reduce absorption by a factor of approximately 10 so that the analyses could be performed without dilution of the stock solution.

MgO concentrations in some samples fell well above the concentration of MgO in any of the standards available. Therefore, a high Mg silicate standard was prepared to more closely match the sample concentrations. The composition of the Mg standard is given in Table A-1. Instrument parameters were a listed in Table A-2. All elements were analyzed on a single stock solution with no dilutions. This

Table A-1. Composition of High Mg-Standard.

Oxide	wt. %
SiO ₂	53.52
Al ₂ O ₃	16.54
FeO*	14.30
MgO	16.60
CaO	6.99
K ₂ O	1.42
Na ₂ O	0.00
MnO	0.10
TiO ₂	1.66

Table A-2. Instrument Parameters and Analytical Conditions for Major and Minor Oxides.

Element	Technique	Light Source	Wavelength (nm)	Lamp Current (ma)	Spectral Band Pass (nm)	Flame	Burner Position	Flame Conditions
Si	AA ¹	HC ³	251.6	20	0.2	N ₂ O-acetylene	Parallel	Highly Reducing
Al	AA	HC	309.3	10	0.5	H ₂ O-acetylene	Parallel	Reducing
Ca	AA	HC	422.7	3	0.5	N ₂ O-acetylene	Perpendic.	Oxidizing
Mg	AA	HC	285.2	3	0.5	N ₂ O-acetylene	Perpendic.	Oxidizing
Ti	AA	HC	364.3	20	0.5	N ₂ O-acetylene	Parallel	Reducing
Fe*	AA	HC	248.3	5	0.2	air-acetylene	Perpendic.	Oxidizing
Mn	AA	HC	279.5	5	0.2	air-acetylene	Parallel	Oxidizing
K	FE ²	None	766.5	0	0.1	air-acetylene	Parallel	Oxidizing
Na	FE	None	589.0	0	0.1	air-acetylene	Parallel	Oxidizing

*Total Fe.

¹Atomic Absorption Spectroscopy.

²Flame Emission Spectroscopy.

³Hollow Cathode Lamp.

insured uniform viscosity among all samples. All samples were fused, dissolved, diluted and analyzed in triplicate to minimize the effects of analytical error. If one of the three analyses varied significantly from the other two and analytical error was suspected, the t-test ($\mu + M = (t)(S_M)$) was employed. If the sample concentration did not fall within the 95% confidence interval for the true mean, it was discarded.

During the course of performing the analyses, standards were reanalyzed after every 2 to 6 analyses (depending on the stability of that element) to check for instrument drift. If necessary, the instrument was then recalibrated.

Dissolution Procedure for the
Analysis of Trace Elements

1. A 0.5 ± 0.0010 g portion of the powdered sample was weighed and transferred to a 100 ml polypropylene beaker.

2. Ten ml of concentrated reagent grade HNO_3 were added to the beaker. The beaker was then covered with a polypropylene cover and heated over a hot plate for 1.5 hours.

3. Six ml of concentrated HF were added and the covered beaker was heated for another hour.

4. The cover was then removed and the solution was evaporated to dryness.

5. Five ml of concentrated HNO_3 and 2 ml of HF were added and the solution was again allowed to evaporate to dryness.

6. The beaker was removed from the heat when the residue became white and very flaky. The residue was not allowed to become dark brown due to the formation of iron oxides.

7. The residue was redissolved for the last time with 2 ml of concentrated HNO_3 and approximately 90 ml of distilled water.

8. The beaker was covered with a polypropylene beaker cover and heated for 10-12 hours.

9. If a residue remained, more water was added and additional heating was required.

10. When the residue was dissolved, the cover was removed and the volume of the solution was reduced by evaporation to about 25 ml.

11. This solution was cooled and transferred to a 50 ml volumetric flask and diluted to volume. The flask was stoppered and shaken well.

12. For each sample solution, a 2 oz. plastic screw topped bottle, cleaned using a combination of the methods of Karin et al. (1975) and Moody and Lindstrom (1975), was filled and labeled.

Procedure for the Analysis of Trace Elements

The instrument and procedures utilized for trace element analysis were generally similar to those already discussed for major elements. No dilutions of the single stock solution were made. If necessary, the machine was recalibrated after every 10 to 12 analyses to correct instrument drift. Instrument parameters were as listed in Table A-3.

Table A-3. Instrument Parameters and Analytical Conditions for Trace Elements.

Element	Technique	Light Source	Wavelength (nm)	Lamp Current (ma)	Spectral Band Pass (nm)	Flame	Burner Position	Flame Conditions
Co	AA ¹	HC ²	240.7	7	0.2	air acetylene	Parallel	Oxidizing
Cr	AA	HC	357.2	7	0.2	air acetylene	Parallel	Reducing
Ni	AA	HC	232.0	3.5	0.2	air acetylene	Parallel	Oxidizing
Cu	AA	HC	324.7	3.5	0.5	air acetylene	Parallel	Oxidizing
Zn	AA	HC	213.9	5	1.0	air acetylene	Parallel	Oxidizing
Rb	AA	HC	780.0	20	0.2	air acetylene	Parallel	Oxidizing
Sr	AA	HC	460.7	10	0.5	NO ₂ acetylene	Parallel	Highly Oxidizing
V	AA	HC	318.5	20	0.2	NO ₂ acetylene	Parallel	Highly Reducing

¹Atomic Absorption Sepctroscopy.

²Hollow Cathode Lamp.

Interferences

Various types of interferences are potentially significant in the analysis of silicates by atomic absorption spectroscopy. These include radiation, atomic spectral, physical, ionization and chemical interferences.

Radiation interference. This is due to a substance that emits radiation at the wavelength being used for measurement, for example, background emission from the flame or the solvent aspirated into the flame. This was not a problem because the instrument was calibrated to zero while burning pure solvent.

Atomic spectral interference. If the absorption lines of two or more elements are superimposed or if an emission line is superimposed on an absorption band, spectral interference could result. However, the width of the resonance line generally measured in atomic absorption is very narrow, giving excellent resolution, resulting in relative freedom from this type of interference.

Molecular absorption, one type of spectral interference, can occur if molecular species that arise in the flame cause absorption. This effect is only important where species such as SrO and CaOH are in substantial concentration. Use of a high temperature flame with low concentrations of elements with absorbing species eliminated this problem.

Physical interference. This arises as a result of differences in the matrices of the sample and standards. Such differences could include salt concentration, bulk composition, sample homogeneity and viscosity. Disparity between matrices may affect nebulization or flame properties. The samples and standards under study contained similar matrices and consequently, the effect of this type of interference was minimized.

Ionization interference. This occurs when atoms of elements of low ionization potential become ionized at flame temperatures, resulting in a reduced population of atoms remaining in the ground state, thus lowering absorbance. The extent of ionization depends on the composition of the sample, because the presence of certain species can inhibit or enhance ionization and consequently, absorption. Ionization interference was controlled by closely matching standards to samples.

Chemical interference. Chemical combinations of the element of interest with other elements of compounds may result in interference. This was alleviated by using a very hot or reducing flame and by closely matching standards with samples.

Calibration Curves

In order to test for linearity between the absorbance and concentration of an element, three single element standards with concentrations covering the range of sample concentrations were analyzed. Absorbance versus concentration values of the standards were plotted in addition to zero absorbance and concentration. If a linear relationship existed, only one rock standard was used in the analysis as the instrument automatically assumes a linear response between zero and the concentration of the standard. If the relationship was not linear, two rock standards were used to set a calibration curve. Figure A-1 shows the nonlinear calibration curve of Mg. All other elements were linear over the concentrations of interest.

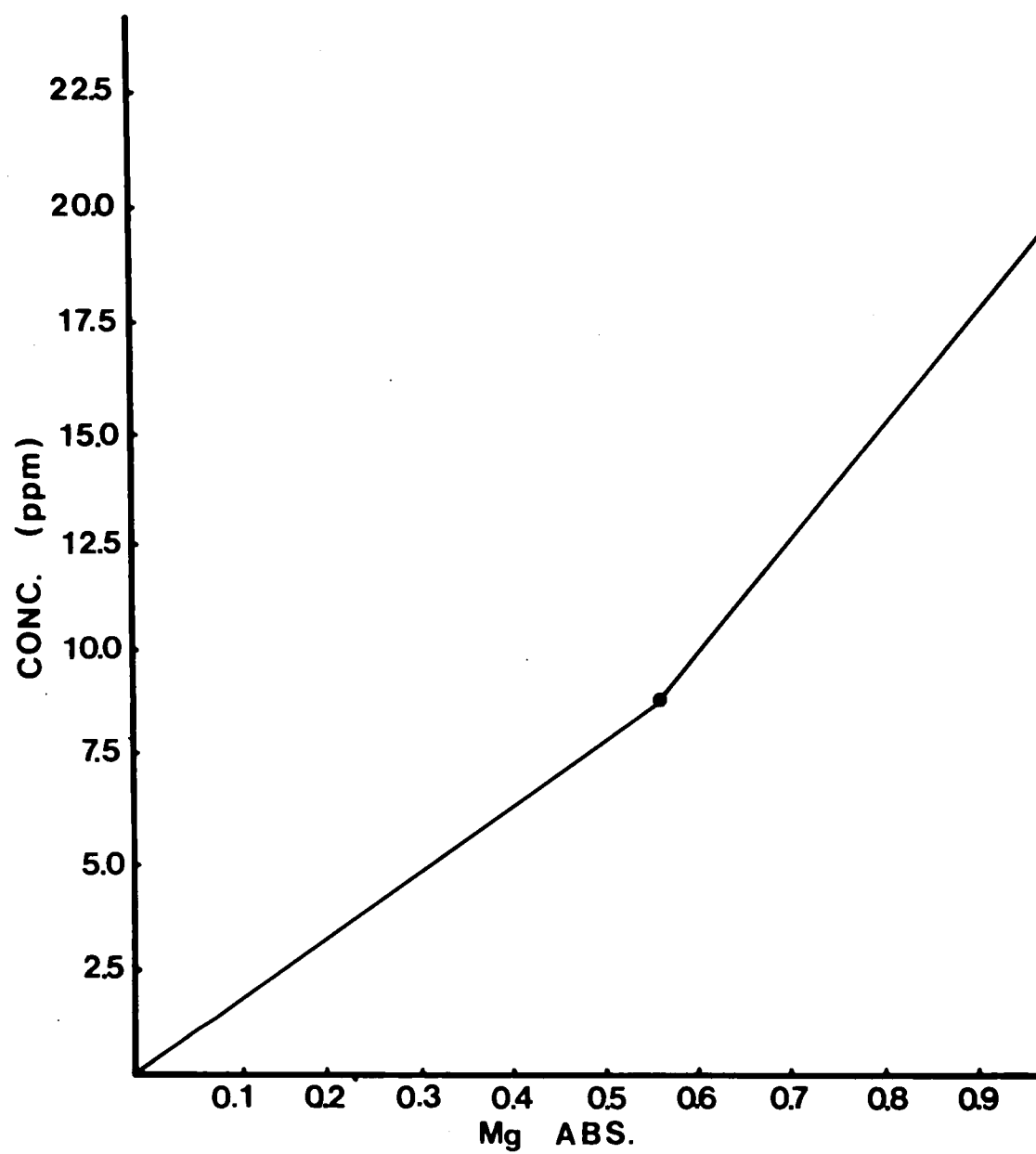


Figure A-1. Plot of concentration versus absorption of MgO.

VITA

Elizabeth Allison Strange was born in Nashville, Tennessee on July 7, 1958. She attended Farragut Elementary and High School in Knoxville, Tennessee, and graduated in 1976. In the fall of 1976 she entered The University of Tennessee, Knoxville, and studied a Liberal Arts curriculum for two years. In January 1979, she entered Florida State University and received her Bachelor of Arts degree in Geology when she graduated with honors in 1980. In September 1980, she moved back to Knoxville and began her graduate studies in the Department of Geological Sciences at The University of Tennessee, where she accepted a teaching assistantship. She received her Master of Science degree in Geology in December 1983.