GEOCHEMISTRY AND GEOCHRONOLOGY OF THE SIMS GRANITE, EASTERN CAROLINA SLATE BELT, NORTH CAROLINA

by

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NORTH CAROLINA

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ABSTRACT

The Sims pluton, a medium to coarse-grained calc-alkaline granitic stock, is intruded into low rank metamorphic rocks of the Eastern Carolina Slate Belt. The granite is non-porphyritic and shows no metamorphic foliation. Major and trace element analyses of fifteen samples indicate that the granite is peraluminous, with average molecular $Al_2O_3/Na_2O + K_2O + CaO = 1.57$. SiO_2, FeO, and TiO_2 average 73.6, 1.78, and 0.3% respectively. Trace element distributions correlate well with those in other late Paleozoic granites of the southeastern Piedmont. The average Rb/Sr ratio is 0.60.

The granite is composed of quartz, two feldspars, and minor biotite and chlorite. Locally it is hydrothermally altered. Epidote and calcite commonly coat joint surfaces and sericite and sulfide phases are abundant in altered zones.

Rb-Sr whole rock age determination establishes the time of emplacement at 285 ± 2 my. Excellent correspondence of the whole rock and mineral isochrons indicates that there was no postemplacement metamor-

phism. The initial Sr^{87}/Sr^{86} ratio is 0.7044 ± 0.0005, suggesting an upper mantle or lower crustal origin for the granite magma. This age further supports 300 my as a time of major plutonic activity in the eastern portion of the southeastern Piedmont of the Appalachians.

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Introduction and Previous Work

The Sims pluton is located 19 kilometers west of Wilson, North Carolina, adjacent to Highway US 264 in Wilson County. The granite was first quarried in 1917 for railroad ballast and jetty stone. Production was intermittent until 1940 (Councill, 1954). Since then, the granite has been mined for crushed stone by the Nello L. Teer Contracting Company.

A brief discussion of the Sims granite was provided by Councill (1954). A study of the disseminated molybdenum and copper mineralization (Cook, 1972) yielded a partial geochemical characterization of the granite. In one greisen zone more than 127 ppm molybdenum and 650 ppm copper were detected. Wanger (1974) determined the uranium and thorium contents of several Piedmont plutons. The Sims granite averaged 24.7 ppm thorium and 7.1 ppm uranium. Speer (1978) in a study of molybdenum-copper mineralization in Piedmont intrusives described the Sims pluton as having greisen zones with molybdenite, pyrite, sphalerite, and galena. Speer concluded that the mineralization is probably a late stage magmatic feature. Figure 1 shows the relationship of Sims to other molybdenum-bearing intrusives in the southeast.

Sando (1979) studied the trace element geochemistry of postmetamorphic plutons in the southeastern Piedmont, and he included some geochemical data for the Sims. Coarse-grained granites were studied as a subgroup of postmetamorphic granites in the southeastern Piedmont (Speer and others, 1979).

Since no previous age determination had been made and no detailed

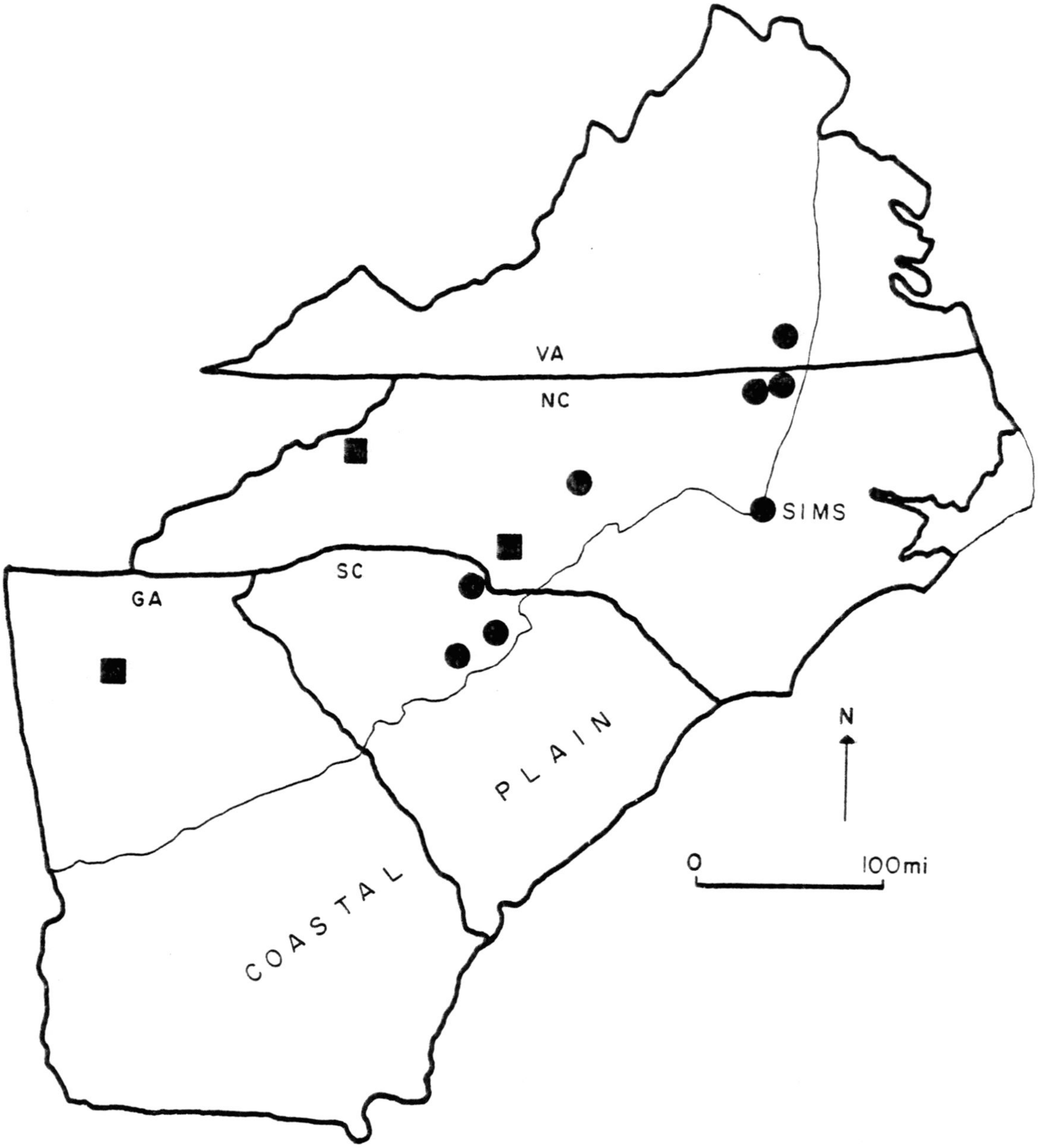


Figure 1. Generalized map showing locations of known molybdenum mineralization in granitic rocks of the Appalachian Piedmont. Circles are vein-disseminated molybdenum mineralization in late Paleozoic plutons. Squares are molybdenum mineralization in pegmatite (modified from Speer, 1978).

petrographic or geochemical work was done on the Sims pluton, the main goals of this study were: 1) to describe the granite in terms of major and trace element geochemistry, 2) to determine the time of emplacement of the pluton, and 3) to compare this pluton to other postmetamorphic plutons of the southwestern Appalachian Piedmont.

Geologic Setting

The geology of the southeastern Piedmont has been discussed by Overstreet and Bell (1965), Brown (1970), Overstreet (1970), and Sundelious (1970). The southeastern Piedmont has been conveniently divided into structural-lithologic belts by King (1955). Later revisions are those of Butler and Ragland (1969). Williams (1978) has depicted the various tectonic regimes of the region in a map of the Appalachian orogen.

Kings Mountain Belt

The Kings Mountain Belt consists essentially of low to medium rank metavolcanic and metasedimentary rocks. Common lithologies include marble, quartzite, conglomerate, schists, and several intrusives called granitic gneisses and metatonalites by Horton and Butler (1977). This narrow belt is exposed from an uncertain northeasterly extent in the southwestern portion of North Carolina to the Georgia-South Carolina border where it pinches out.

Charlotte Belt

The Charlotte Belt consists mostly of mafic to felsic rocks in the amphibolite facies, but some higher rank metamorphic rocks are present. Common lithologies include amphibolites, gneisses, and rocks with staurolite-kyanite assemblages. Intrusives in the Charlotte Belt range in composition from granites to mafic rocks. Certain schists and gneisses in the Charlotte Belt may be equivalent to some metavolcanic and metasedimentary rocks of the Kings Mountain Belt (Secor and Snoke, 1978).

Kiokee Belt

The Kiokee Belt is composed of high grade metamorphic rocks. Migmatite gneisses are common as are metaquartzites and sillimanite schists. The belt is exceedingly complex structurally. Tewhey (1977) believes that certain Carolina Slate Belt rocks are equivalent to some Kiokee Belt rocks, but this is not certain.

Raleigh Belt

The Raleigh Belt is essentially a high grade metamorphic zone composed mostly of gneisses and schists. The schists are commonly pelitic and contain kyanite, staurolite, and garnet. Ultramafic rocks are common in small volumes in several locations.

Carolina Slate Belt

The Carolina Slate Belt consists of a wide range of low rank metavolcanic and metasedimentary rocks. Lithologies include lava flows, tuffs, breccias, phyllites, argillites, and greywackes. Intrusives in the Slate Belt include late Paleozoic granites, granodiorites, and gabbros. The eastern portion of the belt is overlain by Cretaceous and Tertiary Coastal Plain sediments. The Sims pluton is located in the extreme eastern flank of the exposed crystalline rocks. The western portion of the pluton is in contact with Slate Belt rocks. In the southern and eastern portions of the quarry, the granite is overlain by Tertiary Coastal Plain sediments. Figure 2 shows the relationship of the various lithologic-structural belts. Figure 3 is a closer view of the area immediately surrounding the Sims pluton.

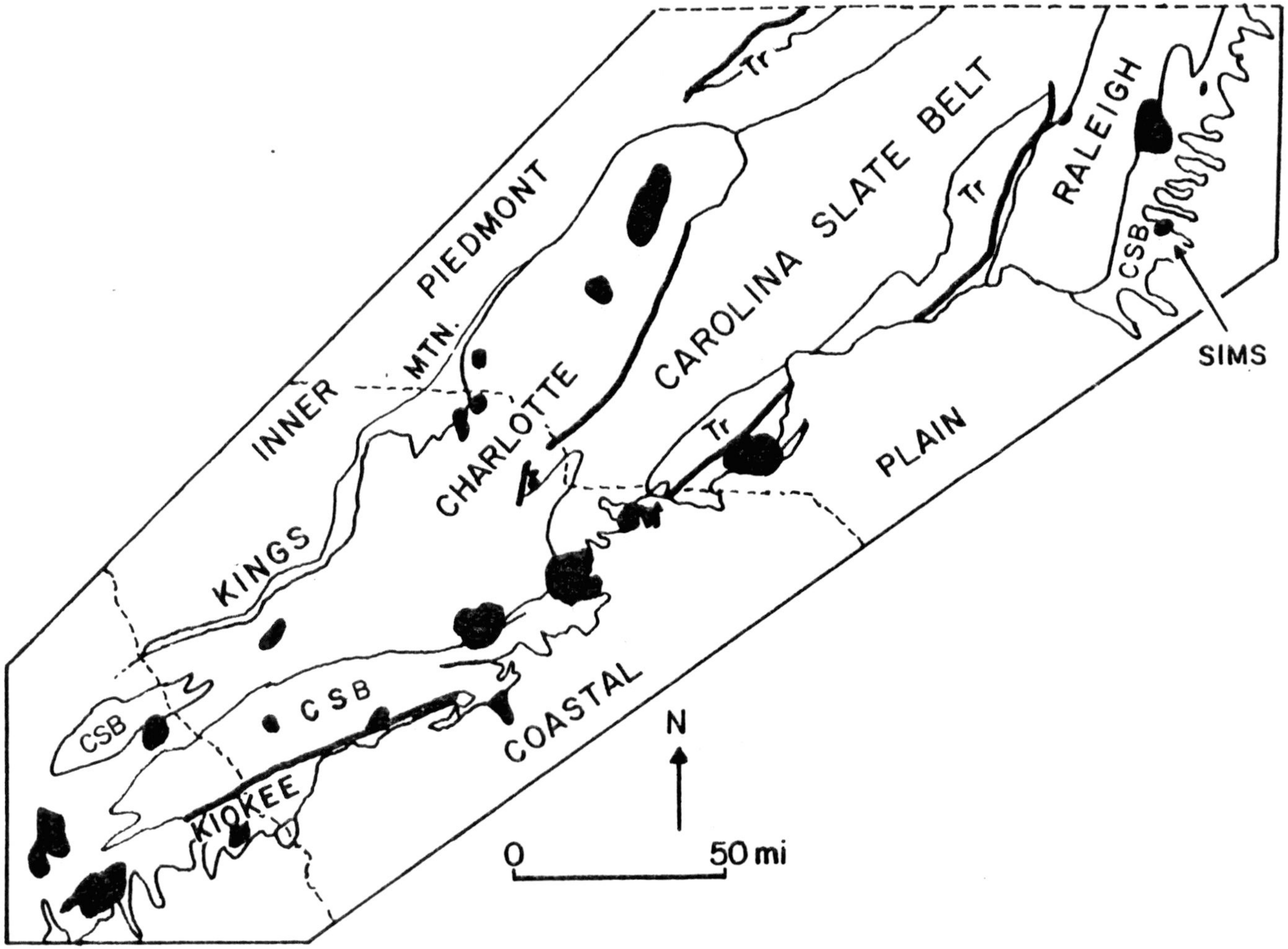


Figure 2. Generalized geologic map showing locations of late Paleozoic plutons (solid black areas) in the central and eastern Appalachian Piedmont of North Carolina, South Carolina, and Georgia. Inner Piedmont, Charlotte, Kiokee, and Raleigh are litho-structural belts. CSB is the Carolina Slate Belt (modified from Fullagar and Butler, 1979).

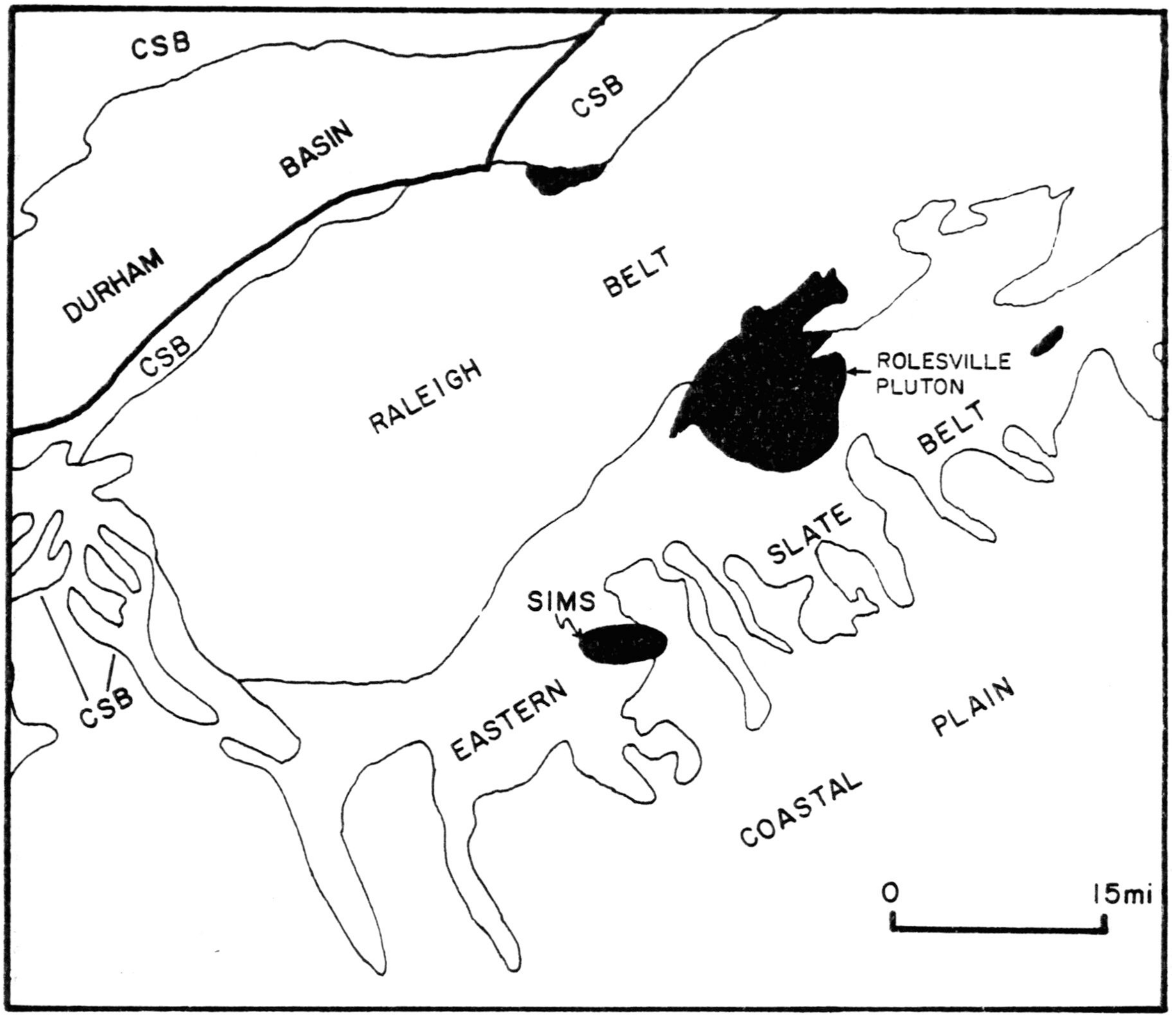


Figure 3. Detailed view of the geology immediately surrounding the Sims pluton (modified from Williams, 1978; Snoke, 1978; and Sando, 1979).

Igneous Intrusives of the Southeastern Appalachian Piedmont

On the basis of major element analyses, field data, and petrography, Butler and Ragland (1969) divided intrusive granitic rocks into either premetamorphic or postmetamorphic types. Fullagar (1971) has speculated that the thermal peak during the last major Appalachian metamorphism was probably between 380 and 420 my ago.

Premetamorphic (metamorphosed) intrusives exhibit one of two different chemical trends. The first is a calc-alkaline trend (West-Farington trend) and the second trend shows Na_20 enrichment (Salisbury trend).

Postmetamorphic plutons studied thus far were emplaced in the late Paleozoic (325 to 265 my ago). Based mainly upon Rb-Sr isotopic analyses, Fullagar and Butler (1979) have defined two compositional groups of postmetamorphic granitic intrusions: 1) the York-Churchland (Western) group of five plutons located in the northern Charlotte Belt; and 2) the Main (Eastern) group of seventeen plutons located in the eastern Piedmont of North Carolina, South Carolina, and Georgia. Plutons in both groups are very similar to premetamorphic West-Farington type rocks (enriched in alkalis and silica).

Characteristics of Postmetamorphic Plutons

These postmetamorphic plutons range in size from small stocks to batholiths. The largest plutons are typically porphyritic and medium- to coarse-grained, but some are non-porphyritic. Textural differences between plutons are probably reflections of their environment of emplacement and water content of the magma.

Compositions of the plutons vary from granite to tonalite to syenite. With very few exceptions, quartz, microcline, and plagioclase make up over 80 percent of each pluton. Biotite (up to 15%) and muscovite (up to 10%) are common accessory minerals. Hornblende is common in several plutons and sphene is present in most.

The foliation in some plutons is a magmatic flow foliation and is not due to regional deformation. Aureoles developed from contact metamorphism are obvious only in the larger plutons, notably those in the Carolina Slate Belt.

Major element analyses show that both groups are average calc-alkaline granites. There is slight K_2O enrichment in the main group. Enrichment of Sr in the York-Churchland group is a distinguishing characteristic. By plotting Sr against SiO_2 the two groups are clearly discernable (Figure 4). Harker and AFM diagrams show overlapping trends and there are relatively insignificant variations in major element chemistry between eastern and western groups. Southeastern Piedmont plutons are depleted in MgO and CaO relative to rocks of the Southern California and Sierra Nevada Batholiths (Fullagar and Butler, 1979).

Sando (1979) has noted several features of trace element distribution in postmetamorphic granites. Nickel and chromium are uniformly low in concentration. Zirconium does not appear to follow any significant trends with bulk composition, although its concentration is about normal for calc-alkaline granites. Western group plutons generally have higher V/Fe ratios than eastern group plutons. The distribution of barium seems to follow closely that of strontium. The western group exhibits a range of 600-2000 ppm for barium. This exceeds the median

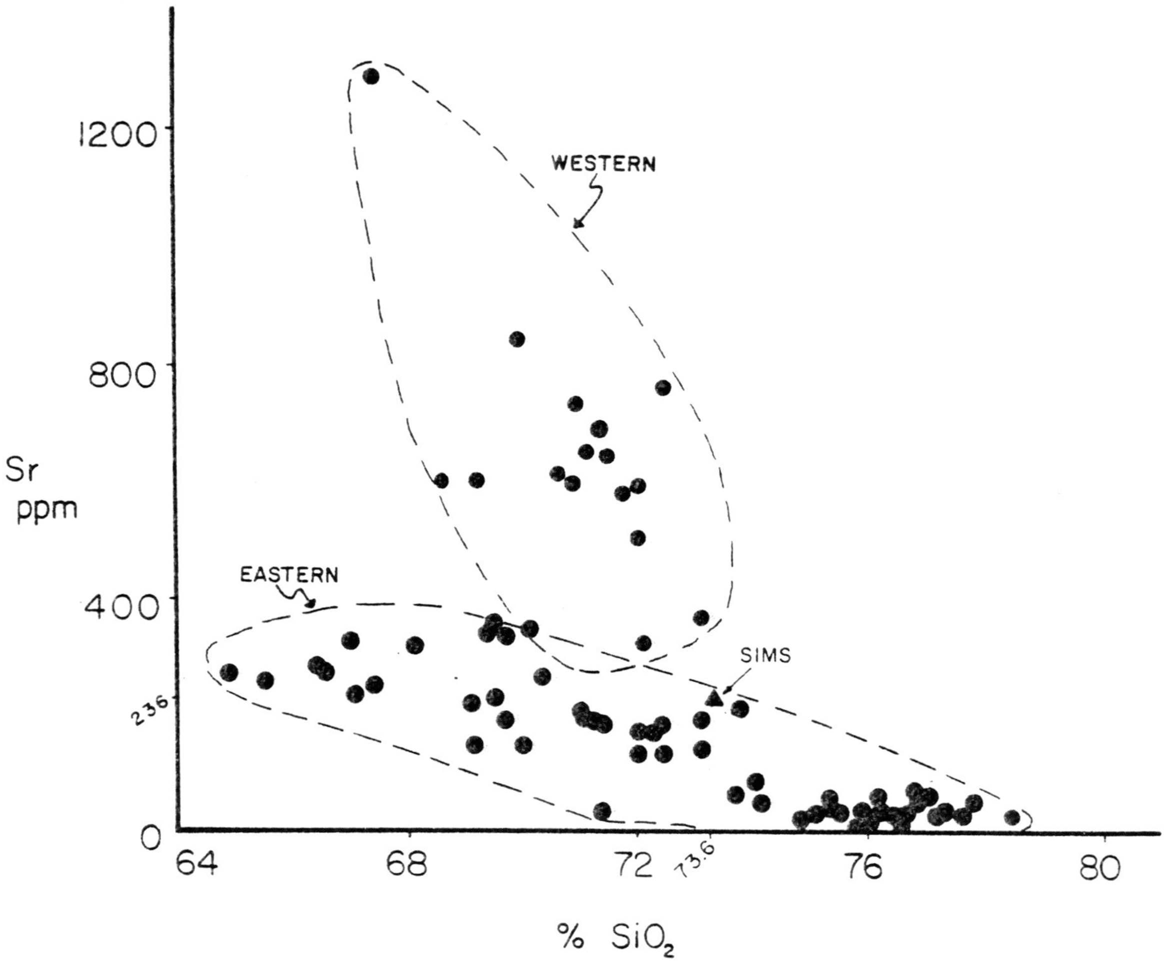


Figure 4. SiO_2 versus Sr for samples from the Main (Eastern) and York-Churchland (Western) groups of late Paleozoic plutons showing the addition of the Sims pluton (modified from Fullagar and Butler, 1979).

barium concentration for most granites according to El Bouseily and Sokkary (1975). The eastern group of plutons also has a wide range in barium concentration, from less than 100 to more than 1300 ppm.

Rare earth elements (REE) also appear to exhibit certain trends. Sando notes that Charlotte Belt plutons generally show large fractionation of heavy and light REE, and low concentrations of heavy REE. Europium anomalies are small or absent. Slate Belt plutons exhibit much greater variability, especially in fractionation of heavy and light REE. Slate Belt plutons have large negative europium anomalies. Kiokee and Raleigh Belt plutons have somewhat smaller negative europium anomalies and the abundances of heavy REE are similar to those of the Slate Belt.

Initial Sr^{87}/Sr^{86} ratios for postmetamorphic plutons range from 0.7024 to 0.7052. These consistently low values and the large volumes of rock involved suggest that the plutons were formed from magmas that originated in the lower crust or upper mantle (Fullagar and Butler, 1979).

Field Characteristics

Quarrying has exposed the dome-like surface of the Sims pluton (Figure 5). The actual geometry of the pluton is not known, since drill core data from the quarry are not available. Probably the pluton is a small stock. Simple Bouguer gravity maps with the smallest available contour interval do not unequivocally delineate the form of the intrusion.

The granite has a weathering zone which varies in thickness from 4 to 8 meters. This zone is pink to red in color, and the weathered material is composed mostly of kaolinite. Weathered dikes can be seen in the zone at the southern edge of the quarry (Figure 6).

With the exception of the extreme western portion of the quarry, the granite does not appear to be extensively fractured. There are two predominant vertical joint directions, due north and N 65 E. Dikes, characteristically high in K-spar, are present but not numerous. There is no evidence of a metamorphic foliation or a flow foliation in the rock. No xenoliths have been found.

Hydrothermal alteration of the granite is locally conspicuous, but a large mass of altered rock has been removed by mining. This zone of alteration was roughly circular in cross section with a diameter of approximately 40 meters. Calcite, muscovite, and euhedral pyrite crystals dominate the mineralogy. Malachite, galena, and chalcopyrite are also present (Barwick, et al, 1978). Throughout the quarry, epidote, and calcite with muscovite coat joint surfaces. Locally within the quarry and particularly within the main altered mass potassium feldspars

Figure 5. View of the Sims quarry looking South.

Figure 6. View of the weathered zone above the fresh granite containing a weathered dike. This zone is overlain by Tertiary Coastal Plain sediments visible just above the hammer.

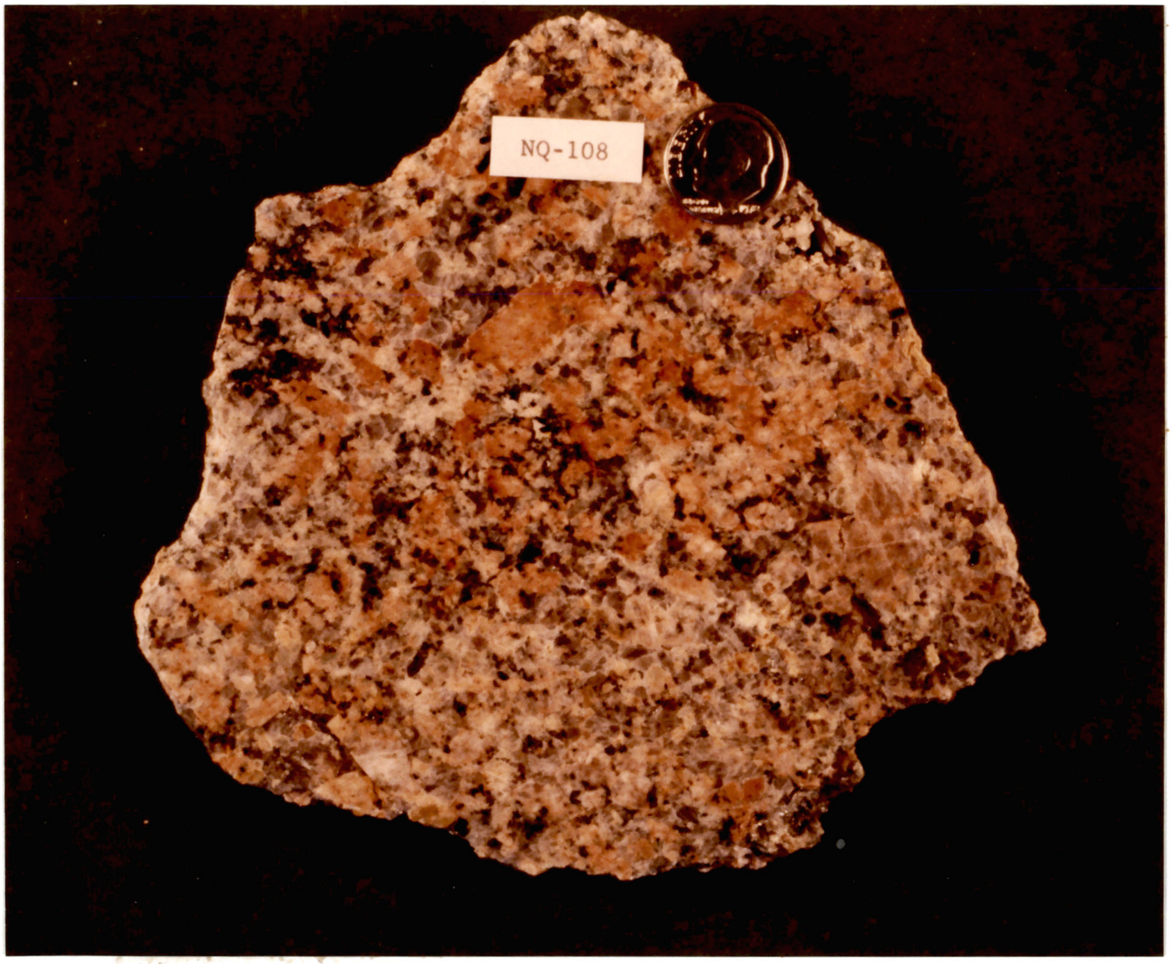


Figure 7. Sample NQ-108 showing the typical appearance of red clouded potassium feldspar occurring locally throughout the quarry.

have a red and clouded appearance (Figure 7).

A contact metamorphic aureole is not evident. Some biotite-hornblende rocks can be found outside the quarry on the western flank of the pluton, but these are not in place. The lack of a contact metamorphic aureole is not surprising considering the apparent small size of the intrusion.

Petrographic Characteristics

The granite is medium to coarse-grained and is essentially non-porphyritic. Sample BB-5 (Figure 8) represents the typical appearance of the unaltered granite. Petrographic analyses of 53 thin-sections from 25 samples reveal that the granite has the following modal composition: alkali feldspar 50-60%; quartz 20-30%; biotite 2-8%; muscovite 1-5%; plagioclase 1-5%; chlorite 1-3%; and sulfide phases 3-8%. Accessory minerals include apatite, tourmaline, sphene, and zircon.

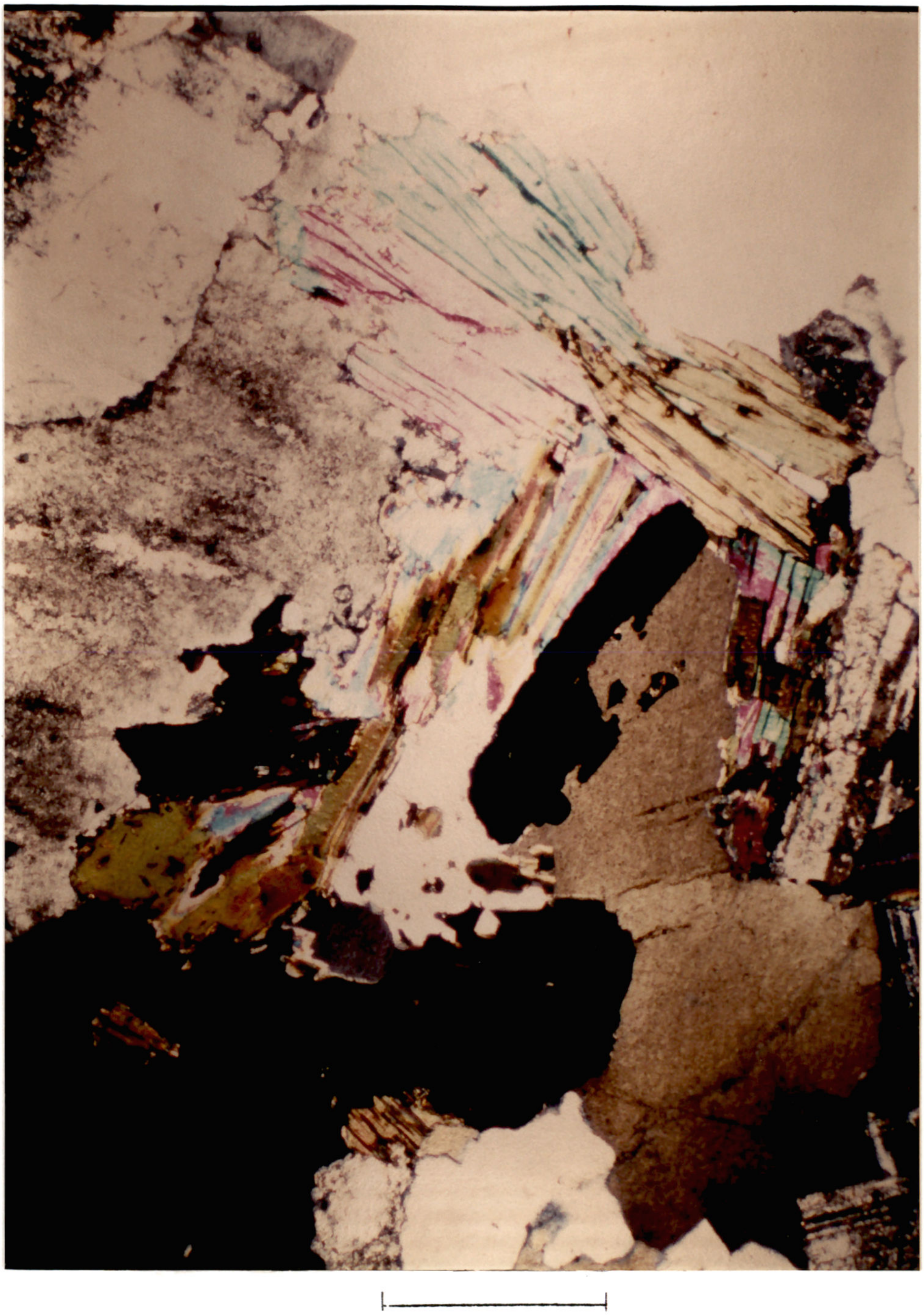
Based on optical and x-ray diffraction analyses it is certain that both microcline and orthoclase are present. Cross-hatch twinning is common in many grains, while some that do not show twinning have low 2V angles. Analyses of the 201, 060, and 204 diffraction peaks confirm the presence of a monoclinic phase (Wright, 1968). Groundmass potassium feldspar as well as phenocrysts are present. Locally, phenocrysts range in size up to 2.5 centimeters and they are subhedral to euhedral. Groundmass feldspars are generally microperthitic or cryptoperthitic and grains are anhedral. Perthite types include vein perthite and braid perthite grading into patch perthite (Smith, 1974). Replacement perthite is present but not common.

Quartz is anhedral and occupies interstices between the other grains. Often the quartz grains contain acicular or dusty inclusions, many of which are apatite (Figure 9). Undulatory extinction was not seen.

Biotite does not show inclusions with the rare exception of some apatite. Biotite-chlorite and muscovite-biotite intergrowths are common. Biotite appears to alter to chlorite in many samples (Figure 10).

Figure 8. Sample BB-5 showing the typical appearance of fresh granite in the Sims quarry.

Figure 9. Sample BB-5 showing quartz grains containing dusty inclusions of apatite. Inclusions are particularly visible in the lower right grain. Crossed nichols.



0.5 millimeters

Figure 10. Sample BB-1 showing the typical alteration of biotite to chlorite. Crossed nichols.

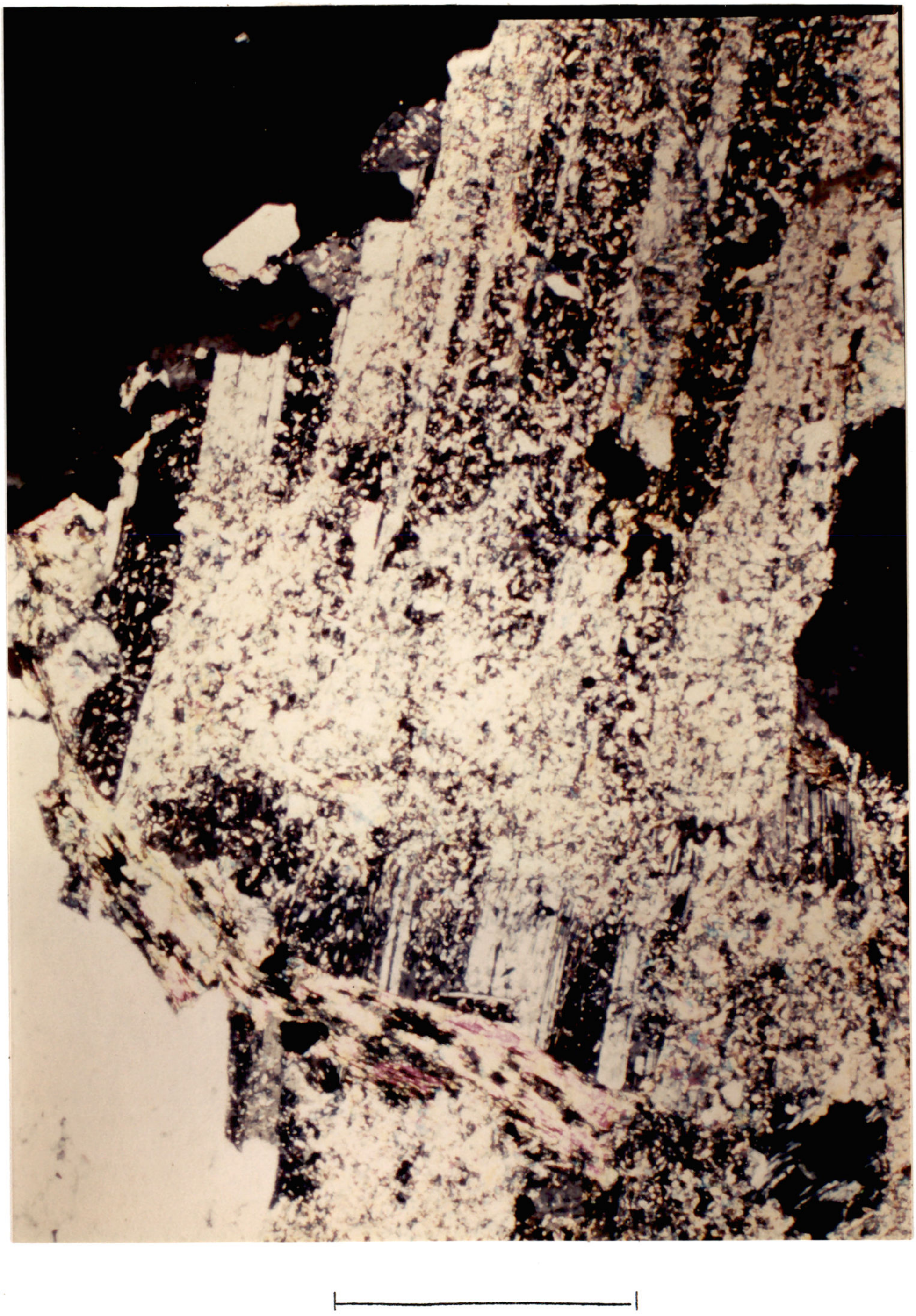


Figure 11. Plagioclase grain with associated sericite hash. Crossed nichols.

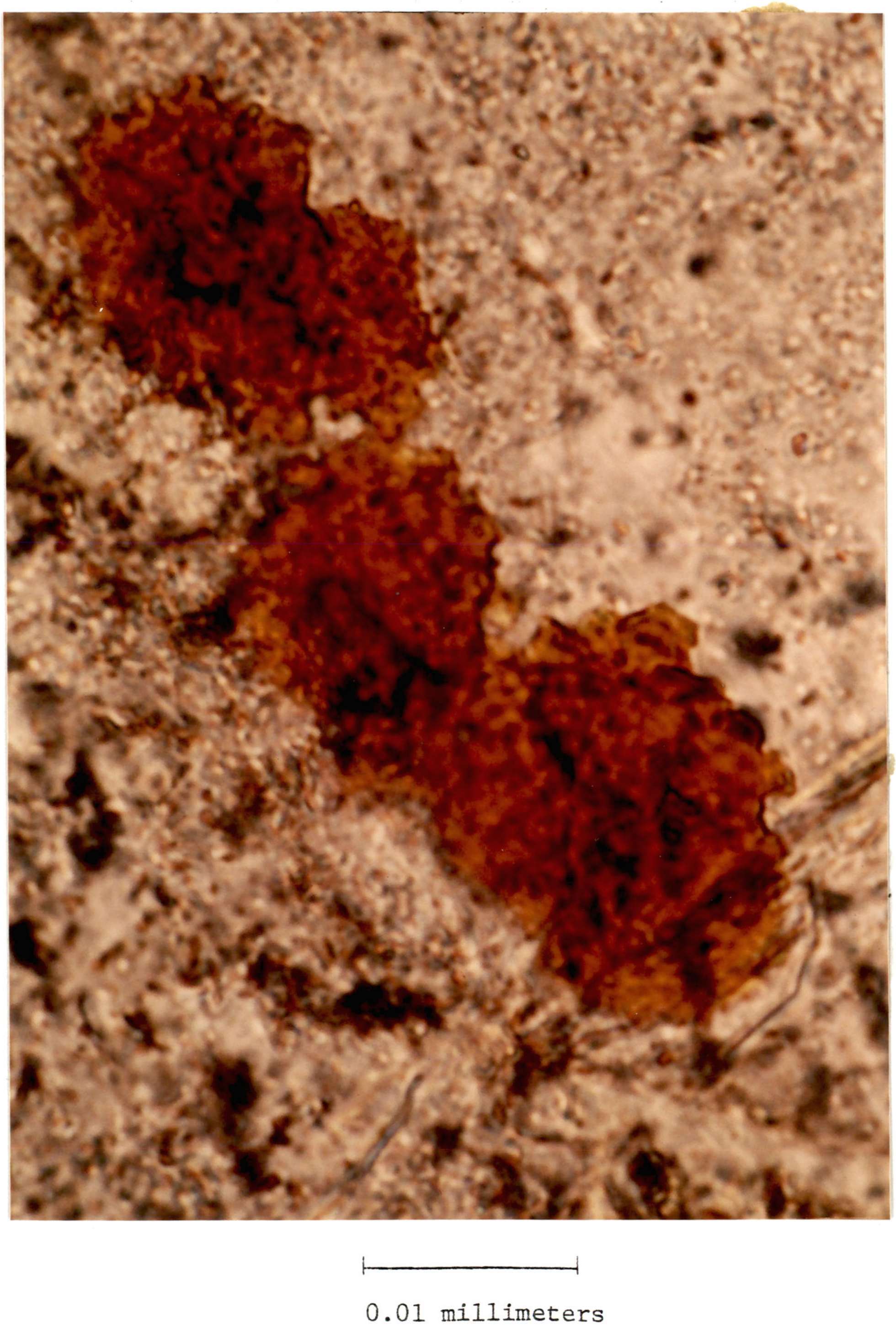


Figure 12. Hematite flakes in a potassium feldspar grain taken from the main altered mass. Plane light.

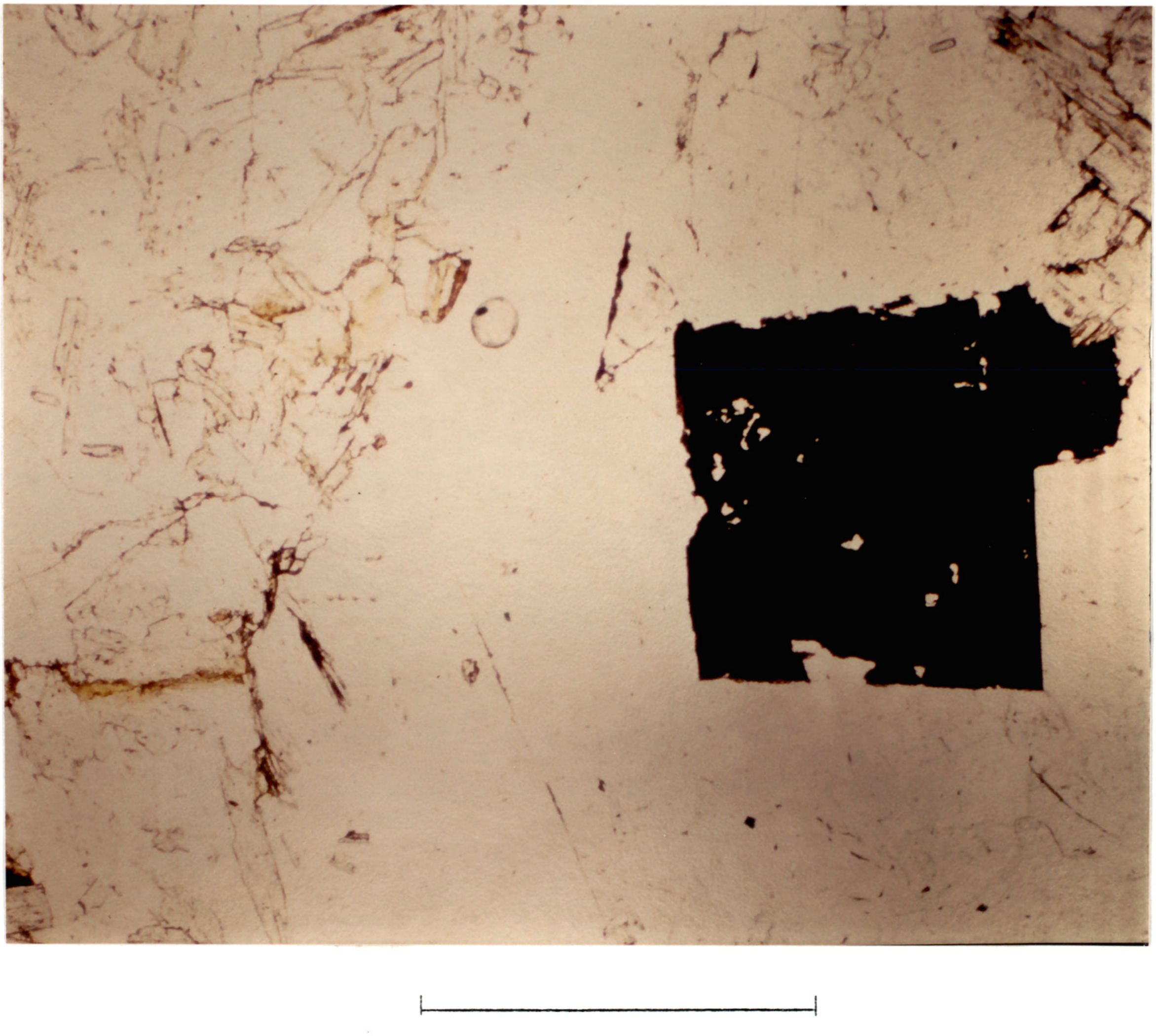
Plagioclase grains are oligoclase. The grains are smaller than potassium feldspar grains, ranging from 1 to 8 millimeters in diameter. Most grains are subhedral to anhedral. Oscillatory zoning and albite rims are present in most grains. Plagioclase is commonly associated with a sericite hash (Figure 11).

Petrography of the Main Altered Mass

Several thin-sections were made from each of 10 samples collected from the main altered mass. Petrographic examinations suggest that the granite was probably subjected to circulation of high temperature residual solutions and possibly vapors during late stage magma consolidation. Biotite has mostly been altered to chlorite and much of the potassium feldspar and plagioclase has been altered to sericite. Potassium feldspars within this zone are predominantly red and clouded where not completely converted to sericite. The presence of hematite is apparently responsible for this characteristic red coloration (Figure 12).

Muscovite accounts for as much as 20 percent by volume in some samples of the altered rock. Apatite and sphene are notably absent. Tourmaline, fluorite, and lithium mica are present in trace amounts. Presumably these phases are related to late stage solutions attacking feldspars. Epidote was deposited along fractures throughout the altered mass.

Pyrite and other sulfide phases are common. Pyrite often forms euhedral crystals as large as 5 millimeters in diameter (Figure 13). Molybdenite occurs locally as disseminated grains up to 1 millimeter in diameter.



5 millimeters

Figure 13. Thin section from sample NQ-111 showing a large pyrite crystal. Plane light.

Major Element Chemistry

Major and trace element analyses were made on 15 samples using XRF techniques. Appendix B gives details on procedures for sample preparation and analyses. Appendix E lists the accuracy for the analyses.

Table 1 lists data obtained from major element analyses. The granite is an average calc-alkaline granite and it is peraluminous. Average molecular Al_2O_3 / $Na_2O + K_2O + CaO = 1.57$. Figure 14 is a Na_2O-K_2O-CaO diagram showing that the Sims pluton plots in the central part of the field for other late Paleozoic plutons in the southeastern Piedmont. This field plots near the high alkali end of the Southern California Batholith trend.

Table 2 compares major element chemistry of the Sims pluton to the eastern and western groups of plutons defined by Fullagar and Butler. Average SiO_2 content is slightly greater than both eastern and western groups, but the difference is not considered significant.

Samples BB-7, BB-8, and K-7 show major element compositions that are quite distinct from the other eleven samples. These four samples were not used in any statistical averaging of major element data for comparison to eastern or western groups. Samples in this anomalous group have relatively low Na_2O and K_2O concentrations (Figure 15). These samples are correspondingly enriched in SiO_2. Modal analyses show that they have lower contents of potassium and plagioclase feldspars and relatively higher quartz contents (Table 3).

Sample	BB-1	BB-2	BB-3	BB-4	BB-6	BB-7	BB-8	BB-9	BB-10
Oxide+									
SiO_2	74.0	73.2	72.1	72.4	75.1	75.0	78.1	76.5	76.4
TiO_2	0.31	0.40	0.21	0.31	0.29	0.51	0.27	0.49	0.41
Al_2O_3	12.5	12.31	12.15	13.85	14.43	13.82	13.61	14.7	14.5
FeO*	1.77	1.81	2.10	1.16	1.59	1.62	1.99	1.67	1.81
MnO	0.05	0.02	0.04	0.08	0.07	0.06	0.04	0.04	0.02
MgO	0.12	0.31	0.61	0.22	0.09	0.41	0.40	0.53	0.38
CaO	1.21	1.20	1.17	1.31	1.19	1.11	1.30	1.24	1.25
Na_2O	4.26	3.60	5.10	3.61	4.01	0.99	0.07	0.06	1.19
K_2O	4.50	5.11	3.96	3.11	2.99	0.98	1.67	2.52	2.65
P_2O_5	0.10	0.-1	0.01	0.33	0.03	0.13	0.02	0.04	0.14
	98.82	98.07	99.45	96.38	99.49	94.62	97.47	97.79	98.75

+concentrations in weight percent
*FeO as total iron

Table 1. Raw data from XRF analyses of 15 samples for their major element content.

Sample	B-1	K-5	K-6	K-7	BB-5	NQ-1	Mean
Oxide+							
SiO_2	73.2	74.9	75.7	76.9	70.1	72.0	74.6
TiO_2	0.20	0.32	0.20	0.19	0.33	0.36	0.32
Al_2O_3	13.91	13.87	12.97	12.85	14.1	14.0	13.47
Feo*	1.61	1.59	1.75	1.69	2.01	2.03	1.70
MnO	0.04	0.03	0.06	0.05	0.03	0.05	0.05
MgO	0.32	0.27	0.33	0.26	0.55	0.52	0.33
CaO	1.27	1.29	1.23	1.40	1.41	1.45	1.24
Na_2O	4.21	2.15	1.01	0.88	4.02	4.03	2.55
K_2O	4.88	3.98	2.52	1.91	4.66	4.91	3.14
P_2O_5	0.08	0.05	0.14	0.17	0.08	0.10	0.10
Total	101.72	98.45	95.91	96.30	97.29	99.45	97.94

+concentrations in weight percent
*FeO as total iron

Table 1. Continued.

	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	MgO	MnO	CaO	K_2O	Na_2O
Eastern Group (99 samples)	71.9	14.4	0.35	2.42	0.53	0.06	1.31	4.99	3.49
Western Group (18 samples)	70.7	15.4	0.46	2.19	0.69	0.05	1.96	4.06	3.61
Sims (11 samples)	73.6	13.5	0.30	1.78	0.34	0.04	1.27	3.97	3.38

Table 2. Comparison of major element chemistry for the Main (Eastern), the York-Churchland (Western), and the Sims pluton (Main and York-Churchland data from Fullagar and Butler, 1979).

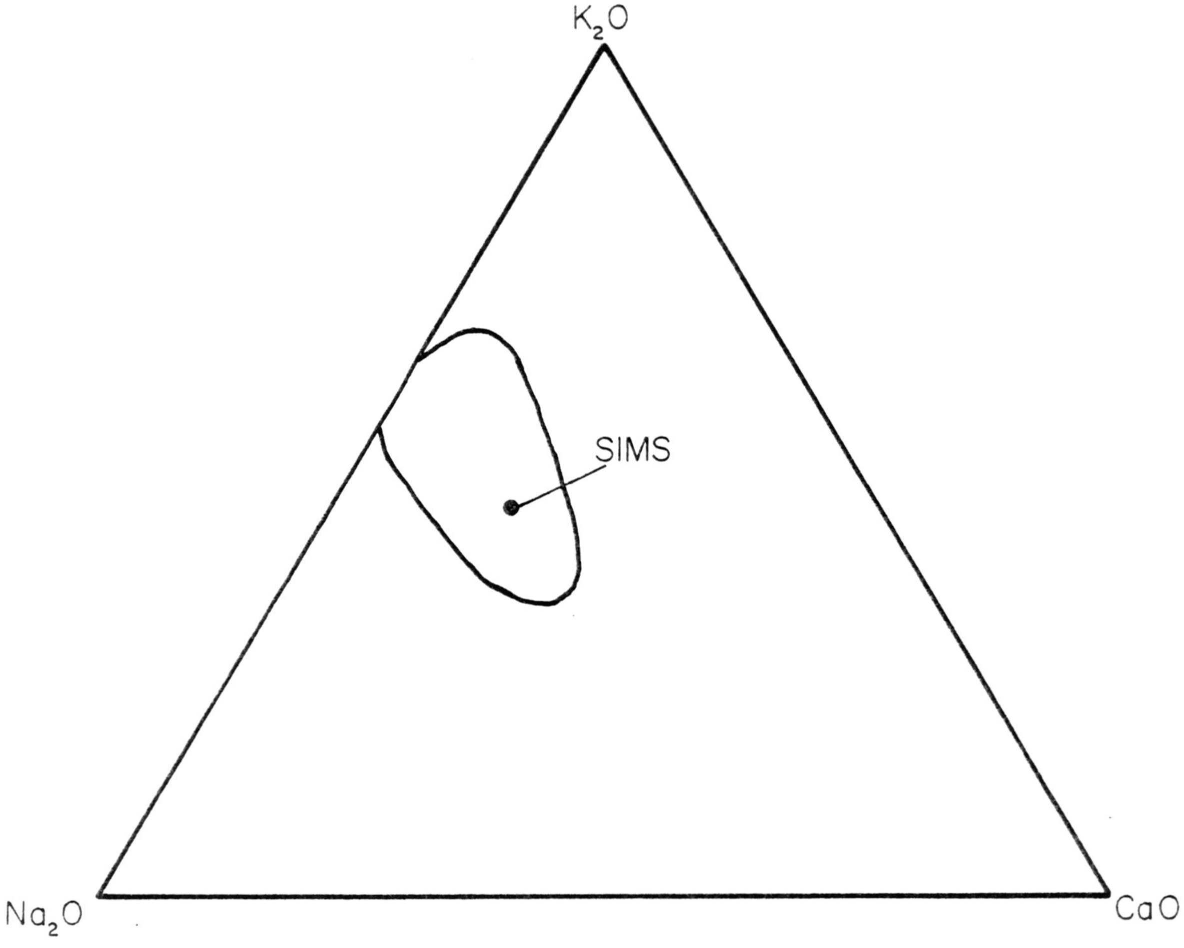


Figure 14. A K_2O-Na_2O-CaO diagram showing the field outlined by data from late Paleozoic plutons (modified from Fullagar and Butler, 1979).

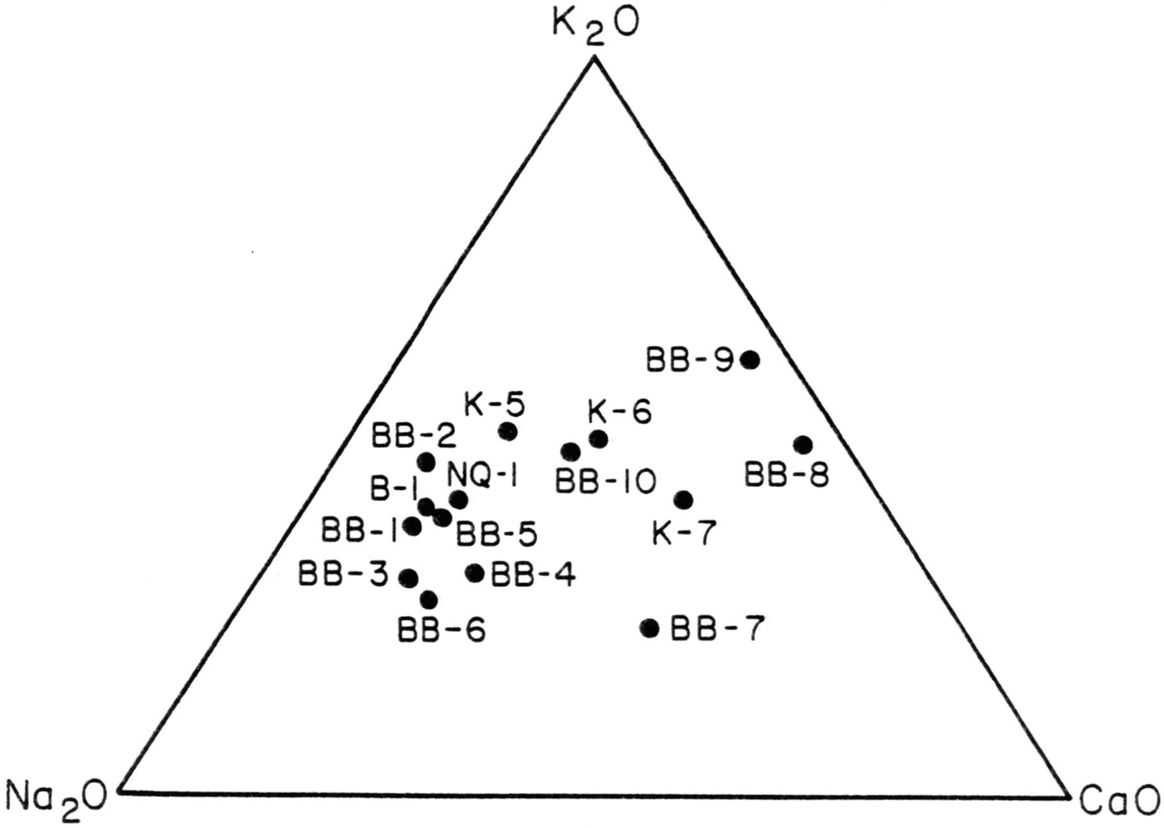


Figure 15. A K_2O-Na_2O-CaO diagram for 11 samples from the Sims pluton.

	Quartz	K-spar
Anomalous Group (4 samples)	50-55	10-20
Normal Group (11 samples)	20-30	45-60

Table 3. A comparison of modal percentages of quartz and K-spar between four anomalous samples and eleven samples in a normal group.

The anomalous samples were collected in close proximity to the main altered mass (Appendix A). Their modal analyses closely resemble those of the rocks from the altered mass (Appendix J). A relationship between the genesis of the altered mass and the apparent mobilization of Na_20 and K_20 is probably present. Hydrothermal alteration resulted in the formation of a low-temperature, high-potassium feldspar through mobilization and leaching of sodium. This low temperature exchange with fluids may have resulted in the formation of the red clouded potassium feldspars in the altered mass. Included in the complex geochemical effects brought by hydrothermal alteration was certainly a reduction of the Fe/Mg ratio of ferromagnesian minerals (as in the biotite to chlorite reaction). Boone (1969) noted that red clouded feldspars containing hematite were limited to rocks where mafics are at least partly chloritized.

Trace Element Geochemistry

Fifteen samples were analyzed for their concentrations of Mo, Zr, Y, Sr, Rb, Th, Pb, Zn, Cu, Ni, Co, Mn, Ti, and Ba. Instrumentation and computer reduction of data are discussed in Appendices C and D. Appendix F lists the accuracy of the analyses. Molybdenum, Cu, Pb, Zn, and Ni were selected because of their possible enrichment in greisen zones of granitic rocks. Analyses were made on fresh rock in an attempt to discover possible trends within the stock. Mineral phases in which Mo, Cu, Pb, and Zn are important cations are abundant in the Sims greisen zone (Cook, 1972). Barium was chosen because of its highly variable concentration in late Paleozoic plutons of the southeastern Piedmont and its extensively studied behavior as a trace element in igneous rocks. Strontium and Rb are important in differentiating eastern from western group plutons. The remaining elements were chosen for use in making a general comparison with other postmetamorphic plutons. Table 4 summarizes data obtained from XRF analyses. Appendix K lists the raw data.

Molybdenum, Zinc, Nickel, and Cobalt

Molybdenum, Zn, Ni, and Co were detected in concentrations of less than 5 parts per million in all samples of fresh granite. Since these low values approach the detection limit, the data have little value for geochemical interpretations. It is important to note that these low concentrations are characteristic of both eastern and western group plutons and of normal calc-alkaline granites.

Titanium and Zirconium

Titanium and Zr concentrations average 734 and 133 parts per mil-

Mo	0.3
Cu	37
Zr	133
Y	18
Th	16
Pb	31
Zn	1
Ni	3
Co	2
Mn	166
Ti	734
Ba	490

concentrations
in ppm

Table 4. Mean concentrations of trace elements in the Sims pluton for 15 samples.

lion respectively. This Zr concentration is somewhat lower than the average of eastern group plutons (135 to 155 ppm). The Zr is uniformly distributed within the pluton. Titanium concentrations vary from 87 parts per million to 4075 parts per million. Samples BB-1, BB-6, and BB-9 have the highest Ti concentrations. Biotite in these samples is 4 to 5 modal percent higher than in the other 13 samples. Since no Ti phase was found in thin sections, hand samples, or magnetic separates of BB-1, BB-6, and BB-9, I conclude that the Ti is contained in the biotite. Titanium concentration seems to closely follow Ba concentration. This is probably due to biotite containing both Ba and Ti.

Rubidium and Strontium

The pluton averages 142 parts per million Rb and 236 parts per million Sr. The average Rb/Sr ratio is 0.60. Clearly the Sims pluton has an average Sr concentration similar to that for eastern group plutons (Table 5). Strontium concentrations are generally higher in western group plutons and correspondingly the Rb/Sr ratios of western group plutons are lower than eastern group plutons. The Sims Rb/Sr ratio is roughly halfway between values of eastern and western groups.

	Rb	Sr	Rb/Sr
Eastern Group	178	138	1.28
Western Group	133	636	0.21
Sims	142	236	0.60

Table 5. A comparison of Rb, Sr, and Rb/Sr between eastern and western groups of plutons and the Sims pluton.

Barium

Barium concentration in the Sims pluton averages 490 parts per million. This average is lower than the western group of plutons, but the concentration is highly variable. This observation fits with the highly variable range of Ba concentrations of eastern group plutons. In normal calc-alkaline granites Ba is generally partitioned into alkali feldspars and for this reason Ba concentration is linked to the total amount of alkali feldspar. Figure 16 is a plot of Ba concentration against weight percent SiO_2. There are two fields: one with a higher mean SiO_2 content and lower mean Ba concentration. Mean K_2O content is given for each field. A comparison of modal analyses for samples within each field reveals that the K-spar phase is relatively depleted in samples within the higher mean SiO_2 field. Thus, Ba concentration is reduced for samples in which the alkali is locally depleted and the quartz phase is relatively enriched.

Yttrium, Thorium, Manganese, and Lead

Average concentrations of Y in the Sims pluton is 18 parts per million. All plutons in both eastern and western groups average less than 40 parts per million, and there appears to be no significant trend in Y distribution for postmetamorphic plutons. Concentrations of Y are relatively constant in the Sims pluton.

Thorium was detected in the granite at an average of 16 parts per million. This corresponds well with the concentrations of Th found by Wanger (1974).

Manganese shows wide fluctuations in its distribution. Concentrations range from 415 to 21 parts per million. The average concentra-

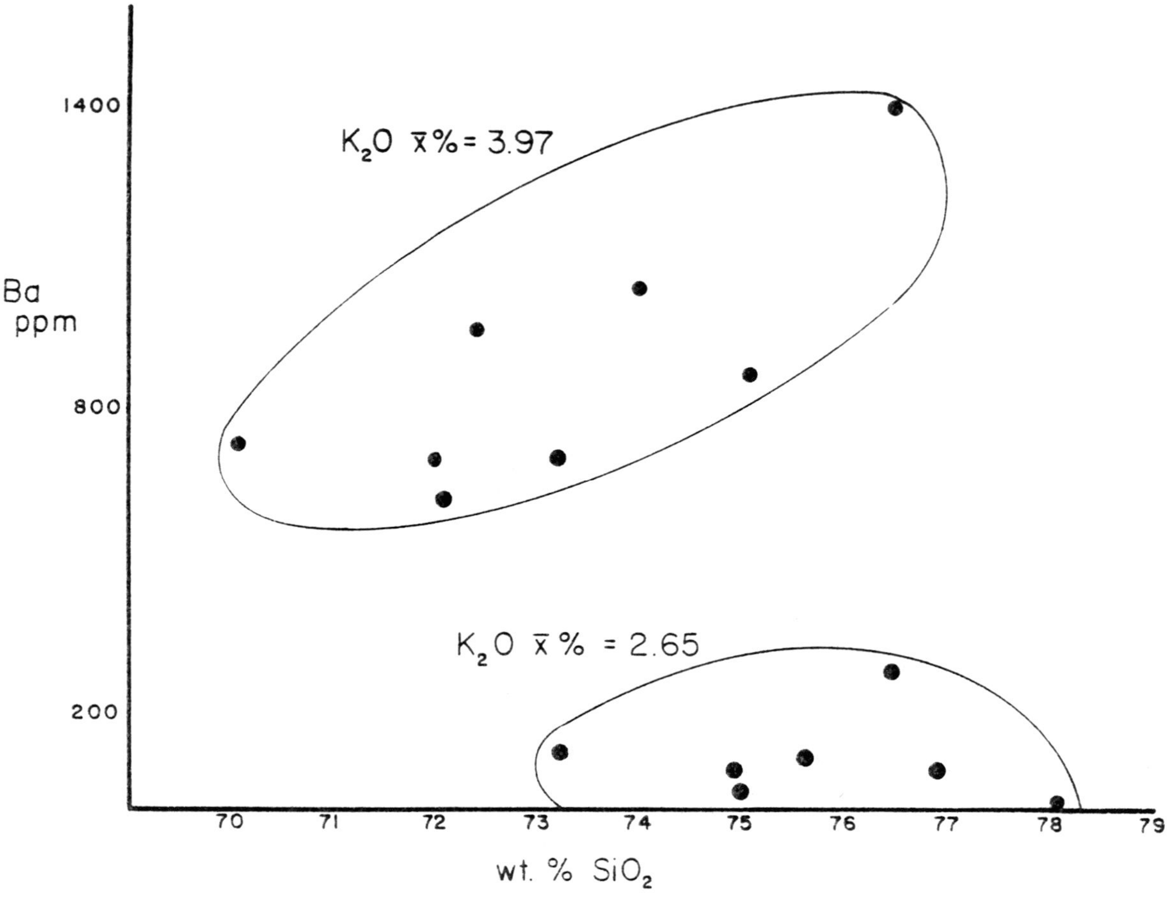


Figure 16. Diagram of SiO_2 versus Ba showing two sample groupings and their corresponding mean K_2O values for 15 samples.

tion of 167 parts per million is within the concentration range for "normal" granites. No data is available for the average concentrations of Mn in plutons in eastern or western groups.

Average Pb concentration in the granite is 16 parts per million. Distribution of Pb is fairly even; no sample contained more than 75 parts per million.

Geochronology

Whole rock specimens were crushed and pulverized to less than 200 mesh. Heavy liquid separation was used to obtain mineral separates. Rubidium and Sr concentrations were obtained using isotope dilution methods, and isotope ratios were analyzed on a 60-degree, 30 centimeter-radius, solid-source mass spectrometer. All data was reduced by computer.

Data points for the isochron were subjected to the York (1966) regression analysis. Errors are $< 1\sigma$. The geochronologic data represented are based on a Rb^{87} half-life of 48.9×10^9 years.

Figure 17 depicts the whole rock isochron for the pluton. The initial Sr^{87}/Sr^{86} ratio was calculated to be 0.7044 ± 0.0005. This value correlates well with other postmetamorphic plutons and suggests an upper mantle or lower crust origin for the parent magma.

The whole rock age of the pluton was calculated to be 288 ± 13 million years. A more precise age, based upon a biotite-whole rock-plagioclase isochron, is 285 ± 2 million years. This further supports 300 million years as a time of extensive plutonism in the eastern portion of the southern Appalachian Piedmont.

Figure 18 shows the biotite-whole rock-plagioclase isochron. The isochron shows excellent correlation to the whole rock isochron, and indicates that there was no major re-equilibration due to postemplacement metamorphic effects. The biotite separate is contaminated with plagioclase, hence the Rb/Sr ratio is lower than expected.

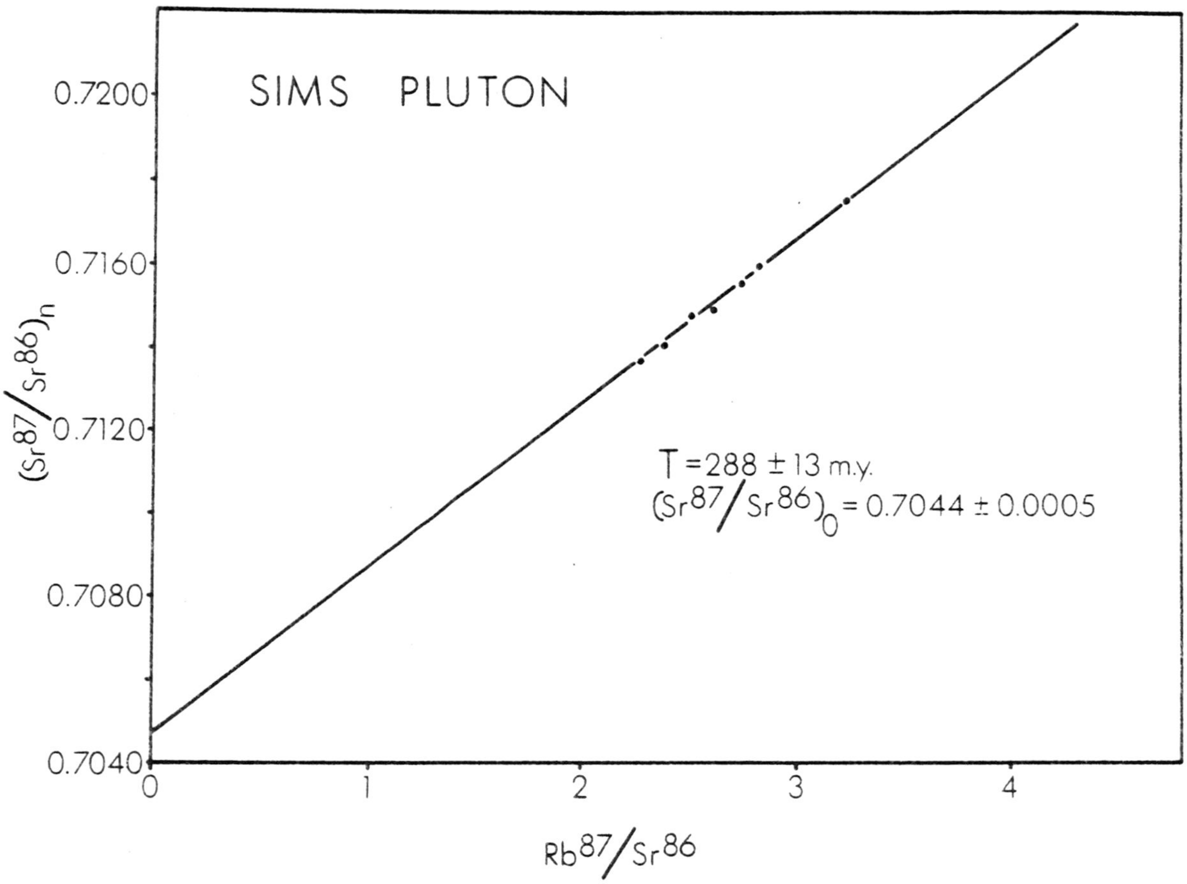


Figure 17. Whole rock isochron for the Sims granite.

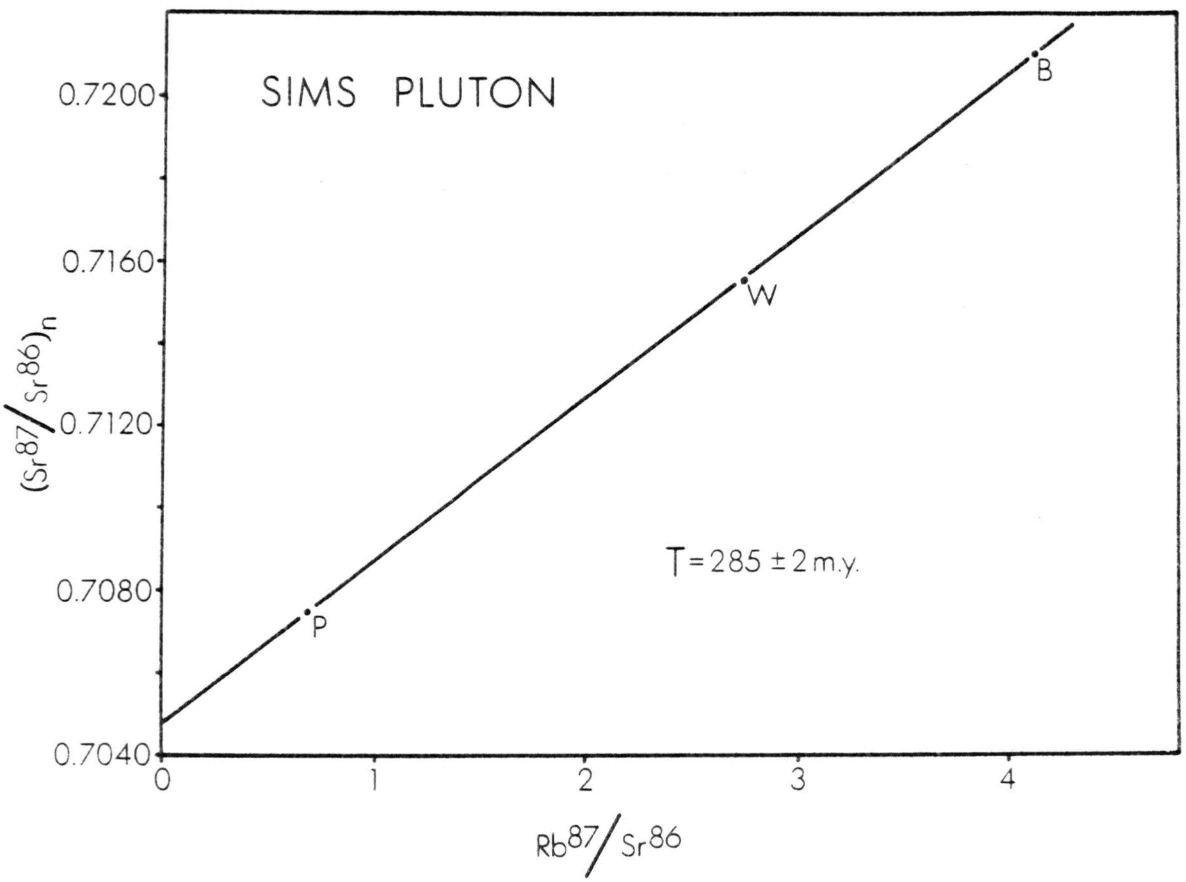


Figure 18. Biotite-whole rock-plagioclase isochron for the Sims granite.

Regional Perspective

Age trends within the 300 my old group of plutons are somewhat controversial. Jones and Walker (1975) believe that the granites in the eastern Piedmont are progressively younger from the northeast to the southwest. Fullagar and Butler (1979) conclude that this trend is not as definite, and one can only say that younger plutons occur in the southern portion of the eastern Piedmont while somewhat older plutons occur in the northern portion. Their linearity immediately suggests that the plutons may have originated above a subduction zone. The Sims granite and many of the larger plutons are localized along the Coastal Plain trace. It is possible that this alignment is spurious because other 300 my old plutons are probably covered by Coastal Plain sediments.

Several plate tectonic models have been proposed for the origin of the Carolina Slate Belt. Glover and others (1978) maintain that the belt was essentially a back-arc basin. Whitney and others (1977) believe that their petrological and geochemical data suggest an island arc system for the Slate Belt in Georgia and South Carolina. They note that island arc development should have given rise to a calc-alkaline trend in volcanism in central North Carolina. Long (1979) maintains that the Carolina Slate Belt is an old continental rift zone. His conclusions are based upon interpretations of gravity data.

A major problem with the 300 my old group of plutons is the lack of widespread deformation. It is unlikely that they could have escaped deformation resulting from compression and large-scale thrusting of the Blue Ridge. Hatcher and others (1977) speculate that a fault system may extend through the eastern Piedmont, and Fullagar and Butler (1979) conclude that in the east, uplift was followed by gravitational spreading. To the west thrusting, faulting, and folding was the result of the plate margin collision. Uplift of the eastern region would account for the lack of deformational features in the 300 my old plutons. Dennison (1976) used this model for explaining Valley and Ridge structural features.

Tull (1979) points out that deformation is not necessarily uniform in space and time. Hence, it is not simultaneously recorded in equal intensities in all areas. He speculates that some areas may not have been subjected to stress at all. There is evidence of localized deformation in a few of the 300 my old granites (Farrar and others, 1981), but there is no obvious geographical pattern that links these plutons. Thus, orogenic activity within the southern Appalachians may best be described as occurring in geographical and temporal pulses. It is probable that a simple model will not explain this localization of deformation. Current models should take into account the spacially limited effects of the collision of irregularly-shaped continental margins and the effects of small-scale features such as microcontinents as Tull (1979) has suggested.

As more gravity, geochemical, and structural data become available, the complex nature of the entire Appalachian system may become clearer. It may be possible to eventually relate individual orogenic pulses to specific structural features. The notion that a single deformational orogenic event is manifested in many structures throughout the region may have to be significantly modified.

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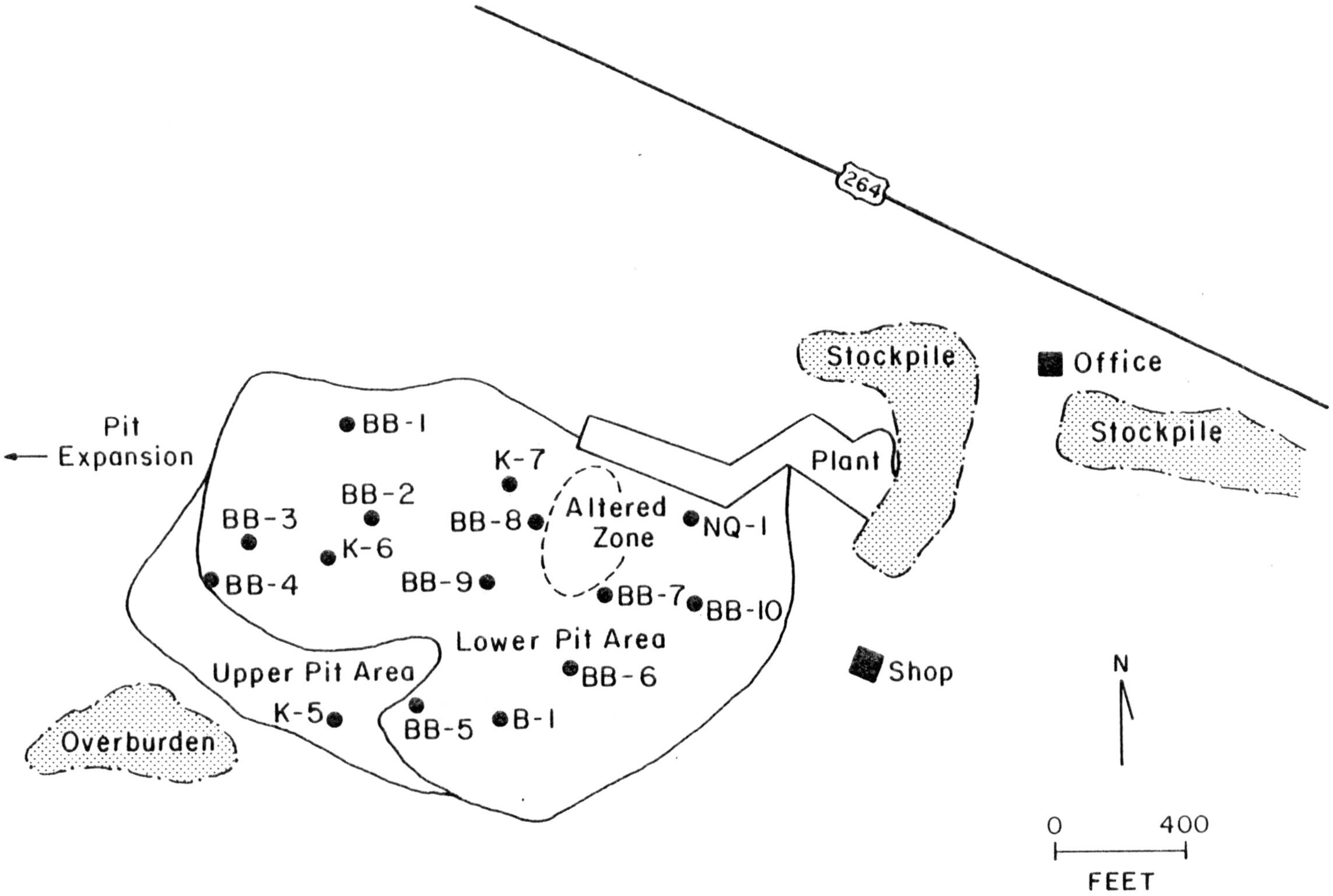
Appendices



Appendix A

Map of the Sims quarry based upon 1972 pit outlines.

Appendix B

Analytical Procedures

Fresh samples of the granite were chosen for study by X-ray fluorescence. Sample pellets were prepared using the following technique:

1. Approximately 1 kilogram of sample was hand crushed with a tungsten carbide hammer and plate to minus 0.75 centimeters.
2. The coarse crushed sample was split until approximately 100 grams was obtained.
3. This split was crushed to minus 100 mesh in a Spex ball mill using tungsten carbide balls.
4. This powder was mixed with fibrous cellulose in a 4:1 ratio.
5. This mixture was mixed with 15-20 milliliters of acetone and ground in a micronizer mill for approximately 5 minutes. This was allowed to dry.
6. The powder was pressed into a 1.5 inch diameter receptacle under 20 tons/inch^2 pressure.

The resulting pellets were analyzed using a Philips 1410 X-ray spectrometer and associated Philips XRG-3000 X-ray generator.

Appendix C

Computer Reduction of Data

Data was reduced on a CDC Cyber 70 computer utilizing FORTRAN programs written and modified by Dr. J. C. Stormer and Dr. Willis B. Hayes, Department of Geology, University of Georgia. Several component programs were used:

1.	BXLAVE	Calculates counts per second and performs deadtime and drift calculations.
2.	BXCOMP	Calculates oxide percents from whole rock X-ray fluorescence data, output from BXLAVE, and standard data.
3.	BNORM	Calculates modified C. I. P. W. normative compositions from whole rock analyses.
4.	BXTRACE	Corrects for background at the 20 position for each trace element by a procedure using ratios to a quartz blank.
5.	BXABS	Calculates absorption coefficients for unknowns and standards using major element oxide analyses.

Appendix D

Instrument Settings for Major Element Analysis

Element	Crystal	20	Filter	Collimator	Count Time (sec)
Fe	LiF200	57.52	in	fine	10
Mn	LiF200	62.97	in	fine	40
Ti	LiF200	86.14	out	fine	10
Ca	LiF200	113.09	out	fine	10
K	LiF200	136.69	out	fine	10
P	Ge	141.00	out	fine	40
Si	PET	109.21	out	fine	20
Al	PET	145.13	out	fine	20
Mg	TlAP	45.17	out	fine	80
Na	TlAP	55.10	out	coarse	80

Appendix E

Composition of Standard Pellets and Accepted and Found Values of Major Elements

Element	G H	Found	G-2	Found
Fe_2O_3	1.34	1.33	2.65	2.68
MnO	0.05	0.06	0.03	0.05
TiO_2	0.08	0.06	0.50	0.53
CaO	0.69	0.72	1.94	1.99
K_2O	4.76	4.80	4.51	4.55
SO_2	0.01	UNDET	0.01	UNDET
P_2O_5	0.01	UNDET	0.14	0.11
SiO_2	75.80	75.89	69.11	70.05
Al_2O_3	12.50	12.66	15.40	15.45
MgO	0.03	UNDET	0.76	0.80
Na_2O	3.85	3.88	4.07	4.11

Appendix F

Trace Element Composition of Standard Pellet and Concentration Found in this Study

Element*	USGS Sample #G-2	Found
Ba	1870	1860.5
Co	5.5	6.2
Cu	11.7	11.9
Mn	260	269.3
Mo	.36	UNDET
Ni	5.1	5.9
Rb	168	173.2
Sr	479	491.2
Th	24.2	25.3
Ti	2780	2785.5
Y	12	16
Zn	85	89.4
Zr	300	309.2

*Concentrations given in parts per million

Appendix G

Instrument Settings for Initial Scan of Trace Elements by XRF

Filter	in
Collimator	fine
Detector	first order scintillation
Initial 20	20°
Range	500, miltiplier switch at 1.0
Time Constant	10
Chart Speed	30
Scan Rate	1°/minute

Instrument Settings for Trace Element Analysis by XRF

W tube

50 kv

40 ma

spinner on

fine collimation

filter out

vacuum on

Appendix H

Trace Element Groupings, Associated Instrument Settings, Peak 20 Values, and Potential Interference Elements

Element	Line	Two-Theta	
Group 1: LiF220 crystal; scintillation detector			
Mo	KA	28.90	
Group II: Same conditions			
Zr	KA	32.10	
Y	KA	33.90	
Sr	KA	35.85	
Rb	KA	37.99	
Th	LA1	39.23	
Pb	LB1 & 2	40.36	
Group III: Flow detector on for this and following groups			
Pb	LA1	48.73	(As interference)
Zn	KA	60.58	
Cu	KA	65.56	(Slight W interference)
Group IV: Same conditions			
Co	KA	77.90	(Fe interference)
Group V: Same Conditions			
Mn	KA	95.20	
Ti	KA	123.94	(V interference)

Appendix I

Modal Analyses for 15 Samples of Unaltered Granite

	BB-1	BB-2	BB-3	BB-4	BB-5	BB-6	BB-7	BB-8	BB-9	BB-10	K-5	K-6	K-7	B-1	NQ-1
K-spar	61	46	52	59	59	62	25	26	29	51	56	40	37	55	62
Quartz	20	20	28	26	21	20	57	56	57	29	27	36	56	23	15
Plag.	3	9	5	3	2	4	2	1	1	4	4	1	1	8	4
Biotite	13	8	5	4	9	12	2	3	11	2	6	4	1	6	9
Musc.	2	8	4	5	4	1	4	5	1	4	2	3	3	4	6
Chlor.	0	4	2	1	1	0	3	2	1	5	2	1	2	1	1
Opaques	1	5	3	2	3	1	6	4	0	4	3	2	0	2	2
Other	0	0	1	0	1	0	1	3	0	1	0	0	0	1	1

Appendix J

Modal Analyses for 10 samples of Altered Granite

	NQ-100	NQ-101	NQ-102	NQ-103	NQ-104	NQ-105	NQ-108	NQ-109	NQ-110	NQ-111	$\bar{x}$
K-spar	37	45	60	25	50	25	53	39	35	23	39.2
Quartz	30	11	14	20	40	20	21	49	37	11	25.3
Plag.	1	2	6	4	1	8	5	2	8	2	3.9
Biotite	4	3	1	2	1	2	5	1	4	2	2.5
Musc.	11	10	5	30	3	221	5	2	2	30	11.9
Chlor.	2	23	10	8	2	6	3	4	10	5	7.3
Opaques	15	5	4	6	1	10	4	2	3	20	10.9
Other	0	1	0	6	2	8	4	1	1	7	3.0

Appendix K

Trace Element Content of 15 Samples of Granite Based on XRF Analyses

Sample	BB-1	BB-2	BB-3	BB-4	BB-6	BB-7	BB-8	BB-9	BB-10
Element+									
Mo	1	0	0	1	0	1	0	0	0
Zr	193	190	125	150	140	92	101	161	77
Y	24	22	21	30	19	21	15	20	12
Sr	240	253	225	238	219	239	251	226	221
Rb	137	142	151	159	129	138	148	139	138
Th	24	11	8	15	6	4	27	19	21
Pb	12	15	35	41	72	19	35	44	28
Zn	1	0	1	2	1	3	2	1	0
Cu	51	41	13	19	62	53	28	23	43
Ni	4	3	2	3	4	4	2	5	4
Co	3	2	0	0	1	1	4	3	2
Mn	415	350	128	171	56	28	310	369	107
Ti	4075	26	92	475	1198	51	17	3275	119
Ba	1048	722	619	965	871	46	27	1403	286

*concentrations in parts per million

Appendix K Continued

Sample Element+	B-1	K-5	K-6	K-7	BB-5	NQ-1	Mean
Mo	0	1	0	0	0	0	0.3
Zr	52	129	149	170	192	208	133.0
Y	11	17	9	13	20	21	18.0
Sr	234	229	246	241	209	211	236
Rb	145	141	132	140	211	195	142
Th	14	24	18	12	11	7	16
Pb	4	49	39	15	9	8	31
Zn	1	1	3	1	0	1	1.3
Cu	26	46	59	21	4	3	37
Ni	3	1	5	5	14	19	3.5
Co	1	3	2	2	1	0	1.9
Mn	118	21	58	37	26	78	167
Ti	57	30	27	99	261	196	734
Ba	101	87	109	86	736	701	490

+concentrations in parts per million