ULTRAMAFIC AND RELATED ROCKS IN THE VICINITY OF LAKE CHATUGE

by

MARVIN E. HARTLEY III

GEORGIA DEPARTMENT OF NATURAL RESOURCES
Joe D. Tanner, Commissioner
EARTH AND WATER DIVISION
THE GEOLOGICAL SURVEY OF GEORGIA
Sam M. Pickering, Jr., State Geologist and Director

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BULLETIN 85

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April 2, 1973

His Excellency, James E. Carter
Governor of Georgia
Atlanta, Georgia

Dear Governor Carter:

I have the honor to submit herewith Bulletin No. 85, entitled "Ultramafic and Related Rocks in the Vicinity of Lake Chatuge," by Marvin E. Hartley III. The report describes in detail the geology, structure, and petrography of a series of previously little-known basic rocks in Towns County. It includes a review of the minerals known to be of economic importance. The work will be of particular value in our efforts at completion of the new geologic map of Georgia.

Very respectfully yours,

S. M. Pickering, Jr.

Sam M. Pickering, Jr.
Director and State Geologist

SMP:ldj

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ULTRAMAFIC AND RELATED ROCKS IN THE VICINITY OF LAKE CHATUGE

by

Marvin E. Hartley III

ABSTRACT

Ultramafic and related rocks in the vicinity of Lake Chatuge occur as a sill between a biotite gneiss sequence and a garnet muscovite schist sequence. The area is located in the Blue Ridge thrust sheet in the sillimanite zone of mid-Paleozoic metamorphism. Structurally the sill occurs along the limbs of an anticlinal saddle. The foliation and jointing of the sill and the country rock, previously termed Carolina Gneiss, are parallel suggesting contemporaneous deformation.

Generally the sill is concentrically zoned. Dunite occurs in the center and is locally surrounded by coronite troctolite. Rhythmic banding consisting of alternating olivine and bytownite layers separated by a reaction zone of orthopyroxene-amphibole-spinel is present in several of the ultramafic units. These units are locally surrounded by olivine gabbro. Outwards, towards the margin of the sill, troctolite and olivine gabbro show a progressive alteration into amphibolite which consists of an assemblage of hornblende-andesine-clinozoisite-corundum. In addition, a garnet pyroxene gneiss occurs locally within the sill.

Evidence that the amphibolite margin, previously termed Roan Gneiss, is orthoamphibolite (metagabbro), consists of gradational boundaries with the olivine gabbro and mantle values of 0.7031 and 0.7047 for the Sr^{87}/Sr^{86} ratio. The coronite troctolite, olivine gabbro, and garnet pyroxene gneiss also have mantle values for their ratios.

It is proposed that the sill was emplaced in the early stages of regional metamorphism as a gabbroic magma transporting olivine crystal mush. Bhattacharji's model of magmatic flowage differentiation may be applicable in explaining the concentric zoning of the sill. It is probable that during the mid-Paleozoic metamorphism only enough water was available from the country rocks to hydrate (amphibolitize) the margin of the sill, because the country rocks had been depleted of water during the Grenville metamorphism.

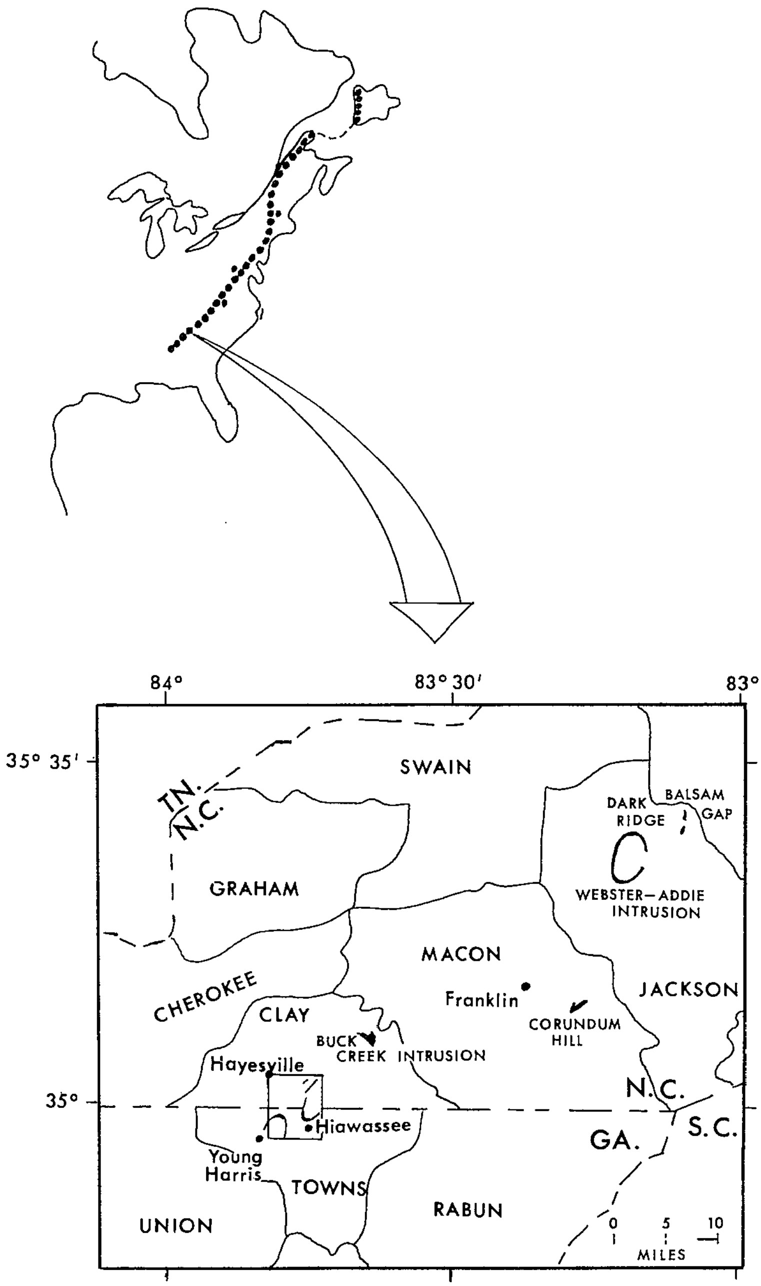

Figure 1. The ultramafic belt of eastern North America (Hess, 1955, p. 396) and location of the Lake Chatuge area and nearby major intrusions.

INTRODUCTION

This paper describes a geologic investigation of a 40 square-mile area in the vicinity of Lake Chatuge, Towns County, Georgia and Clay County, North Carolina (Figure 1). A geologic map showing the distribution of major rock units is presented in Plate 1. In this report pertinent characteristics of field occurrence and petrographic features of the rocks are described with emphasis on the ultramafic and mafic intrusive rocks. Detailed petrographic descriptions of the intrusives are presented as well as an investigation of Sr^{87}/Sr^{86} ratios of the rock units. Information obtained in this study is interpreted in terms of the emplacement history of the ultramafic rocks and their bearing on the origin of alpine-type peridotites. Known economic mineral deposits are also described and an appraisal of the mineral potential of the area is made.

Geographic Setting

The study area is located in the Blue Ridge province. The relief is approximately 1,800 feet. Ridgetops are typically underlain by resistant quartzites. The less resistant ultramafic rocks are exposed along several of the major valleys.

Lake Chatuge, a storage reservoir of the Tennessee Valley Authority system, occupies 10 square miles in the center of the area. Pool elevations range from about 1,923 feet in the summer to about 1,905 feet in the winter. Several of the ultramafic zones at the reservoir are exposed only during low-water levels.

Methods of Investigation

The area was mapped geologically at a scale of 1:2520 on photographic enlargements of portions of the following 7½ minute (1:24,000) quadrangles: Hiawassee, Ga.—N. C. (151-NE); Hayesville, N. C. (150-SE); Shooting Creek, N. C. (159-SW); and Macedonia, Ga.—N. C. (160-NW). A well-exposed ultramafic zone in the vicinity of the Hog Creek Mine was mapped at a scale of 1:600 on a base map prepared in the field by a triangulation survey. Field studies were made during the summers of 1969 and 1970, and the winter of 1970. Approximately 700 rock samples were collected from the area for reference and for laboratory investigation.

Several analytical methods were employed in an investigation of the rock samples. One hundred and fifty thin sections were studied by standard petrographic analysis. Opaque minerals were studied in 20 polished sections. Minerals that could not be identified by optical methods were identified by X-ray powder diffraction techniques. Plagioclase analyses were made by the refractive index method of Chayes (1952). Strontium extractions with exchange columns using Dowex resin no. 50W-X8 were made according to the procedure of Jones (1969, p. 306-308). Spectrographic determinations of the Sr^{87}/Sr^{86} ratios were made at the Analytical Chemical Division of the Oak Ridge National Laboratory. Mineral analyses for Ca, Mg, Fe, Na, V, and Ta in several samples were made using the MAC 400S electron microprobe.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to the people who helped with this study. Dr. Robert Carpenter advised, assisted, and critized the study. Drs. Thomas H. Pearce and Anton Brown critically read the manuscript. Dr. Lois M. Jones guided the strontium isotope study. The mass spectrometric measurements of the strontium were made by Raymond L. Walker of the Analytical Chemistry Division of the Oak Ridge National Laboratory which is operated for the U. S. Atomic Energy Commission by Union Carbide Corp. Dr. Dennis Radcliffe and Stephen C. Libby guided the electron microprobe analyses. Financial assistance for the field mapping was given by the Geology Branch of the Tennessee Valley Authority. Special thanks are given to Robert H. Carpenter and John M. Kellberg who recommended that this study be made.

PREVIOUS WORK

Early work on the ultramafic bodies concentrated on the associated deposits of corundum and asbestos. In Towns County, Ga., King (1894, p. 87-89) described the occurrence of corundum and several mine operations, and Hopkins (1914, p. 149-153) subsequently described asbestos occurrences. Investigations in North Carolina were more extensive. Genth (1873, p. 462) and Lewis (1896) described corundum localities. The geology of Clay County is included in the Nantahala Folio of Keith (1907). A discussion of the origin of peridotites and associated mineral deposits is given in Pratt (1898, p. 50-51) and Pratt and Lewis (1905).

The Tennessee Valley Authority and the North Carolina Division of Mineral Resources later continued investigations in the area. Kellberg (1943) noted the occurrence of several ultramafic bodies containing troctolite and "eclogite" in the vicinity of

Lake Chatuge, some of which had not been previously recognized. Hunter (1941) described the occurrence and evaluated the economic potential of dunite in North Carolina and Georgia. Conrad, Wilson, Allen, and Wright (1963) described the occurrence of anthophyllite asbestos in North Carolina.

The U. S. Bureau of Mines and U. S. Geological Survey made several investigations in Clay and Towns Counties for corundum. Ballard (1943, 1946, 1948) investigated the Bell Creek Corundum Mine, the Hog Creek Corundum Mine, and the Track Rock Corundum Mine. Hadley (1949) described the Buck Creek ultramafic body which is located about 15 miles northeast of Hiawassee.

GENERAL GEOLOGY

Ultramafic intrusions occur in the intensely metamorphosed portions of the Appalachian orogenic belt from Alabama to Newfoundland, a distance of 1,800 miles (Fig. 1). These intrusions are very similar to those in orogenic belts elsewhere in the world and are considered to be examples of alpine intrusions by Turner and Verhoogen (1960, p. 308-309).

The lithologies of ultramafic rocks in this belt are generally limited. Dunite is the most abundant. Pyroxenites are commonly present, and olivine gabbro, olivine norite, and harzburgite also occur. Troctolite occurs in only a few localities. Alteration processes which have affected these rocks include serpentinization, chloritization, steatitization, and amphibolization.

The Nantahala Folio of Keith (1907) shows associated ultramafic-amphibolite bodies within a thick interlayered sequence of mica schist and gneiss in North Carolina. Keith termed the latter Carolina Gneiss and concluded that it is an Archean sedimentary sequence that was intensely metamorphosed prior to deposition of the Ocoee Series. He also concluded that the Ocoee Series was regionally metamorphosed during the Paleozoic Era. Later work by Davis, Tilton, and Wetherill (1962) substantiated the relative timing of metamorphic events and concluded that they occurred at approximately 1050 and 340 m.y. These correspond respectively to the Grenville event and the mid-Paleozoic Barrovian-type metamorphism. Carpenter (1970) notes that the ultramafic rocks are mainly confined to the kyanite and sillimanite zones of the mid-Paleozoic metamorphism.

In the Lake Chatuge area the ultramafic, mafic, and metamafic rocks occur as a tabular unit that commonly parallels the foliation and is interpreted to be a sill. The sill has been folded into an anticlinal saddle. On Plate 1 this appears as two opposing plunging anticlines. The hingeline of one is offset compared to the other. One of the following possibilities may explain this:

1. The folds may be *en echelon*. In such cases the axial traces are offset in a step-like manner.

2. The folds may represent a cross-folded anticline forming two plunging folds which have subsequently been offset by an unobserved fault underlying the lake. However, the lack of any offset of the sillimanite schist unit shown on Plate 1 or the extensions of the unit shown by Hash and Van Horn (1951) indicates that any such fault is fairly short or does not exist.

Several minor similar folds of various magnitudes occur on the saddle. The hinge lines of these folds are commonly parallel but have divergent axial planes. Since true attitudes of folds of several magnitudes are measurable only in large roadcuts, it is likely that many of the attitudes measured at small outcrops represent some of the smaller minor folds.

The attitudes of about 150 foliations were measured and are shown on Plate 1. Foliations of the rocks generally strike about N40E and dip steeply to the southeast, but local variations are common, especially in the noses of folds. Foliation is locally present in dunite, but is discordant with other planar features and may represent closely spaced shear fractures.

Contouring of the attitudes of 150 joint attitude measurements have been plotted on a Schmidt net lower hemisphere (Fig. 2). These form a strong point maximum, and a weaker bimodal concentration occurs which has been interpreted by inspection as a set striking N40E, dipping 90°, and a set striking N52W, dipping about 85° southwest. Since the anticlinal axis trends N40E, they correspond to the common *bc* and *ac* joints respectively.

STRONTIUM ISOTOPE INVESTIGATION

In order to obtain more information about the emplacement and subsequent alteration history of the mafic and ultramafic rocks, strontium isotope compositions were investigated. The significance of this approach is based upon the theory that the crust of the earth was enriched in rubidium, relative to the mantle, during chemical differentiation in the early geologic history of the earth

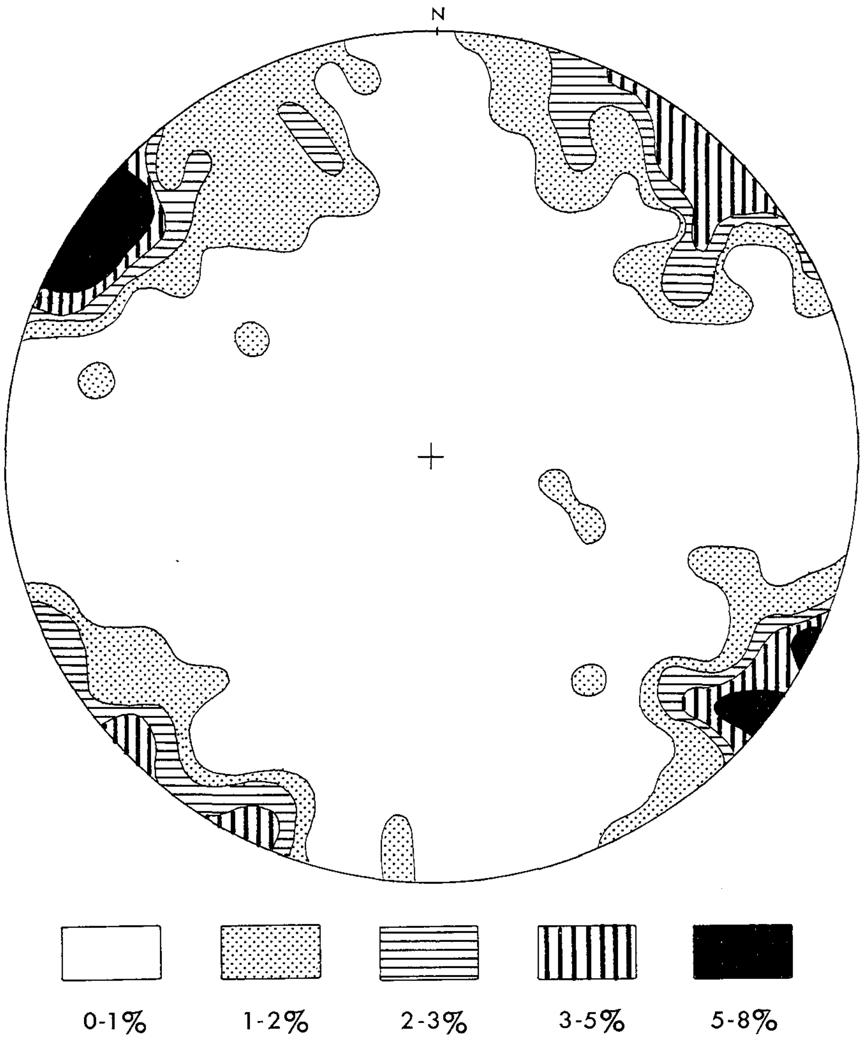

Figure 2. Contour diagram of 150 joints in the Lake Chatuge area.

(Faure and Hurley, 1963); and, that the radioactive rubidium isotope Rb^{87} decays to Sr^{87} with a half-life of about 50 billion years. Thus with time the Sr^{87} has increased relative to Sr^{86}, a naturally occuring stable isotope, in a way that is directly proportional to the original Rb/Sr ratio. Faure and Hurley (1963, p. 31) estimate that the Rb/Sr ratio of near-surface continental crust is 0.25, and they reported that a 2 billion year old crustal rock with an initial Sr^{87}/Sr^{86} ratio of 0.704 would theoretically have a present value of 0.725. Their measurements of two Paleozoic shales averaged 0.7215, a number close to what would be calculated. Rocks of the same age derived from the mantle should theoretically have a lower value because of a lower Rb content unless they have been substantially altered or contaminated.

Table 1 shows the results of analyses of the Lake Chatuge rocks (Hartley, Walker, and Jones, 1971). The Precambrian country rock samples (numbers 69C 10 and 70C 609) have values of 0.7321 and 0.7258 respectively, which approach the value 0.725 estimated by Faure and Hurley.

Hurley (1967, p. 374-375) assigns a range for the Sr^{87}/Sr^{86} ratio of 0.702-0.705 for mantle-derived oceanic island basalts and tholeiites. He also shows a "typical range" of 0.706-0.714 and assigns a "common range" of 0.707-0.725 for alpine-type ultramafic rocks. He states, "Clearly there is no contemporary relationship between alpine-type ultramafics and other common materials reaching the surface from the mantle, in oceanic or continental regions." However, the Sr^{87}/Sr^{86} ratios of the mafic rocks around Lake Chatuge (Table 1) indicate a direct association with mantle-derived material. Values obtained for dunite and amphibolite are discussed in subsequent sections.

METAMORPHIC COUNTRY ROCKS

The country rocks in the northern half of the Lake Chatuge area were termed Carolina Gneiss and Archean granite by Keith (1907). In this study Keith's Carolina Gneiss is divided into several distinct units. These include biotite gneiss, garnet mica schist, garnet kyanite rock, clinozoisite rock, sillimanite schist, and quartzite. Also, Keith's Archean granite is herein termed coarse-banded biotite gneiss due to the presence of a foliation and thick banding. Modal analyses of several country rock samples are shown in Table 2.

Table 1. Strontium isotope compositions (Hartley, Walker, and Jones, 1971)

Rock type	Sample no.	Sr^{87}/Sr^{86}*
Olivine gabbro	70C 389	0.7029
Coronite troctolite	69C 23	0.7026
Coronite troctolite, rhythmically banded	70C 379	0.7024
Diallage-bytownite (mafic) vein	69C 55	0.7031
Hornblende-andesine (metamafic) vein	69C 63	0.7036
Amphibolite	70C 599	0.7031
Amphibolite	70C 314a	0.7047
Amphibolite	70C 314b	0.7047
Garnet pyroxene gneiss	69C 29	0.7039
Serpentinized dunite	70C 475a	0.7068
Olivine from 475a	70C475b	0.7023
Chloritized-serpentinized dunite	70C 116	0.7036
Serpentinized wehrlite	69C 85	0.7041
Serpentinized dunite	70C 493	0.7058
Serpentinite	69C 70	0.7058
Country rocks:		
biotite gneiss	69C 10	0.7321
garnet mica schist	70C 609	0.7258

*Eimer and Amend $SrCO_3$ interlaboratory standard = 0.7083 ± 0.0002 Sr^{87}/Sr^{86} ratio normalized to Sr^{86}/Sr^{88} = 0.1194.

Table 2. Modal Analyses of Country Rocks in Volume Percent Mineral Composition

Sample no.	1	2	3	4	5	6	7	8	9
Amphibole			8					tr	
Biotite	16	15		7	16	8			tr
Clinozoisite	tr		7					52	
Epidote		1							
Garnet		tr	10	1		6	37		
Kyanite	tr						60		
Microcline	24								
Muscovite	6	1		5	22	42	3		2
Plagioclase	4	23	2	20	6	8		11	tr
Quartz	48	58	70	58	55	35		35	98
Sillimanite									
Rutile	tr				tr	tr			
Sphene			1	tr				1	
Allanite		tr	tr					1	
Zircon	tr								
Total opaques	1	1	2	tr	1	1	—	tr	tr
Total	99	99	100	100	100	100	100	100	100

1. Biotite gneiss (69C 10)
2. Biotite gneiss (70C 802)
3. Hornblende gneiss (70C 805)
4. Biotite gneiss (70C 628)
5. Mica Schist (70C 609b)
6. Mica schist (70C 609c)
7. Kyanite-garnet rock (70C 811)
8. Clinozoisite rock (69C 175)
9. Quartzite (70C 783)

Garnet Mica Schist

Apparently, the oldest unit in the area is a strongly foliated garnet mica schist that occurs in the center of the anticline and crops out in the northeastern and southwestern corners of the area (Pl. 1). The unit contains less quartz and plagioclase than the biotite gneiss unit and is less resistant to weathering and erosion. Biotite schist, quartzite, and biotite gneiss bands up to 100 feet thick are present and are most abundant in the central area of exposure. Quartz veins are common throughout the unit. Hills are typically underlain by biotite gneiss and/or quartzite bands.

Outcrops of the garnet mica schist are distinctive. They are well-foliated and crinkled with characteristic reddish-brown garnet idioblasts ranging in diameter from 1 to 10 mm. Most outcrops contain abundant muscovite and biotite. Upon weathering the rocks commonly yield a yellow to reddish-brown saprolite.

Muscovite, biotite, quartz, and plagioclase are the dominant minerals observed in thin section. Mica appears to have been pushed aside during the growth of the garnets. The garnets lack a helicitic ("snowballed") structure, and poikiloblastic (sieve) texture is not well-developed. Quartz has sutured contacts, abundant fractures, undulatory extinction and a xenoblastic outline. The refractive index range of plagioclase indicates that its composition is andesine. Minor amounts of clinozoisite, epidote, and allanite are present and sphene occurs in trace amounts.

Several opaque minerals occur in minor and trace quantities. The dominant ones are pyrrhotite and rutile. Magnetite, ilmenite, and chalcopyrite occur in lesser abundance. Locally, grains of pyrrhotite and rutile are large enough to be visible in hand specimen.

Biotite Gneiss

The most extensively exposed country rock unit is a well-banded biotite gneiss. Most of Lake Chatuge is underlain by this unit, and excellent exposures occur along the shoreline. The unit is fairly homogenous; however, some zones of mica schist, hornblende gneiss, and quartzite are present and quartz veins are common. Hills and small peninsulas along the lake are commonly underlain by quartzose gneiss, quartzite or quartz veins. Stratigraphically the gneiss unit overlies the sill.

Outcrops of the unit are distinctive, and are gray and well-banded. Most of the bands are less than 5 mm thick. Reddish-brown anhedral garnet porphyroblasts are characteristic. Biotite and quartz are abundant in most specimens, but the muscovite and feldspar content is widely variable. Upon weathering the gneiss yields a reddish-brown saprolite.

The dominant minerals observed in this section are quartz, biotite, plagioclase, muscovite, and garnet. The bands appear to have been pushed aside during the growth of the lense-shaped garnets, some of which appear to be slightly rotated. Poikiloblastic texture, osberved as quartz inclusions in garnet (Fig. 3), is common. Quartz has sutured contacts, abundant fractures, undulatory extinction, and a xenoblastic outline. Augens of fractured lenticular quartz grains 2 to 20 mm in diameter occur locally. Plagioclase is commonly coarser grained than quartz and has well-developed albite twinning and a subhedral outline. Refractive indices of plagioclase indicate an andesine composition. Clinozoisite, epidote, and allanite (Fig. 4) are common accessory minerals. The dominant opaque mineral observed is monoclinic pyrrhotite, which is obvious in some outcrops. Magnetite, ilmenite, and chalcopyrite appear to occur in lesser abundance. A trace of rutile was noted in one thin section.

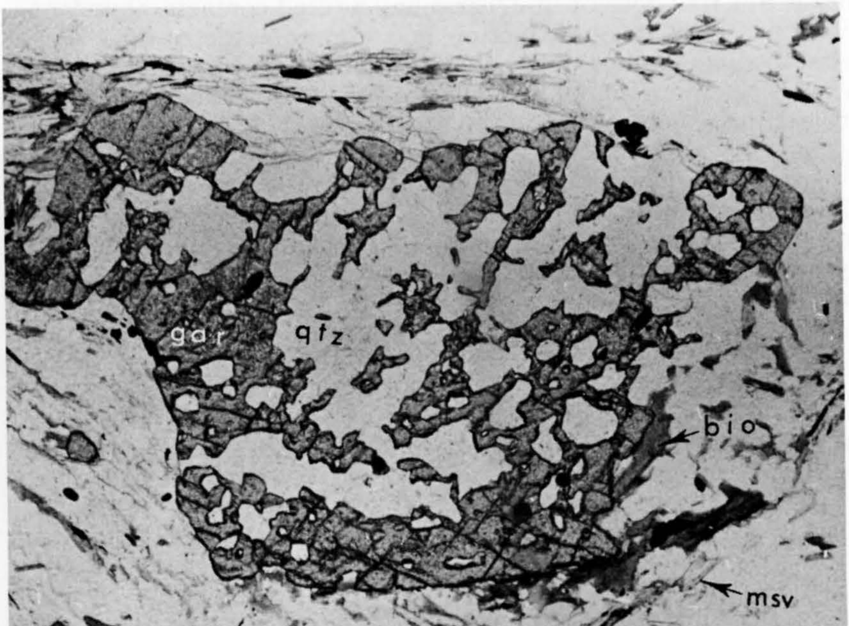

Figure 3. Garnet showing sieve texture in biotite gneiss. Garnet (gar), quartz (qtz), biotite (bio), and muscovite (msv).

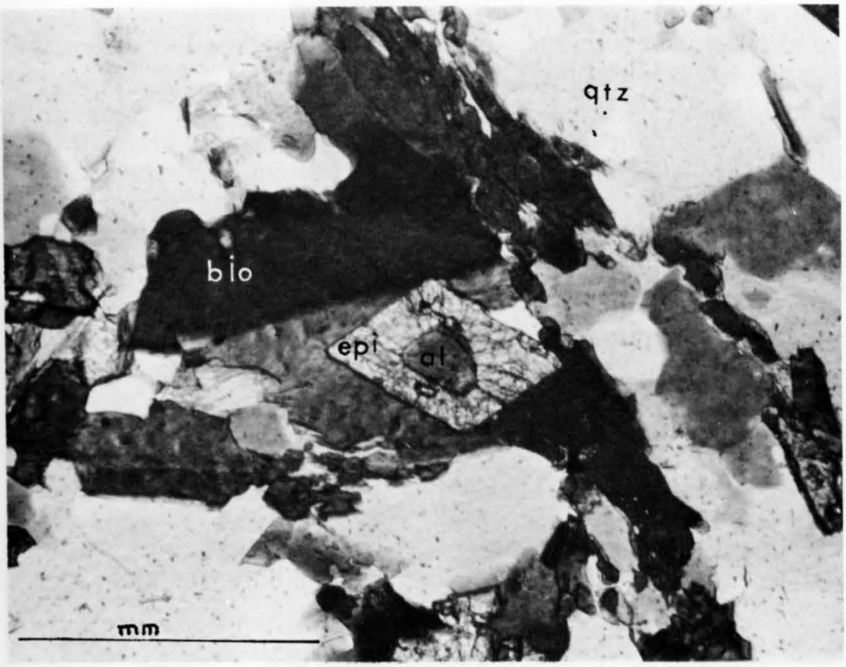

Figure 4. Allanite core in epidote in biotite gneiss. Allanite (al), epidote (epi), biotite (bio), and quartz (qtz).

Coarse-Banded Biotite Gneiss

A very coarse-banded biotite gneiss crops out in the northwestern quarter of the study area adjacent to the sillimanite schist unit. It occurs in a zone several hundred yards thick parallel to regional foliation. Keith (1907) termed this unit Archean granite although he noted that it was composed of both biotite granite and granite gneiss. Good outcrops of the unit are exposed in the roadcuts along Highway 64 where it consists of gray and white bands up to 2 meters in thickness. The gray bands, composed mostly of fine to medium grained quartz, biotite, muscovite, and feldspar are fairly homogenous except for a poor to fairly well-developed foliation imparted by biotite and muscovite. The white bands are composed of medium to coarse grained quartz and feldspar grains. Thin schistose bands consisting of biotite and muscovite and small augens of quartz and microcline occur locally. Upon weathering the rock forms a yellow-brown to reddish-brown saprolite.

Kyanite-Garnet Rock

Cobble float of a reddish-brown rock containing kyanite and weathered garnet occurs along the southeastern lake shore of Jackrabbit Mountain Campground. The cobbles are composed of blue kyanite blades up to 20 mm in length which comprise about 60 percent of the rock. Intensely weathered garnet crystals 2 to 3 mm in diameter (Fig. 5) constitute the remainder. Although no outcrops were observed, the cobbles are probably a lag deposit from a localized kyanite-garnet lens in the biotite gneiss unit.

Sillimanite Muscovite Schist

A sillimanite schist unit is exposed near the Oak Forest Church about one and one-half miles southeast of Hayesville. The unit, mapped by Hash and Van Horn (1951), is composed of two parallel bands of sillimanite schist that occur between the two biotite gneiss units. The two bands are 100 to 300 feet thick and are separated by a band of biotite gneiss approximately 200 to 400 feet thick. The foliation of the bands is commonly parallel to the foliation of adjacent country rocks.

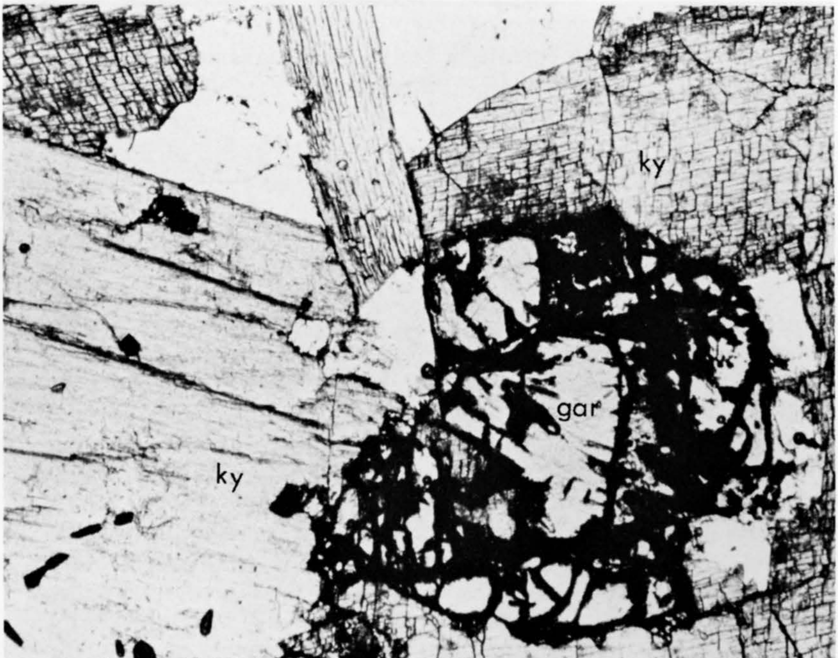

Figure 5. Kyanite-garnet rock. Blue kyanite blades (ky) show a well-developed cleavage. Garnet idioblast (gar) is well weathered.

All outcrops examined were too weathered or friable for thin sectioning. In hand specimen, the dominant mineral appears to be muscovite. Quartz and feldspar are less abundant. Several percent of short fibrous sillimanite crystals were noted in the outcrops and on the surface of the soil. Channel soil samples taken by Hash and Van Horn (1951, p. 23) from near the Oak Forest Church contain up to 6 percent fibrous sillimanite. During the present study large tabular sillimanite crystals up to 80 mm in length were found as float near the northern edge of the study area. Hash and Van Horn reported that sillimanite boulders were found in the same vicinity.

Two possibilities exist for the origin of the sillimanite zone. The zone may represent either a metamorphosed soil or metamorphosed aluminous sedimentary rocks. Espenshade and Potter (1960, p. 1) suggest that the kyanite and sillimanite deposits in the Blue Ridge and Piedmont were metamorphosed aluminous sedimentary rocks. Hash and Van Horn (1951, p. 3) relate the formation of the sillimanite in southwestern North Carolina to pegmatites intruded into schist; however no such pegmatites were observed in the unit in this study.

Clinozoisite Rock

A rock unit containing abundant clinozoisite occurs between the sill and the biotite gneiss unit on the tip of the peninsula south of Elf. The unit parallels the foliation of the biotite gneiss unit. Mineralogically it contains approximately 50 percent greenish-yellow euhedral clinozoisite crystals 1 to 40 mm long (Fig. 6). Allanite, which comprises about 1 percent of the rock, occurs near the center of some clinozoisite crystals. The allanite grains are almost isotropic (metamict) and are surrounded by a brown halo probably formed by radiation. Quartz and weathered plagioclase comprise most of the rest of the rock. Sphene occurs in quantities averaging about 1 percent. Only a trace of opaque minerals is present.

Quartzite

Quartzite bands and lenses are present throughout the country rock units. Most are less than 10 cm thick; however, several thicker bands and lenses form the major hills in the area. An example is Bell Mountain, mapped by Hurst and Horton (1964). Quartzite ranges in color from white to yellow-brown to reddish-brown to pink. In thin section the rock appears to be composed of anhedral granoblasts commonly about 1 mm in diameter. Textures indicating post-metamorphic deformation such as fractures, undula-

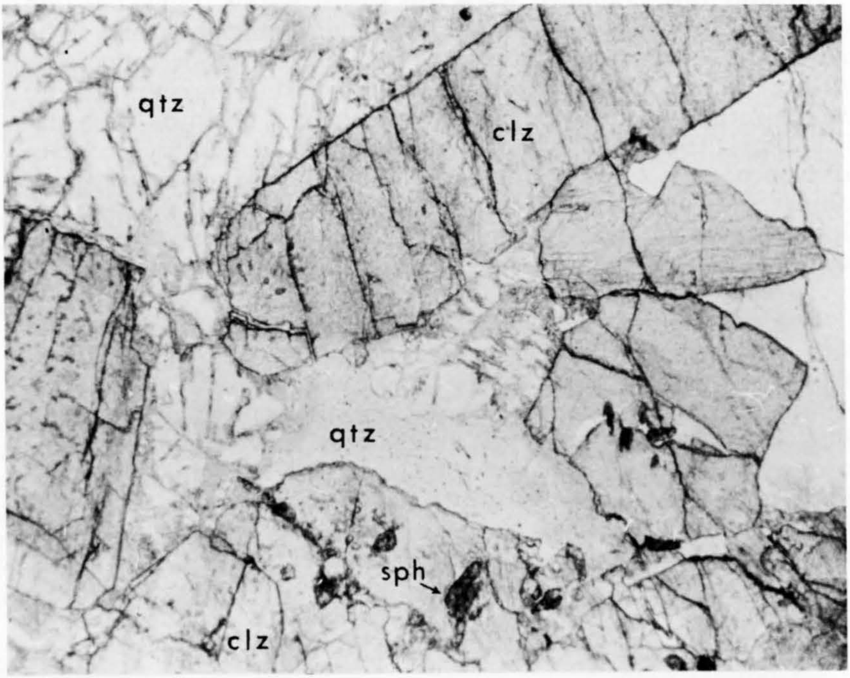

Figure 6. Clinozoisite-quartz-plagioclase rock. Clinozoisite (clz), quartz (qtz) and sphene (sph).

tory extinction, and sutured contacts are abundant. Commonly up to 10 percent of muscovite and biotite are present.

ULTRAMAFIC AND RELATED ROCKS

Ultramafic and related rocks occur in a band marked by discontinous outcrops which extend from the southwestern to the northeastern corners of the area. The best exposures occur along the shore of Lake Chatuge. Because the band occurs at the same stratigraphic position throughout the area, it is interpreted to be a sill. The rock units present include dunite, coronite troctolite, olivine gabbro, wehrlite, mafic and metamafic veins and pods, orthoamphibolite, and garnet pyroxene gneiss. A small number of float fragments of several other mafic rocks, including anorthosite, picrite, pyroxenite, and norite, were found during mapping.

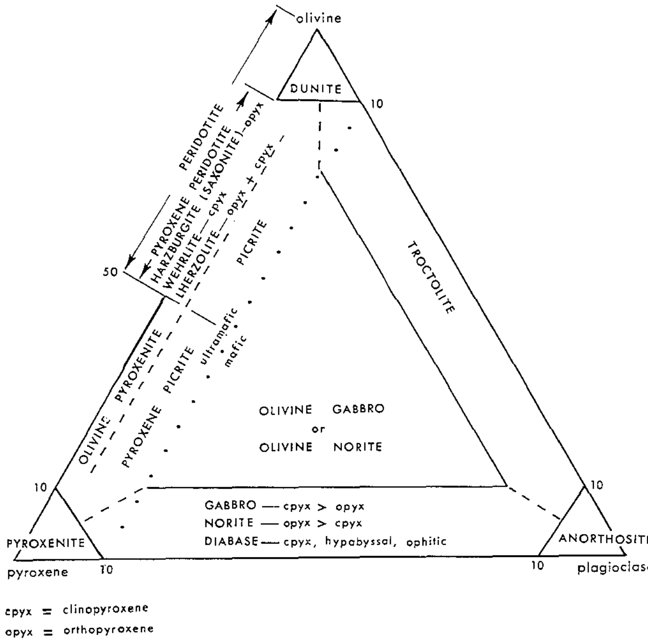

Figure 7. Classification of ultramafic and mafic rocks.

Classification of Ultramafic and Related Rocks

Figure 7 illustrates the classification used to name the ultramafic and mafic rocks in the Lake Chatuge sill. The classification is primarily based upon rock definitions in the U. S. Bureau of Mines dictionary (1968) and the A. G. I. Dictionary (1957).

An attempt was made to designate lithologies on the basis of primary mineral assemblages. The term coronite troctolite is an example. A coronite is simply defined (A. G. I. Glossary Supplement, 1960) as a "Corona-bearing rock." Variable quantities of pyroxene, amphibole, and spinel are present in the coronas and were formed by reaction between olivine and plagioclase which constituted over 90 percent of the primary mineral composition. Since it is probable that most of the pyroxene is of secondary origin, the rock is not classified as an olivine gabbro or olivine norite even if the secondary pyroxene exceeds 10 percent of the rock. Similarly, the term dunite is used when the rock is intensely serpentinized, as relict textures indicate that this was the initial lithology.

Table 3. Modal Analyses of the Mafic and Ultramafic Rocks in Volume Percent

Sample no.	1	2	3	4	5	6	7	8	
Amphibole	1	1	1	0.5					
Allanite					tr				
Chlorite						tr		tr	
Corona minerals:									
orthopyroxene	1	4	10	27	28	12	19	21	
amphibole-spinel*	1	8	9	38	55	15	13	58	XX
Clinozoisite		1	2	tr	0.5		0.5	tr	
Epidote	tr								
Olivine	0.5	11	12	1	10	43	9	13	XX
Plagioclase	55	33	31	17	4		48	7	
(An content)	(76)	(75)	(76)	(83)	(75)		(77)	(78)	
Primary Pyroxenes:									
diallage	41	41	30	15		3	9		
hypersthene		tr	4	tr			tr		
Serpentine		tr	tr		tr	25	tr	1	
Brown Spinel	tr	tr	1	0.5	2	0.5	1	0.5	
Total opaques	tr	0.5	1	1	tr	2	1	tr	
Total	99.5	99.5	101	100	99.5	100.5	100.5	100.5	

1. Gabbro (70C 228)
2. Olivine gabbro (70C 631)
3. Olivine gabbro (70C 598)
4. Olivine gabbro (70C 502)
5. Coronite troctolite (70C 390)
6. Dunitic troctolite (70C 230a)
7. Coronite troctolite (70C 603a)
8. Coronite troctolite (70C 382)

* The amphibole-spinel intergrowths contain approximately one-third spinel and two-thirds amphibole.

Sample no.	9	10	11	12	13	14	15
Amphibole							
Allanite							
Chlorite		tr		9			
Corona Minerals:							
orthopyroxene	20	21	7				
amphibole-spinel	41	28	20				
Clinozoisite	1	tr					
Epidote							
Olivine		26	55	62	77	75	5
Plagioclase	37	23					
(An content)	(76)	(76)					
Primary pyroxenes:							
diallage		1			6	5	
hypersthene							
Serpentine			15	26	15	18	88
Brown spinel	1	0.5	2				
Total opaques	tr	tr	1	3	2	2	7
Total	100	99.5	100	100	100	100	100

XX

9. Coronite troctolite (69C 18)
10. Coronite troctolite (69C 91)
11. Dunitic troctolite (69C 56)
12. Dunite (69C 116)
13. Dunite (70C 475)
14. Dunite (70C 493)
15. Serpentinite (70C 84)

XX

Dunite

The dominant ultramafic rock unit is a light green, medium-grained allotriomorphic dunite that occurs along the center of the sill (Pl. 1) occuring mainly as scattered outcrops near the Lake Chatuge shoreline. Locally it is darker in color due to the presence of alteration products. Outcrops are characterized by a thin, light brown, weathered rind and solution-pitted surfaces. Foliation, locally present in the dunite, is enhanced by differential weathering. Weathered dunite yields a reddish-brown saprolite containing some chlorite flakes. Pebbles and cobbles of geothite and chalcedony are locally abundant in soils derived from dunite.

The primary mineralogy of dunite is as follows. Olivine occurs as fractured equant grains about 1 mm in diameter. Electron microprobe analysis indicates a composition of Fo_{90+2}. Compositional zoning was not observed. Locally diallage and bytownite occur in quantities up to 10 percent, especially at gradational contacts with troctolite and olivine gabbro. Disseminated chromite grains up to 2 mm in diameter occur in small quantities. In polished section the highest percentage noted was 5 percent from a sample from the Hog Creek area. Some rounded chromite grains are embayed into olivine whereas others occur as irregular masses in serpentine similar to the altered chromite from Webster Addie

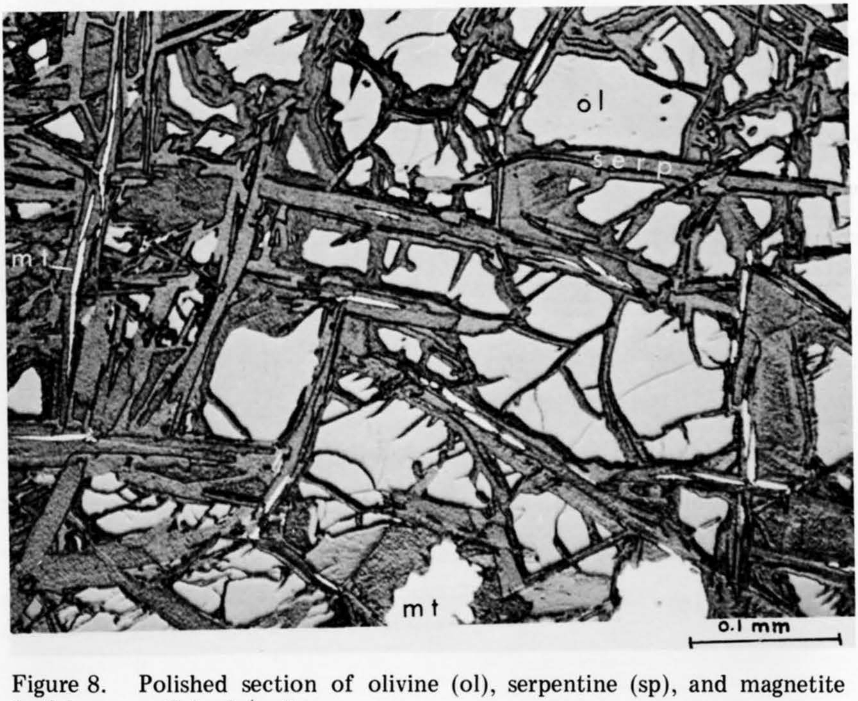

Figure 8. Polished section of olivine (ol), serpentine (sp), and magnetite (mt) in serpentinized dunite.

(Miller, 1953, p. 1141-1145). Pyrrhotite and rutile occur in trace quantities between olivine grains.

The dunite is partially altered and as the modal analyses (Table 2) indicate, antigorite serpentine occurs in quantities between 10 and 85 percent with a probable average of about 20 percent. The typical occurrence of antigorite along grain boundaries and fractures is shown in Figure 8. Secondary magnetite is intimately associated with serpentine and occurs as stringers parallel and adjacent to serpentine masses (Figs. 8 and 9). Moreover, magnetite is commonly the dominant opaque mineral in the rock, and in some samples represents as much as 7 percent of the total volume. Serpentine, containing magnesia and silica, represents the original forsterite component of the olivine, and magnetite, containing iron, represents the fayalite component.

Serpentine is reported to form at temperatures of less than 500°C (Turner and Verhoogen, 1969, p. 318-319). The following simple hydration reactions have been suggested for the serpentinization process (Turner and Verhoogen, 1969; Hopkins, 1914; Deer, Howie, and Zussman, 1963).

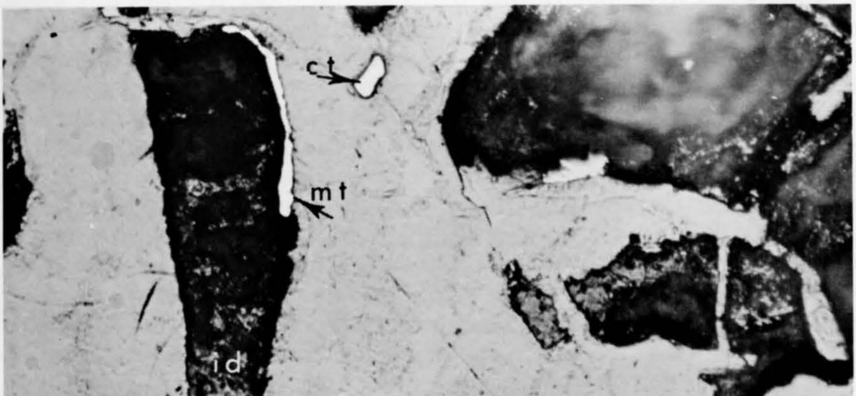

Figure 9. Polished section of serpentine (sp), iddingsite (id), chromite (ct), and magnetite (mt) in serpentinite. Iddingsite has been removed by plucking during sample preparation.

$$2Mg_2SiO_4 + 2H_2O + CO_2 \text{-----} H_4Mg_3Si_2O_9 + MgCO_3$$

$$3Mg_2SiO_4 + 4H_2O + SiO_2 \text{-----} 2H_4Mg_3Si_2O_9$$

$$Mg_2SiO_4 + MgSiO_3 + 2H_2O \text{-----} H_4Mg_3Si_2O_9$$

$$5Mg_2SiO_4 + 4H_2O \text{-----} 2H_4Mg_3Si_2O_9 + 4MgO\ SiO_2$$

$$3Mg_2SiO_4 + H_4SiO_4 + 2H_2O \text{-----} 2H_4Mg_3Si_2O_9$$

None of the above reaction products except serpentine are present in the dunites of this study. Therefore, if other compounds were formed they have been subsequently removed.

The time of serpentinization relative to emplacement of the sill cannot be determined with certainty. The primary serpentine magma proposed by Hess (1938, p. 328-329) has been refuted by the experimental work of Bowen and Tuttle (1949, p. 453). However, Hess (1955, p. 331) noted that ultramafics which were intruded into hydrous sediments are more serpentinized than those intruded into gneisses at greater depth. Bowen and Tuttle (1949. p. 455) suggested that during tectonic transport the ultramafics may be serpentinized by fluids derived from country rocks. This hypothesis appears to be widely accepted. Most of the ultramafics in the Blue Ridge have been metamorphosed to temperatures in excess of that at which serpentine dehydrates to olivine. Therefore, because serpentine occurs today, these rocks must have been serpentinized at least twice if the rocks were serpentinized prior to or during intrusion. Strontium isotope analyses, discussed in another section and shown in Table 1, provide evidence that the dunite in the vicinity of Lake Chatuge was not serpentinized prior to emplacement. The Sr^{87}/Sr^{86} ratios (Table 1) of the dunites are notably higher than those of the mafic rocks. However, olivine (475b) separated from a partially serpentinized dunite (475a) with a ratio of 0.7068 has a value of 0.7023 which is the lowest value obtained from any mafic or ultramafic sample. Although this is the only olivine analysis presently available, it does indicate that the serpentinizing fluids contained fairly high Rb^{87} and/or Sr^{87}, a feature consistant with a country rock source. If the olivine had formed by the dehydration of serpentine as proposed by J. R. Carpenter (1969, p. 261-263) for other North Carolina occurrences then it probably would have retained a fairly high Sr^{87}/Sr^{86} ratio.

Chlorite occurs as disseminated flakes in some dunite outcrops but is not as prevalent as in altered troctolite, and occurs locally adjacent to veins in dunite. Chlorite occurs as green flakes up to several millimeters in diameter, which imparts a platy appearance to the outcrop. It probably formed by hydrothermal alteration of the dunite involving hydration, the addition of alumina, and the removal of part of the magnesium and iron.

Anthophyllite asbestos occurs sporadically in dunite as fibers several centimeters long. It is abundant only in the highly altered ultramafic zone west of Elf mapped by Kellberg (1943). The zone is mostly underwater, and only a small part can be seen even at low water level. Therefore, it was not possible to study this zone during this investigation; however, Kellberg's interpretation is shown in Plate 1. The formation of anthophyllite from dunite involves the addition of silica or the removal of part of the magnesium and iron.

Talc occurs locally in dunite, especially near the edge of the dunite unit. It also occurs in veins, but is not as abundant as chlorite. It is abundant only in the previously mentioned zone west of Elf where it occurs with anthophyllite. Some talcose float occurs along the shore of the lake near the northeastern side of Jackrabbit Mountain and near Lower Bell Creek. Steatitization of dunite may occur by hydrothermal alteration involving the removal of iron and a large part of the magnesium content.

Coronite Troctolite

Coronite troctolite, an olivine-plagioclase rock with well-developed coronas, surrounds the dunite unit and locally occurs as lenses within dunite. The contact between the two units is gradational in some localities and sharp in others. Outcrops and float of troctolite are commonly more abundant than dunite because the coronas are most resistant to weathering.

The appearance of troctolite outcrops varies considerably due to the arrangement of the coronas and wide variation in the olivine/plagioclase ratio. Feldspathic troctolite is light colored and has bluish-green coronas surrounding olivine, whereas olivine-rich troctolite is green and has coronas surrounding plagioclase. The coronas range in diameter from 1 to 30 mm with an average of about 3 mm. They may be isolated, connected to form a network arrangement, or arranged in bands. On weathered surfaces the coronas impart a knobby appearance to the rock while olivine is represented by brown spots or depressions. Upon complete weathering troctolite yields a spotted light brown to reddish-brown saprolite, the color depending upon the olivine/plagioclase ratio of the rock.

Figure 10. Rhythmically banded coronite troctolite dipping vertically, near Lower Bell Creek Church.

Rhythmically banded coronite troctolite (Fig. 10) occurs locally as lenses within dunite. It is composed of alternating layers of plagioclase and olivine with a reaction zone layer in between. The bands range in width from 1 to 15 mm with an average of approximately 3 mm. The rock is best exemplified by the Hog Creek occurrence in the southwest portion of the study area (Fig. 11). In some outcrops banding is abundant, whereas in others only a few bands are present (Fig. 12). The bands dip almost vertically and appear to be parallel with the sill contact.

The coronite troctolite consists mainly of olivine, plagioclase, and the minerals in the coronas. Olivine is texturally similar to that in dunite. Probe analysis indicates an olivine composition of

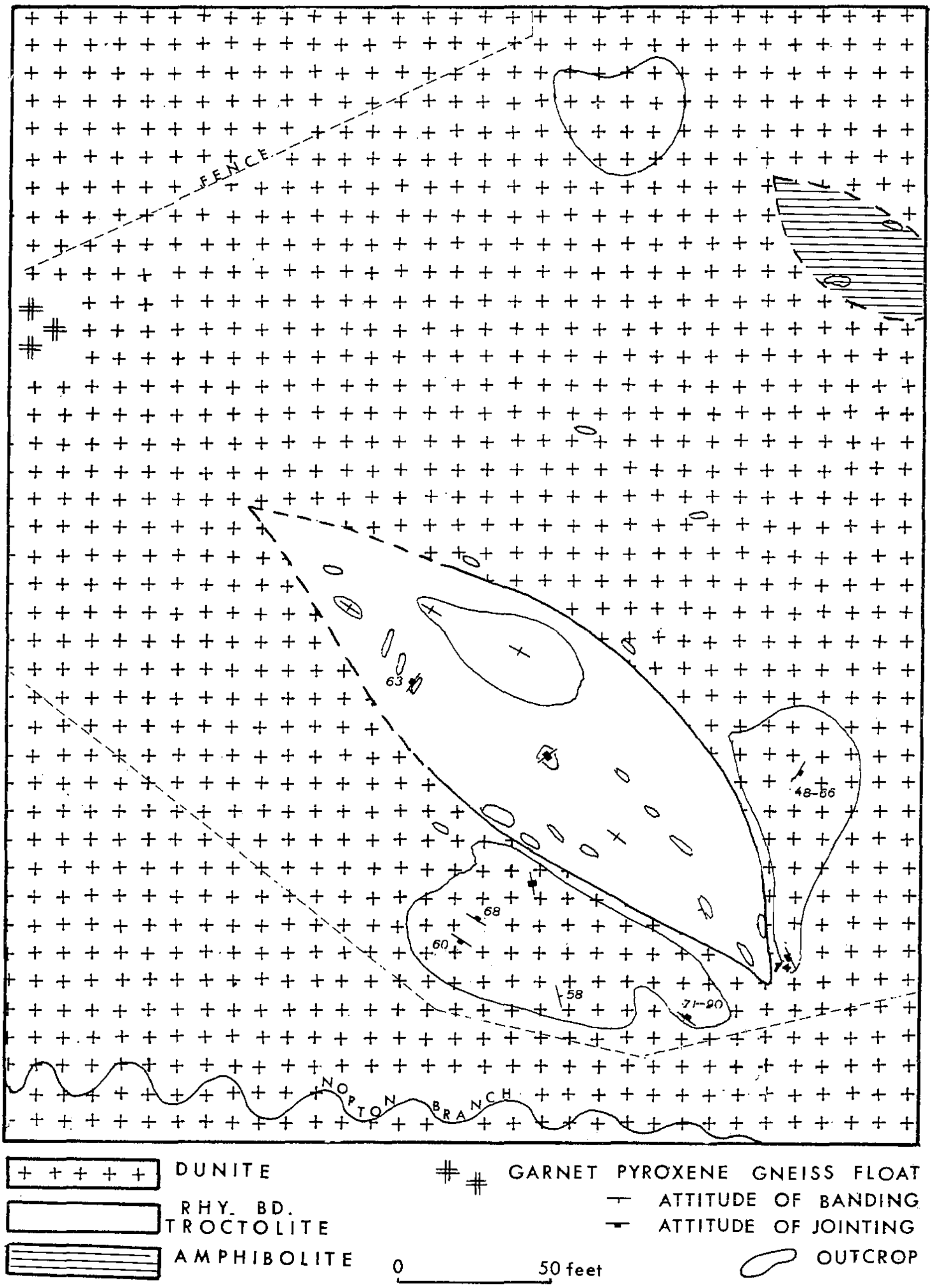

Figure 11. Geologic map of a rhythmically banded coronite troctolite lens in dunite on the Ed Birch property in the Hog Creek area.

Fo_{90+2} which is also similar to that in dunite. Unaltered plagioclase ranges in composition from An_{75} to An_{83} (bytownite) but zoning was not observed. However, it becomes less calcic as amphibolization progresses. Well-developed Carlsbad and albite twinning are present. Diallage is similar to that in olivine gabbro but comprises less than 10 percent of the rock. Serpentine occurs in olivine-rich samples.

Several opaque minerals occur within the troctolite. Secondary magnetite, formed during serpentinization, occurs within the olivine-rich samples. The other opaque minerals commonly occur in quantities between a trace and 1 percent. Some textural features of pyrrhotite, pentlandite, and chalcopyrite composite grains are shown in Figure 13. Pentlandite, which occurs only in trace quantities in pyrrhotite, has the characteristic flame texture. Ilmenite occurs as small grains in trace quantities.

The coronas invariably separate olivine from plagioclase grains. The original grain boundary relationships have been obliterated by development of phases intermediate in composition. Commonly the coronas have two distinct zones. The zone adjacent to olivine

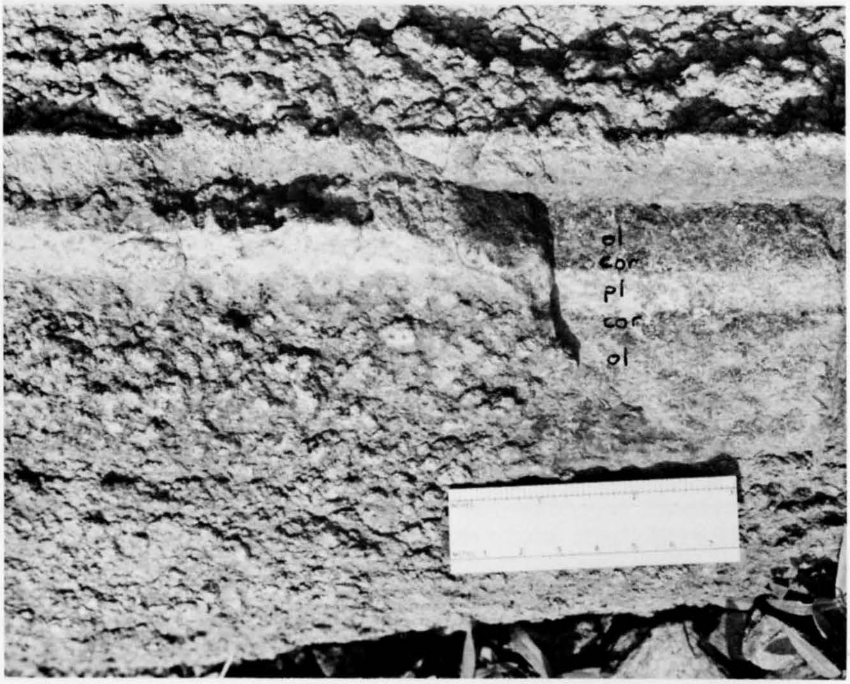

Figure 12. Olivine (ol), plagioclase (pl), and corona (cor) bands in coronite troctolite. Weathered surfaces show knobby texture above and below bands.

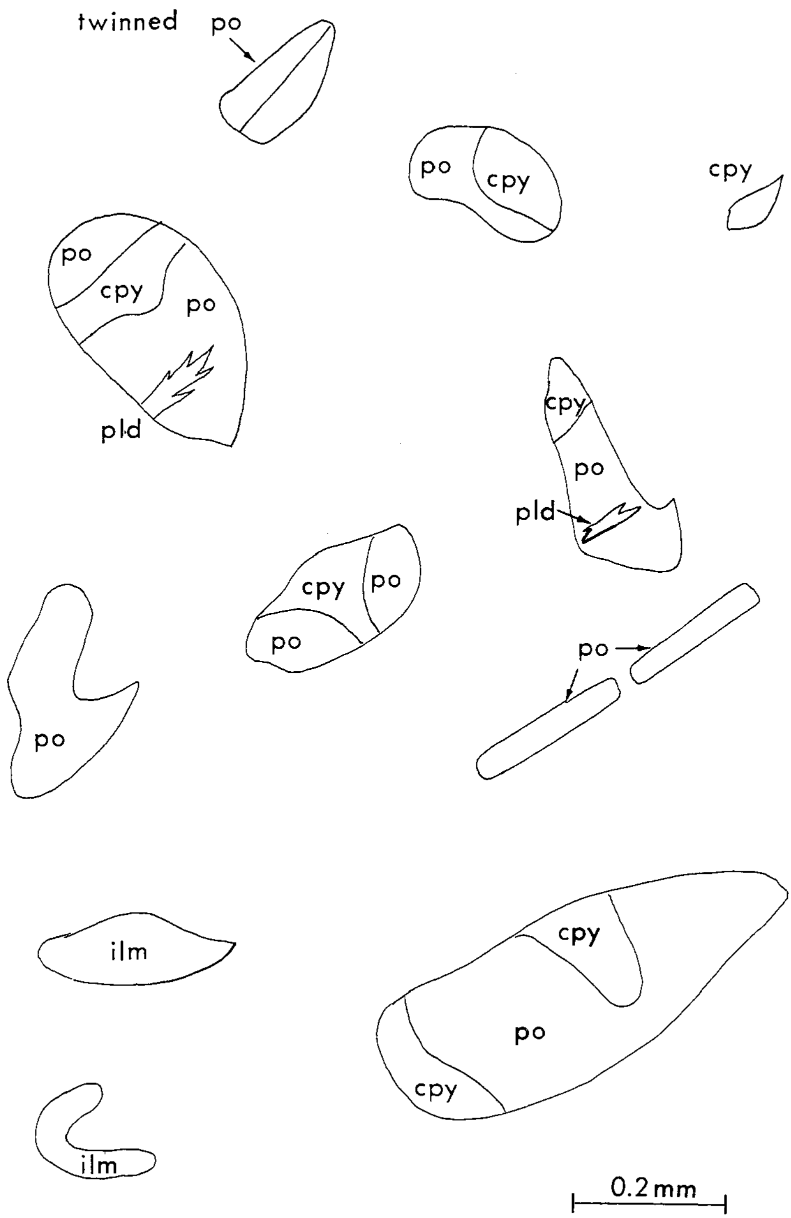

Figure 13. Opaque minerals in troctolite and olivine gabbro. Pyrrhotite (po), chalcopyrite (cpy), pentlandite (?) (pld), and ilmenite (ilm).

is composed of orthopyroxene (Figs. 14 and 15), while the zone adjacent to plagioclase is composed of green vermicular spinel, approximately 3 to 8 microns in thickness, and pale bluish-green amphibole (Figs. 15 and 16). Brown spinel occurs locally as anhedral crystals up to 1 mm in diameter, and locally clinopyroxene occurs between the rims.

Various explanations for the coronas are cited in the literature. Possible conditions of formation include: (1) a granulite facies metamorphism (Kushiro and Yoder, 1966); (2) a magmatic or peritectic reaction of olivine and plagioclase (Herz, 1951); (3) thermal metamorphism (Huang and Merrit, 1954); (4) regional metamorphism (Gjelsvik, 1952) and (5) a subsolidus diffusion at 700° C (Grieve, 1969, p. 83-84). The invariable occurrence of the reaction rims as layers separating the two minerals suggests that the rims were formed after the layering of olivine and plagioclase, perhaps in the final stages of crystallization of the sill, thus suggesting that possibility 2 is applicable. Furthermore, the replacement of some of the coronas by amphibole, interpreted to be mid-Paleozoic, indicates that they were formed prior to the mid-Paleozoic metamorphism.

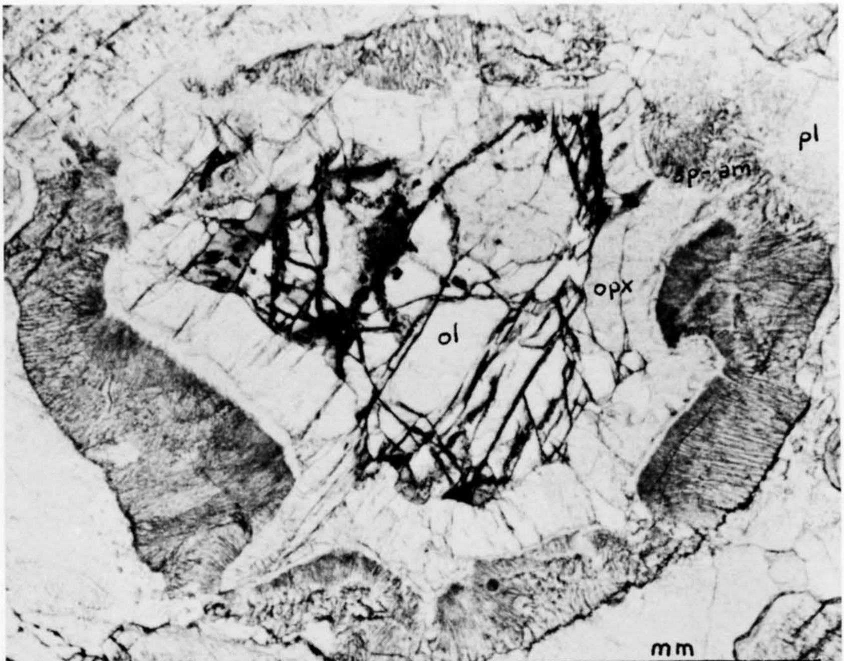

Figure 14. A corona, in transmitted light. Olivine (ol), orthopyroxene (opx), spinel-amphibole intergrowth (sp-am), and plagioclase (pl).

Alteration of olivine-rich troctolite is similar to that of dunite, whereas in feldspathic troctolite the olivine appears to have been protected by the enveloping coronas. The most common hydrothermal alteration in troctolite is chloritization. The necessary constituents except water are contained in the troctolite. Chloritization is most pronounced along jointing planes. Valleys or depressions cutting across ridges underlain by troctolite are commonly underlain by chloritized troctolite which is less resistant to weathering. It is estimated that about 25 percent of the troctolite unit has been altered to chlorite schist.

Olivine Gabbro

Locally olivine gabbro occurs between troctolite and amphibolite. This rock is similar to the troctolite except that it contains over 10 percent diallage, the primary pyroxene. Commonly the contact between the two units is gradational, and locally small pods of olivine gabbro and gabbro occur with the troctolite. Much of the olivine gabbro could be more specifically classified as troctolitic olivine gabbro. Areas underlain by the unit are represented by small outcrops, knobby float fragments, and reddish-brown saprolite.

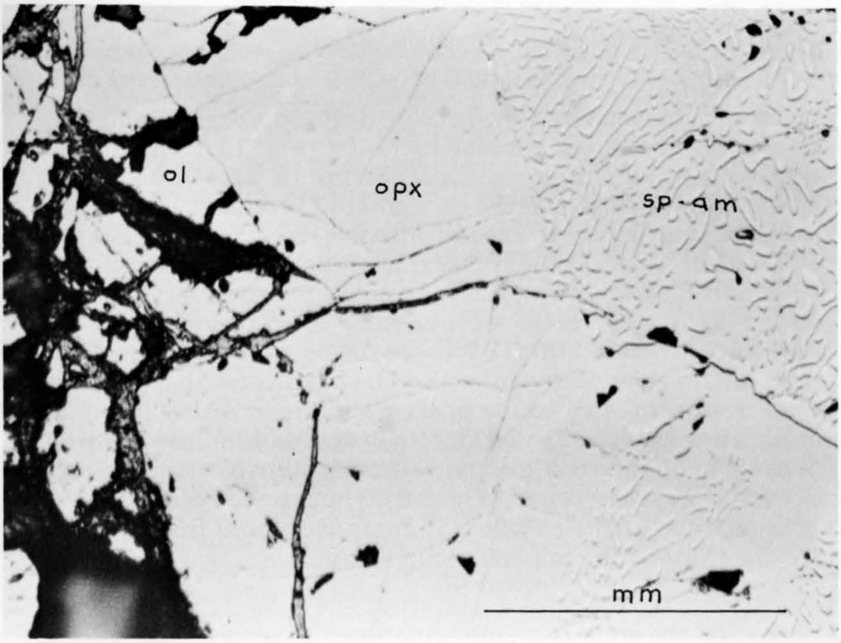

Figure 15. Cross-section of a corona, in reflected light. Olivine (ol), orthopyroxene (opx), and spinel-amphibole (sp-am).

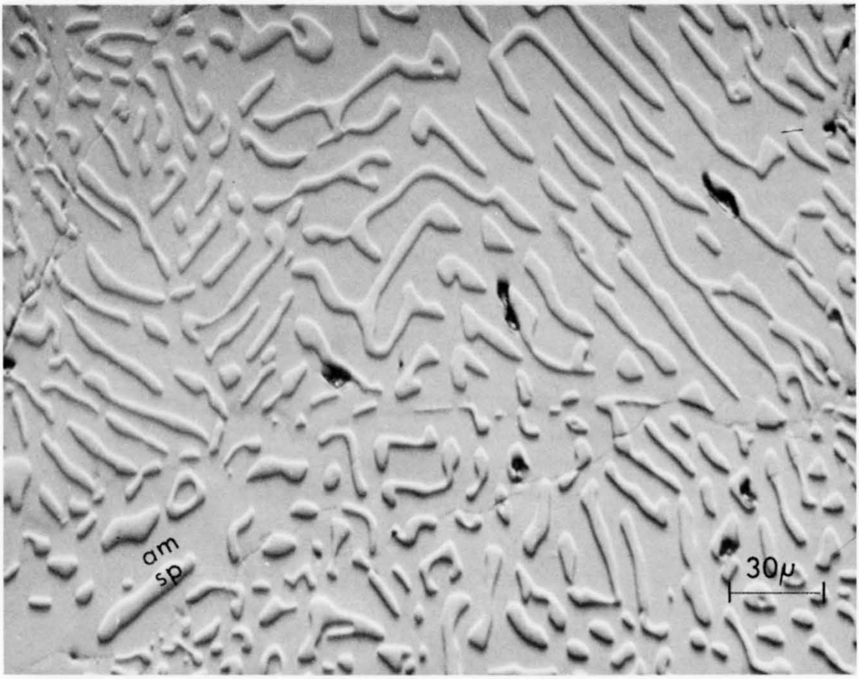

Figure 16. The spinel-amphibole zone of a corona in reflected light. Spinel (sp) has a vermicular habit in amphibole (am).

The unit is characterized by diallage, a clinopyroxene containing a well-developed parting parallel to (100) (Fig. 17). The diallage present has schiller texture and except for its dark brown color appears similar to infrequently encountered bronzite. In thin section the parting and higher birefringence serve to distinguish it from bronzite. Electron microprobe analysis indicates a composition of approximately $Wo_{50}En_{42}Fs_{08}$. In polished section small orientated exsolution blebs of pyroxene are apparent, but the crystallographic orientation of these blebs is not known. An electron microprobe scan across the blebs indicates that they are enriched in iron relative to the diallage and are probably pigeonite in composition. Generally the diallage crystals comprise from 10 to 50 percent of the rock and range in size between 2 and 8 mm. Locally large crystals occur (Fig. 18). Diallage appears to be a cumulus phase in rocks in which it comprises more than approximately one-third of the mineral composition.

The rest of the rock is mainly composed of plagioclase, olivine, and the minerals in the coronas. Plagioclase has well-developed albite and Carlsbad twinning. Investigations of the refractive

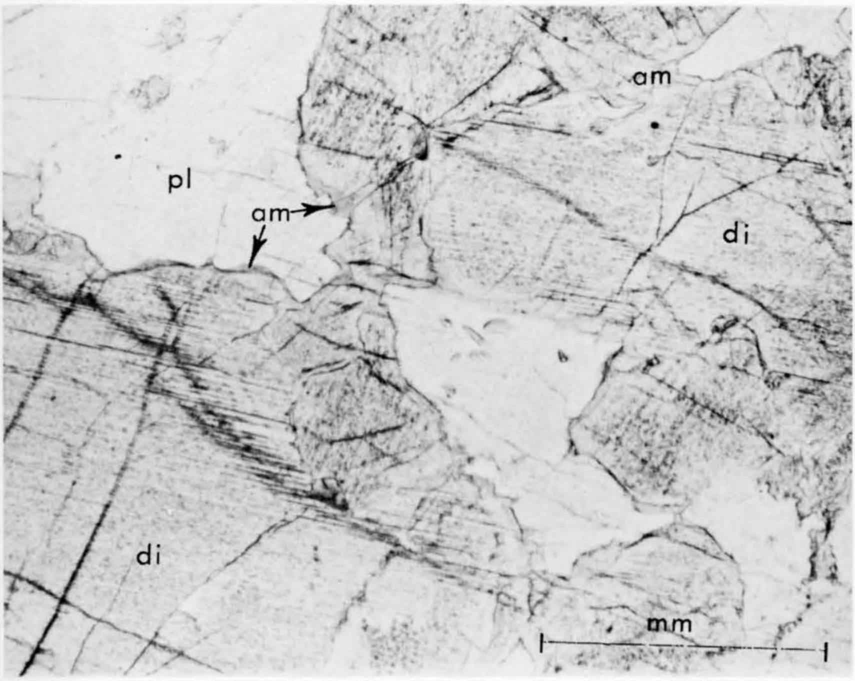

Figure 17. Diallage (di) and plagioclase (pl) in olivine gabbro. Parting is well-developed in the diallage. Schiller texture is shown by small dark inclusions. A light green amphibole (am) rims the diallage. Transmitted light.

indices indicate that the plagioclase composition ranges from An_{68} to An_{79} (labradorite-bytownite). Clinozoisite occurs as a minor phase and is an alteration product of plagioclase. Olivine abundance ranges from less than 30 percent to about 80 percent. Commonly much of the olivine has reacted to form coronas similar to those described for troctolite. Opaque minerals were only observed in quantities of 1 percent or less. These are very similar to those described in troctolite and are illustrated in Figure 13.

Alteration of olivine gabbro to chlorite and serpentine is similar to that described for troctolite. Uralitization of some diallage crystals was observed.

Wehrlite

Wehrlite, a pyroxene peridotite composed of clinopyroxene and olivine (Fig. 7), occurs in minor quantities as layers within the sill. A layer several feet thick crops out in the vicinity of Lower

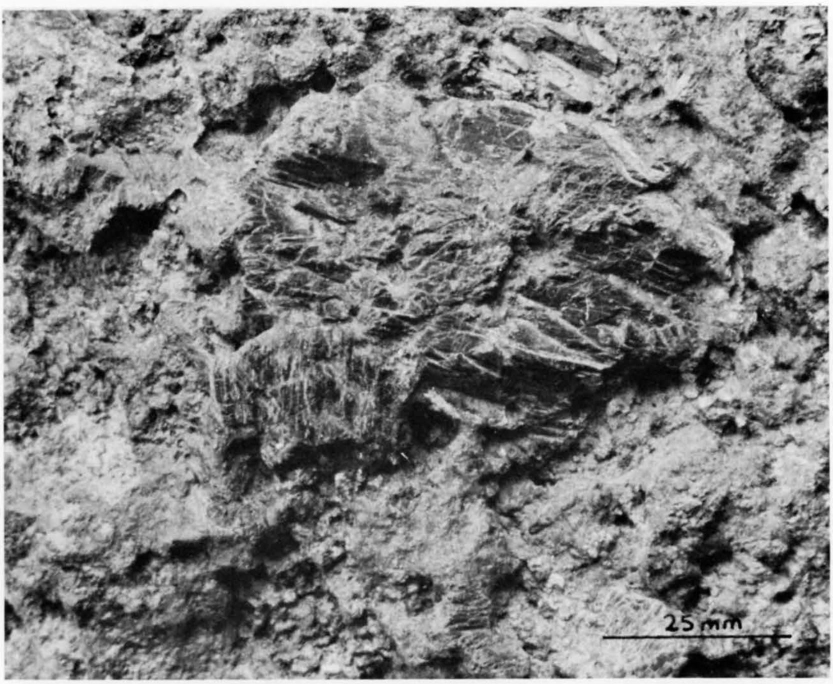

Figure 18. Large diallage crystal in coronite troctolite.

Bell Creek (Pl. 1). Kellberg (1943) reported a similar rock northeast of the intersection of Ga. Highway 75 and the Jackrabbit Mountain Campground road; however, outcrops at this location were not observed during this study, probably because of land changes by local land owners.

Outcrops of the unit are tan to dark gray. Crystals of diallage 1 to 4 mm are common and comprise about one-third of the rock. One outcrop located about 100 yards south of Lower Bell Creek Church is partially enveloped by a thin selvage of amphibolite composed almost entirely of hornblende which separates it from garnet pyroxene gneiss.

In thin section the rock is composed primarily of olivine, pyroxene, amphibole, and serpentine. Serpentine with several percent associated magnetite is the most abundant mineral and has replaced most of the olivine. Much of the pyroxene has been replaced by an amphibole with properties similar to hornblende. This is similar to the alteration of the rock reported by Kellberg.

Orthoamphibolite

In this paper the term amphibolite is used to denote any amphibole-plagioclase rock whether or not obvious banding is present. The term hornblende gneiss is restricted to well-banded rocks containing abundant amphibole, plagioclase, and quartz. The latter occurs mainly within the country rock units. The term hornblende is given only to very dark green, almost black, amphiboles (Dana, 1932, p. 575). All others are simply termed amphibole due to insufficient chemical data; however, optical data indicates that they are within the actinolite compositional field. The term uralite is applied only to elongated amphibole blebs formed by the alteration of pyroxene along cleavage planes and partings.

One of the most significant aspects of this study is the various types of evidence which indicate that the amphibolite zone surrounding the mafic and ultramafic units is orthoamphibolite formed by the hydration of part of the olivine gabbro and troctolite units during metamorphism. The close relationship between amphibolites and mafic-ultramafic bodies in western North Carolina has been noted by earlier authors. Nelson (1969) suggested that nearby amphibolites to the northeast are orthoamphibolites. The Nantahala Folio of Keith (1907) shows Roan Gneiss (amphibolite) enveloping the ultramafic rocks in the northern half of the study area, Buck Creek, Corundum Hill, and several other localities. Keith (1907, p. 2) suggested that most of the Roan Gneiss was probably derived from gabbro or diorite. Hunter (1941, p. 26) noted olivine in amphibolites adjacent to dunite bodies in Clay and Yancey counties and suggested that the two originated from the same parent magma.

In the Lake Chatuge area amphibolite envelopes the mafic and ultramafic units (Pl. 1). This was first noted by Kellberg (1943). Commonly the amphibolite is more resistant than the mafic or ultramafic rocks with the exception of troctolite. Foliation of the amphibolite is parallel to the biotite gneiss unit. The contact between the two units is sharp; however, in some localities abundant biotite occurs in the country rock near the contact. A few quartz veins occur within the orthoamphibolite unit.

Outcrops of amphibolite are fairly abundant. Lineation formed by parallel amphibole laths is well-developed, while outcrops with well-developed feldspathic bands are fairly common. The color of the amphiboles ranges from light green near the mafic rock to dark green or black further away. Upon weathering the outcrops yield a reddish-brown saprolite with a well-developed boxwork structure.

The amphibolite consists mainly of amphibole, plagioclase, and clinozoisite. Modal analyses of thin sections are shown in Table 4.

Table 4. Modal Analyses of Amphibolites in Thin Section

Sample no.	1	2	3	4	5	6
Amphibole	44	76	41	64	54	62
Clinozoisite	3	1	4	33	3	
Epidote						3
Plagioclase	53	20	53		35	32
(An content)	(83)	(42)	(44)		(46)	(53)
Quartz				2	5	tr
Rutile					1	1
Sphene		1	1	tr		
Total opaques	tr	2	1	1	2	2
Total	100	100	100	100	100	100

1. 70C 632
2. 70C 328
3. 70C 460
4. 69C 16
5. 69C 6a
6. 70C 325

The amphibole content ranges from about 10 to 90 percent with an average of about 60 percent. The light green colored variety of amphibole is slightly pleochroic from very light green to light medium green. The dark variety (hornblende) is strongly pleochroic from light yellow-brown to medium green to dark olive green. Crystal shape for both varieties ranges from xenoblastic to idioblastic, while the length of the crystals range from 1 to 8 mm. Porphyroblasts of hornblende occur locally and were observed up to 40 mm in length. Plagioclase occurs in quantities from about 10 to 90 percent with an average of about 35 percent. Investigation of the refractive indices indicates that the composition ranges from An_{83+2} (bytownite) in the varieties containing uralite to An_{42+2} (andesine) in varieties containing hornblende. Clinozoisite occurs in most samples in quantities averaging about 3 to 4 percent. The grain size of clinozoisite is commonly smaller than that of plagioclase and hornblende; however, several porphyroblasts up to 30 mm were observed. Small amounts of epidote were noted adjacent to and within some hornblende crystals. Small amounts of sphene were noted in some samples that do not contain rutile. The quantity of opaque minerals ranged from a trace to 4 percent with an average of about 2 percent. The dominant opaque mineral observed in polished section is pyrrhotite, but chalcopyrite, magnetite, and rutile commonly occur in smaller quantities.

The following arguments and deductions are presented as evidence that the amphibolite zone is a metamorphosed segment of the sill.

1. Amphibolite almost perfectly envelopes the mafic and ultramafic rock units (Pl. 1). It would be very coincidental for a mafic-ultramafic unit to intrude into the very center of such a lengthy amphibolite body.

2. The gradational contact between amphibolite and mafic rocks is visible in the field. Early stages of the transformation of troctolite to amphibolite are visible in outcrops near the troctolite unit. The altered coronas appear as a homogenous light green mass. The previous sharp contacts between the corona and plagioclase become unclear resulting in a mottled texture in the rock. Further from the troctolite unit amphibolite outcrops show a progressive development of foliation and a progressive loss of knobby texture. The color of the amphibole shows a progressive change in color from light green to dark green. At the Behr Mine (Pl. 1) a bright green amphibolite occurs. It appears similar to the edenite amphibolite (smaragdite) present at Buck Creek. Early stages of the transformation of olivine gabbro to amphibole are visible in outcrops near the olivine gabbro unit as color changes. As the diallage alters to amphibole it changes color

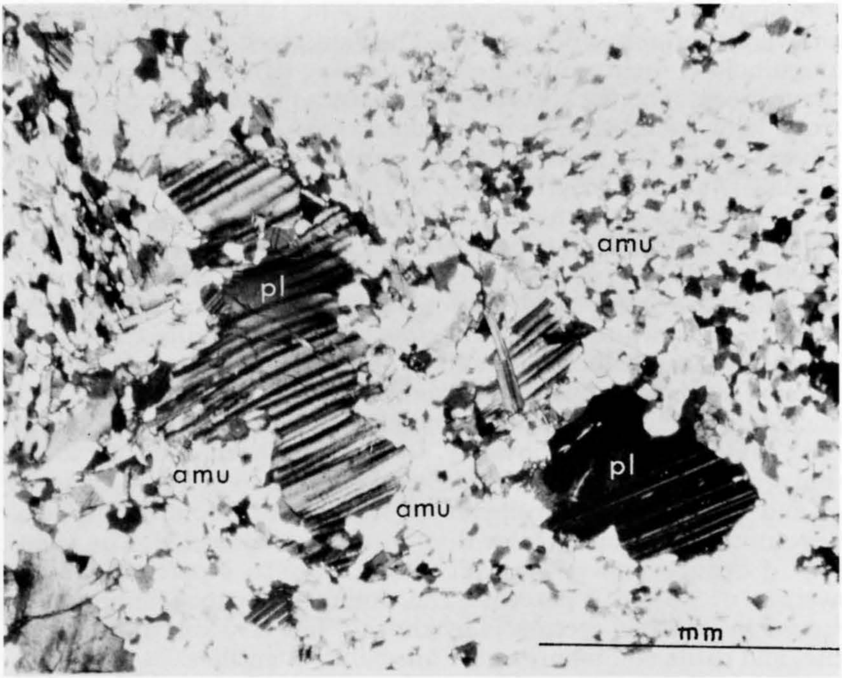

Figure 19. Troctolite in an intermediate stage of amphibolization. Plagioclase (pl) is relict from the corona core. Coronas and olivine are engulfed by small amphibole blebs (amu). Crossed nicols.

from brown to green. Further from the olivine gabbro unit amphibolite outcrops show a progressive development of foliation and a progressive darkening of the green color. In the early stages of the transformation from both troctolite and olivine gabbro, clinozoisite crystals up to 30 mm in diameter are visible. Corundum crystals occur rarely. Commonly the stages of the transformations are visible over a distance of less than 20 feet. In one boulder found on the tip of the peninsula south of Elf, it was visible over a distance of only 2 feet.

3. The step-by-step alteration of mafic rocks to amphibolites is visible in thin sections of samples taken at various spots across the gradational contact. Amphibolites were observed in thin sections in various stages of transformation from troctolite and olivine gabbro. In the first stage, small elongated amphibole blebs (uralite) appear to have developed (nucleated) within the corona. In the next stage amphibole blebs appear to have enveloped all of the corona and adjacent olivine (Fig. 19). By the final stage there appears to have been a union of the blebs to form amphibole crystals (Fig. 20).

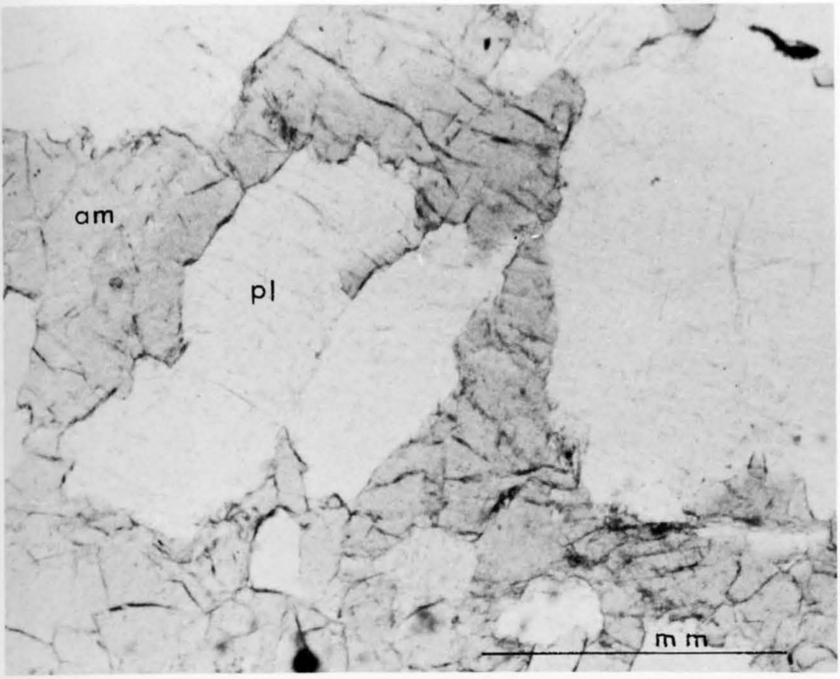

Figure 20. Troctolite in an advanced stage of amphibolization. Plagioclase (pl) is similar to that in Figure 21; however, the amphibole blebs have crystallized into larger amphibole crystals (am) by this stage. Plain transmitted light.

In the first stage of transformation from olivine gabbro, amphibole blebs appear to have nucleated along the parting planes of diallage crystals (Fig. 21). In the second stage the blebs appear to have engulfed the entire crystal including the thin amphibole rim present on the diallage crystal. By the final stage there appears to have been a union of the blebs to form amphibole crystals (Fig. 22). In both types of transformation the plagioclase composition changed from bytownite to andesine. This results in the liberation of calcium and alumina. These appear to go mainly into the formation of hornblende and clinozoisite. Corundum occurs locally, probably by the crystallization of excess alumina.

4. Schiller texture, relict from diallage crystals, is present in many, but not all, amphibole crystals (Fig. 22).

5. Hornblende porphyroblasts occur sporadically in the amphibolite unit similar to the diallage phenocrysts (Fig. 18) that occur in troctolite and olivine gabbro.

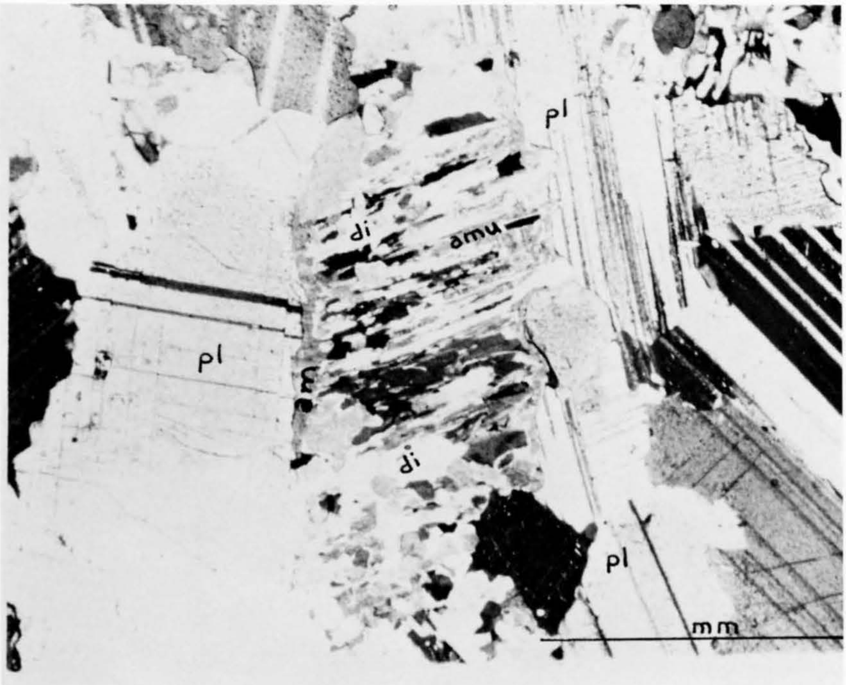

Figure 21. Partially amphibolitized olivine gabbro. Diallage crystal (di) in the center is altered along parting planes to uralite (amu). The amphibole rim (am), similar to that shown in Figure 17, is still visible at this stage of amphibolization. Crossed nicols.

6. Veins and pods of diallage and bytownite occur in the mafic units, while veins and pods of similar size and grain texture consist of hornblende, andesine, clinozoisite, and corundum in the amphibolite unit.

7. The quartz content of the amphibolite is very low. Most thin sections contained no quartz. The highest quantity observed was 5 percent.

8. The low Sr^{87}/Sr^{86} ratios (0.7047, 0.7047, and 0.7031) for the amphibolite samples (Table 1) alone indicate that the amphibolite is orthoamphibolite. Para-amphibolites would probably have a value closer to the high values (0.7321 and 0.7258) obtained for the country rock samples. In addition, the Sr^{87}/Sr^{86} ratios of the amphibolite samples are similar to those of the mafic rock samples. The values for the amphibolites (0.7047, 0.7047, and 0.7031) are only slightly higher than those of troctolite and olivine gabbro (0.7029, 0.7026,

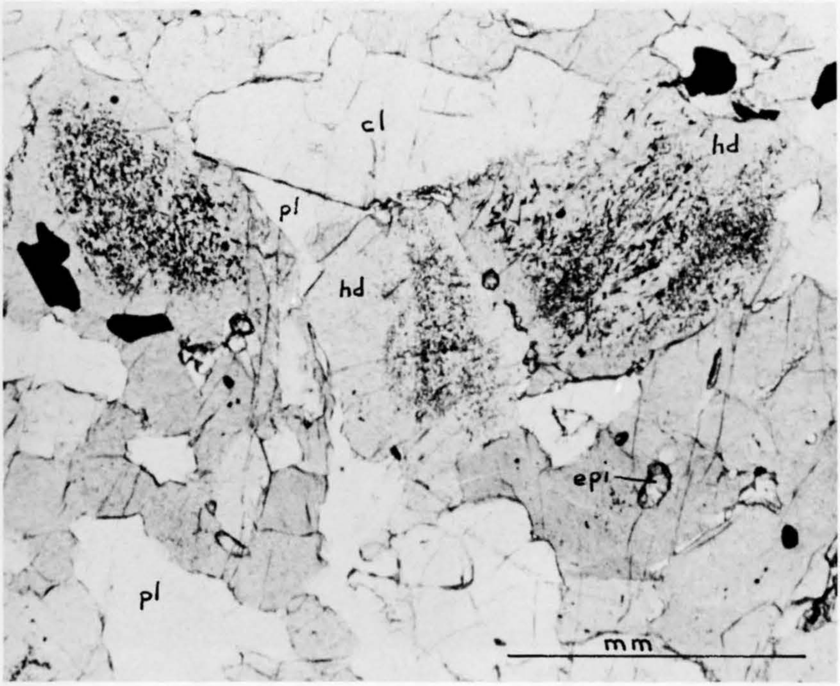

Figure 22. Hornblende (hd), clinozoisite (cl), epidote (ep), and plagioclase (pl) in amphibolite. Schiller texture in hornblende is relict from diallage. Plain transmitted light.

and 0.7024). The difference can be explained by the introduction of fluids containing some radiogenic strontium and/or rubidium derived from the country rocks during metamorphism.

Veins and Pods within the Sill

Veins and/or pods of the following compositions were observed in the sill: (1) diallage and bytownite, (2) hornblende, andesine, clinozoisite, and corundum, (3) diallage, and (4) hornblende. The diallage-bytownite veins are similar to the medium-grained to pegmatitic dikes reported by Thayer (1963, p. 59) as being "...common features in many alpine complexes." The diallage-bytownite veins and pods are generally restricted to mafic and ultramafic units within the sill. The best exposures are in the vicinity of the Lower Bell Creek Church. Veins and pods only a few centimeters in thickness are common (Fig. 23); however, one vein with a thickness of about 70 centimeters was observed.

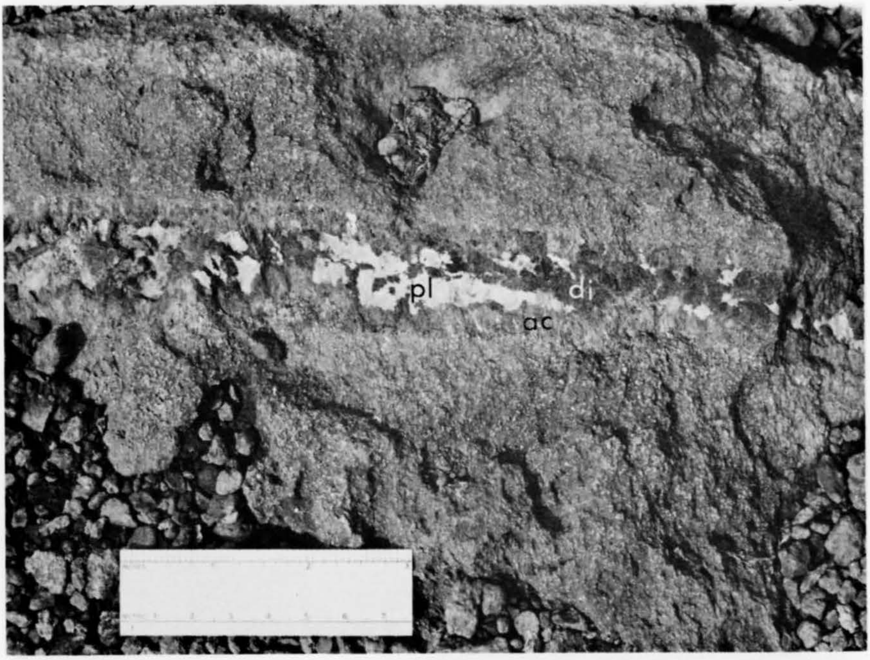

Figure 23. Diallage (di) and plagioclase (pl) vein with an actinolite selvage (ac) in dunite.

Generally it is not possible to trace a vein for more than a few meters due to limited outcrops. Subhedral to euhedral diallage crystals are similar to, but generally larger than, those in olivine gabbro. Crystals 8 to 10 mm in diameter are common, and some approach 50 mm in diameter. Although many of the diallage crystals are partially uralitized, some appear unaltered. Contacts between the veins and mafic rocks are generally sharp; however a zone of actinolite up to several centimeters thick commonly occurs between veins and dunite. Commonly the actinolite blades are enlongated perpendicular to the vein. In some veins a zone of chlorite occurs between the actinolite zone and the vein. This is similar to the veins in dunite reported at the nearby Buck Creek dunite body (Hadley, 1947). It is inferred that the diallage-bytownite veins represent the last stage of crystallization of the sill.

As the margin of the sill is approached, the diallage-bytownite veins and pods appear to be gradational into an assemblage of hornblende, andesine, clinozoisite, and corundum. These are mostly restricted to amphibolite, but some occur in dunite and in chlorite schist. Except for the mineral assemblage these are similar to the dillage-bytownite veins and pods. Commonly, exposures of the larger veins have been destroyed during mining for corundum. Hornblende crystals in float from some of the larger veins were observed up to about 40 mm in length but have been reported up to at least 12 inches (approximately 30 cm) long (R. H. Carpenter, 1971, personal communication). Clinozoisite occurs in quantities up to several percent, either as disseminated crystals throughout the vein, or as a layer in the center of the vein. Corundum occurs locally as disseminated crystals (Fig. 24). One white and blue aggregate weighing about 1 pound was found near the Lower Bell Creek Corundum Mine. Other crystals found were tan to dark blue (sapphire) to pink (ruby). It is thought that corundum forms from some of the alumina liberated from plagioclase during the change from bytownite to andesine during the metamorphism of diallage-bytownite veins located near the margin of the sill; however, most of the alumina probably goes into the formation of clinozoisite. Several aggregates of corundum crystals observed contained a few percent of transparent mica between individual crystals. Studies of the refractive indices of the mica indicate that it is muscovite rather than the similar mineral margarite reported by local corun-

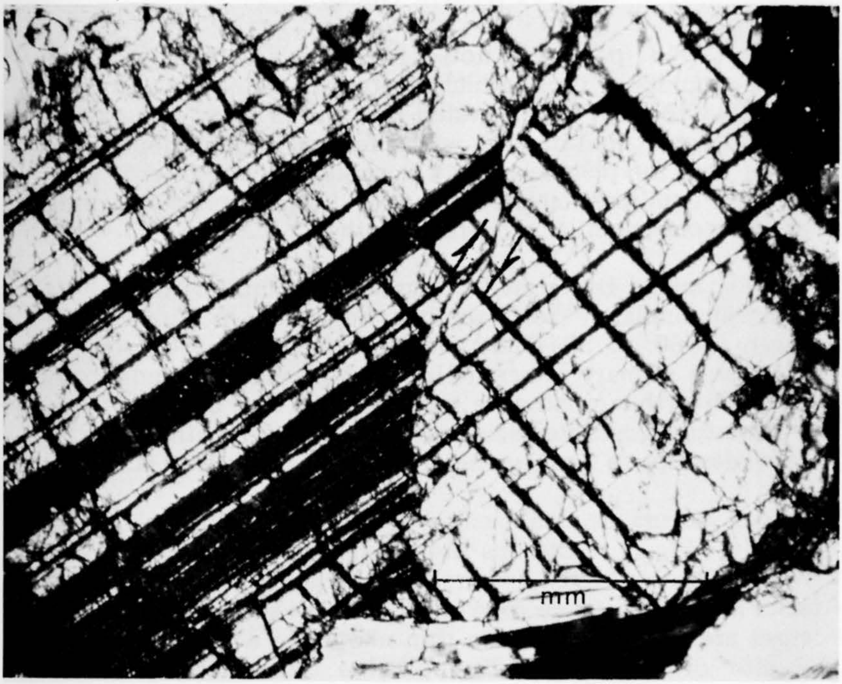

Figure 24. Corundum crystal twinned on (1011). Displacement of part of the crystal is indicated by arrows. Only left half shows stress twinning. Transmitted polarized light.

dum collectors. One crystal of corundum was found adjacent to a kyanite crystal.

Veins and, rarely, pods of diallage are generally restricted to the mafic and ultramafic units. Commonly the veins are thinner than the diallage-bytownite veins and more uralitized. The veins cut some diallage-bytownite veins but are cut themselves by other diallage-bytownite and diallage veins. An aggregate of partially uralitized diallage crystals weighing several pounds was found near Hog Creek. Textures indicate that during injection of some of the diallage-bytownite veins and pods, the bytownite component was squeezed away leaving only earlier crystallized euhedral to subhedral diallage.

A few coarse-grained hornblende veins up to 50 mm thick were observed in some dunite outcrops near the southern tip of the Hog Creek zone. The large hornblende crystals are generally elongated perpendicular to the vein wall. The contact between the vein and dunite is sharp. These veins are probably the metamorphosed equivalent of the diallage veins.

Garnet Pyroxene Gneiss

Kellberg (1943, p. 21-24) noted lenses of a garnet-pyroxene-plagioclase-amphibole rock, which he termed eclogite, occurring locally within the sill. He suggested that the primary minerals of the rock are garnet and diallage which formed at great depths. He considered that the plagioclase and hornblende components were formed in an equilibration process under different physical conditions after emplacement at moderate depths.

The rock might be termed a pyroxene granulite due to its mineralogical similarity to granulites described in Turner and Verhoogen (1960, p. 554-556) and because the garnet does not appear to be a primary mineral. However, because of gradational contacts with orthoamphibolite (metagabbro) and a lack of evidence indicating granulite facies metamorphism in other nearby rocks the descriptive term garnet pyroxene gneiss was adopted.

The rock occurs as small lenses in the orthoamphibolite and dunite units (Pl. 1). Outcrops are abundant in the vicinity of Lower Bell Creek Church, where it underlies several small hills due to its higher resistance to erosion than the surrounding rocks. The lenses are gradational into a thin margin of a hornblende-rich amphibolite or typical orthoamphibolite. In addition, several pieces of small boulder-sized float of orthoamphibolite were observed with a core of pyroxene granulite. Upon weathering the rock yields a reddish-brown saprolite similar to that of orthoamphibolite.

Table 5. Modal Analyses of Garnet Pyroxene Gneiss in Volume Percent

	69C 29e	69C 29a	69C 13	69C 29b	
Amphiboles:					
hornblende	20	5	1	16	
green amphibole rimming diallage	8	6	8	10	
Clinozoisite	tr	tr	tr	tr	XX
Garnet	21	29	32	14	
Plagioclase	21	16	30	22	
(An content)	(43)	(42)	(61)	(48)	
Diallage pyroxene	28	41	26	34	
Quartz				1	
Rutile	1	1	1	1	
Total opaques	1.5	2	2	2	
Total	100.5	100	100	100	

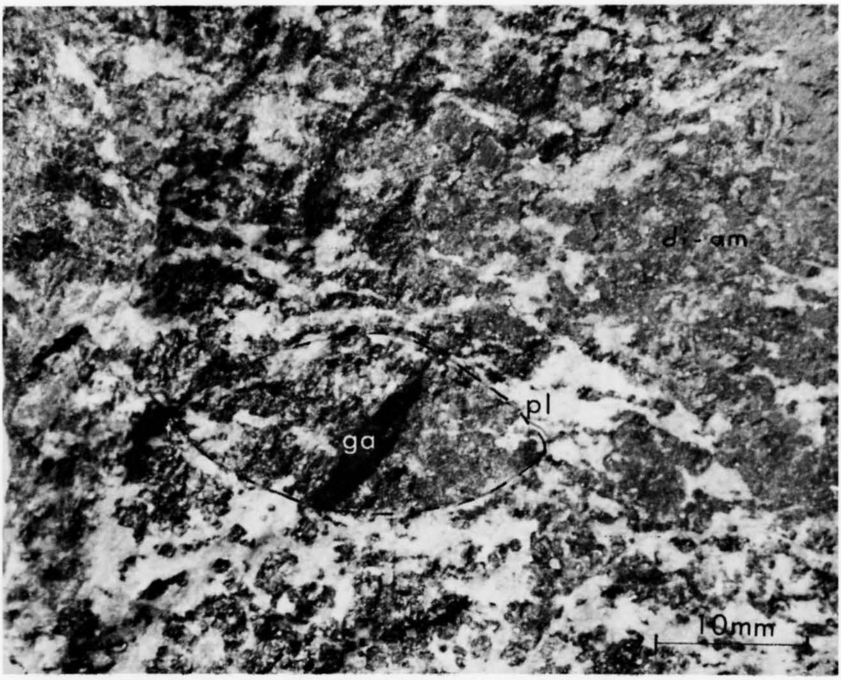

Figure 25. Garnet pyroxene gneiss. The dark areas are mostly diallage with some hornblende (di-am). The light areas are plagioclase (pl). The outlined garnet crystal (ga) contains inclusions of plagioclase and diallage.

Outcrops of pyroxene granulite are distinctive. Some poor to fairly well-developed gneissic structure is present, but more commonly the rock appears "streaky" (Fig. 25). Red garnets ranging in approximate diameter from 1 to 50 mm are characteristic of the rock and crystals about 10 mm in diameter are common. The pyroxene and amphibole crystals are smaller, and are dark brown to black in hand specimen.

In thin section the rock appears to be mainly composed of diallage, andesine, hornblende, and garnet (Figs. 26 and 27). Modal analyses of typical samples are shown in Table 5. The primary minerals are diallage and plagioclase. Oriented inclusions of diallage and plagioclase in the garnet indicate that the garnet is not a primary mineral, while the lack of hornblende inclusions in garnet probably indicates that hornblende formed after garnet. Diallage crystals inside and outside the garnets are surrounded by a thin rim of light green amphibole and are similar to the diallage described in olivine gabbro. Except for the thin rim of amphibole the diallage inclusions in garnet appear to be unaltered; however,

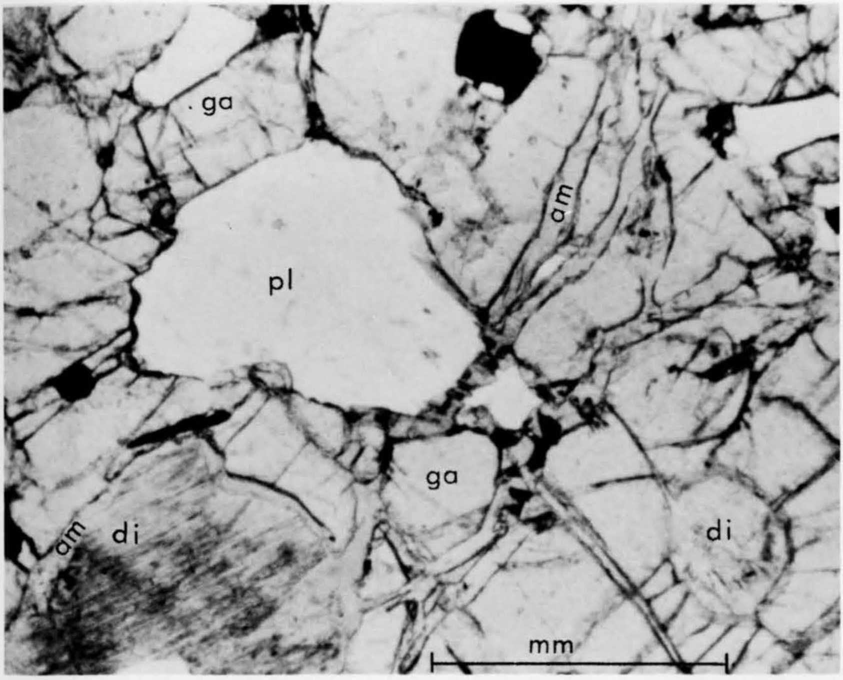

Figure 26. Garnet pyroxene gneiss. Light green amphibole (am) occurs along fractures and around diallage (di). Inclusions of plagioclase (pl) and diallage are present in garnet (ga). Transmitted light.

many of the other diallage crystals outside the garnets are partially altered to hornblende. Some samples contain only a few percent hornblende. Generally the hornblende is strongly pleochroic and is similar to the hornblende in orthoamphibolite. Refractive indices of the plagioclase indicate that it has a composition of An_{42} to An_{61} (andesine-labradorite). Abundant garnet was observed in every sample. It has an anhedral to subhedral outline. abundant fractures, and abundant inclusions. Locally, fractures in garnet are filled with a light green amphibole (Fig. 26). In polished section approximately 1 percent rutile was observed, while less than 2 percent pyrrhotite and only a trace of chalcopyrite are present.

It is inferred that the garnet pyroxene gneiss lenses are metamorphosed or partially metamorphosed lenses of olivine gabbro. This is based upon the similar nature of the diallage in both units, the secondary nature of the garnets, and the gradational contacts with orthoamphibolite. It is questionable, however, as to why a garnet pyroxene gneiss was formed instead of the typical orthoamphibolite during the metamorphism. Part of the answer may be concerned with the bulk chemistry of such olivine gabbro lenses.

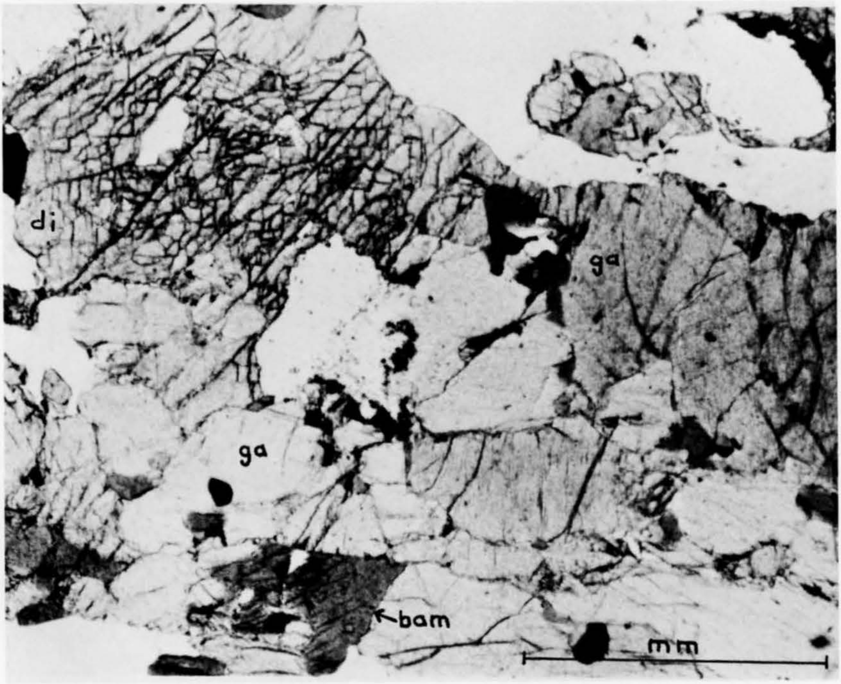

Figure 27. Garnet pyroxene gneiss. Brown amphibole (bam) occurs in garnet (ga). Diallage exhibits pyroxene cleavage.

It may also be possible that the rock represents xenoliths of a pyroxene granulite, formed at depth from eclogite, garnet granulite, or olivine gabbro and rafted upwards during intrusion of the mafic and ultramafic rocks. Ringwood and Green (1969, Figs. 1 and 3) show phase transitions from eclogite to garnet granulite to gabbro or granulite for any of the major basalt types. The similarity of the mineral composition and streaky appearance of the rock compared to some granulites would support this possible origin.

ECONOMIC GEOLOGY

Rutile

Surficial concentrations of rutile, which formed during weathering and erosion of the host rock, occur in the area underlain by the garnet mica schist unit which outcrops in the northeastern and southwestern portions of the area. Stratigraphically the deposits occur beneath the sill. None occurs in the biotite gneiss unit. The deposits consist of loose rutile crystals on the surface and in the alluvium and soil.

Specimens of rutile are black to reddish-brown and range in diameter from less than 1 mm to 70 mm. They generally consist of single crystals which are commonly twinned and whose edges are rounded. In polished section a replacement (?) rim of ilmenite occurs adjacent to the margin and fractures of the crystal (Fig. 28). Weathering of the ilmenite to anatase and subsequent removal may explain the rounding. The dark color of the specimens prompted an investigation of the tantalum and vanadium content. Electron microprobe analysis, however, indicated that none was present. A small percentage of iron replacing titanium in rutile may be enough to distort the crystal lattice and cause the coloration.

Ford, Bacon, and Davis (1927) estimate that the Shooting Creek deposit, approximately a third of which is located in the study area, contains 11 million cubic yards of material which could yield 172,000 tons of recoverable concentrate (40% TiO_2).

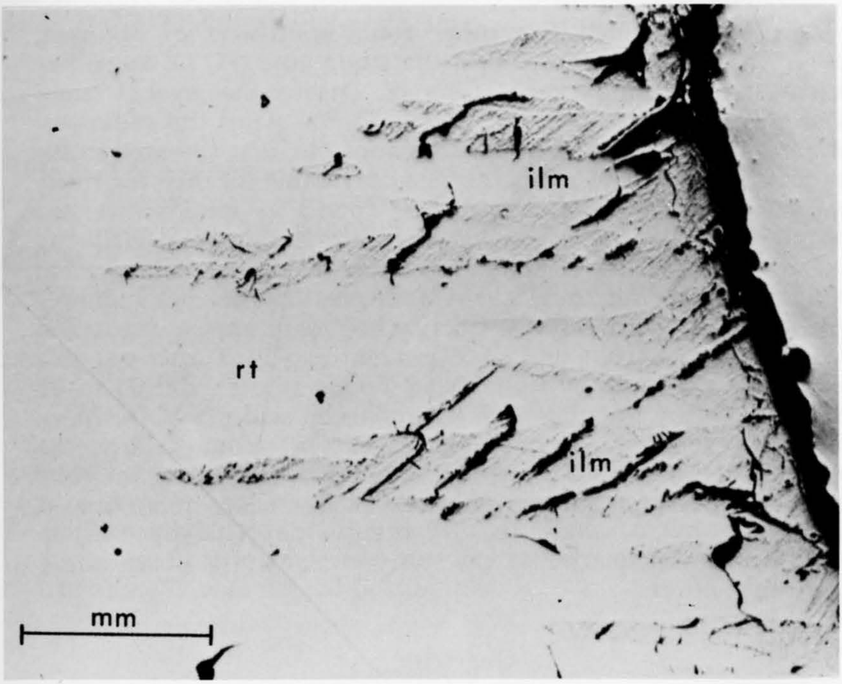

Figure 28. Ilmenite (ilm) occurring along the margin and fractures of a rutile crystal (rt). Reflected light.

Van Horn (1945) outlined nine rutile zones totaling 618.5 acres in the Shooting Creek area and measured the thickness of the rutile bearing alluvium. In several zones the alluvium was over 5 feet thick. He reports that rutile from zone 4 (Pl. 1) contains 86.64 percent titanium oxide and 8.58 percent iron oxide. Williams (1964, Table 2) shows that Shooting Creek alluvium contains 0.44 percent TiO_2 and 30.5 pounds of heavy mineral concentrate including 12 pounds of rutile per cubic yard. He estimated that the area contains 68.812 tons of TiO_2 with a "total relative value" of $4,153,000. At the 1971 price of $185/ton of 96 percent rutile (Engineering and Mining Journal, May 1971, p. 114) the value of this quantity is $12,730,220. However, a penality might be placed on rutile from the Shooting Creek area because of the ilmenite present.

Van Horn (1945, p. 1) states that these deposits are at least marginal. Several companies have asked the Tennessee Valley Authority about the rutile zones, including the American Smelting and Refining Company which leased the mining rights of several hundred acres in the early 1950's but later dropped them. Recent increased demand for titanium metal may warrant re-evaluation of these deposits.

Van Horn outlined five other zones southwest of Shooting Creek. Three of these are within the study area (Pl. 1). The other two are near Young Harris, Georgia. During the present study other rutile occurrences were noted (Pl. 1). After the geological mapping was completed, it became apparent that the area stratigraphically below the sill is the most favorable locality for rutile exploration. One rutile crystal was found in mica schist and several others in the overlying saprolite. An analysis made by L. H. Turner of the Georgia Department of Mines, Mining and Geology in 1945 for the T. V. A. indicates that one rutile sample from near the North Carolina-Georgia boundary has a composition of 82.40 percent TiO_2 and 14.87 percent Fe_2O_3. Turner was able to upgrade a sample of rutile from Young Harris from 64 to 80 percent TiO_2 by leaching with hydrochloric acid (T. V. A. files). With the exception of one deposit east of Young Harris the concentration of rutile in soil is less than that present at Shooting Creek and, therefore, may not be as economically important. It should be noted, however, that other rutile deposits, especially in the southwestern quarter of the study area, may be obscured by thick forest cover.

Quartzite

The only quartzite deposit of potential economic significance is a steeply dipping lens-shaped body that outcrops on the top of

Bell Mountain, about 1 mile east of Hiawassee. The body is 500 feet wide and 1,600 feet long. The depth is not known. The color range of the rock is snow white to pink to yellow. Hurst and Horton (1964) made a comprehensive investigation of the deposit. They reported that core drilling and mapping indicate that at least 2 million tons or 901,900 cubic yards of silica are present and that the actual tonnage may be as much as 2 times higher. They suggested that iron oxides resulting from the weathering of finely disseminated pyrite caused the pink coloration. Their investigation indicates an iron content range of 1.2 to 0.005 percent and an alumina range of 0.8 to 0.001 percent. In order to separate the less valuable colored varieties from the white, Hurst devised a photo-electrical-mechanical device for their separation after crushing; however, the company mining the property at the time did not utilize the device. Mining operations ceased two years later. Hurst (1971, personal communication) suggests that the white as well as the pink grades of quartzite have potential as cast stone.

Several major problems for mining operations exist. The nearest railroad is at Murphy, North Carolina, 25 miles away. A major highway occurs only 2 miles from the deposit; however, the last mile of the dirt road leading to the deposit has a very steep gradient. Another problem is that the closest water supply is approximately 1,200 feet down the mountain.

Sillimanite

Most of the sillimanite in the area occurs in a thin zone southwest of Hayesville, North Carolina (Pl. 1). Hash and Van Horn (1951) investigated the zone but found only a small percentage of sillimanite present. They (p. 25) report that the zone does not contain a sufficient quantity to be of important commercial value.

Kyanite

Several tons of pebble and cobble float of a kyanite-garnet rock containing about 60 percent coarse-bladed blue kyanite occur on the southwestern shore of the Jackrabbit Mountain Campground. The apparent low tonnage and adjacent recreation facilities probably negate any commercial possibilities.

Corundum

In the latter part of the nineteenth century several corundum mines were opened for abrasive and gem quality corundum at several ultramafic localities in northern Georgia and western North Carolina. The mines produced corundum until the introduction of artificial abrasives in the early part of the twentieth century. Only a small quantity of the corundum mined was of gem quality. At the present time no mines are in operation.

In the study area, most of the old mines and prospects have been covered by Lake Chatuge or filled by land owners. The three major mines are partially preserved and are shown on Plate 1. The Hog Creek Corundum Mine, located 0.5 mile west of the Union Hill Church (Pl. 1) on the property of Ed Birch was investigated by King (1894, p. 88-89) and the U. S. Bureau of Mines (Ballard, 1946). The mine consists of a vertical shaft about 45 feet deep and a trench 190 feet long. The lithologies present at the mine are weathered chloritized troctolite and hornblende-clinozoisite-plagioclase-corundum veins. Corundum occurs locally in both units. The amount of production from the mine is not known.

The Bell Creek Corundum Mine, located 1,000 feet west of the Lower Bell Creek Church, was also investigated by King (1894, p. 87) and the U. S. Bureau of Mines (Ballard, 1943). The mine consisted of a shaft, several pits, and a trench. The geology of the mine site can only be inferred from the mine dump because the mine was blasted full by an "irascible prospector" before King visited the property (King, 1894, p. 87). The mine dumps consist of chloritized troctolite and aggregates of coarse crystalline hornblende, plagioclase, clinozoisite, and corundum. An outcrop of chloritized troctolite (chlorite schist) occurs near the collar of the mine. The quantity and value of corundum produced from the property is not known.

The Behr Corundum Mine, located 0.7 mile N55E of the Elf schoolhouse at the edge of Lake Chatuge, was investigated by Pratt and Lewis (1905, p. 36, 37, 240). Corundum at this locality occurs as disseminated pink and tan crystals in a grass green edenite amphibolite unit. This is similar to a mode of occurrence at Buck Creek located 8 miles to the northeast. A description of the original workings is not available; however, two shafts are visible at the present time. The workings were extensive enough to warrant the construction of a steam cleaning plant; however, only two carloads of corundum were produced during the 10 years that the mine was in operation. The mine was closed in 1890 because of flooding problems. At the present time the mine is visible only when the water level of the lake is low.

Future profitable mining of corundum from the area is considered doubtful in part because of the apparent lack of reserves.

Nowhere in the area is corundum as abundant in outcrop as at Buck Creek, which is not being mined.

Asbestos

During the last century a few mining attempts and investigations were made of the asbestos occurrences associated with dunite in the Lake Chatuge area. Commonly early reports do not differentiate the varieties of asbestos present; however, it appears that most is the anthophyllite variety although some chrysotile also occurs. Hopkins (1914) investigated the asbestos occurrences in Towns County, but noted that there was little or no commerical promise for each deposit due to the small quantities present. Kellberg (1943, p. 6) reported that about 15 tons of asbestos were mined in 1941 from a locality west of Elf in Clay County before it was flooded during the development of Chatuge Reservoir. Kellberg (Pl. 1) also shows an abandoned asbestos mine near the lake shore on the northeastern slopes of Jackrabbit Mountain. Production from this mine is not known. During this study only a very small amount of asbestos was found as surface float and in small veins in dunite. Thus, it is probable that the commerical possibility of asbestos production in the area is not good.

DISCUSSION

Speculation on the Geology of Adjacent Areas

The Lake Chatuge sill is continuous outside the study area. The western limb probably underlies part of the large valley at Young Harris, Georgia. The rutile deposits located to the east and south of Young Harris, reported by Van Horn (1945), are probably located to the east of the sill within the garnet mica schist unit. The chromite occurrence in dunite 2¾ miles southwest of Hiawassee reported by Hopkins (1914, p. 48) is probably part of the eastern limb of the sill. Northward, Keith's Nantahala Folio (1907) shows an amphibolite band almost continuous to the Buck Creek dunite body which is located 8 miles from the northeast corner of the study area and 16 miles from Young Harris. This indicates that the sill may be extensive and that the major anticlinal structure has a several mile elongation.

In addition, other intrusions in western North Carolina and northern Georgia may be similar to the Lake Chatuge sill. Hunter

(1941) shows geologic maps of 13 of the largest ultramafic intrusions in that area. Eleven of the maps show hornblende gneisses nearby. These may be similar to the Lake Chatuge orthoamphibolite. Also, many dunite bodies in the belt have similar olivine compositions (approximately Fo_{88-92}). The amount of alteration products varies for each intrusion; however, this may be explained by localized conditions. For example, such rocks intruded into higher levels may have been emplaced into sediments of Ocoee age which may have supplied abundant water for subsequent alteration and metamorphism (Carpenter, 1971, personal communication).

Origin of the Lake Chatuge Sill

Based on the various types of evidence previously described, certain conclusions regarding the origin of the Lake Chatuge sill are warranted. The low Sr^{87}/Sr^{86} ratios of the mafic rocks suggest a direct relationship with the earth's mantle which is probably ultramafic in composition as suggested by Green and Ringwood (1967). Because of the isolated SiO_4 structure of olivine, it has been proposed that dunites may be injected in the solid state (Bowen and Tuttle, 1949, p. 455). Also it is possible that serpentine can flow under high pressure. However, it is not probable that solid blocks of olivine gabbro and troctolite were squeezed up from the mantle; therefore, it is likely that a magma existed. The very low Sr^{87}/Sr^{86} ratio (0.7023) of one olivine sample (475b) from dunite indicates that it also had a direct relationship with the mantle; however, the nature of the relationship between the mafic magma and olivine in the mantle cannot be definitely established from isotopic evidence.

The injection of the magma, and perhaps even the initial differentiation of the magma in the mantle, may have been triggered by the early stages of mid-Paleozoic metamorphism. Carpenter (1970) notes a correlation between the Blue Ridge ultramafic belt and the thermal axis of the mid-Paleozoic metamorphism. He suggests that the generation of such magmas in the mantle represented a phase of the same thermal event that subsequently affected the regional metamorphism in the crust.

The well-ordered concentric zoning of the sill suggests that Bhattacharji's (1967) model for magmatic flowage may be applicable. This approach is similar to that used by Simkin (1967) to explain the origin of picrite sills at Skye, Scotland. Accordingly, olivine settled out of the magmas as crystal cumulates in a magma pipe after injection into the crust. The resulting olivine crystal mush is the same as Bowen's early concept.

Continued movement of the magma after the settling of olivine crystals may tend to concentrate the olivine mush in the center of the pipe. Simkin (1967, p. 68) describes that in simple axial migration "....particles move toward an equilibrium position at the tube axis during flow". In the next step of the model a flowing mixture of olivine mush surrounded by magma intrudes higher into the crust. The mass then spreads out forming the sill and retaining the olivine mush core. Bhattacharji (1967, p. 70) notes that gravity settling of the mush only becomes significant below certain flow rates and ".....chilling of the lower margin and increased crystallization, which produce an increase in the viscosity of the magma, tend to hinder crystal settling close to the margin". It is possible, however, that locally part of such a magma may be squeezed away leaving dunite adjacent to the country rock. This relationship was noticed in some localities in the study area.

The occurrence of an orthoamphibolite margin around the sill with a well-developed foliation parallel to that of the country rock indicates that a high grade metamorphic event or the peak of such an event occurred after emplacement. The high grade metamorphism may have obliterated the texture of any contact metamorphism formed during emplacement. If emplacement occurred during the early stages of regional metamorphism, the country rocks would have been warm. In such a situation a high thermal gradient may not have existed between the magma and country rocks, thereby reducing contact metamorphic effects.

Other types of alteration, including serpentinization and chloritization, may have occurred at a later time. Strontium isotype evidence, presented previously, indicates that serpentinization of the ultramafic units was probably post-metamorphic.

It has been proposed by several investigators that the Blue Ridge in the study area is an allochthonous block that has been tectonically transported no less than 40 miles to the northwest. Carpenter (1970, p. 760) notes that metamorphic isograd relationships at windows in the Blue Ridge indicate that the thrust faulting occurred after the mid-Paleozoic metamorphism, probably near the end of the Paleozoic Era. Thus the connections between the ultramafic bodies in the Blue Ridge and the mantle, such as pipes or dikes, have been severed. Erosion of the overlying rocks has since exposed the sill.

SUMMARY

Lake Chatuge is located in the Blue Ridge province on the Georgia-North Carolina boundary. Appalachian type ultramafic rocks occur as discontinuous outcrops across the area which covers about 40 square miles.

The country rocks are predominantly schists and gneisses which are probably sedimentary in origin. The rocks have been intensely metamorphosed during both the Grenville and mid-Paleozoic events. The occurrence of sillimanite schist within the area indicates that the mid-Paleozoic metamorphism was locally at the sillimanite grade. The rocks are folded in a complex manner. Large structures, which may be *en echelon* folds, appear on the geologic map of the area as two opposing plunging anticlines outlining an anticlinal saddle. Minor folds of several magnitudes are common. The fold trends are commonly northeastwards and commonly dip very steeply to the southeast. The main joint sets are composed of *ac* and *bc* joints.

The ultramafic and related rocks occur as a tabular unit between a garnet mica schist unit and a biotite gneiss unit, and are, therefore, considered to comprise a sill. The sill is generally concentrically zoned, with partially serpentinized dunite of composition Fo_{90+2} occuring at its center. Coronite troctolite locally surrounds dunite and occurs as lenses within it. Both gradational and sharp contacts are present. Rhythmically banded coronite troctolite, perhaps formed by flow banding, is locally present. Olivine gabbro, consisting mainly of diallage and bytownite, locally surrounds the troctolite and dunite units. In places chlorite, serpentine, amphibole, and other alteration products are present.

Strontium isotope evidence indicates that the ultramafic and mafic rocks were derived from the mantle. The Sr^{87}/Sr^{86} ratios for these rocks are similar to the values reported for basalts but are lower than those reported for most other alpine intrusions.

Coronas, composed of an orthopyroxene rim and an adjacent amphibole-spinel rim, occur between the olivine and plagioclase in coronite troctolite and olivine gabbro. Similar reaction rims occur as layers in rhythmically banded coronite troctolite. The invariable occurrence of the reaction rims as layers separating the two minerals suggests that the rims were formed after the layering of olivine and plagioclase, perhaps in the final stages of crystallization of the sill. Furthermore, the replacement of some of the coronas by amphibole, interpreted to be mid-Paleozoic, indicates that they were formed prior to the mid-Paleozoic metamorphism.

As the margin of the sill is approached the olivine gabbro and troctolite are gradational into amphibolite. On the geologic map of the area the amphibolite appears to envelope the mafic and ultramafic rocks. Evidence that the amphibolite is orthoamphibolite includes gradational contacts, relict textures, and low Sr^{87}/Sr^{86} ratios. Stages of the transformation from olivine gabbro and troctolite to amphibolite are observable in thin sections of samples collected across gradational contacts.

Several small rock units, including garnet pyroxene gneiss, wehrlite, and diallage-bytownite veins, occur within the sill. The garnet pyroxene gneiss occurs locally as small lenses and is commonly gradational into orthoamphibolite. Wehrlite is present in a few localities. Diallage-bytownite veins cut the center of the sill and show a progressive alteration into an assemblage of hornblende, andesine, clinozoisite, and corundum as the margin of the sill is approached.

It is inferred that the sill was emplaced in the early stages of the mid-Paleozoic metamorphism as olivine crystal mush transported by a gabbroic magma. Magmatic flowage differentiation may explain the concentric zoning of the sill. A contact metamorphic zone was not observed around the sill; however, the peak of the mid-Paleozoic metamorphism may have obliterated any contact metamorphic effects formed during intrusion. It is probable that only enough water from the country rocks was available to hydrate (amphibolitize) the margin of the sill during the mid-Paleozoic metamorphism because the country rocks had been previously depleted of water during the Grenville event. In addition, any crystal zoning of olivine crystals may have been destroyed during this "dry" mid-Paleozoic metamorphism. Similar rock types occurring several miles to the northeast and southwest may be part of the sill. In addition, other alpine-type intrusions in western North Carolina may have a similar origin.

The area contains several abandoned corundum and asbestos mines. The economic potential of these minerals within the area is not very good. However, the economic potential of locally occurring deposits of rutile and one quartzite deposit may be at least marginal.

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EXPLANATION

INTRUSIVE IGNEOUS ROCKS

D — DUNITE

T — CORONITE TROCTOLITE. ATTITUDE SHOWN WHERE BANDED

OG — OLIVINE GABBRO

W — WEHRLITE

METAMAFIC ROCKS

A — AMPHIBOLITE

GP — GARNET PYROXENE GNEISS

AT — ABESTOS TALC SCHIST (KELLBERG, 1943)

COUNTRY ROCKS

CBG — COARSE-BANDED BIOTITE GNEISS

SS — SILLIMANITE SCHIST

BG — BIOTITE GNEISS

K — KYANITE GARNET ROCK

Q — QUARTZITE

CR — CLINOZOISITE ROCK

GMS — GARNET MICA SCHIST

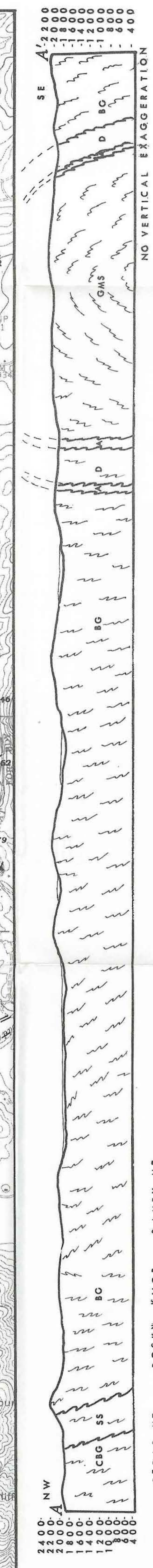
CONTACT, DASHED WHERE APPROXIMATE

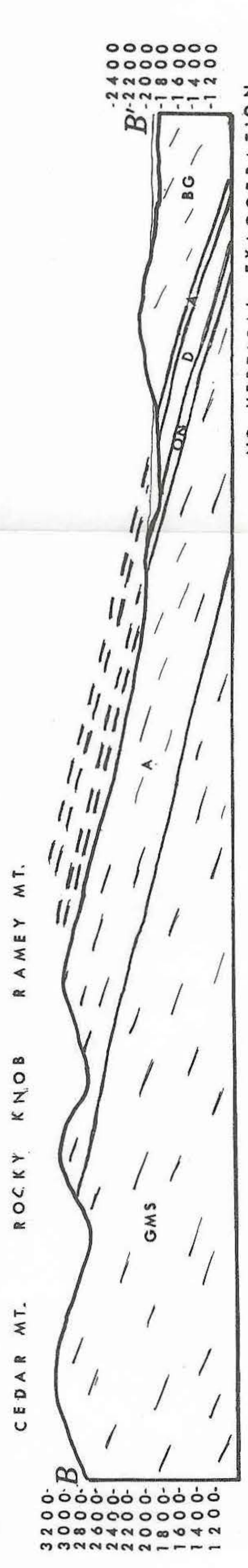
UNCLASSIFIED FAULT

STRIKE AND DIP OF FOLIATION

PLUNGE OF SMALL ANTICLINES AND SEVERAL SMALL FOLDS

VERTICALLY DIPPING FOLIATION AND JOINTING





MINES, PROSPECTS AND MINERAL LOCALITIES

A ⚒	Asbestos mine, abandoned
C ⚒	Corundum mine, abandoned
C x	Corundum prospect
C ○	Corundum locality
Ct–N x	Chromite–nickel prospect
G ⚒	Gravel quarry, abandoned
R (R1)	Rutile zone and number (Van Horn, 1945
R ○	Other rutile localities
x	Prospect pit

GEOLOGIC MAP AND CROSS SECTIONS OF THE LAKE CHATUGE AREA, CLAY COUNTY, NORTH CAROLINA AND TOWNS COUNTY, GEORGIA

SCALE 1:24,000

0 — 1 — 2 MILES

0 — 1 — 2 KILOMETERS

CONTOUR INTERVAL – 40 FEET

1971