Bedrock Geology and Mineral Resources of the Knoxville 1°x2° Quadrangle, Tennessee, North Carolina, and South Carolina

By G.R. ROBINSON, Jr., F.G. LESURE, J.I. MARLOWE II,
N.K. FOLEY, and S.H. CLARK

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By G.R. Robinson/ Jr./ F.G. Lesure, J.I. Marlow II, N.K. Foley, *and* S.H. Clark

Abstract

The Knoxville 1°x2° quadrangle spans the Southern Blue Ridge physiographic province at its widest point from eastern Tennessee across western North Carolina to the northwest corner of South Carolina. The quadrangle also contains small parts of the Valley and Ridge province in Tennessee and the Piedmont province in North and South Carolina. Bedrock in the Valley and Ridge consists of unmetamorphosed, folded and thrust-faulted Paleozoic miogeoclinal sedimentary rocks ranging in age from Cambrian to Mississippian. The Blue Ridge is a complex of stacked thrust sheets divided into three parts: (1) a west flank underlain by rocks of the Late Proterozoic and Early Cambrian Chilhowee Group and slightly metamorphosed Late Proterozoic Ocoee Supergroup west of the Greenbrier fault; (2) a central part containing crystalline basement of Middle Proterozoic age (Grenville), Ocoee Supergroup rocks east of the Greenbrier fault, and rocks of the Murphy belt; and (3) an east flank containing the Helen, Tallulah Falls, and Richard Russell thrust sheets and the amphibolitic basement complex. All of the east flank thrust sheets contain polydeformed and metamorphosed sedimentary and igneous rocks of mostly Proterozoic age. The Blue Ridge is separated by the Brevard fault zone from a large area of rocks of the Inner Piedmont to the east, which contains the Six Mile thrust sheet and the Chauga-Walhalla thrust complex. All of these rocks are also polydeformed and metamorphosed sedimentary and igneous rocks. The Inner Piedmont rocks in this area occupy both the Piedmont and part of the Blue Ridge physiographic provinces.

The intensity of deformation and metamorphism increases from west to east in the Blue Ridge. The west flank is mostly chlorite grade or relatively unmetamorphosed, and the central part of the Blue Ridge is mostly staurolite, garnet, or biotite grade, although sillimanite grade rocks occur along the eastern part of the central Blue Ridge in the vicinity of the leading edge of the Hayesville fault. The east flank of the Blue Ridge and much of the Inner Piedmont are at kyanite or sillimanite grade of regional metamorphism except for a zone of retrograde rocks in the Brevard fault zone and a small area of biotite-grade rocks in the extreme southwest part of the Grandfather Mountain window in the northeast corner of the quadrangle.

The major mineral resources in the Knoxville 1°x2° quadrangle are construction materials and a variety of industrial minerals mostly related to either granite and pegmatite or ultramafic rocks. Past production in the quadrangle of metals, which are of secondary importance relative to construction materials and industrial minerals, include copper in massive sulfides of the Besshi type, gold-bearing quartz veins, and residual iron and manganese deposits. Resources are discussed in relation to the Valley and Ridge, Blue Ridge, and Piedmont provinces.

The following resources are the most important:

A. Construction materials:
   1. Dimension stone of the Tennessee marble district in the Valley and Ridge.
   2. Limestone and dolomite of the Valley and Ridge.
   3. Sand and gravel and crushed stone, widespread throughout the quadrangle.

B. Industrial minerals:
   1. Feldspar, flake mica, and quartz produced by flotation methods from the Spruce Pine Alaskite (muscovite granodiorite) in the east flank of the Blue Ridge. The district produces about half of the U.S. feldspar and significant amounts of the U.S. flake mica.
   2. Olivine produced from alpine-type dunite bodies in the east flank of the Blue Ridge.
   3. Talc and marble from the Murphy belt in the central part of the Blue Ridge,
   4. Vermiculite produced from a large deposit near Tigerville, S.C-, in the Inner Piedmont. Deposit worked out and mine backfilled. Smaller deposits associated with ultramafic rocks in the east flank of the Blue Ridge are now uneconomic and have not been worked in the past 20 years.

C. Metals:
   1. Copper in three deposits, the Fontana and Hazel Creek mines in the Great Smoky Mountains

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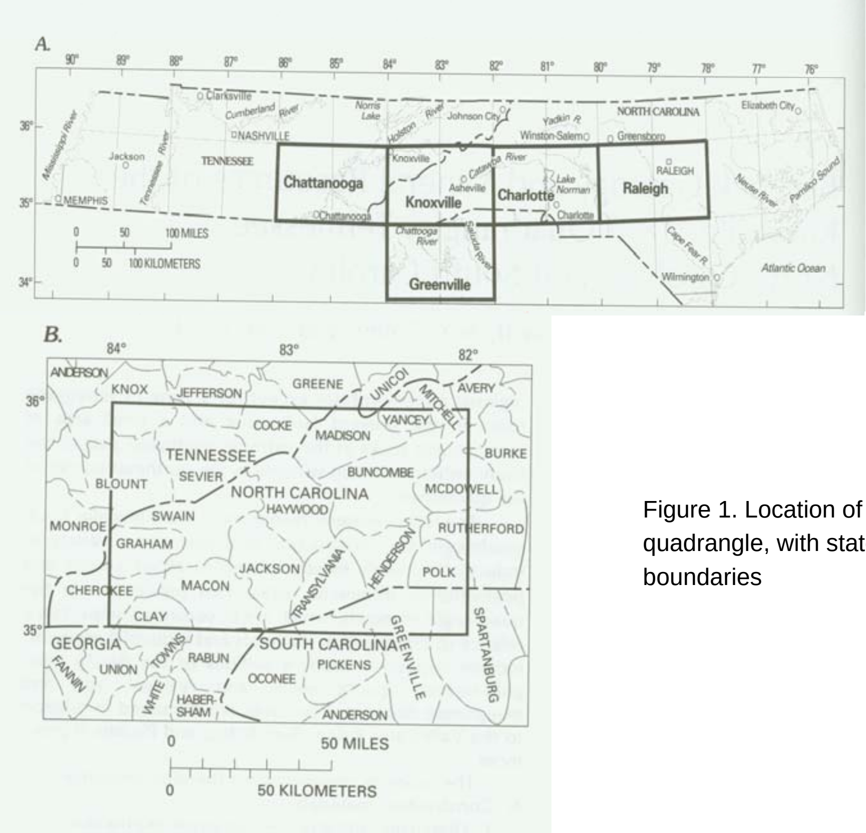

Figure 1. Location of the Knoxville 1ºx2º quadrangle, with state and county boundaries

National Park in the Central Blue Ridge, and the Cullowhee mine in the east flank of the Blue Ridge.

D. Organic fuels:

1. The rocks of the quadrangle contain no coal and probably lie outside the maximum range in thermal maturity permitting the survival of oil. The rocks in the Valley and Ridge and for a short distance eastward below the west flank of the Blue Ridge probably lie within a zone of thermal maturity permitting the survival of natural gas. Consequently the western part of the quadrangle is an area of high risk for hydrocarbon exploration. No exploration drilling has been done in this belt.

DESCRIPTION OF THE AREA

Geography

The Knoxville l°x2° quadrangle covers about 7,773 sq mi in western North and South Carolina and eastern Tennessee between 35° and 36° north latitude and 82° and 84° west longitude (fig. 1). Three-fourths of the quadrangle is in North Carolina; 18 percent is in Tennessee, and about percent is in South Carolina. The quadrangle includes all or parts of 17 counties in western North Carolina, 8 in eastern Tennessee, and 4 in northwestern South Carolina (fig. 1) and spans the widest and most rugged part of the Blue Ridge Mountains physiographic province in the Southern Appalachians (fig. 2). A small wedge of the Piedmont province of North and South Carolina is in the southeastern comer of the quadrangle, and a slightly larger wedge of the Valley and Ridge province in Tennessee is in the northwestern comer. The area is completely covered by good 7 1/2-min quadrangle topographic maps (fig. 3) and also by new 100,000 scale maps.

Most of the quadrangle is mountainous. Altitudes in the Blue Ridge range from lows of about 1,000 ft above sea level on the west side along the Pigeon River where it leaves the mountains in Tennessee and along the base of the Blue Ridge Front on the east side in North and South Carolina to a high of 6,684 ft above sea level on the top of Mount Mitchell, the highest point in eastern North America. Within the quadrangle the Blue Ridge contains several other peaks above 6,000 ft and numerous ridges ranging from

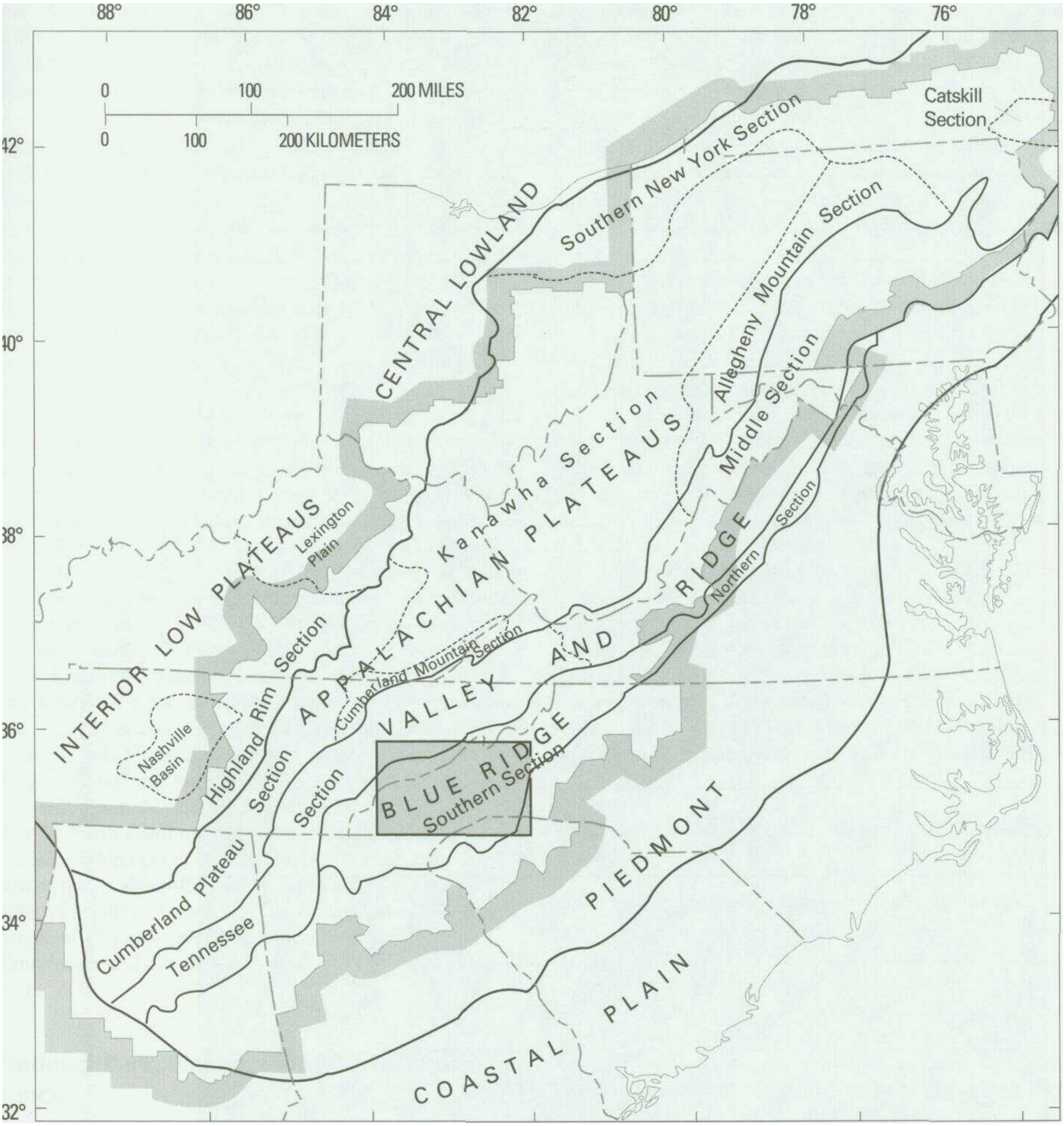

Figure 2. Physiographic provinces of the Appalachian region (modified after Davis, 1968, p. 38).

3,000 to more than 5,000 ft. Local relief ranges from 1,000 ft or less to more than 4,000 ft. Most of the mountain area has narrow valleys, steep hillsides, and narrow, rugged ridge crests. Much of the land is thickly wooded in second-growth pine, oak, and hemlock.

Altitudes in the Piedmont, which are much lower, range from 800 to 1,100 ft above sea level; local relief is generally less than 200 ft. In the Valley and Ridge the range in altitudes is from 800 to 1,500 ft, and local relief ranges from 100 to 500 ft. Both Piedmont and Valley and Ridge have more cleared farm land than the mountains but also contain considerable amounts of woodland.

The quadrangle is well drained by mostly dendritic-patterned streams and rivers. West of the Blue Ridge front the drainage is to the west and includes from north to south the Toe, French Broad, Pigeon, Little Tennessee, Cheoah,

Figure 3: Knoxville 1º x 2º quadrangle showing available 7 ½-min topographic maps.

and Hiawassee Rivers, all tributaries of the Tennessee River. The Piedmont and eastern slopes of the Blue Ridge are drained to the east by many tributaries of the Catawba, Broad, Saluda, Savannah, Chattooga, and Tallulah Rivers.

Some of the Tennessee Valley Authority (TVA) reservoirs are wholly or partly within the quadrangle. These include, from north to south, Douglas Lake on the French Broad River east of Knoxville; Fort Loudon Lake on the Tennessee River at Knoxville; Fontana Lake, Lake Cheoah, and Calderwood Lake on the Little Tennessee River south of Great Smoky Mountains National Park; Nantahala Lake and Santeetlah Lake on the Nantahala and Cheoah Rivers; and Chatuge Lake on the Hiwassee River. Near the center of the quadrangle along the eastern side of the Blue Ridge are Cedar Cliff, Bear Creek, Wolf Creek, and Thorpe reservoirs on the Tuckasegee River, a tributary of the Little Tennessee. East of the Blue Ridge front are Lake Toxaway and parts of Lake Jocassee along the North and South Carolina border on headwaters of the Keowee River. Other small reservoirs in North Carolina include Lake Lure on the Broad River, Lake Adger, and Lake Summit on the Green River. In South Carolina there are Poinsett Reservoir on the North Saluda, Table Rock Reservoir on the South Saluda, Lake Lanier on the North Pacolet, and Lake William C. Bowen on the South Pacolet Rivers.

Knoxville, Tenn., population more than 250,000, and Asheville, N.C., population more than 50,000, are the principal population centers in the quadrangle. Other larger towns include Maryville, Newport, Sevierville, and Gatlinburg in Tennessee; Hendersonville, Waynesville, Canton, Brevard, Black Mountain, Marion, Franklin, and Spruce Pine in North Carolina; and Inman and Landrum in South Carolina. Population of the North Carolina part of the quadrangle is about 451,000 or about 80 people per square mile. Population of the South Carolina part is about 46,800 people or 85 people per square mile, and population of the Tennessee part is about 420,000 or 300 people per square mile.

National Park, National Forest, and Indian Lands

Nearly half (49 percent, or 3,710 sq mi) of the Knoxville quadrangle is covered by lands belonging to the U.S. Forest Service (38 percent, or 2,985 sq mi), National Park Service (10 percent, or 813 sq mi), and Cherokee Indians (1 percent, or 88 sq mi) (fig. 4). The quadrangle includes at least 85 percent of the Nantahala National Forest and 65 percent of the Pisgah National Forest in North Carolina and about 15 percent of the Cherokee National Forest in Tennessee. It also contains about 3 percent (19 sq mi) of the Sumter National Forest in South Carolina. These forest lands are acquired forest, and the Forest Service does not own all the land within the outer boundaries of the forest. The distribution of Federal and other tracts creates a mosaic of private, Federal, State, county, and municipal ownership. In North Carolina the Federal Government owns an average of 46 percent of the land within the Pisgah National Forest and 42 percent of the land within the Nantahala National Forest. In Tennessee the Federal lands amount to 51 percent in the Cherokee National Forest, but in South Carolina only 25 percent of the land in that part of the Sumter National Forest within the Knoxville quadrangle is Federal land.

The Great Smoky Mountains National Park, spanning the Tennessee-North Carolina border, is wholly within the Knoxville quadrangle, and much of it has been mapped (Hadley and Goldsmith, 1963; King, 1964b; Neuman and Nelson, 1965). It consists of 520,269 acres, of which 467,000 acres have been recommended for designation as wilderness by a bill introduced in Congress. The Wilderness Act of 1964 requires the U.S. Geological Survey (USGS) and the U.S. Bureau of Mines to study the mineral resources of wilderness areas, but no funds are currently available for eastern wilderness studies.

Adjoining the national park on the east side are the Cherokee Indian lands. These consist of the Qualla tract (more than 50,000 acres) and a nearby 3,200-acre tract in Jackson and Swain Counties, and five smaller tracts in the southeast corner of the quadrangle in Cherokee County, N.C. Resources of these lands have been studied by USGS (Lesure and Dunn, 1975), but the report is available only through the Cherokee Tribe or the Bureau of Indian Affairs.

Wilderness, Wilderness Study, and Roadless Areas

The Knoxville quadrangle contains all of two and parts of three wildernesses, three wilderness study areas, and 11 roadless areas in the National Forests plus the large proposed wilderness in the Great Smoky Mountains National Park (fig. 4). Wilderness resource assessments have been completed on some of these areas. The Shining Rock Wilderness, an area of 13,400 acres in the Pisgah National Forest near the center of the quadrangle in Haywood County, N.C. (Lesure and Dunn, 1982) was established as a wilderness in 1964. In 1984 the Shining Rock Additions of 5,100 acres were added to the north and southwest of the original wilderness, and the Middle Prong Wilderness of 7,900 acres was established a few miles to the west. These additional areas have not been studied by USGS. About 4,000 acres of the Ellicott Rock Wilderness lie in the Nantahala and Sumter National Forests along the southern border of the quadrangle where Georgia, North Carolina, and South Carolina meet (Luce and others, 1983). The northern part of the Southern Nantahala Wilderness, consisting of about 10,000 acres in the Nantahala National Forest, lies along the southern border of the quadrangle in

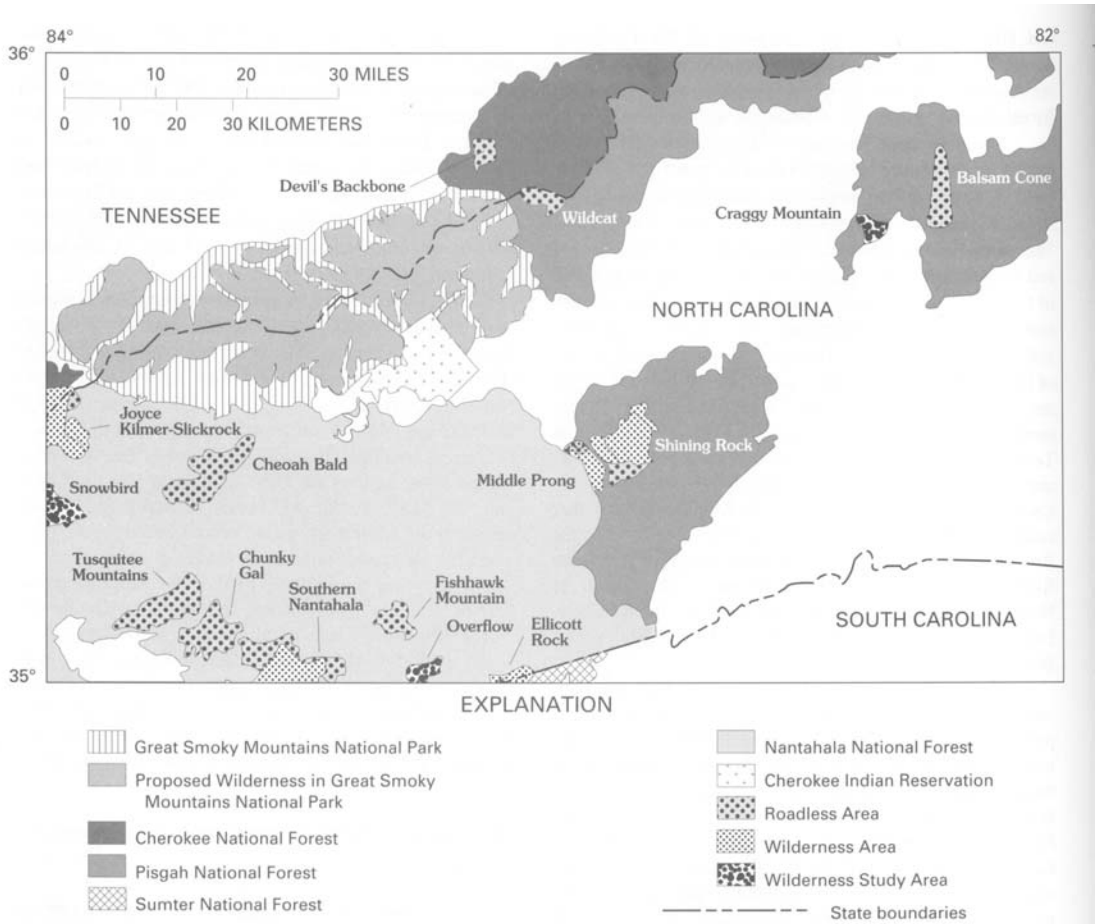

Figure 4. Areas of National Forest, National Park, and Indian lands in the Knoxville 1°x2° quadrangle, with wilderness, wilderness study, and roadless areas.

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Clay and Macon Counties, N.C., 20 mi west of Ellicott Rock (Peper and others, 1991). The eastern three-fourths of the Joyce Kilmer-Slickrock Wilderness in the Nantahala and Cherokee National Forests straddles the North Carolina-Tennessee border in the southwestern part of the quadrangle (Lesure and others, 1977).

The three wilderness study areas—Craggy Mountain, Overflow, and Snowbird—are in North Carolina and were so designated by the North Carolina Wilderness Act of 1984. These areas were recommended as further planning areas in 1979 by the Second Roadless Area Review and Evaluation (RARE II) and have been studied by USGS. The Craggy Mountain Wilderness Study Area of about 2,300 acres is 10 mi northeast of Asheville in the Pisgah National Forest (Lesure and others, 1982). The Snowbird Wilderness Study Area of 8,490 acres is in the Nantahala National Forest along the western edge of the quadrangle about 5 mi south of the Joyce Kilmer-Slickrock Wilderness (Lesure and Chatman, 1983), and the north half of the Overflow Wilderness Study Area of 3,200 acres is in the Nantahala National Forest 5 mi west of Ellicott Rock Wilderness (Koeppen and others, 1983).

The remaining roadless areas defined in RARE II were recommended for multiple use and have not been studied by USGS (fig. 4). These include the following in the Pisgah National Forest: Balsam Cone, 13,529 acres; Middle Prong, 2,265 acres; Wildcat, 7,120 acres; and Shining Rock Extension, 4,876 acres. In the Nantahala National Forest there are Fishhawk Mountain, 5,430 acres; Southern Nantahala, 11,412 acres; Chunky Gal, 12,445 acres; Tusquitee Mountains, 16,860 acres; Cheoah Bald, 21,434 acres; and Joyce Kilmer-Slickrock Addition, 1,179 acres. In the Cherokee National Forest there is Devil's Backbone, 4,100 acres.

Geology of the Knoxville Quadrangle

Introduction

The Knoxville quadrangle lies in the west-central part of the Appalachian orogen in the Southeastern United States, where Middle Proterozoic to late Paleozoic sedimentary, igneous, and metamorphic rocks compose the bedrock (pi. 1). The quadrangle covers parts of three major lithotectonic provinces, which correspond approximately with the Piedmont, Blue Ridge, and Valley and Ridge physiographic provinces shown in figure 2. Rocks in the Valley and Ridge consist of unmetamorphosed early to middle Paleozoic miogeoclinal sediments deposited on a continental shelf, and late Paleozoic shales deposited in a restricted marine basin. Because fossil control and distinctive stratigraphic units have greatly assisted mapping efforts, the geology of this province is generally well understood. In contrast, rocks in the Blue Ridge and Piedmont provinces are polydeformed and metamorphosed volcanic, plutonic, and sedimentary rocks. All are deeply weathered, saprolitized, and only poorly exposed locally. The metasedimentary rocks have yielded no unquestionable fossils. Age relationships have been determined largely from geochronologic studies on the variety of intrusive igneous rocks that occur in these areas (table 1); unfortunately some of the isotopic and geochronologic data on these intrusive rocks are ambiguous and contain large uncertainties. Many of the isotopic and geochronologic studies remain as unpublished data, except for abstracts and short notes. The geology of parts of the Blue Ridge and Piedmont has not been mapped in detail and is poorly understood because of the complexity of deformation and metamorphism and the general lack of reliable age relationships and distinctive marker units. The geology of some less deformed and metamorphosed pans of the Blue Ridge is better understood because workers have been more successful in working out relative ages and stratigraphic relationships.

Previous Work

A great many geologists have worked within the Knoxville quadrangle or in adjoining areas. A compilation of recent mapping (table 2) at a detailed scale (generally 1:24,000) is shown in figure 5 and areas of mapping at smaller scales are shown in figures 6 and 7. Only those contributions that are especially pertinent are mentioned here.

In the Blue Ridge, the earliest significant and comprehensive work was that of Keith (1895, 1904a, 1905, 1907a, b), who showed some major lithologic units with the same general outline as mapped by later workers, although different age and structural relationships are accepted now. Later work in the western part of the Blue Ridge by Hamilton (1961), Hadley and Goldsmith (1963), King (1951, 1964a and b), Neuman and Nelson (1965), Hadley and Nelson (1971), and, in the Grandfather Mountain window area, by Bryant and Reed (1970) has been the basis for many current concepts of stratigraphy and structure.

Significant geologic studies in the Piedmont have been mostly outside the quadrangle, such as the early work by Keith and Sterrett (1931). Recent work by Griffin (1969), Hatcher (1972), Nelson and others (1987), and Goldsmith and others (1988) forms the basis for the current concepts of structure and stratigraphy in the Inner Piedmont.

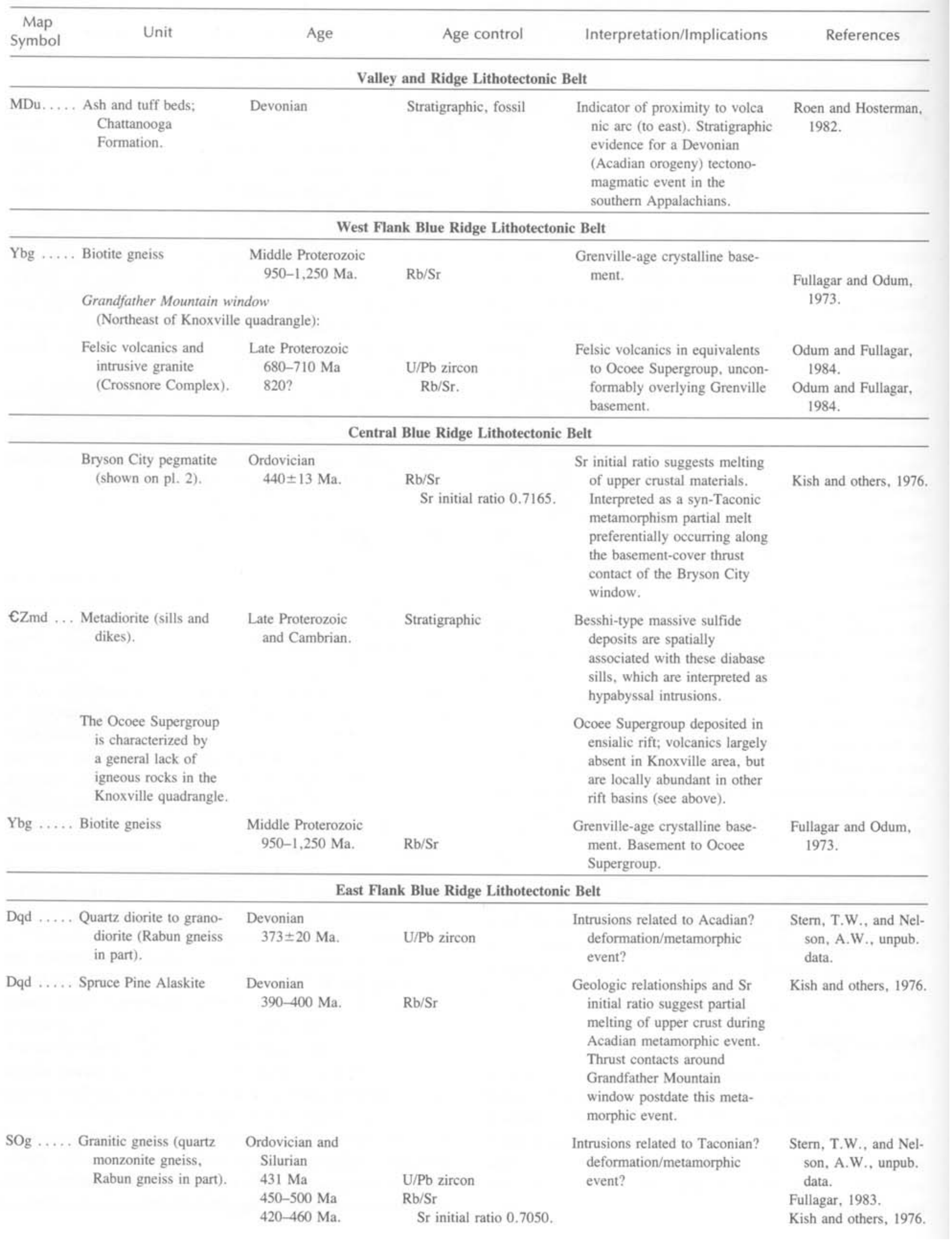
Work in the Valley and Ridge that is pertinent here includes early mapping by Keith (1895), the compilation by Rodgers (1953), and detailed mapping by Cattermole (1955, 1958, and 1962), Neuman (1960), Neuman and Wilson (1960), and Swingle and others (1967).

Geologic Overview

Thrust sheets transported toward the west have been known for many years to be the dominant structural feature in ihe Valley and Ridge province. Recent mapping has shown that the same structural style also dominates the crystalline terrane east of the Valley and Ridge (Nelson and others, 1987). Tectonic windows have been recognized in the crystalline rocks, such as the Hot Springs window in eastern Tennesee (Oriel, 1951) and the Grandfather Mountain window in northwestern North Carolina (Bryant and Reed, 1970). The tectonic windows and major faults in the Knoxville quadrangle are shown and identified in figure 8. The Grandfather Mountain window demonstrates that the crystalline rocks in the Blue Ridge of northwestern North Carolina are allochthonous and have been transported westward at least 43 mi. In addition, Bryant and Reed (1970) provide evidence that all rocks exposed in the Grandfather Mountain window are also allochthonous.

Recent seismic-reflection studies by the Consortium for Continental Reflection Profiling (COCORP) (Cook and others, 1979), and USGS (Harris and Bayer, 1979; Harris and others, 1981) provide a transect of the southern Appalachian orogen from the Appalachian Plateaus on the northwest to the Coastal Plain on the southeast. These seismic studies present southeast-trending profiles across many of the regional structural elements present in the Knoxville quadrangle. The interpretation, based on regional geologic mapping, that the belts of sedimentary, metamorphic, and igneous rocks in the Knoxville quadrangle are allochthonous is clearly supported by these seismic studies.

Table 1. Ages of igenous rocks in the Knoxville quadrangle and vicinity, by lithotechtonic belt

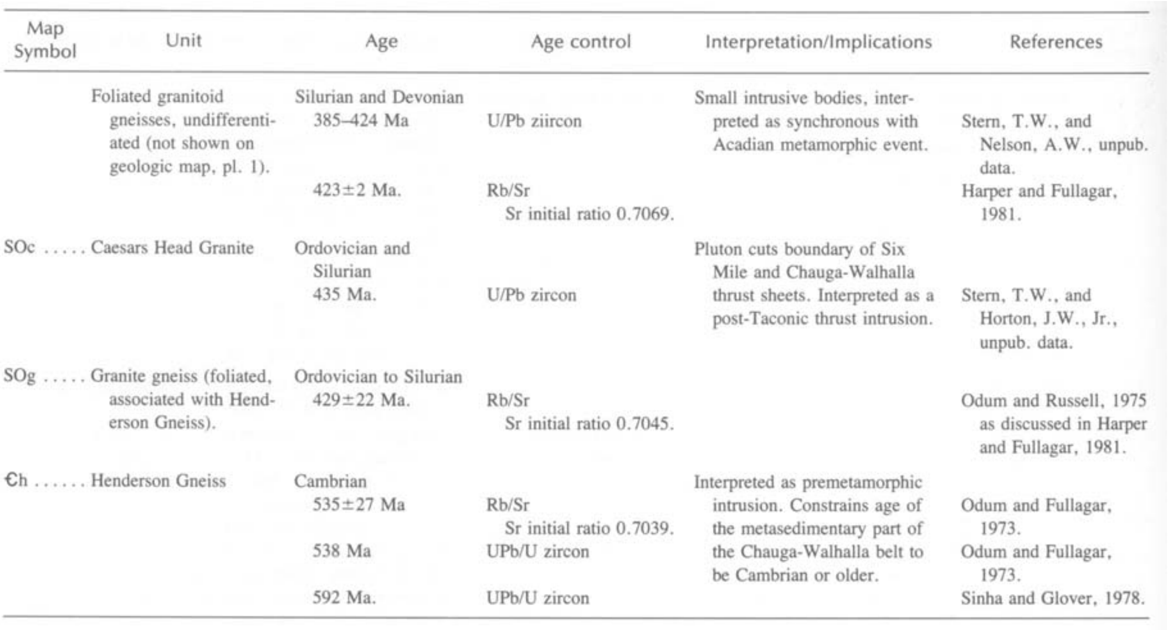


Map Symbol	Unit	Age	Age control	Interpretation/Implications	References
			Valley and Ridge Lithotectonic Belt		
MDu	Ash and tuff beds; Chattanooga Formation.	Devonian	Stratigraphic, fossil	Indicator of proximity to volcanic arc (to east). Stratigraphic evidence for a Devonian (Acadian orogeny) tectonomagmatic event in the southern Appalachians.	Roen and Hosterman, 1982.
			West Flank Blue Ridge Lithotectonic Belt		
Ybg	Biotite gneiss	Middle Proterozoic 950–1,250 Ma.	Rb/Sr	Grenville-age crystalline basement.	Fullagar and Odum, 1973.
	Grandfather Mountain window (Northeast of Knoxville quadrangle):				
	Felsic volcanics and intrusive granite (Crossnore Complex).	Late Proterozoic 680–710 Ma 820?	U/Pb zircon Rb/Sr.	Felsic volcanics in equivalents to Ocoee Supergroup, unconformably overlying Grenville basement.	Odum and Fullagar, 1984. Odum and Fullagar, 1984.
			Central Blue Ridge Lithotectonic Belt		
	Bryson City pegmatite (shown on pl. 2).	Ordovician 440±13 Ma.	Rb/Sr Sr initial ratio 0.7165.	Sr initial ratio suggests melting of upper crustal materials. Interpreted as a syn-Taconic metamorphism partial melt preferentially occurring along the basement-cover thrust contact of the Bryson City window.	Kish and others, 1976.
ꞒZmd	Metadiorite (sills and dikes).	Late Proterozoic and Cambrian.	Stratigraphic	Besshi-type massive sulfide deposits are spatially associated with these diabase sills, which are interpreted as hypabyssal intrusions.	
	The Ocoee Supergroup is characterized by a general lack of igneous rocks in the Knoxville quadrangle.			Ocoee Supergroup deposited in ensialic rift; volcanics largely absent in Knoxville area, but are locally abundant in other rift basins (see above).	
Ybg	Biotite gneiss	Middle Proterozoic 950–1,250 Ma.	Rb/Sr	Grenville-age crystalline basement. Basement to Ocoee Supergroup.	Fullagar and Odum, 1973.
			East Flank Blue Ridge Lithotectonic Belt		
Dqd	Quartz diorite to granodiorite (Rabun gneiss in part).	Devonian 373±20 Ma.	U/Pb zircon	Intrusions related to Acadian? deformation/metamorphic event?	Stern, T.W., and Nelson, A.W., unpub. data.
Dqd	Spruce Pine Alaskite	Devonian 390–400 Ma.	Rb/Sr	Geologic relationships and Sr initial ratio suggest partial melting of upper crust during Acadian metamorphic event. Thrust contacts around Grandfather Mountain window postdate this metamorphic event.	Kish and others, 1976.
SOg	Granitic gneiss (quartz monzonite gneiss, Rabun gneiss in part).	Ordovician and Silurian 431 Ma 450–500 Ma 420–460 Ma.	U/Pb zircon Rb/Sr Sr initial ratio 0.7050.	Intrusions related to Taconian? deformation/metamorphic event?	Stern, T.W., and Nelson, A.W., unpub. data. Fullagar, 1983. Kish and others, 1976.

Table 1. Ages of igenous rocks in the Knoxville quadrangle and vicinity, by lithotechtonic belt (cont.)

Map Symbol	Unit	Age	Age control	Interpretation/Implications	References
ud, up, us, ▲, ●, ■, ★	Dunite, peridotite, pyroxenite, and other ultramafic rocks.	Late Proterozoic and early Paleozoic.	Stratigraphic, structural	Generally interpreted as metamorphosed blocks in a melange (some demonstratively tectonic, some may be sedimentary), although some bodies (particularly pyroxenites) may be intrusive. Generally believed to be fragments of oceanic basement (possibly Iaptian, but this restricts age to latest Proterozic to early Paleozoic).	
H.......	Bakersville metadiorite dike swarm.	Late Proterozoic 734±26 Ma.	Rb/Sr Sr initial ratio 0.70444.	Dikes are restricted to Late Proterozoic paragneiss (Yg) and orthogneiss (Ybg) basements. Dikes unmetamorphosed in the west flank of the Blue Ridge, metamorphosed to garnet amphibolite in central Blue Ridge and east flank of the Blue Ridge. Dikes are interpreted as related to Late Proterozoic crustal extension; Low Sr initial ratio precludes significant crustal contamination and suggests a mantle to lower crust magma source.	Goldberg and others, 1986.
Yga	Hypersthene orthogneiss in biotite gneiss and amphibolite unit.	Middle Proterozoic 1,035 Ma 1,214 Ma.	U/Pb zircon Rb/Sr	Grenville-age orthogneiss and paragneiss contains relict granulite facies metamorphic assemblage that is partially retrograded to amphibolite facies [Grenville-age orthogneiss.]	Stern, T.W., and Nelson, A.W., unpub. data. Fullagar and others, 1979, and Fullagar and Odum, 1973.
PzYa.....	Layered amphibolites	Middle Proterozoic to early Paleozoic.	Stratigraphic	Interpreted as metamorphosed extrusive and intrusive mafic rock. In places, the amphibolites and associated ultramafic rocks are locally voluminous in a metasedimentary section that is otherwise lacking in metavolcanic rocks; these amphibolites may, in part, be pre- or syn-tectonic blocks in melange (either tectonic and (or) sedimentary).	
		Inner Piedmont Lithotectonic Belt			
bz	Blastomylonite and ultramylonite of Henderson Gneiss in Brevard fault zone.	Permian 273±30 Ma Devonian ? 356±8 Ma.	Rb/Sr Rb/Sr	Interpreted as age of late movement along Brevard zone. Age of 273 Ma interpreted as last age of blastomylonization and hydration. The age of 356 Ma may represent either a tectnothermal event at this age (Biotite prograde assemblage of Sinha and others, 1988) or a hybrid age resulting from isotopic mixing.	Sinha and others, 1988. Odum and Fullagar, 1973.

Table 1. Ages of igenous rocks in the Knoxville quadrangle and vicinity, by lithotechtonic belt (cont.)



Map Symbol	Unit	Age	Age control	Interpretation/Implications	References
	Foliated granitoid gneisses, undifferentiated (not shown on geologic map, pl. 1).	Silurian and Devonian 385–424 Ma	U/Pb ziircon	Small intrusive bodies, interpreted as synchronous with Acadian metamorphic event.	Stern, T.W., and Nelson, A.W., unpub. data.
		423±2 Ma.	Rb/Sr Sr initial ratio 0.7069.		Harper and Fullagar, 1981.
SOc	Caesars Head Granite	Ordovician and Silurian 435 Ma.	U/Pb zircon	Pluton cuts boundary of Six Mile and Chauga-Walhalla thrust sheets. Interpreted as a post-Taconic thrust intrusion.	Stern, T.W., and Horton, J.W., Jr., unpub. data.
SOg	Granite gneiss (foliated, associated with Henderson Gneiss).	Ordovician to Silurian 429±22 Ma.	Rb/Sr Sr initial ratio 0.7045.		Odum and Russell, 1975 as discussed in Harper and Fullagar, 1981.
Ꞓh	Henderson Gneiss	Cambrian 535±27 Ma	Rb/Sr Sr initial ratio 0.7039.	Interpreted as premetamorphic intrusion. Constrains age of the metasedimentary part of the Chauga-Walhalla belt to be Cambrian or older.	Odum and Fullagar, 1973.
		538 Ma	UPb/U zircon		Odum and Fullagar, 1973.
		592 Ma.	UPb/U zircon		Sinha and Glover, 1978.

The seismic studies also suggest that Paleozoic sedimentary rocks in several thrust sheets continue from the Valley and Ridge beneath the rocks of the Blue Ridge and Piedmont provinces.

Each of the regional provinces contains distinctive rock suites that can be further subdivided into at least five distinctive northeast trending lithotectonic belts (fig. 9). From east to west across the Knoxville quadrangle, the major lithotectonic belts are as follows:

a. Inner Piedmont, containing the Six Mile thrust sheet and the Chauga-Walhalla thrust complex, which are not shown separately.
b. East flank of the Blue Ridge thrust stack, containing the Helen, Tallulah Falls, and Richard Russell thrust sheets and the amphibolitic basement complex of Brewer and Woodward (1988).
c. Central Blue Ridge thrust stack, containing crystalline basement of Middle Proterozoic age (Grenville), Ocoee Supergroup rocks southeast of the Greenbrier fault, and rocks of the Murphy belt.
d. West flank of the Blue Ridge thrust stack, containing crystalline basement of Middle Proterozoic age (Grenville), Ocoee Supergroup rocks northwest of the Greenbrier fault, and rocks of the Chilhowee Group.
e. Valley and Ridge thrust complex, containing early to late Paleozoic sedimentary rocks in a stacked series of folded thrust slices.

The generalized geologic map (pi. 1) of the Knoxville quadrangle was compiled from the geologic map of North Carolina (North Carolina Geological Survey, 1985), from the geologic map of the Knoxville quadrangle (Hadley and Nelson, 1971), and geologic maps of the eastern part of Tennessee (Swingle and others, 1966), with some modifications to reflect other sources of more detailed mapping within the Knoxville quadrangle and extrapolation into the Knoxville quadrangle of geologic contacts from recent mapping in the Charlotte quadrangle (Goldsmith and others, 1988) to the east and the Greenville quadrangle (Nelson and others, 1987) to the south. Because the five lithotectonic belts in the Knoxville quadrangle differ in geologic character and mineral resource potential, the geology of each is described separately.

Inner Piedmont Lithotectonic Belt

The Inner Piedmont lithotectonic belt lies athwart the eastern border of the Knoxville quadrangle. It is separated from the east flank of the Blue Ridge by the Brevard fault zone (figs. 8 and 9) and from the Charlotte and Kings Mountain belts to the east of the Knoxville quadrangle by the Lowndesville shear zone and the Kings Mountain and Eufola fault zones (Goldsmith and others, 1988). Stratified rocks of the Inner Piedmont consist predominantly of metamorphosed, poly deformed, thinly layered mica schist and biotite gneiss, which are interlayered with lesser amounts of amphibolite, calcsilicate rock, hornblende gneiss, quartzite, and rare marble. Protoliths of these rocks were largely sedimentary and in part volcanic.

Table 2. References for geologic map coverage as shown in figures 5, 6, and 7
[Quadrangle names shown on fig. 3]

Figure 5. At a scale aif 1:24,000 or larger

Area No.		Area No.	
1.	Cattermole, 1958	28.	Espenshade, 1963
2.	Cattermole, 1955	29.	Mohr, 1975
3.	Gordon and others, 1924	30.	Cameron, 1951
4.	Swingle and others, 1967	31.	Edelman, unpub. data
5.	Keller, 1980	32.	Morrow, 1977
6.	Ferguson and Jewell, 1951	33.	Dabbagh, 1975
7.	Brobst, 1962	34.	McDaniel and Dabbagh, 1981
8.	Cattermole, 1962	35.	Lemmon and Dunn, 1973b
9.	Neuman, 1960	36.	Lemmon and Dunn, 1973a
10.	Hamilton, 1961	37.	Quinn, 1991
11.	Oriel, 1950	38.	Acker, 1976
12.	Merschat, 1977	39.	Lemmon, unpub. data
13.	Merschat, unpub. data	40.	Davis, unpub. data
14.	Howell, unpub. data	41.	Van Horn, 1948
15.	Lewis, unpub. data	42.	Ausbum, 1983
16.	Neuman and Wilson, 1960	43.	Hatcher and Ausbum, unpub. data
17.	Neuman and Nelson, 1965	44.	Eckert, 1984
18.	Merschat and Wiener, 1988	45.	Lesure, unpub. data
19.	Wiener, unpub. data	46.	Yurkovich, unpub. data
20.	Lesure and others, 1982	47.	Witherspoon, 1979, 1981
21.	Butler, unpub. data	48.	Wickstrom, 1979
22.	Conley and Drummond, 1981	49.	Marr, 1975
23.	Hadley and Goldsmith, 1963	50.	Horton, 1982
24.	Nelson, 1972	51.	Hartley, 1973
25.	Butler, 1972b	52.	Hatcher, 1980
26.	Hurly, 1974	53.	King, 1964b
27.	Whisnant, 1979	54.	Brewer, 1986

Figure 6. At a scale of 1:25,000 to 1:62,500

1.	Tennessee Division of Geology, 1973	8.	Lesure, 1986b
2.	Neuman and Nelson, 1965	9.	Eckel and others, 1938
3.	King, 1964b	10.	Lesure, 1981b
4.	Hadley and Goldsmith, 1963	11.	Loughlin and others, 1921
5.	Oriel, 1951	12.	Peper and others, in press
6.	Bryant and Reed, 1970	13.	Nelson and Koeppen, 1986
7.	Lesure and others, 1977	14.	Bell and Luce, 1983

Figure 7. At a scale of 1:63,360 or 1:125,000

1.	Harris and Laurence, 1974	6.	Keith, 1905
2.	Keith. 1895	7.	Keith, 1907a
3.	Keith, 1950b	8.	Keith, 1950s
4.	Dahners, 1949	9.	Keith, 1907b
5.	Keith, 1904a	10.	Bayley, 1923a
		11.	King and others, 1968

Much of the biotite gneiss was probably graywacke, but some may have been intermediate volcanic flows or tuffs. The age of the stratified rocks in the Inner Piedmont is unknown, but, because they are intruded by granite that is probably as old as Cambrian (table 1), they are probably of Proterozoic age, but no younger than Cambrian.

Rocks in the central core of the Inner Piedmont are in the sillimanite-muscovite zone of Barrovian metamorphism, while the western and eastern flanks are mostly in the staurolite-kyanite zone (pi. 2). Both zones contain areas of retrograde greenschist metamorphism and sericite alteration. Retrograde alteration is particularly prevalent along the Brevard fault zone (pi. 2).

The rocks of the Inner Piedmont are polydeformed, and an early-formed foliation parallel to layering has been isoclinally folded about gently plunging northeast-trending axes (Goldsmith, 1981). Small granite dikes have been emplaced along shears, and the positions of some larger granite masses appear to coincide with discordances in the foliation map pattern that are probably major shear zones (Goldsmith and others, 1988). Gently dipping anastomosing faults and sheared recumbent folds are seen in many

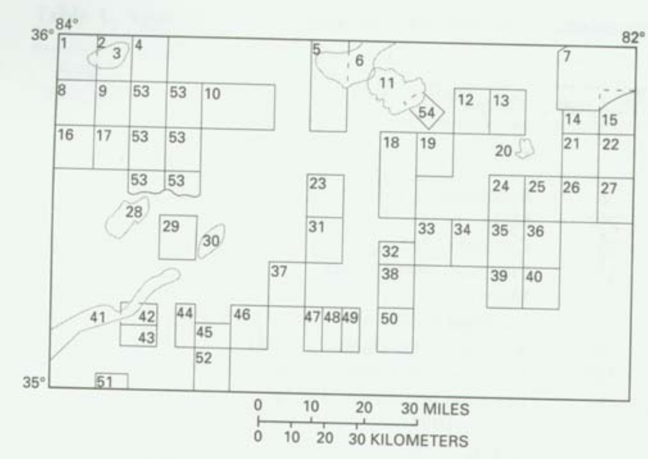


Figure 5: Areal coverage of geologic mapping at scale of 1:24,000 or larger in the Knoxville quadrangle.

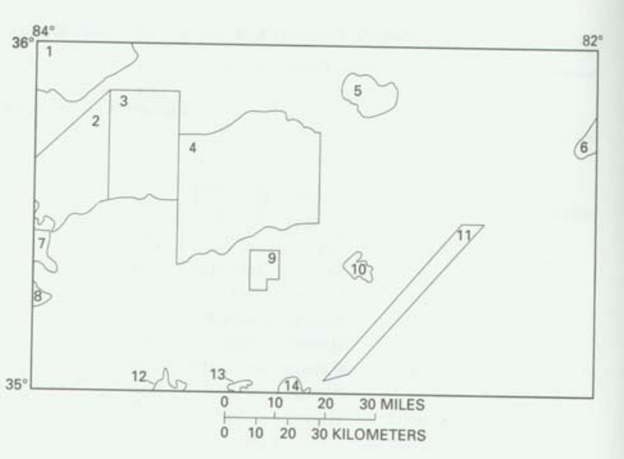


Figure 6: Areal coverage of geologic mapping at a scale of 1:25,000 to 1:62,500 in the Knoxville quadrangle.

outcrops. The overall structural pattern of the Inner Piedmont is an asymmetric northeast-trending synform. Foliations and axial surfaces of early folds dip moderately southeast near the Brevard fault zone, flatten toward the core of the Inner Piedmont, and predominately dip west along the eastern side of the Inner Piedmont bordering the Charlotte belt in the Charlotte quadrangle Goldsmith and others, 1988). The structural and metamorphic pattern of the Inner Piedmont suggests either a stacked metamorphic thrust package or the inverted limb of a fold nappe structure (Goldsmith, 1981).

A few diabase dikes of probable Jurassic age, which trend north-northwest across earlier structures, are present in the Inner Piedmont of the Knoxville quadrangle. In the Charlotte quadrangle, one of these dikes crosses the Brevard fault zone into the Blue Ridge (Bryant and Reed, 1970; Goldsmith and others, 1988). En echelon linear zones of silicified breccia trend north-northeast across the Inner Piedmont in the southeast comer of the Knoxville quadrangle and may belong to a fault system ofMesozoic or younger age (Snipes and others, 1979).

Based on recent mapping in the Inner Piedmont south of the Knoxville quadrangle, at least two major composite thrust sheets (the Chauga-Walhalla sheet and the Six Mile sheet) should be present in the Inner Piedmont of the Knoxville quadrangle. These thrust sheets are undefined at present in the Knoxville quadrangle and are not shown on the geologic map (pi. 1). Geologic relations south of the Knoxville quadrangle suggest that the thrust sheets within the Inner Piedmont in the quadrangle are separated by a poorly defined thrust fault or tectonic slide and may be delineated in part by differing lithic assemblages and metamorphic grade (Griffin, 1969; Hatcher, 1972; Nelson and others, 1987). The sheets are described in ascending stacking order.

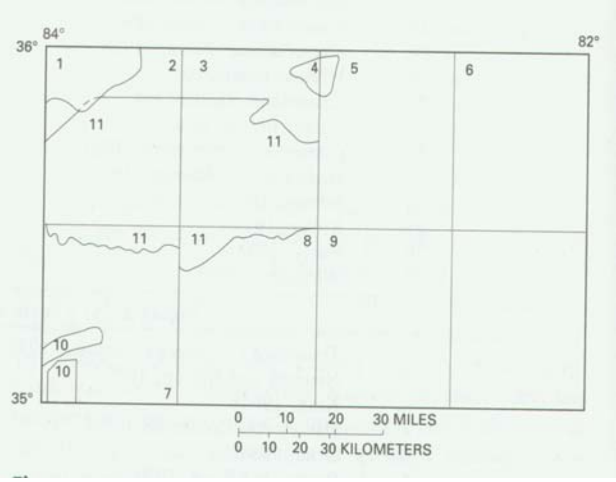


Figure 7: Areal coverage of geologic mapping at a scale of 1:63,360 to 1:125,000 in the Knoxville quadrangle.

Chauga-Walhalla thrust complex of Nelson and others (1987), which contains smaller thrust sheets separated by poorly defined thrust faults or tectonic slides, trends northeastward from the Greenville quadrangle into the Knoxville quadrangle but has not been defined in the Charlotte quadrangle (Goldsmith and others, 1988) to the east. This thrust complex, which includes rocks assigned by Hatcher (1972) to the Chauga belt and by Griffin (1969) to his Walhalla nappe, lies immediately southeast of the Brevard zone, along which it structurally overlies rocks of the Blue Ridge. Various feldspathic and biotite gneisses, schists, metasandstones, metasiltstones, carbonate rocks, quartzite, phyllonitic schist, pegmatites, and amphibolites are present in the complex. The Henderson Gneiss (Ch), granite gneiss (SOg), and amphibolite and biotite gneiss (CZab) shown on the geologic map (pi. 1) are probably part of the Chauga-Walhalla thrust complex.

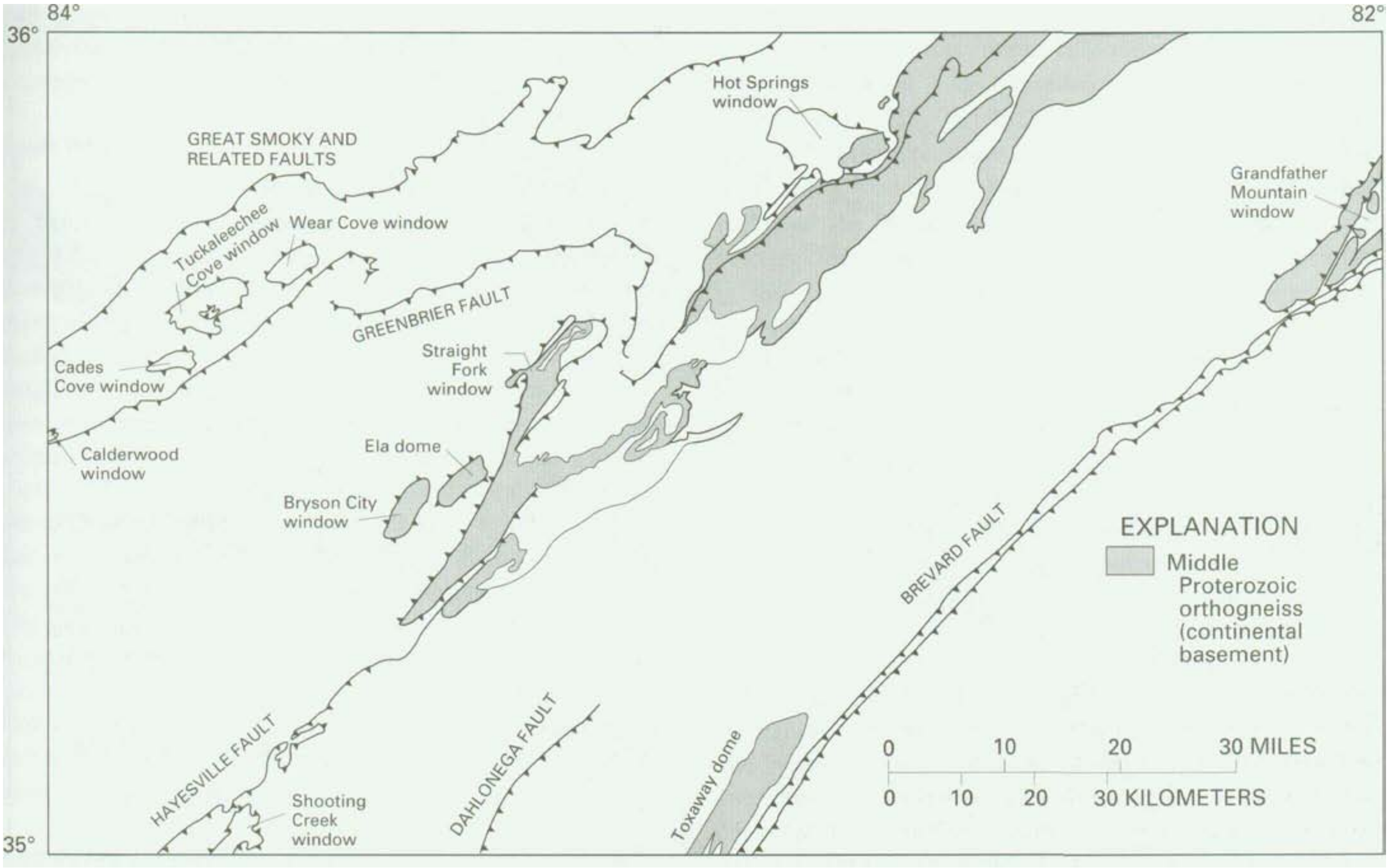


Figure 8. Named faults and windows of the Knoxville quadrangle.

The Six Mile thrust sheet of Griffin (1974) also enters the Knoxville quadrangle from the Greenville quadrangle to the south (Nelson and others, 1987). The contact between the Chauga-Walhalla and Six Mile thrust sheets cannot be defined in the Knoxville quadrangle from existing mapping, and this contact has not been defined in the Charlotte quadrangle to the east (Goldsmith and others, 1988). Rock units consisting of various combinations of mica schist, sillimanite schist, manganiferous schist, felsic gneiss, amphibolite, quartzofeldspathic gneiss, megacrystic biotite gneiss, metagraywacke, quartzite schist, and quartzite are widespread in the Six Mile thrust sheet. The layering varies from thin to massive. A distinctive lithology, gondite (quartz-gamet rock), and a variety of plutonic gneisses, pegmatites, and quartz veins also occur in this thrust sheet, which structurally overlies the Chauga-Walhalla thrust complex. The mica schist (-CZms) unit and adjacent units shown on plate 1 probably belong to the Six Mile sheet.

Griffin (1974) interpreted the lithologic, structural, and metamorphic discontinuities between the Chauga-Walhalla and Six Mile sheets to be formed by a tectonic slide, with the higher metamorphic grade Six Mile sheet structurally overlying the Chauga-Walhalla thrust complex along a low-angle thrust fault. A low-angle thrust fault separating these sheets has been observed by Nelson and others (1987) in the Greenville quadrangle, but they report that the contact is difficult to map. In addition, the Caesars Head pluton of apparent Ordovician and Silurian age appears to intrude along the contact between these sheets.

Blue Ridge

The Blue Ridge (following the usage of King, 1955) of western North Carolina is a northeast-trending anticlinorium that has a core of Middle Proterozoic granitic gneiss (about 1.1 billion years old) that is overlaid nonconformably on each flank by younger Proterozoic and early Paleozoic metasedimentary and volcanic rocks. In the east flank of the Blue Ridge, local areas of Middle Proterozoic granitic gneiss are exposed in structural (foliation) domes, and bodies of Middle Proterozoic orthogneiss with relict granulite facies metamorphic assemblages (Merschat and Wiener, 1988) have been recognized in a gneiss belt of probable Middle Proterozoic age (the amphibolitic basement complex of Brewer and Woodward, 1988). The anticlinorium is part of a chain of anticlinoria exposing older Proterozoic rocks located along the western margin of the crystalline portion of the Appalachian orogen from Georgia to Newfoundland. During Paleozoic time, these rocks in the Knoxville quadrangle were regionally metamorphosed from chlorite grade on the northwest to sillimanite grade of Barrovian metamorphism on the southeast limb

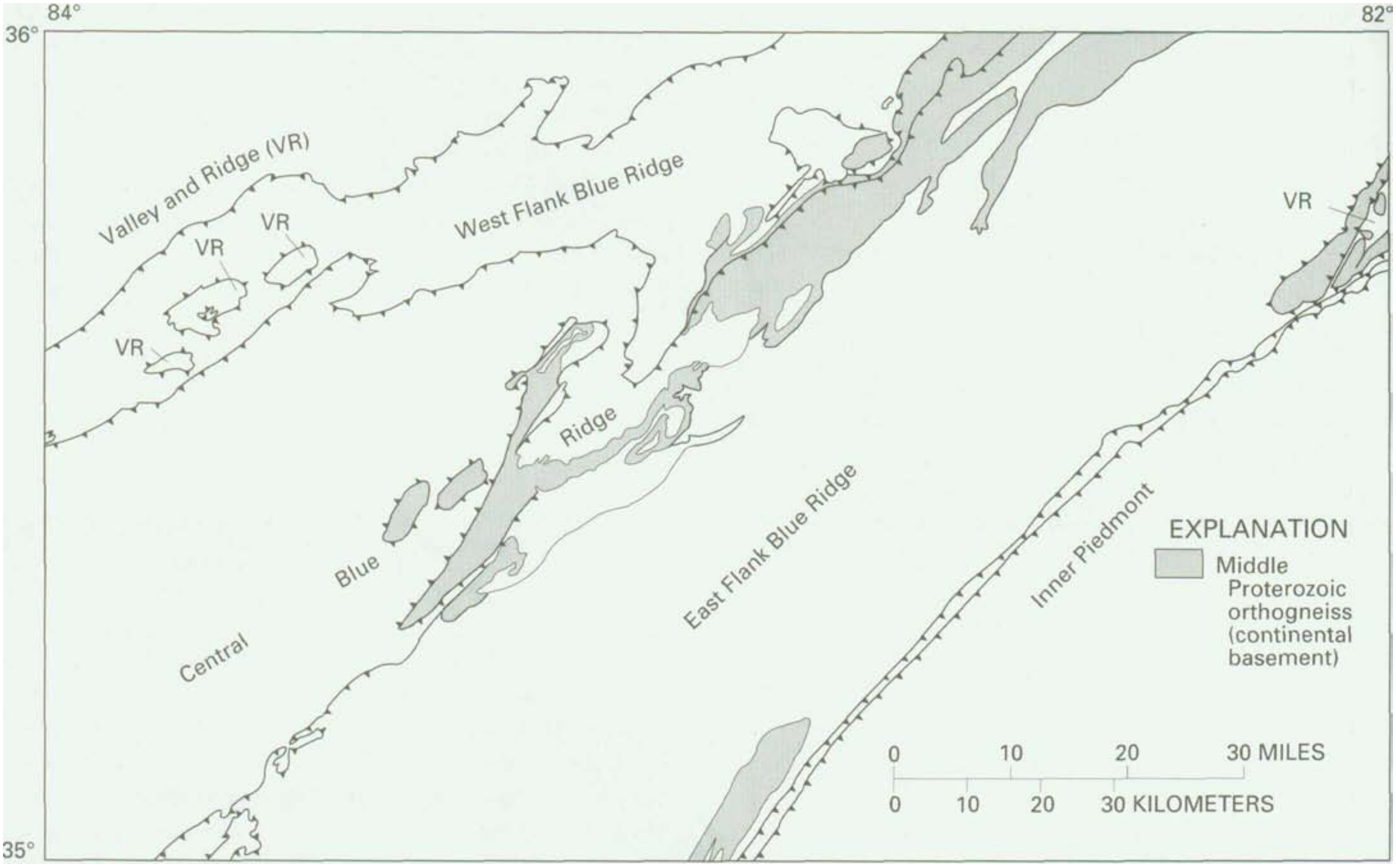


Figure 9. Generalized lithotectonic map of the Knoxville quadrangle.

of the anticlinorium (pi. 2). Imbricate thrust faulting both predated and postdated metamorphism; displacement on the order of tens to hundreds of kilometers has occurred along some of these thrust faults, which divide the Blue Ridge into discrete belts with differing stratigraphies and metamorphic characteristics. In these nonfossiliferous crystalline rocks, it is difficult to correlate units across thrust faults. The following sections describe the geology of three major lithotectonic belts that we have defined in the Blue Ridge of the Knoxville quadrangle.

East Flank Blue Ridge Lithotectonic Belt

The east flank of the Blue Ridge belt lies between the Inner Piedmont to the east and the central Blue Ridge to the west (fig. 9). It is separated from the Inner Piedmont by the Brevard fault zone and from the central Blue Ridge by the Hayesville fault (Hatcher, 1978a) in the southern part of the Knoxville quadrangle (fig. 8) and by a zone of Middle Proterozoic mylonitic gneisses separating the amphibolitic basement complex of Brewer and Woodward (1988) from Middle Proterozoic granitic orthogneisses (fig. 9) in the northern part of the quadrangle.

Rocks in the east flank of the Blue Ridge include metamorphosed layered rocks of various types, foliated granitoid rocks interpreted as crystalline basement of Grenvillian age, intrusive plutonic rocks of early to middle Paleozoic age, and bodies of amphibolite and ultramafic rocks. The common occurrence of small bodies of ultramafic rock in the east flank of the Blue Ridge and their general absence from the other lithotectonic belts in the Knoxville quadrangle identify the east flank of the Blue Ridge as a distinctive lithotectonic package. The oldest rocks in the east flank of the Blue Ridge are layered gneiss and migmatite in the western part (amphibolitic basement complex of Brewer and Woodward (1988) and rocks in the Richard Russell thrust sheet) and orthogneiss exposed in structural domes (the Toxaway and Tallulah Falls domes) along the eastern portion in the Knoxville and Greenville quadrangles. The Late Proterozoic Ashe Metamorphic Suite (Ashe Formation of Rankin and others, 1973) unconformably overlies Middle Proterozoic crystalline basement in its type area (Rankin and others, 1973) and overlies Middle Proterozoic biotite gneiss of unit Ybg (pi. 1) in what is interpreted as an unconformable contact around the Toxaway and Tallulah Falls domes; however, most of the contacts in the Knoxville quadrangle between Middle Proterozoic gneisses (units Ybg and Yga) and Ashe are thrust faults. The Ashe consists of metawacke, gneiss, pelitic schist, and amphibolite.

Four thrust sheets, in part composite sheets, have been defined in the east flank of the Blue Ridge by Nelson and others (1987). Three of these sheets occur in the Knoxville quadrangle (fig. 10) and are described in ascending stacking order.

Helen Thrust Sheet

A variety of metamorphosed sedimentary rocks, including siltstone, sandstone, shale, and a variety of unusual lithologies that may have formed from chemically precipitated sediments, such as magnetite quartzites and manganiferous quartzites, form the Helen thrust sheet. Also included are metamorphosed volcanic rocks such as amphibolites and intrusive rocks such as granitic pegmatites, which are rare in the Ocoee Supergroup rocks in the central Blue Ridge. Rocks of the Helen thrust sheet overlie rocks of the Ocoee Supergroup in the central Blue Ridge thrust sheet along an unnamed fault zone southwest of the Greenville quadrangle; however, rocks of the Helen sheet are missing from the area of the Shooting Creek window (fig. 8) and further west, where rocks of the Ocoee Supergroup are tectonically overlain by rocks of the Richard Russell sheet along the Hayesville fault (fig. 8). The Dahlonega fault (fig. 8) forms the boundary between the Helen thrust sheet and the Tallulah Falls thrust sheet to the southeast.

Amphibolitic Basement Complex and Richard Russell Thrust Sheet

The amphibolitic basement complex of Brewer and Woodward (1988) occurs along the northwest margin of the east flank of the Blue Ridge in the Knoxville quadrangle (fig. 10). The amphibolitic basement complex consists of highly deformed migmatitic gneisses of Middle Proterozoic age that have been overprinted by Paleozoic metamorphic events of variable intensity. The complex contains locally migmatitic, biotite-hornblende granitic gneisses intruded by and complexly intermixed with amphibolite and other mafic and ultramafic rocks. Other less abundant lithologies in the complex include foliated (locally mylonitic) granitic rock, garnet-chlorite schist, schistose augen gneiss, and calcsilicate rock. In the Mars Hill area of North Carolina, gneissic rocks in this complex contain hypersthene, reflecting a relict granulite-facies metamorphic assemblage. These hypersthene-bearing granitoid gneisses in the Mars Hill area have yielded a Middle Proterozoic Rb/Sr whole rock age of 1,270±44 Ma (unpublished data of Fullagar, 1983, in Merschat and Wiener, 1988, p. 12). Dikes of Late Proterozoic Bakersville Gabbro intrude both the amphibolitic basement complex and Middle Proterozoic orthogneisses in the central Blue Ridge thrust sheet, and a body of metamorphosed granite, texturally and petrographically similar to and tentatively correlated with the Crossnore Complex (table 1), intrudes across the contact between these basement units (Brewer and Woodward, 1988, p. 961). The contact between the amphibolitic basement complex of the east flank of the Blue Ridge and the Middle Proterozoic orthogneisses of the central Blue Ridge is marked by both the appearence and the truncation of amphibolites and ultramafic bodies; this contact is interpreted as a fault that is no younger than Late Proterozoic in age (Brewer and Woodward, 1988, p. 962), constrained by the age of intrusion of the Crossnore Complex and Bakersville Gabbro (table 1). Dikes of the Bakersville Gabbro do not intrude rocks of the Ashe Metamorphic Suite, and the contact between the Ashe and the amphibolitic basement complex in the east flank of the Blue Ridge is interpreted as a premetamorphic fault of Paleozoic age (Brewer and Woodward, 1988).

The Richard Russell thrust sheet structurally overlies rocks in the central Blue Ridge thrust sheet along the Hayesville fault and overlies rocks in the Helen sheet along a fault that is interpreted by Nelson (1988, p. 8) to be the northern extension of the Hayesville fault. The Richard Russell sheet appears to be a composite sheet composed of (1) gneiss and amphibolite of probable Middle Proterozoic age (rocks probably correlative with the amphibolitic basement complex of Brewer and Woodward, 1988, as suggested by Merschat and Wiener, 1988, p. 9); (2) Middle Proterozoic granitic gneiss; (3) bodies of ultramafic rock and layered amphibolites; and (4) layered gneiss of Middle Proterozoic to Paleozoic age (Merschat and Wiener, 1988). Many of these lithologic units may be separated by poorly defined tectonic contacts. The oldest dated rock in the Richard Russell sheet is a granitic gneiss in the Greenville quadrangle that has yielded a Middle Proterozoic zircon U/Pb age of 1,035 Ma (Stem and Nelson, unpub. data), and most of the rocks in the Richard Russell sheet may be Middle Proterozoic metamorphic rocks.

The major lithologies that make up the units of the Richard Russell thrust sheet are of metasandstone, quartzofeldspathic gneiss, metagraywacke, biotite gneiss, some schist, and lesser amounts of amphibolite, together with granitic gneiss, granodiorite gneiss, and pegmatite. Intrusive rocks include granitic and dioritic gneisses, pegmatites, and quartzofeldspathic segregations. Most of the sheet is at sillimanite or higher metamorphic grades (pi. 2), and the central part of the sheet is at granulite facies (Force, 1976; Absher and McSween, 1985). In general, compositional layering is discontinuous, and bedding is rarely preserved. This discontinuous layering is interpreted as metamorphic differentiation and transposition of bedding into the regional foliation (Nelson, 1983a,b). Lithologies in the western part of the sheet near the Hayesville fault are generally more heterogeneous and more variably layered than in the eastern part of the sheet. Rocks of the Coweeta Group of Hatcher (1979) in North Carolina appear to belong structurally with the Richard Russell sheet; however, they also appear to be less deformed than the Middle Proterozoic gneisses that make up the bulk of this thrust sheet (Peper and others, in press) and are possibly Late Proterozoic (North Carolina Geological Survey, 1985) and Paleozoic in age.

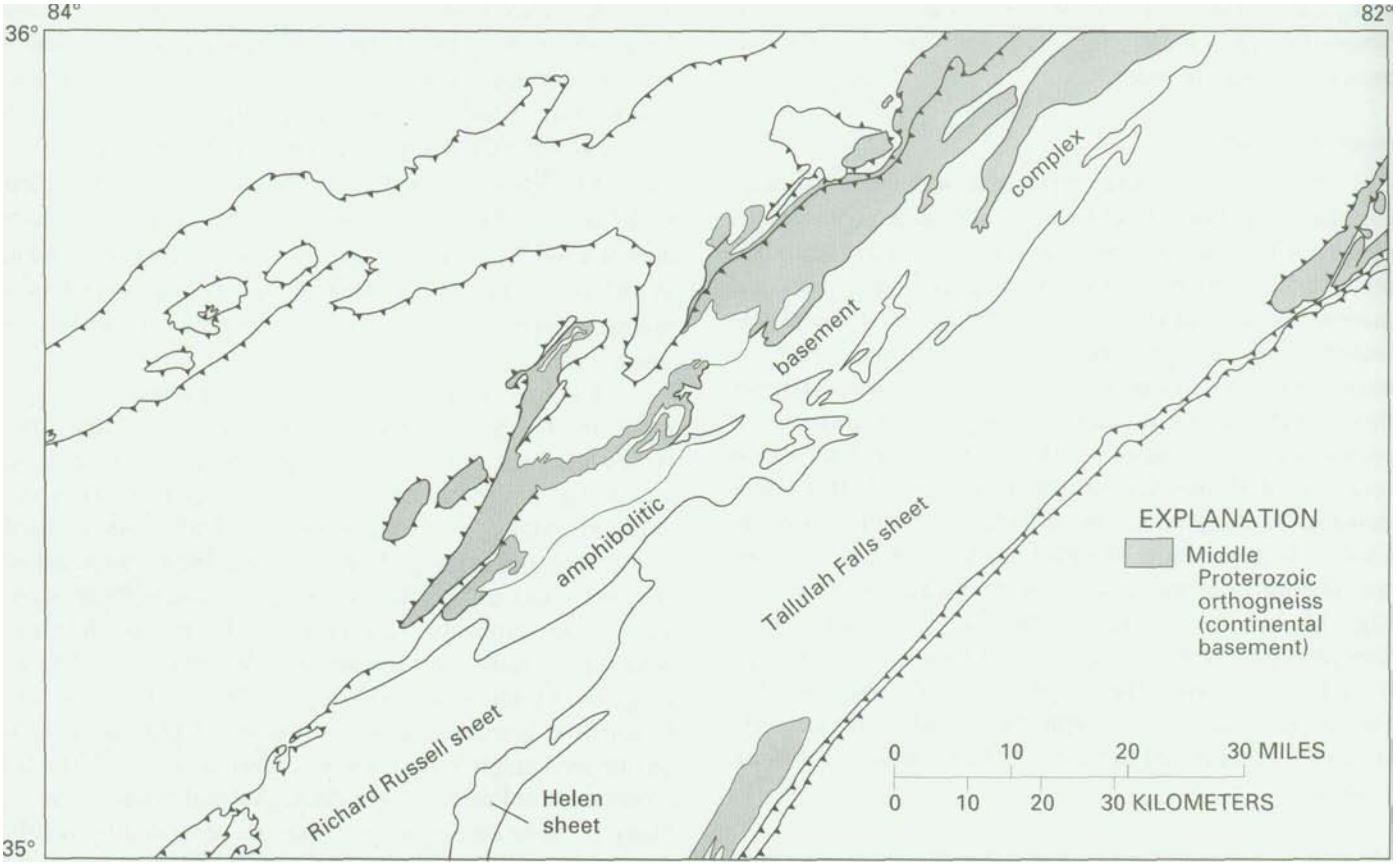


Figure 10. Subunits of the east flank of the Blue Ridge.

All thrust sheets above the central Blue Ridge thrust stack contain a variety of ultramafic and mafic rocks, usually as small discontinuous pods but locally as larger mappable units. The ultramafic and mafic bodies contain masses of gabbro, troctolite, dunite, pyroxenite, talc schist, wehrlite, and amphibolite and may, in part, represent tectonic melange. A discontinuous complex of mafic and ultramafic rocks (the Young Harris thrust sheet of Nelson and others, 1987) lies along the thrust contact between the central Blue Ridge and the Richard Russell thrust sheets and is exposed in narrow belts around the Brasstown Bald and Shooting Creek windows in the northwest part of the Greenville and southwest part of the Knoxville quadrangles. In addition, the Webster-Addie ultramafic body may also be in the structural position of a domed thin thrust sheet, as suggested by Rankin and others (1988).

Tallulah Falls Thrust Sheet

The Tallulah Falls thrust sheet comprises metamorphosed sedimentary rock assemblages, a variety of intrusive igneous rocks, layered amphibolites, pegmatites, and granitoid crystalline basement of Grenville age. The Tallulah Falls sheet overlies the Helen thrust sheet in the southern portion of the Knoxville quadrangle and the Richard Russell sheet and amphibolitic basement complex in the central and northern portion of the quadrangle along the Dahlonega fault (Crickmay, 1952). The Dahlonega fault juxtaposes migmatitic rocks of the Tallulah Falls sheet with rocks of the Helen thrust sheet, whose rocks are nonmigmatitic and at lower metamorphic grade (Nelson, 1988). Early ductile deformation along the Dahlonega fault formed mylonites and blastomylonites, but later brittle deformation formed button schists and intensely fractured the rocks (Bowen, 1961; McConnell and Costello, 1980; Gillon, 1982). Ductile deformation along the Dahlonega fault probably began near peak metamorphism. The Tallulah Falls thrust sheet is bounded to the southeast by the Brevard fault zone.

Bodies of Middle Proterozoic (1,203±54 Ma, Fullagar and others, 1979) orthogneiss intrepreted as crystalline Grenville basement rock are exposed in the Toxaway dome along the North Carolina-South Carolina border (fig. 8) and in the Tallulah Falls dome in the Greenville quadrangle in adjacent Georgia. These Middle Proterozoic basement rocks occur in structural domes defined by foliation in areas of complexly isoclinally folded rocks of probable Late Proterozoic and early Paleozoic age metamorphosed to kyanite and sillimanite-muscovite grade during the Paleozoic. The basement domes are interpreted to result from the refolding of crystalline nappe structures, although the basement-cover relations may be either a stratigraphic

Figure 11. Distribution of Middle Proterozoic crystalline rock and rocks of the Late Proterozoic Ocoee Supergroup in the Blue Ridge.

nonconformity or a tectonic (premetamorphic thrust) contact (Rankin and others, 1988).

The principal metasedimentary lithologies in the Tallulah Falls sheet include interlayered metagraywacke, mica schist, amphibolite, aluminous schist, quartzite schist, biotite gneiss, biotite schist, and quartzofeldspathic gneiss of the Ashe Metamorphic Suite. Gillon (1982) considered some of these metasedimentary rocks to represent sediments deposited in a fluvial-delta to distal-turbidite environment. Intrusive rocks include pegmatites and gneisses of granitic, granodioritic, quartz monzonitic, and tonalitic composition. Only the larger bodies of intrusive rocks, including pegmatite, granitic and granodioritic gneisses, and quartz diorite and granite, are shown on the geologic map of the Knoxville quadrangle (pi. 1).

Central Blue Ridge and Proterozoic Portion of the West Flank Blue Ridge

The central Blue Ridge lithotectonic belt and the Proterozoic portion of the west flank of the Blue Ridge thrust complex include Middle Proterozoic crystalline orthogneisses, rocks of the Late Proterozoic Ocoee Supergroup nonconformably deposited on Middle Proterozoic crystalline basement, and rocks in the Late Proterozoic to Early Cambrian Murphy belt (fig. 11).

Ocoee Supergroup

The Late Proterozoic Ocoee Supergroup is the predominant unit exposed in the central and west flank belts of the Blue Ridge. The Ocoee Supergroup is a metamorphosed, very thick sequence of mainly terrigenous clastic sediments that rests unconformably on Grenville basement (Hatcher and Butler, 1979). These Late Proterozoic clastic sedimentary rocks are thought to have been deposited in a belt of Late Proterozoic extensional basins (Hadley, 1970; Rast and Koles, 1986). The Ocoee Supergroup in the Knoxville quadrangle has been divided into three major groups—the Snowbird, Great Smoky, and Walden Creek Groups—that occur in thrust slices (King and others, 1958). Several formations have been mapped in these groups. However, because of the repetitive nature of sequences, structural complexity, lack of marker beds, and the local lack of lateral continuity of mapped units, stratigraphic subdivision is difficult, and correlation of map units from one area to another is not always possible (King and others, 1968; Wiener and Merschat, 1978; Slack and others, 1984). The earliest sediments of the Ocoee Supergroup (Snowbird Group) have been interpreted as having provenance to the southeast. Distinct differences in stratigraphy have been recognized on both sides of the Greenbrier fault, with the Walden Creek Group largely restricted to areas northwest of the fault and the Great Smoky Group to areas southeast of it.

The Snowbird Group contains gray sandy slate, pebbly to sandy feldspathic sandstone and graywacke, sericitic and chloritic phyllites interbedded with siltstone, and greenish quartzofeldspathic siltstone. Graded bedding is not common, but current bedded and crossbedded units are common in the lower formations in the group. In the area of thickest accumulation, the Snowbird Group is estimated to be on the order of 13,000-20,000 ft (4,000-6,000 m) thick (Hadley and Goldsmith, 1963).

The Great Smoky Group, which includes the host rocks of the massive sulfide deposits of the Ducktown district, is estimated to be on the order of 25,000 ft (7,600 m) thick (Wiener and Merschat, 1978). Most of the rocks are metagraywacke, slate, and mica schist. The sediments were commonly deposited under reducing conditions, and iron sulfides are a common constituent of the rocks. In particular, the predominantly pelitic rocks in the Anakeesta Formation, Wehutty Formation, and slate of the Copperhill Formation are locally graphitic and sulfidic. Graded bedding and other diagnostic primary features of cyclic sedimentation are commonly preserved in the rocks. The sequence probably originated as submarine fans and turbidites deposited in a deep, elongated marine rift basin (King and others, 1968; Lesure and others, 1977; Force and Gazdik, 1983; Rast and Kohles, 1986; Force, oral commun., 1988).

The Walden Creek Group consists of metaquartzite, dolomitic marble, metaconglomerate, and pelitic metasandstone. The sediments of the Walden Creek Group were shallow-water elastics and are lithologically the most heterogeneous of the three groups of the Ocoee Supergroup. Exposures of the Walden Creek Group occur in isolated thrust sheets of the western Blue Ridge of Tennessee (Kish and others, 1975), and rocks of the Walden Creek Group are found only northwest of the Greenbrier fault in the Knoxville quadrangle.

The Ocoee Supergroup is thought to have formed during the Late Proterozoic continental rifting event associated with the opening of lapetus to the east (Rankin, 1975). Based on analysis of sedimentology and structure in the Ocoee Supergroup, Rast and Kohles (1986) have suggested a model of deposition in which the Snowbird Group and the Great Smoky Group occupied two distinct basins, most likely grabens, separated by a ridge, probably a horst, with the apparent provenances of the two groups being away from the ridge (to the southeast and the northwest). They suggested that the strata of the Walden Creek Group had a more diverse source and overstepped these deposits. Present-day relationships are explained by later overthrusting.

The rocks of the Blue Ridge were deformed several times during the Paleozoic. Superposition of structures is the major aspect of the deformation in the central and eastern Blue Ridge (Hatcher, 1978a). Premetamorphic as well as Alleghanian thrusts have been recognized (Hadley and Goldsmith, 1963; Hatcher, 1978b). Several events are related to the Taconian orogeny, and Alleghanian thrusts are prominent along the western edge of the Blue Ridge (Hatcher and Butler, 1979). Passive-slip folds with axial-plane slaty cleavage and low-angle thrust faults are important structures in the western portion of the Blue Ridge (Hatcher, 1978b). Further east, major folds dominate the structural style. A major dislocation of Alleghanian age, the Great Smoky fault system, has brought the Proterozoic and Cambrian rocks into juxtaposition with younger Paleozoic strata at the western border of the Blue Ridge belt (Wiener and Merschat, 1978).

The Blue Ridge has also been affected by multiple periods of metamorphism ofBarrovian style (pi. 2). Middle Proterozoic paragneiss locally preserves relict granulite-facies assemblages that have been partially retrograded by Paleozoic metamorphism (Merschat, 1977), and Middle Proterozoic orthogneiss has been distinctively epidotized and altered by Paleozoic metamorphism to unakite in the Unaka Mountains of Tennessee. Paleozoic metamorphism generally increases from west to east across the Blue Ridge province, with kyanite-staurolite and sillimanite-muscovite facies present in the eastern part of the exposures of the Great Smoky Group in the Knoxville quadrangle (Wiener and Merschat, 1978) and granulite facies present in the central part of the Richard Russell sheet (Force, 1976; Absher and McSween, 1985). An exception to this pattern is the Murphy belt, where metamorphic assemblages are indicative of the greenschist facies (North Carolina Geological Survey, 1985) and may reflect postmetamorphic downfolding or retrograde reequilibration. The major metamorphic assemblages were formed in an event during the Taconian orogeny about 440-480 Ma (Butler, 1972a; Dallmeyer, 1975) and possibly during the Acadian orogeny about 370 to 420 Ma associated with granitoid intrusion. One or more retrograde events has affected rocks in some areas.

Murphy Belt

The Murphy belt, exposed in the southwestern part of the Knoxville quadrangle (North Carolina Geological Survey, 1985), is a sinuous, northeast-trending lithotectonic feature (fig. 11) that extends nearly 100 mi from Cartersville, Ga., to Bryson City, N.C. The rocks of the Murphy belt include metamophosed thin-bedded argillaceous siltstone, shale, and fine-grained sandstone (Hadley, 1970). A small body of metadiorite, interpreted as a metamorphosed intrusive diabase sill, occurs in the northeast part of the Murphy belt in the quadrangle. Lithologies in the Murphy belt differ from the surrounding rocks of the Great Smoky Group in that the Murphy belt rocks include clean metaquartzite and marble units. The formations in the Murphy belt were first named and described by Keith (1907a). Subsequent workers have included Van Horn (1948), Hurst (1955), Fairley (1965), and Power and Forrest (1971 and 1973).

The Murphy belt includes three distinct sedimentary sequences (Groszos and Tull, 1987). The lowest units are a fining and thinning upward clastic sequence that includes the graphitic and sulfidic Nantahala Formation. The middle unit, which includes the Murphy Marble, is dominated by carbonate units (a carbonate bank?). The upper sequence is a diverse package of clastic units under the name Mineral Bluff Formation of Hurst (1955).

The Murphy belt is generally considered to be a synclinal structure with at least one major fault near the center of the belt (Hatcher, 1978a). Ordovician(?) fossils have been found in the Murphy Marble (Mclaughlin and Hathaway, 1973), raising questions about the range of ages included in the belt and correlation. However, this fossil assignment has been discredited by Chapman and Klatt (1983), and other recent reinvestigations of the Murphy belt have failed to identify further evidence of Ordovician fossils (Anita Harris, oral commun., 1989). Recent field work suggests that the Murphy belt in Georgia contains a series of faults and that the area has a complex history (Higgins and others, 1988).

Valley and Ridge and Paleozoic Portion of the West Flank Blue Ridge

The west flank of the Blue Ridge and the Valley and Ridge provinces contain sediments deposited in the Appalachian basin that are at present exposed in thrust sheets. The Appalachian basin was an elongate geoclinal depositional trough along the eastern margin of the North American continent beginning after Late Proterozoic rifting and formation of the lapetus Ocean and continuing until the beginning of the Late Pennsylvanian and Early Permian Alleghanian orogeny. In a generalized restored basin model, constructed by Harris and Milici (1977), Paleozoic rocks ranging in age from Cambrian to Pennsylvanian form a wedge-shaped sequence that thins markedly from east to west. The sequence records three major depositional episodes separated by regional unconformities.

Late Proterozoic to Early Ordovician

The Late Proterozoic to Early Ordovician Appalachian basin sequence is exposed primarily in the Valley and Ridge physiographic province. The lower part of the sequence and the underlying Late Proterozic Sandsuck Formation (Walden Creek Group) make up the western portion of the Blue Ridge province in the Knoxville quadrangle.

The Late Proterozoic to Early Ordovician sediments that were deposited in the miogeoclinal Appalachian basin during the first depositional episode are a westward-transgressive sequence that gradually changes upward from dominantly clastic to dominantly carbonate (Harris and Milici, 1977). The basal Late Proterozoic and Cambrian clastic rocks of the Chilhowee Group and the overlying carbonate-shale sequence of the Lower and Middle Cambrian Shady Dolomite and Rome Formation and Middle and Upper Cambrian Conasauga Group are exposed near the western border of the Blue Ridge belt and in the Valley and Ridge Province (Miller and others, 1968; Swingle and others, 1966). The Chilhowee Group consists of sandstones that were deposited in nearshore shallow water marine environments and shales and siltstones deposited offshore in deeper water (Whisonant, 1974). The lowermost units may be alluvial in nature. Most of the sediment came from cratonic sources to the west (Colton, 1970). The Sandsuck Formation, included here as the upper part of the Walden Creek Group, is overlaid disconformably by the Chilhowee elastics and is generally considered to be latest Proterozoic in age, while the Chilhowee in this area is considered to be entirely Cambrian. It has been suggested that the Sandsuck Formation had a similar history to that of the Chilhowee Group, but in a less stable depositional environment, as suggested by poorer sorting, a greater range in size of detritus, and more discontinuous sandstone units (Wiener and Merschat, 1978).

The Shady Dolomite is a carbonate shelf-rim sequence and is the first indication of the formation of a carbonate bank following the earlier clastic sedimentation. The Shady Dolomite thins northwestward in Tennessee and interfingers with the Rome Formation. The Rome Formation consists of terrigenous clastic rocks that were deposited in intertidal and shallow subtidal environments west of the carbonate bank (Hatcher and Butler, 1979).

After the deposition of the Lower and Middle Cambrian Rome Formation, the Appalachian basin gradually subsided, so that offshore marine environments prevailed throughout the area (Hatcher and Butler, 1979). The Conasauga Group consists of shallow-water marine carbonate shelf units that interfmgered with fine-grained clastic rocks to the west (Hatcher and Butler, 1979; Hasson and Hasse, 1988). In the western part of the Valley and Ridge and the adjacent Cumberland Plateau physiographic province, the Conasauga Group consists of a relatively deep-water lagoonal sequence of shale, siltstone, and thin-bedded limestone that interfingers with the shallow marine carbonate sequences to the east (Milici and others, 1973). The Consauaga sequence was deposited in a regional intrashelf basin and includes the following depositional environments: (1) shallow-water shale-dominated peritidal settings to the northwest, (2) mixed carbonate-shale intrashelf basin, and (3) shelf-margin carbonate-dominated shoal and peritidal complex (Hasson and Hasse, 1988).

During the Late Cambrian, shallow-water carbonate shelf deposits that form the lower Knox Group transgressed westward and eventually covered the entire Appalachian Basin (Harris and Milici, 1977). The Knox Group is mainly dolomite in the central and western parts of the Valley and Ridge Province and mainly limestone in the eastern part. The regional distribution of limestone and dolomite was related to the development of a subtidal salinity system over much of the southern and eastern United States during Late Cambrian and Early Ordovician time (Harris, 1973).

Middle Ordovician to Devonian

A regional unconformity truncates the top of the Knox Group (Colton, 1970; Thomas and Neathery, 1980) and records a major regression that marked the beginning in the Early and Middle Ordovician of instability of the shelf as a response to the Taconian orogeny. The paleokarst in the upper Knox Group, which occurs below the regional Taconian unconformity, has been important in localizing the zinc and barite deposits in the Valley and Ridge Province of eastern Tennessee (Harris, 1969). From Middle Ordovician to Early Devonian time, the shelf was unstable and alternated between receiving clastic sediment from the southeast and being eroded.

Middle Ordovician deep-water limestones and shales of the Chickamauga Group were deposited above the erosion surface as carbonate shelf deposits on the west border of a deep basin. The Holston Formation, which occurs in the lower part of the Chickamauga Group, is a coarsely crystalline limestone and has been quarried as dimension stone (the "Holston Marble" or "Tennessee Marble") (Gordon, 1924; Maher and Walters, 1960; Hershey and Maher, 1963 and 1985). In many areas the upper part of the Holston Formation is a sandy ferruginous limestone and calcareous shale (called the "Tellico Sandstone"). The major clastic source for these rocks was from the east or southeast of the Appalachian basin beginning in Middle Ordovician time (Hatcher and Butler, 1979), and they represent part of the clastic wedge developed in the foreland-style Appalachian basin as a response to Taconian deformation in the Appalachian orogen.

Late Devonian and Mississippian

Uplift and erosion prior to the deposition of the Upper Devonian and Lower Mississippian Chattanooga Shale removed all rock above the Middle Ordovician sequence in the easternmost part of the Valley and Ridge province and above the Silurian in the central and western parts of the province (Hatcher and Butler, 1979). The Late Devonian sedimentation began with the widespread deposition of the Chattanooga Shale, which is thickest in the central part of the Valley and Ridge and thins to both the east and the west (Harris and Milici, 1977). The Chattanooga Shale is typically a dark-gray to black, carbonaceous, finely laminated shale with pyrite lamellae and nodules (Rheams and Neatherly, 1988). The formation locally contains small lenses and interbeds of sandstone, siltstone, and carbonate. Calcite streaks, phosphate nodules, and cherty layers also occur locally. The Chattanooga Shale is part of a very extensive black shale unit of Late Devonian and Early Mississippian age that extends over large areas of the eastern and central parts of the United States. The Chattanooga Shale probably accumulated in a quiet sea with anaerobic water and at depths between a few tens of feet to 100 ft (Rheams and Neatherly, 1988).

The Chattanooga Shale in the Knoxville Quadrangle is overlaid by Lower Mississippian elastics of the Grainger Formation followed by carbonate shelf sequences of the Upper Mississippian Greasy Cove Formation. These units thin westward (Harris and Milici, 1977).

Structure

The Valley and Ridge of Tenneessee is in a westward salient of the Appalachian orogen. The structure is dominated by gently to steeply dipping thrust faults alternating with rootless synclines (Harris and Milici, 1977). Thrust faults generally appear parallel to bedding in incompetent units and refract steeply across competent units. The faults join a master decollement, which is a low-angle thrust near the sedimentary rock-basement contact. The decollement extends from beneath the Blue Ridge westward as a major detachment zone under the Valley and Ridge and dies out in the Cumberland Plateau to the west (Harris and Milici, 1977). The structural style of the eastern portion of the Valley and Ridge in the Knoxville quadrangle is dominated by thrusts and folds (Rodgers, 1953), and the dominant fold style is flexural slip (Hatcher, 1978b). The major event of deformation in the Valley and Ridge is Alleghanian (Hatcher, 1978b).

Metamorphism

Metamorphic facies in the Knoxville quadrangle range from unmetamorphosed rocks in the Valley and Ridge belt in the northwest to high-grade Barrovian-style metamorphic facies to the southeast (pi. 2). Metamorphic grade generally increases from northwest to southeast across the Blue Ridge province, with chlorite and biotite facies present in the rocks of the west flank, increasing to kyanite-staurolite and sillimanite-muscovite facies in the eastern part of the Great Smoky Group in the central Blue Ridge (Wiener and Merschat, 1978) and granulite facies in the central part of the Richard Russell sheet (Force, 1976; Absher and McSween, 1985) in the east flank. Exceptions to this pattern of progressive increase in metamorphic grade across the Blue Ridge include the kyanite facies rocks of the Helen Group surrounded by sillimanite facies rocks in the Richard Russell and Tallulah Falls sheets (Nelson, 1988) and the greenschist facies rocks in the Murphy belt (North Carolina Geological Survey, 1985). Relict domains of granulite-facies assemblages occur in amphibolite-facies rocks in the east flank of the Blue Ridge north of Asheville, indicating multiple metamorphic events. Retrogression to greenschist-facies metamorphic grade occurs along the Brevard zone.

The ages of deformation and metamorphism in the Blue Ridge and Inner Piedmont are poorly constrained by the lack of precise geochronology. However, the geochronologic, structural, and petrologic information that is available suggests a complex history of repeated deformation, metamorphism, and thrusting. Geochronologic constraints on the ages of metamorphism and deformation are summarized below.

Domains of relict granulite-facies metamorphic assemblages that have been partially retrograded to amphibolite facies are present in some areas of the amphibolitic basement complex (unit Yga, pi. 1) in the east flank of the Blue Ridge (Merschat, 1977; Kuchenback, 1979). Middle Proterozoic Rb/Sr whole rock ages of 1.2 to 1.3 billion years are reported for some migmatitic and granitoid gneisses from this area (Fullagar and others, 1979; unpub. data of Fullagar reported by Merschat and Wiener, 1988, p. 46). The field relations and petrologic information reported by Merschat (1977) and Kuchenback (1979) imply that these Middle Proterozoic Rb/Sr dates are the probable age of this granulite facies metamorphism. A minimum age for the granulite-facies metamorphism is constrained by the age of the Bakersville Gabbro of 734±24 Ma (Goldberg and others, 1986). The Bakersville intrudes rocks containing the granulite-facies assemblages but is itself metamorphosed under amphibolite facies conditions. The mylonitic contact separating the amphibolitic basement complex (unit Yga, pi. 1) from Middle Proterozoic gneiss in unit Yga (pi. 1) postdates the granulite-facies metamorphism (Merschat and Wiener, 1988, p. 36) but predates the Bakersville Gabbro (Brewer and Woodward, 1988), implying a Middle and Late Proterozoic age of faulting.

Rb/Sr isotopic studies of the massive sulfide deposits and metasedimentary host rocks at Ducktown, Tenn., indicate that the regional metamorphism of the Ocoee Supergroup in this part of the central Blue Ridge occurred prior to 475 Ma (Fullagar and Bottino, 1970). Using Ar/Ar isotopic data for hornblendes from the central Blue Ridge and other geologic arguments, Dallmeyer (1975) concluded that the prograde regional metamorphism in this area occurred around 480±30 Ma. Syntectonic pegmatites preferentially occurring along the basement-cover thrust contact of the Bryson City window (pi. 2) have a Rb/Sr whole rock age of 440±13 Ma (Kish and others, 1976). Evaluation of the available geochronologic data and consideration of a variety of geologic arguments led Butler (1972a) to the conclusion that a period of Barrovian-type prograde regional metamorphism affected the Blue Ridge between 470 Ma and 430 Ma, probably during the Taconic orogeny. It is this metamorphic event that probably caused the amphibolite-facies retrogression of the granulite-facies assemblages in the amphibolitic basement complex reported above and the retrograde alteration of Proterozoic orthogneisses to unakite in the Unaka Mountains of Tennessee. The Greenbrier thrust fault and the Hayesville thrust fault both predate this metamorphic event (Hadley and Goldsmith, 1963; Hatcher, 1978b).

Widespread homogenization of Sr isotopes at 370±10 Ma in metasedimentary and metaigneous rocks from Alabama and Georgia that correspond to the Tallulah Falls thrust sheet are interpreted by Odum and others (1976) to indicate a period of regional metamorphism at that time. U/Pb zircon ages from foliated quartz diorite of 373±20 Ma (Stem and Nelson, unpub. data; see table 1) and Rb/Sr whole rock ages of 390-400 Ma from alaskite and pegmatite in the Spruce Pine district (Kish and others, 1976) are consistent with this age of metamorphism for the Tallulah Falls sheet (table 1). The rocks in the Tallulah Falls sheet are polydeformed, and it is unclear whether an early Paleozoic (Taconian) deformation and metamorphic event is present in this area. Structural relations imply that multiple periods of deformation and thrusting predated the emplacement of the middle Paleozoic pegmatites and alaskites in the Tallulah Falls sheet (Merschat and Wiener, 1988).

In the Greenville quadrangle, the Dahlonega fault separates metamorphic rocks at gamet-staurolite grade in the Helen belt from metamorphic rocks at sillimanite and kyanite grades in the Tallulah Falls sheet (Nelson, 1988). This metamorphic discontinuity suggests to Nelson (1988) that the juxtaposition of these sheets postdated the 370^-00 Ma period of regional metamorphism that affected the Tallulah Falls sheet. A metamorphic discontinuity is not evident between the Tallulah Falls sheet and the underlying Middle Proterozic gneisses of unit Yga (pi. 1) to the northeast (Merschat and Wiener, 1988, p. 49); however, a metamorphic discontinuity is possible, because the Middle Proterozoic gneisses do not have a bulk composition that allows the kyanite-sillimanite isograd to be determined in this area (Merschat and Wiener, 1988, p. 46). A metamorphic discontinuity also appears to exist between the Helen belt and the Richard Russell sheet across the bounding fault that Nelson interprets as an extension of the premetamorphic Hayesville fault (Nelson, 1988, p. 8), implying a period of postmetamorphic displacement along this fault in this area.

Structural relations in the Inner Piedmont suggest that a major period of deformation, thrust emplacement, and metamorphism postdated intrusion of the Henderson Gneiss (unit Ch, pi. 1) and predated intrusion of the Caesars Head

Granite (unit SOc, pi. 1) that locally cuts the boundary between the Six Mile and Walhalla thrust sheets in the Greenville quadrangle (Nelson and others, 1987). Both 207Pb/206Pb zircon ages (Odum and Fullagar, 1973; Sinha and Glover, 1978) and Rb/Sr whole rock isotopic ages (Odum and Fullagar, 1973) for the Henderson Gneiss fall between 535 and 592 Ma (table 1). A preliminary discordant 207Pb/206Pb zircon age of 435 Ma has been determined for the Caesars Head Granite (Stem and Horton, 1989, unpub. data). These age constraints suggest that this period of deformation and metamorphism was probably Taconian. However, a Middle Paleozoic metamorphic overprint appears to be present in the Inner Piedmont as well. Two preliminary concordant 207Pb/206Pb zircon ages of 419 and 385 Ma (T.W. Stem and A.E. Nelson, 1989, unpub. data) have been determined for small bodies of foliated granitic gneiss that locally cross the boundary between the Six Mile and Chauga-Walhalla thrust sheets in the Greenville quadrangle. Homogenization of Sr isotopes at 365 ± 10 Ma for metasedimentary and metaigneous rocks in the Inner Piedmont of Georgia (Dallmeyer, 1978) imply that a Middle Paleozoic (Acadian?) metamorphism affected this area of the Inner Piedmont as well.

The Alleghanian thrust sheets are believed to have developed as cold gravity slides moving westward along decollements (Milici, 1975). Uplift and unroofing of the overlying rock column in response to Alleghanian deformation may be responsible for the regional distribution of ^Ar/^Ar and K/Ar ages of 320 to 250 Ma for micas from both metamorphic and igneous rocks in the Inner Piedmont and the central and east flanks of the Blue Ridge (Lesure, 1968, table 1; Dallmeyer, 1975, 1978). Hurst (1970, p. 394, fig. 5; 1973, p. 664) recognized that the K/Ar dates ofbiotite and muscovite are, in general, older to the northwest along the west flank and central Blue Ridge and progressively through erratically younger to the southeast across the Blue Ridge. The K/Ar and ^Ar/^Ar mica dates are interpreted as gas-retention ages, indicating when their host rocks cooled below approximately 300 °C (Dallmeyer, 1978). During Alleghanian thrusting, the collection of previously assembled thrust sheets that make up the Blue Ridge, and possibly the Inner Piedmont thrust sheets as well, moved as a composite unit along a deep master decollement to their present position upon unmetamorphosed Paleozoic rocks of the Valley and Ridge.

The information that exists indicates that a complex history of repeated deformation, thrusting, and metamorphism affected rocks in the Knoxville quadrangle and that compound thrust sheets of varying ages and metamorphic history are juxtaposed (fig. 12). At least three periods of regional metamorphism, deformation, and thrusting during what are interpreted as Grenvillian (approximately 1,200 Ma), Taconian (430^70 Ma), and Acadian (365-400 Ma) events are indicated. Regional thrusting associated with metamorphic retrogression along fault zones occurred during the Alleghanian (270-250 Ma) event. The various rock units and compound thrust sheets in the Knoxville quadrangle were metamorphosed and deformed during one or more of these events.

Geologic Summary

The geology of the Knoxville quadrangle appears to represent a section across the collapsed and telescoped Late Proterozoic and Paleozoic continental margin of eastern North America. The section includes elements of (1) Middle Proterozoic continental basement, (2) Late Proterozoic and early Paleozoic extensional continental margin, (3) early Paleozoic passive continental margin, (4) volcanic arc and arc-associated basins, (5) accretionary wedge complexes, and (6) middle and late Paleozoic unstable continental margin (fig. 13). The oldest rocks in the Knoxville quadrangle are a group of Middle Proterozoic orthogneisses, interpreted as granitoid calcalkaline intrusive plutons comprising Grenville-age crystalline basement, and a belt of Middle Proterozoic gneiss and volcanic rocks (the amphibolitic basement complex of Brewer and Woodward, 1988) that locally contains relict granulite-facies metamorphic assemblages (Merschat, 1977).

The granitoid intrusives in the Middle Proterozoic orthogneiss basement (units Ybg and Zm, pi. 1) have calcalkaline chemical affinities. Similar intrusives in the Adirondack massif. New York, have been interpreted as calcalkaline intrusives associated with a Middle Proterozoic collisional event at approximately 1,300 Ma that predate a high-strain deformation and granulite-facies metamorphic event at 1,050 Ma (McLelland and others, 1988a).

The relict granulite-facies metamorphic assemblages reported in the amphibolitic basement complex by Merschat (1977) are based on the occurrence of hypersthene in gneissic granitoid and mafic rocks in a belt of rocks that generally has mineral assemblages indicative of middle amphibolite facies. The orthopyroxene-bearing rocks described by Merschat (1977) as granulite-facies assemblages may include inherited anhydrous igneous assemblages whose igneous orthopyroxene recrystallized during subsequent metamorphism, as is proposed for many chamockitic and mangeritic rocks in the Adirondack massif of New York by McLelland and others (1988b). The orthopyroxene-bearing rocks in the amphibolitic basement complex have a granoblastic texture resulting from metamorphic recrystallization (Kuchenbuch, 1979).

The amphibolitic basement complex is strongly deformed along its contact with Middle Proterozoic orthogneiss in the north-central portion of the Knoxville quadrangle, and this contact is interpreted as a fault with a Late Proterozoic or older age of movement (Brewer and Woodward, 1988). Brewer and Woodward (1988) interpret the amphibolitic basement complex as a Middle Proterozoic tectonic melange that developed as an accretionary complex

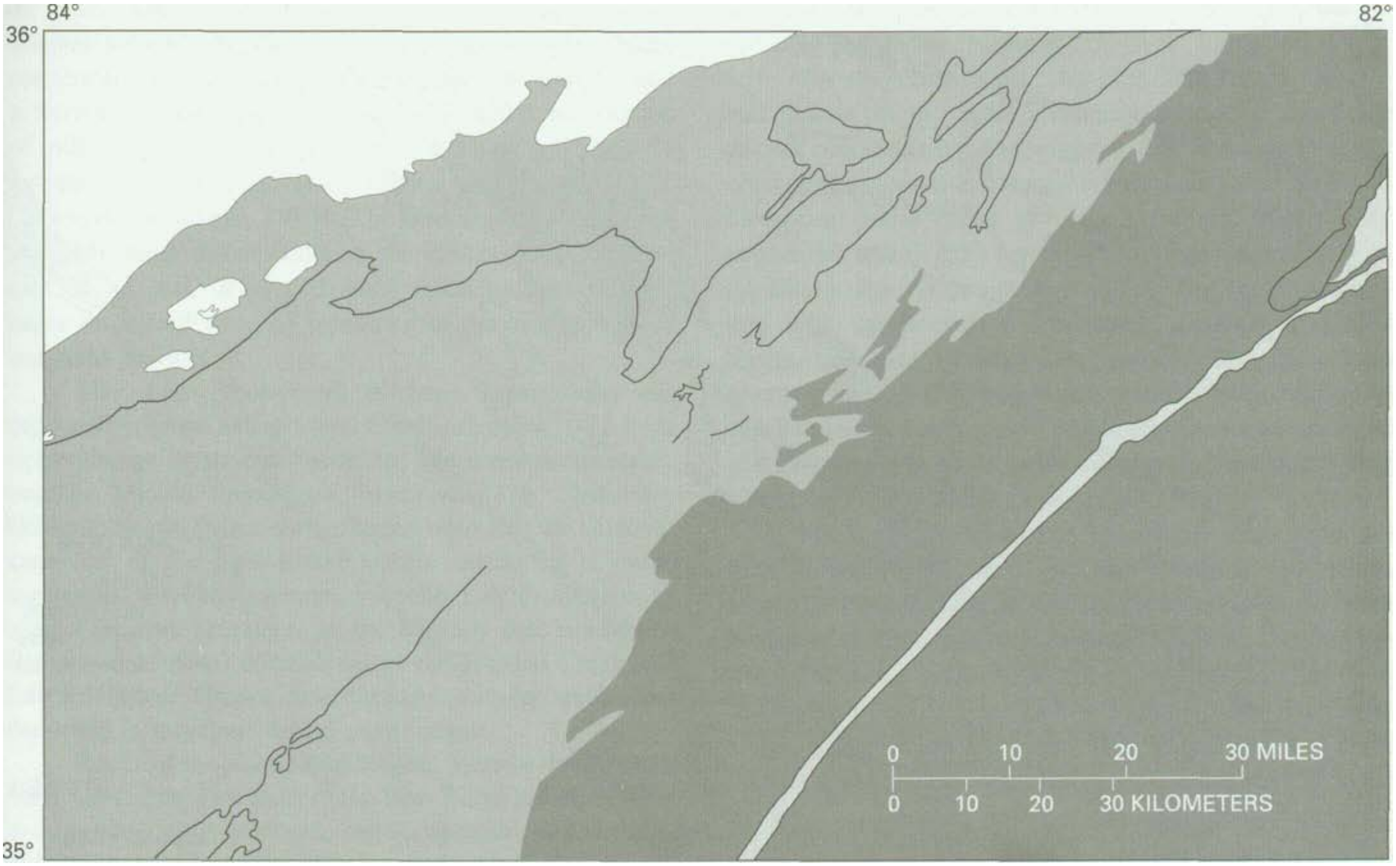


Figure 12. Age of metamorphism. Areas affected by metamorphism during 450^30 Ma (Taconian) are identified by the medium-shaded area. Areas affected by metamorphism during 400-350 Ma (Acadian) are identified by the dark area. Areas affected by metamorphism during approximately 275 Ma (Alleghanian) are identified by the light-shaded area. Alleghanian metamorphism along the Brevard fault is retrograde.

along the eastern margin of the Grenville metamorphic front. This interpretation requires that the mafic and ultramafic bodies in the amphibolitic basement complex and the Ashe Metamorphic Suite be different in age and source, although both belts of mafic and ultramafic bodies may have a similar origin as components of tectonic melange or accretionary complexes. One general difference between the ultramafic rocks in the amphibolitic basement complex and those in the Ashe Metamorphic Suite is that most large and nearly monomineralic dunite bodies, except for a few in the Spruce Pine district, are confined to the amphibolitic basement complex. The interpretation of the amphibolitic basement complex as a Middle Proterozoic metamorphic complex is supported by the presence ofBakersville Gabbro dikes (734±26 Ma, Goldberg and others, 1986) that cut across the metamorphic fabric of the enclosing amphibolitic basement complex and contain metamorphic assemblages and fabrics that differ from those of metabasites in the complex (Goldberg and others, 1986; Merschat, 1989, oral commun.). A dike of Bakersville Gabbro cuts a metabasite body in the Mars Hill, N.C., area, implying a pre-Paleozoic age for this body and its associated ultramafic rocks (Merschat, 1989, oral commun.). This metabasite contains hypersthene-clinopyroxene assemblages in a granoblastic texture, implying metamorphic recrystallization under granulite-facies conditions (Kuchenbuch, 1979), and Merschat (1989, oral commun.) now reinterprets this body (unit bhgb. Mars Hill quadrangle; Merschat, 1977) as a pre-Bakersville mafic intrusive. The Bakersville Gabbro dike, in contrast, retains domains with relict ophitic texture, and orthopyroxene is present only as minor relict igneous phenocrysts; the dike cuts the dominant structural fabric of the metabasite (Merschat, 1989, oral commun.) The implication is that the emplacement of the metabasite and ultramafic bodies, the granulite-facies metamorphism, and much of the deformation in the amphibolitic basement complex predates intrusion of the Bakersville Gabbro and is probably of Middle Proterozoic age.

An alternative interpretation, proposed by Rankin and others (1988; also Rankin, 1989, oral commun.), is that all ultramafic bodies in the east flank of the Blue Ridge are part of a Paleozoic tectonic melange associated with the closing of lapetus. This interpretation redefines the amphibolitic basement complex and rocks in the Richard Russell thrust sheet as a Paleozoic accretionary wedge complex correlateable, in part, with the Ashe Metamorphic Suite; these belts

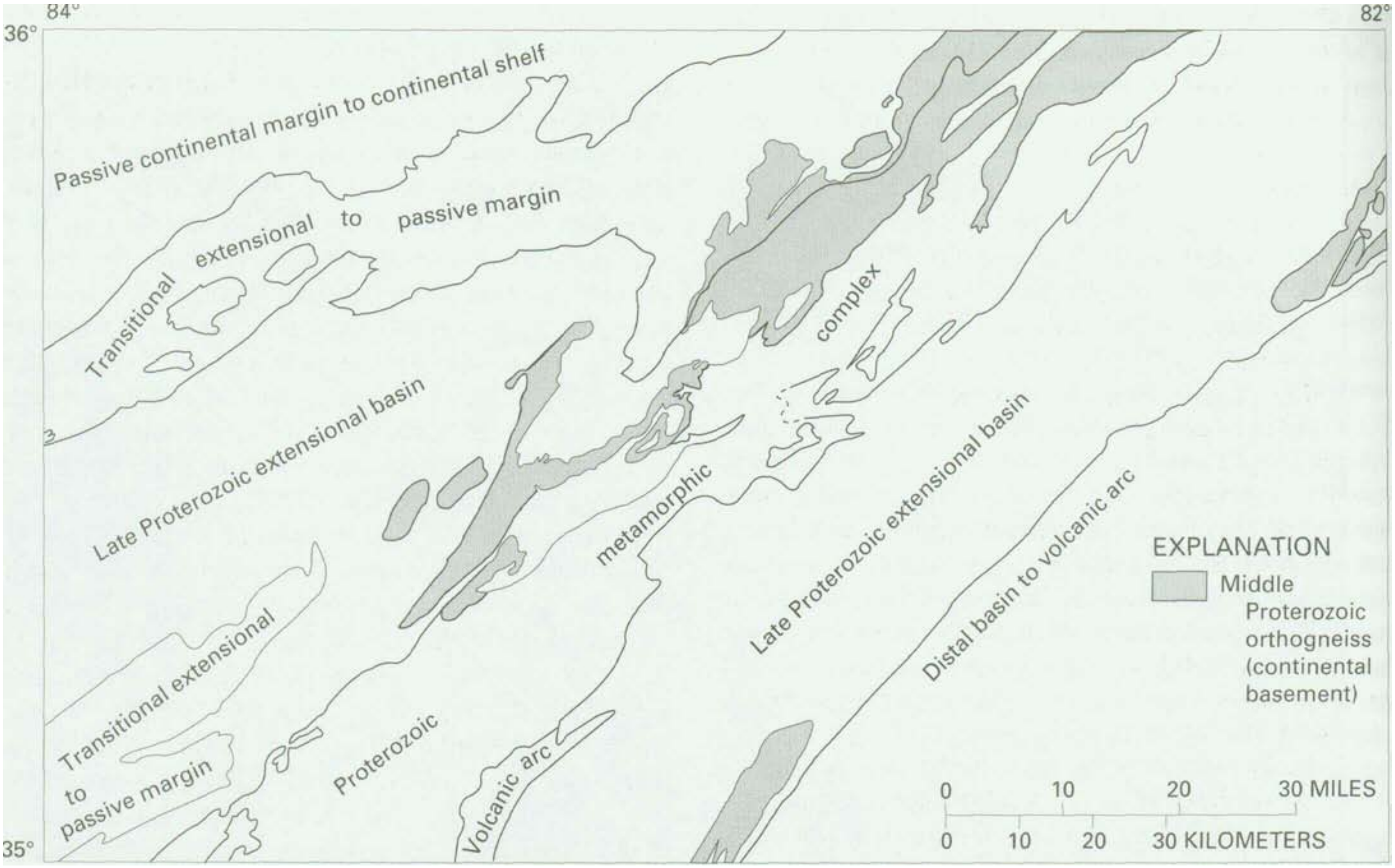


Figure 13. Generalized tectonics of the Knoxville quadrangle.

would be made up of a complex tectonic mixture of (1) Middle Proterozoic basement (including the relict granulite-facies rocks in the Mars Hill area of Merschat (1977) and rocks intruded by the Bakersville Gabbro), (2) gneiss and schist correlatable with Paleozoic lithologies in the Ashe Metamorphic Suite, and (3) ultramafic and mafic bodies as fragments of the Iapetus ocean floor. Basement and cover contact relations are interpreted to have been obscured by tectonics and high-grade metamorphism. Rankin and others (1988) support this alternate interpretation with the following observations: (1) Proterozoic accretionary complexes containing ultramafic bodies are unknown elsewhere in the Grenville orogen, and (2) the structural position of the amphibolitic basement complex is similar to the setting of an early Paleozoic melange containing ultramafic bodies that runs the length of the Appalachian orogen.

In this report the interpretation of the amphibolitic basement complex as a Middle Proterozoic metamorphic complex is followed, based on the detailed mapping of Merschat and Wiener (1988), Merschat (1977), and Brewer and Woodward (1988) in the east flank of the Blue Ridge. However, uncertainty as to geologic relationships in this area makes this interpretation suspect.

The Bakersville Gabbro (734±24 Ma, Goldberg and others, 1986) dike swarm implies an extensional setting that is probably related to the period of Late Proterozoic crustal extension that ultimately formed the depositional basins for the Ocoee Supergroup and perhaps also for the Ashe Metamorphic Suite. If the amphibolitic basement complex is a Proterozoic metamorphic belt, this Late Proterozoic period of crustal extension may have brought this mid-crustal granulite-facies package to shallow crustal levels, possibly in a setting somewhat analogous to the granulite-facies metamorphic core complexes flanked by extensional basins in the Basin and Range province of the Western United States. In the Knoxville area, however, Paleozoic compressional deformation and metamorphism has strongly overprinted (and perhaps reactivated) Proterozoic structures. A model similar to this has been proposed for the Middle Proterozoic Moine complex (approximately 1,000 Ma) and the associated Late Proterozoic Dalradian basin situated in the Caledonian orogen in Great Britain. The great width of middle crust granulite-facies metamorphic assemblages representing a limited depth thickness in the restored Middle Proterozoic Moine assemblage in Scotland led Barr and others (1986) to the interpretation that it had been attenuated by Late Proterozoic crustal stretching, possibly on discrete extensional slides that are difficult to recognize after Paleozoic deformation and metamorphism. The Dalradian basin, developed within and upon this Middle Proterozoic basement, is interpreted to have formed by this Late Proterozoic crustal extension event. Extensional faults developed during this event appear to be reactivated, in part, as thrusts during Paleozoic compression in Scotland (Soper and Anderton, 1984). Fault reactivation of older structures of this type is being increasingly recognized in orogenic belts (Boyer and Elliott, 1982; LePichon and others, 1982). The Greenbrier, Hayesville, and Dahlonega thrust faults in the Knoxville quadrangle may be, in part, developed along reactivated extensional faults associated with the formation of the original Ocoee and Ashe basins.

The Late Proterozoic Ocoee Supergroup was deposited in broad half-grabens filled with debris shed from Grenville-age crystalline basement, and it nonconformably overlies Middle Proterozoic basement. The Chilhowee Group and early Paleozoic sediments represent the apparent transition of the extensional margin setting to a stable continental shelf environment. Probable Late Proterozoic to early Paleozoic sediments in the Murphy belt have been interpreted as distal correlatives of the Walden Creek and (or) Chilhowee Groups (and perhaps younger sediments) deposited in a deeper marine environment.

Rocks of the Ashe Metamorphic Suite in the Tallulah Falls sheet of the east flank of the Blue Ridge are interpreted to represent highly deformed, metamorphosed, and intruded sediments that may be time equivalents of the Ocoee Supergroup and Chilhowee sediments that were deposited in a deeper marine environment on extended continental or perhaps ocean basement. The protoliths of the lithic assemblage in the Ashe Metamorphic Suite of shale, wacke, basalt, ultramafic rocks, and minor carbonates and conglomeratic rocks are characteristic of the lithotectonic assemblage in accreting complexes at convergent plate margin tectonic settings. Many of the ultramafic bodies in this belt occur along thrust contacts, and the linear distribution of other ultramafic bodies possibly indicates that they are also distributed along pre- to syn-metamorphic faults in the lithic package.

Rocks in the Helen belt may have been deposited in a basin flanking a volcanic arc. Rocks in Georgia correlative with the Helen belt are interpreted as being derived from sediments deposited in a back-arc basin or a marine basin proximal to a volcanic arc (New Georgia Group of German, 1988).

The Brevard zone may coincide with a fundamental break in crustal character that defines a boundary between largely ensialic rocks to the west and largely ensimatic rocks to the east. The strong contrast between the negative Bouguer gravity anomalies of the Blue Ridge and positive anomalies of the Inner Piedmont (Griscom, 1963) could be explained by a transition from a Blue Ridge region underlain by thick continental crust across the Brevard fault zone to Piedmont rocks resting on thinner, denser, and possibly oceanic crust. The initial strontium isotope ratios of pre-Silurian granitoid intrusions on both sides of the Brevard fault zone are consistent with this interpretation (table 1) but do not require it.

The strontium initial ratio of 0.7039 for the Henderson Gneiss in the Inner Piedmont precludes significant crustal contamination and suggests that a mantle to lower crust magma source underlay this area during the Cambrian. Strontium initial ratios of 0.7165 for the Bryson City pegmatites and 0.7050 for the granitic gneiss unit SOg in the Blue Ridge indicate magma sources from or contamination with upper crustal continental material. A similar abrupt transition of strontium initial ratio values from greater than 0.7045 to values less than 0.7045 in Idaho and Washington is interpreted to indicate the transition from continental crust to oceanic basement (Armstrong and others, 1977; Fleck and Criss, 1985).

The Inner Piedmont is separated by faults from the Blue Ridge to the west and the Charlotte and Kings Mountain belts to the east, and the relationship of the Inner Piedmont to these belts is uncertain. Similarities among the Kings Mountain belt, Charlotte belt, and the Carolina slate belt suggest that they are part of a single complex terrane, which is interpreted as being a Late Proterozoic and early Paleozoic volcanic arc-basin complex that has been intruded by pre-, syn-, and post-tectonic-metamorphic plutonic suites ranging from Cambrian to Permian in age (Goldsmith and others, 1988). The rocks of the Inner Piedmont may represent deposition in a Late Proterozoic and early Paleozoic back arc basin that developed distal to the Charlotte terrane volcanic arc to the east.

The lithotectonic units in the Knoxville quadrangle occur in a series of stacked allochthons. The general model for stacked allochthons is that the highest is emplaced on the next highest and moves together with it onto a lower allochthon, with the process continuing until the assembled stack is emplaced onto an autochthon. The age of stacking and movement on thrust surfaces generally youngs down the stack sequence and toward the autochthon. However, many of the individual thrust sheets in a stack sequence probably also have moved as members of a composite allochthon. The age of metamorphism and synmetamorphic plutonism should young away from the autochthon as sucessive belts of rocks are collapsed into the orogenic belt. Geologic relations in the Knoxville quadrangle are generally consistent with this simple orogenic model. Thrust fault movement generally youngs down the stacking sequence toward the autochthon (pi. 1), although a number of sheets appear to have moved as composite thrust complexes, perhaps during different deformation events (Nelson, 1988). At least three Paleozoic deformation events associated with plutonism, disruption of the stratigraphic sequence in the Valley and Ridge, and thrusting are recognized: Taconian (Ordovician), Acadian (Early Devonian), and Alleghanian (Permian). The metamorphic belts associated with these deformation events overlap, but the locus of their most intense development appears to young to the east away from the autochthon (fig. 12).

MINERAL RESOURCES

Introduction

Past mineral production in the Knoxville quadrangle has been primarily construction materials and industrial minerals (table 3). Moderate amounts of iron, copper, zinc, and silver; a little lead and gold; and minor amounts of thorium and uranium are the only metals for which any significant production has been reported (table 3). In terms of quantity and value, stone, including both crushed and dimension, is the most important commodity. It is followed by feldspar, sand and gravel, sheet and scrap mica, limestone, and clay.

Prehistoric mineral use consisted of quarrying soapstone for pots by Archaic and Woodland cultures (Coe, 1964) mining of sheet mica for use as grave goods by the Hopewell culture (A.D. 400-900) of the Ohio River Valley (Kerr, 1875, 1881; Phillips, 1888; Simonds, 1896); use of vein quartz from the metamorphic rocks of the Blue Ridge and Piedmont and chert in the limestones and dolomites of the Valley and Ridge for tools, such as scrapers, arrowheads, spear points, and knives; and use of various clays for pottery. Many of the larger mica mines that produced sheet mica in the 19th century had been sites of prehistoric mining or prospecting. Many were thought to be Spanish silver mines by the first European settlers in the North Carolina Blue Ridge.

As early as the 17th century, the Cherokee mined white clay from pegmatite saprolite and carried it on their backs to the seacoast for sale to the European settlers (Kerr, 1881, p. 462; Watts, 1913, p. 9-10). In 1767, Josiah Wedgwood sent T. Griffiths to get clay from the Cherokee Nation at Cowee Town on the Little Tennessee River, about 5 mi northwest of present-day Franklin, Macon County, N.C. Griffiths cleaned out old clay pits, mined 12-15 tons of white clay, and was able with great difficulty to transport 5 tons to Charleston, S.C., for shipment to England (Griffiths, 1929). Good-quality china clay was discovered in 1768 in Cornwall, however, before Griffiths returned to England, and further development of the clay industry in North Carolina was delayed until 1888, when modem mining of kaolin for high-quality ceramic products started near Webster, Jackson County, N.C. (Watts, 1913, p. 9-10).

Although there are rumors or legends that the Spanish mined some gold in the 16th century in northern Georgia, just south of the quadrangle, the earliest known metal mining in the region was for iron. During the Revolutionary War the earliest bloomery forge is supposed to have been built in Bumpass Cove, Washington County, Tenn., about 15 mi north of the Knoxville quadrangle. Several charcoal furnaces and bloomery forges were built in the Tennessee part of the quadrangle during the period 1790-1820 (Lesley, 1859, p. 80-82; 196-205). All used limonite or brown ores, which are residual deposits on Paleozoic carbonate rocks of the Valley and Ridge. In North Carolina two furnaces using magnetite ore were in operation in Ashe County by 1807, just a few miles north of the quadrangle, and several bloomery forges using limonite ore were in operation by 1845 in Cherokee County, in the southwestern comer of the quadrangle (Lesley, 1859, p. 74-75; 185-192).

Gold was being produced in the Piedmont of North Carolina by 1803 (Pardee and Park, 1948, p. 27), and prospecting extended over much of the mountainous part of the state within the next few decades. Total recorded production (table 4) for the period 1880-1980 for all the counties in North and South Carolina wholly or partly within the quadrangle is nearly 17,000 troy oz (U.S. Bureau of Mint, 1882-83, 1884-1906, U.S. Geological Survey, 1883-1927; U.S. Bureau of Mines, 1927-1934, 1933-1988). Production of silver for the same period is 174,186 troy oz, but 171,071 troy oz of this was recovered as a byproduct from copper production from the Fontana and Hazel Creek mines, Swain County, N.C. (U.S. Bureau of Mint, 1882-83, 1884-1906; J.H. DeYoung, Jr., 1984, written commun.; U.S. Bureau of Mines, 1933-1988). Actual production of gold is probably no greater than 2 or 3 times the recorded production.

By the middle of the late 19th century, many of the mineral commodities listed in table 3 were being mined or actively prospected. The following discussion of the resources and resource potential of these commodities is arranged partly according to their importance to the local economies and partly by groupings of related commodities according to geologic occurrence or deposit model. The most important mining district within the quadrangle is the Spruce Pine pegmatite district of Avery, Mitchell, and Yancey Counties, N.C. (Lesure, 1968). This district has **in** the past supplied a large part of the sheet mica produced in the United States and today supplies a large percentage of the feldspar and scrap or flake mica for the country and significant amounts of kaolin and high-purity quartz sand.

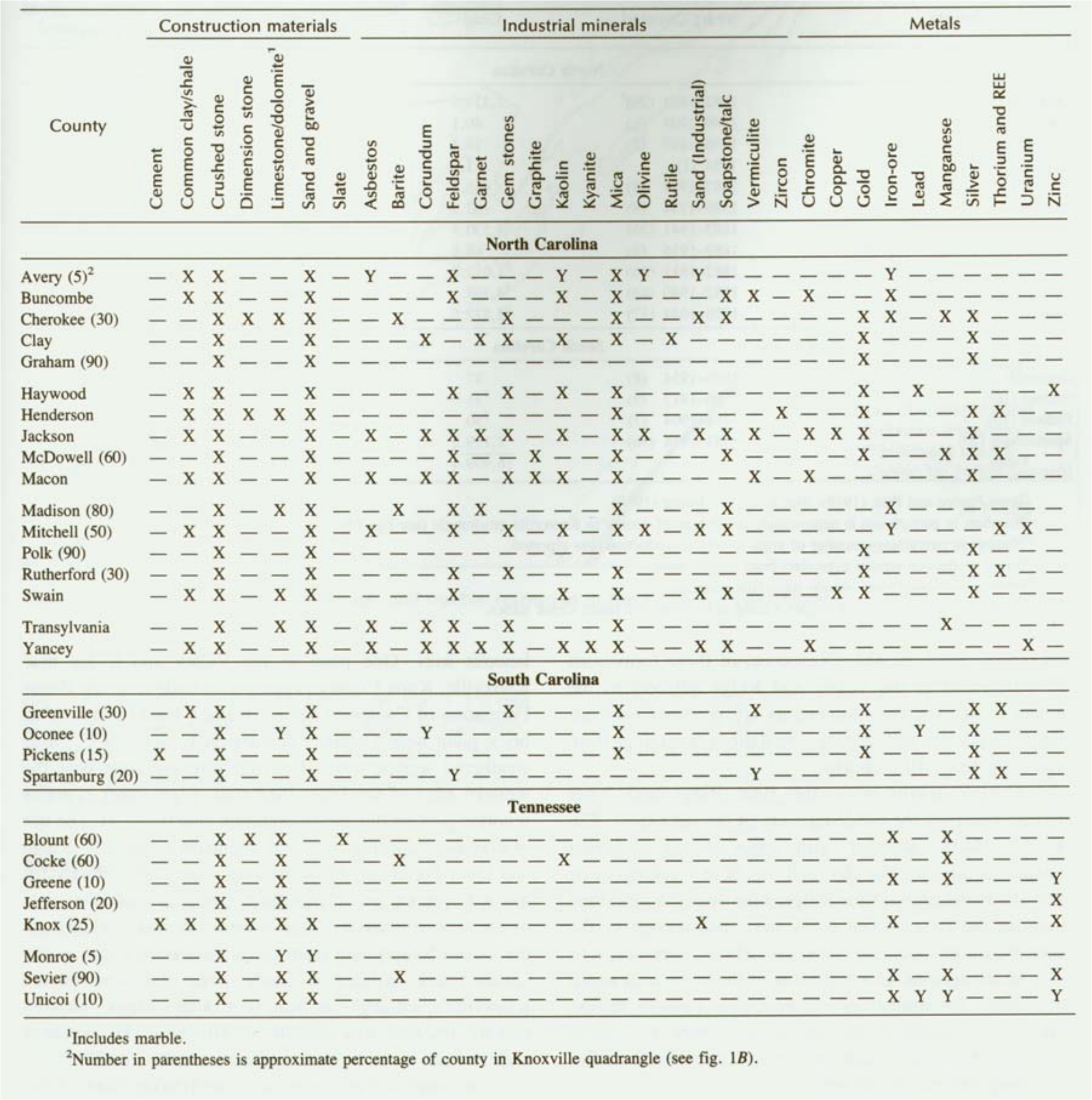
The second most important mining district in the quadrangle is the Tennessee marble district centered around Knoxville, Tenn. This area has been an important supplier of high-quality dimension stone since 1838. This beautiful marble has been used in government buildings nationwide, including many buildings and monuments in Washington, D.C.

Construction Materials

Construction materials are the most important mineral commodities in the region both in total dollar value and

Table 3. Mineral commodities produced in or near the Knoxville 1°x2° quadrangle by State and county

[Symbols: X, production reported, some or all may be outside the quadrangle; Y, production reported but known to be mostly or all outside the quadrangle; dashes indicate no production reported; **REE,** rare-earth elements. Data mostly from *Minerals Yearbook* and its predecessor volumes (USGS, 1883-1927; USBM, 1927-1934, and USBM, 1933-88). Data for North and South Carolina compiled by J.H. DeYoung, Jr., 1984, written commun.]



	Construction materials							Industrial minerals																Metals									
County	Cement	Common clay/shale	Crushed stone	Dimension stone	Limestone/dolomite[1]	Sand and gravel	Slate	Asbestos	Barite	Corundum	Feldspar	Garnet	Gem stones	Graphite	Kaolin	Kyanite	Mica	Olivine	Rutile	Sand (Industrial)	Soapstone/talc	Vermiculite	Zircon	Chromite	Copper	Gold	Iron-ore	Lead	Manganese	Silver	Thorium and REE	Uranium	Zinc
North Carolina																																	
Avery (5)[2]	—	X	X	—	—	X	—	Y	—	—	X	—	—	—	Y	—	X	Y	—	Y	—	—	—	—	—	—	Y	—	—	—	—	—	—
Buncombe	—	X	X	—	—	X	—	—	—	—	X	—	—	—	X	—	X	—	—	—	X	X	—	X	—	—	X	—	—	—	—	—	—
Cherokee (30)	—	—	X	X	X	X	—	—	X	—	—	—	X	—	—	—	X	—	—	X	X	—	—	—	—	X	X	—	X	X	—	—	—
Clay	—	—	X	—	—	X	—	—	—	X	—	X	X	—	X	—	X	—	X	—	—	—	—	—	—	X	—	—	—	X	—	—	—
Graham (90)	—	—	X	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	X	—	—	—
Haywood	—	X	X	—	—	X	—	—	—	—	X	—	X	—	X	—	X	—	—	—	—	—	—	—	—	X	—	X	—	—	—	—	X
Henderson	—	X	X	X	X	X	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	X	—	—	X	—	—	—	X	X	—	—
Jackson	—	X	X	—	—	X	—	X	—	X	X	X	X	—	X	—	X	X	—	X	X	X	—	X	X	X	—	—	—	X	—	—	—
McDowell (60)	—	—	X	—	—	X	—	—	—	—	X	—	—	X	—	—	X	—	—	—	X	—	—	—	—	X	—	—	X	X	X	—	—
Macon	—	X	X	—	—	X	—	X	—	X	X	—	X	X	X	—	X	—	—	—	—	X	—	X	—	—	—	—	—	X	—	—	—
Madison (80)	—	—	X	—	X	X	—	—	X	—	X	X	—	—	—	—	X	—	—	—	X	—	—	—	—	—	X	—	—	—	—	—	—
Mitchell (50)	—	X	X	—	—	X	—	X	—	—	X	—	X	—	X	—	X	X	—	X	X	—	—	—	—	—	Y	—	—	—	X	X	—
Polk (90)	—	—	X	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	X	—	—	—
Rutherford (30)	—	—	X	—	—	X	—	—	—	—	X	—	X	—	—	—	X	—	—	—	—	—	—	—	—	X	—	—	—	X	X	—	—
Swain	—	X	X	—	X	X	—	—	—	—	X	—	—	—	X	—	X	—	—	X	X	—	—	—	X	X	—	—	—	X	—	—	—
Transylvania	—	—	X	—	X	X	—	X	—	X	X	—	X	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—
Yancey	—	X	X	—	—	X	—	X	—	X	X	X	X	—	X	X	X	—	—	X	X	—	—	X	—	—	—	—	—	—	—	X	—
South Carolina																																	
Greenville (30)	—	X	X	—	—	X	—	—	—	—	—	—	X	—	—	—	X	—	—	—	—	X	—	—	—	X	—	—	—	X	X	—	—
Oconee (10)	—	—	X	—	Y	X	—	—	—	Y	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	X	—	Y	—	X	—	—	—
Pickens (15)	X	—	X	—	—	X	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	X	—	—	—	X	—	—	—
Spartanburg (20)	—	—	X	—	—	X	—	—	—	—	Y	—	—	—	—	—	—	—	—	—	—	Y	—	—	—	—	—	—	—	X	X	—	—
Tennessee																																	
Blount (60)	—	—	X	X	X	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	X	—	—	—	—
Cocke (60)	—	—	X	—	X	—	—	—	X	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—
Greene (10)	—	—	X	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	X	—	—	—	Y
Jefferson (20)	—	—	X	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X
Knox (25)	X	X	X	X	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	X	—	—	—	—	—	X
Monroe (5)	—	—	X	—	Y	Y	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Sevier (90)	—	—	X	—	X	X	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	X	—	—	—	X
Unicoi (10)	—	—	X	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	Y	Y	—	—	—	Y

[1] Includes marble.

[2] Number in parentheses is approximate percentage of county in Knoxville quadrangle (see fig. 1*B*).

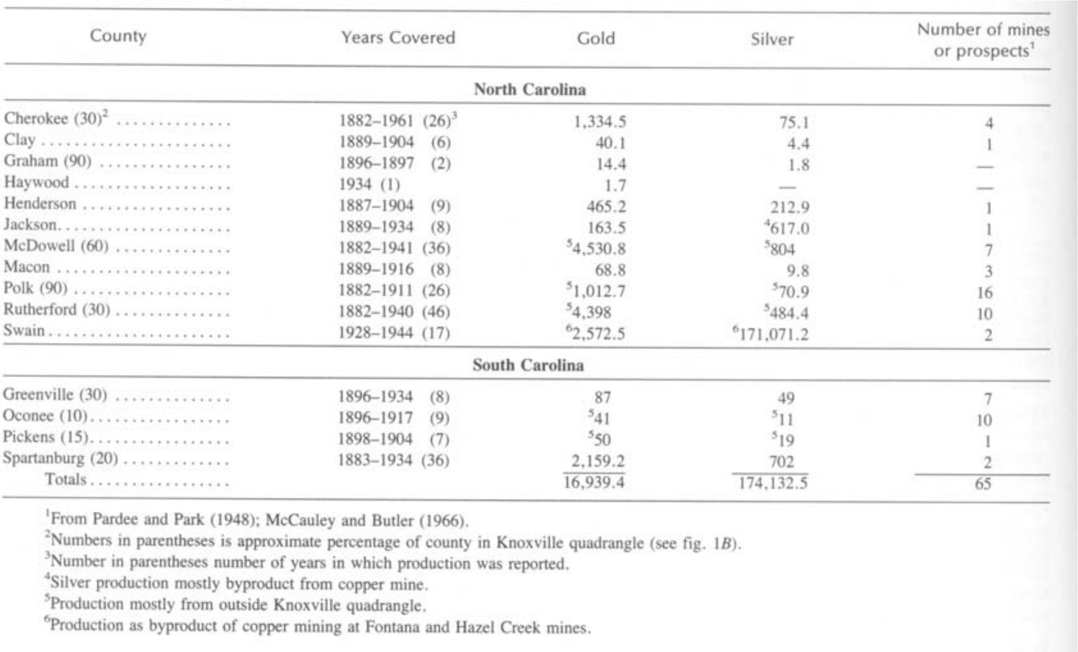
amount produced. In general, they are large-volume, low unit-value commodities whose utilization is largely dependent on the proper physical properties and the proximity to market. The following brief discussion is taken mostly from the U.S. Geological Survey Professional Paper 580, Mineral resources of the Appalachian region, which covers the subject in more detail.

Cement

Dixie Cement Co., Inc., operates a cement plant 1.5 mi north of the northwest corner of the Knoxville quadrangle. The company has an annual capacity of 550,000 tons of clinker and uses Lenoir Limestone, Holston Formation, and Ottosee Shale, all of Ordovician age, for raw materials (Ericksen and Thomson, 1968, p. 165; White

Table 4. Recorded production of gold and silver (in troy ounces) from counties all or partly within the Knoxville quadrangle

[Data mostly from annual reports of the Director of the Mint, USGS, and USBM, assembled by J.H DeYoung, Jr., 1984, written commun.]



County	Years Covered	Gold	Silver	Number of mines or prospects[1]
North Carolina				
Cherokee (30)[2]	1882–1961 (26)[3]	1,334.5	75.1	4
Clay	1889–1904 (6)	40.1	4.4	1
Graham (90)	1896–1897 (2)	14.4	1.8	—
Haywood	1934 (1)	1.7	—	—
Henderson	1887–1904 (9)	465.2	212.9	1
Jackson	1889–1934 (8)	163.5	[4]617.0	1
McDowell (60)	1882–1941 (36)	[5]4,530.8	[5]804	7
Macon	1889–1916 (8)	68.8	9.8	3
Polk (90)	1882–1911 (26)	[5]1,012.7	[5]70.9	16
Rutherford (30)	1882–1940 (46)	[5]4,398	[5]484.4	10
Swain	1928–1944 (17)	[6]2,572.5	[6]171,071.2	2
South Carolina				
Greenville (30)	1896–1934 (8)	87	49	7
Oconee (10)	1896–1917 (9)	[5]41	[5]11	10
Pickens (15)	1898–1904 (7)	[5]50	[5]19	1
Spartanburg (20)	1883–1934 (36)	2,159.2	702	2
Totals		16,939.4	174,132.5	65

[1] From Pardee and Park (1948); McCauley and Butler (1966).

[2] Numbers in parentheses is approximate percentage of county in Knoxville quadrangle (see fig. 1*B*).

[3] Number in parentheses number of years in which production was reported.

[4] Silver production mostly byproduct from copper mine.

[5] Production mostly from outside Knoxville quadrangle.

[6] Production as byproduct of copper mining at Fontana and Hazel Creek mines.

and others, 1988, p. 451). Resources of these formations are widespread in the Valley and Ridge adjacent to the cement plant. The only limitations are probably environmental concerns and zoning regulations resulting from expanding Knoxville suburbs.

Cement resources in the Blue Ridge and Inner Piedmont parts of the quadrangle are of limited extent. The Murphy Marble together with some of the enclosing metapelites of the Murphy belt might be suitable raw materials in the central Blue Ridge. Likewise, the limestone lenses in the Brevard belt along the western edge of the Inner Piedmont (Conrad, 1960, p. 25-30) together with some of the sericite schist saprolite in the same area might be suitable for cement raw materials. Extensive testing would be necessary to determine feasibility. More important, however, might be the market demand studies and transportation capabilities.

Common Clay and Shale

In addition to deposits of kaolin and halloysite of ceramic grade developed on weathered granite and pegmatite and discussed in a separate section, the Knoxville quadrangle contains extensive resources of common clay, clay-rich saprolite, shale, and slate that can be used in making brick, as fillers, and for a wide variety of miscellaneous uses. One plant in the Valley and Ridge near Knoxville, Knox County, Tenn., uses shale from the Rome Formation of Cambrian age for making brick, and another brick plant near Fletcher, Henderson County, N.C., uses weathered sericite schist from the Brevard zone near the western edge of the Inner Piedmont. Eight other counties reported past production of common clay (table 3). The use of clay-rich saprolite, which is abundant in the Blue Ridge and Inner Piedmont, for something other than ordinary fill has not been extensively studied. Ceramic evaluation tests by the U.S. Bureau of Mines on three samples of slate from the Ocoee Supergroup from the central Blue Ridge in the Citico Creek Wilderness Study Area just west of the Knoxville quadrangle in Monroe County, Tenn., showed that the material was suitable for structural clay products such as brick or tile (Slack and others, 1984, p. 27). Resources of common clay, clay-rich saprolite, shale, or slate are present in large quantities in all the lithotectonic belts in the Knoxville quadrangle.

Crushed Stone

All of the counties in the Knoxville quadrangle have produced crushed stone adequate for local use (table 3). Good-quality stone of various types suitable for most uses is available throughout the quadrangle in all the lithotectonic

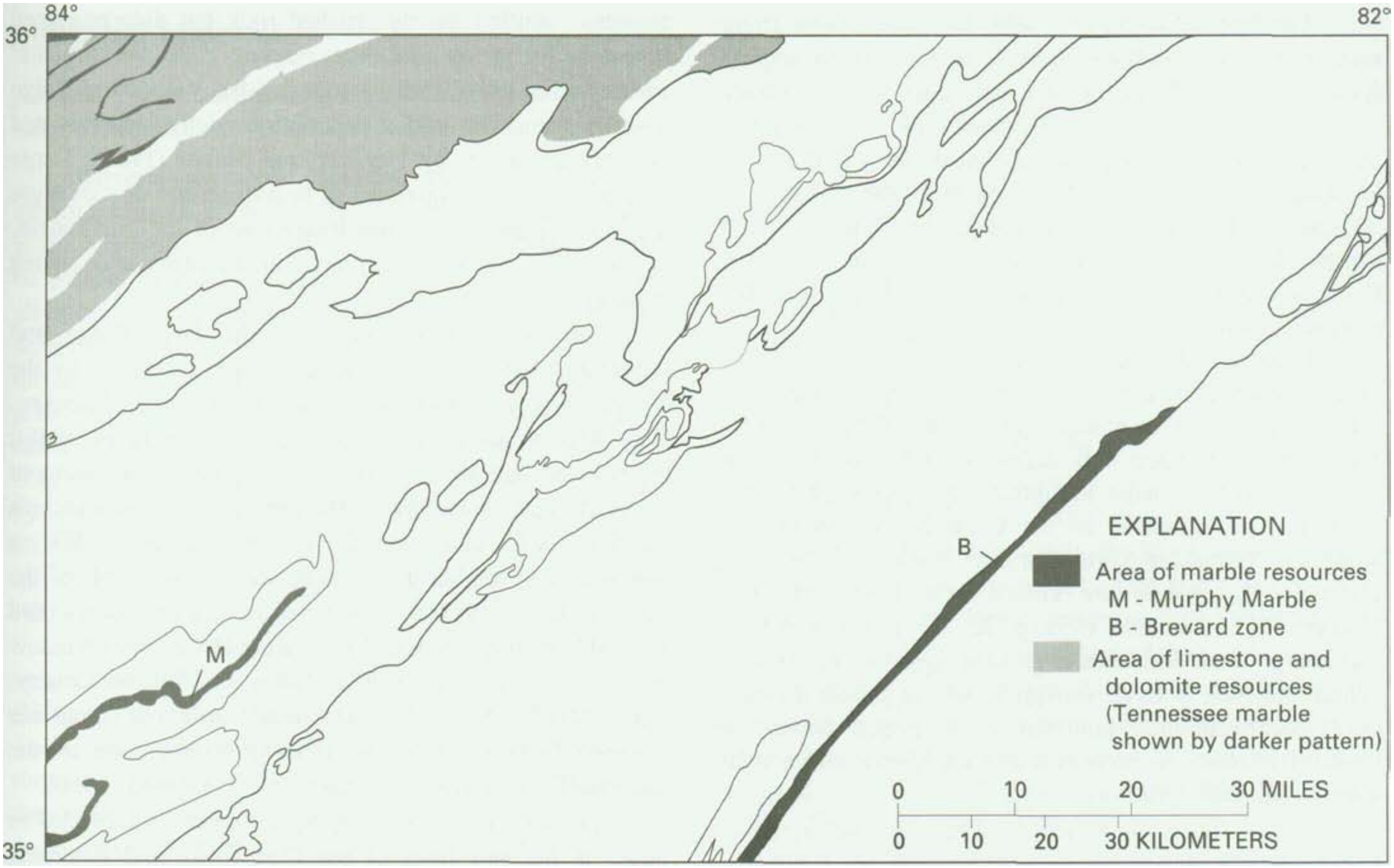


Figure 14. Areas of limestone, dolomite, and marble resources in the Knoxville quadrangle.

belts. Most rock quarries are shown on the 7 1/2-min topographic quadrangles. Resources of stone are enormous, but the principal limiting factors—environmental concerns and zoning regulations—may rule out excellent quarry sites and increase the cost of construction.

Dimension Stone

The two principal dimension stone resources in the quadrangle are the Tennessee marble deposits near Knoxville in Blount and Knox Counties, Tenn. (fig. 14), in the Valley and Ridge (Maher and Walters, 1960) and the Murphy Marble in Cherokee, Clay, Macon and Swain Counties, N.C., in the central Blue Ridge (Van Horn, 1948). Some dimension granite was quarried on a limited scale in the Inner Piedmont in Henderson County, N.C. (Councill, 1954, p. 49), and quartzite for flagstone and building stone was quarried in Swain County in the central Blue Ridge (Councill, 1955, p. 7-10). Slate in Blount County, Tenn., and quartzite in Sevier County, in the west flank of the Blue Ridge (Newman and others, 1968, p. 204-205), have been quarried for flagging and building stone. One distinctive stone that might be used as a decorative rock is the unakite in Madison County, N.C., in the central Blue Ridge (Councill, 1955, p. 22-23).

The Tennessee marble industry, which started in 1838 just north of the quadrangle and has been active since 1852 within the quadrangle, continues to supply high-quality, coarse-grained crystalline limestone from the Holston Formation or lithologically similar rocks, all of Ordovician age. Resources of this material are large and well mapped (Maher and Walters, 1960, p. 7). Environmental concerns and zoning regulations will be controlling factors in future use of this resource.

High-quality white marble is produced from the Murphy belt in Georgia and near Murphy, Cherokee County, N.C., southwest of the quadrangle, and near Marble, Cherokee County, N.C., within the quadrangle. Dimension stone has been produced from only a few quarries in the North Carolina part of the belt. Resources of dimension-stone-quality marble are probably large. The general area in the Murphy belt underlaid by marble is known, but only exploration by industry can add the details needed for resource knowledge.

The quartzite or metasandstone resources in the Ocoee Supergroup and the Chilhowee Group in the central and western Blue Ridge are probably large but have had little use beyond local markets. Other quartzofeldspathic rocks in the east flank of the Blue Ridge could also be utilized as dimension stone if demand were large enough.

The minor deposits of slate in Ocoee Supergroup rocks along the west flank of the Blue Ridge in Sevier and Blount Counties, Tenn., are the only ones known to have been worked in the Knoxville quadrangle. The deposits worked in Blount County are now inside the Great Smoky Mountains National Park (Newman and others, 1968, p. 204-205) and are no longer available. The slate in Sevier County has not been quarried and is poorly known. Decreases in the demand for slate will probably limit the resource potential for this rock.

Unakite is the rock name applied to a unique variety of granite or granite gneiss containing large amounts of bright yellowish-green epidote, pink to red feldspar, quartz, and evenly distributed dark accessory minerals. The type locality is in the Unaka Mountains, a name used for the northeastward extension of the Great Smoky Mountains along the Tennessee-North Carolina border. Large areas underlain by unakite are known near Bluff, Madison County, N.C. (Councill, 1955, p. 22-24). In this area both medium-grained and coarse-grained unakite are found. Where the rock is fresh enough to take a polish it might have good economic potential as a unique decorative dimension stone. At present it is well known and sought after by mineral collectors.

Lightweight Aggregate

Many types of clay, shale, and slate develop a bloated or vesicular structure on high-temperature heating (Bush and Sweeney, 1968, p. 213). Very little testing has been done on the rocks of the Knoxville quadrangle for such use. The Pumpkin Valley Shale in the Conasauga Group of Cambrian age, which occurs in several narrow outcrop belts in Blount, Knox, and Sevier Counties, Tenn. (pi. 1, unit •Cu), has been a source of material for lightweight aggregate just north of the Knoxville quadrangle. This unit may also be a potential source within the quadrangle but would have to be tested. The many shales and slates of the Ocoee Supergroup in the central and west flank of Blue Ridge are also potential sources of material for testing. Only an extensive testing program could furnish data needed to outline formations that have bloating potential.

Limestone and Dolomite

The principal sources of limestone and dolomite in the Knoxville quadrangle are in the Valley and Ridge province in the northwest comer of the quadrangle (fig. 14) where lower Paleozoic carbonate rocks are widespread (Ericksen and Cox, 1968, p. 227-252). One report shows locations of 31 limestone quarries, 31 marble quarries, 2 natural cement quarries, and a terrazo quarry in Knox County alone (Tennessee Division of Geology, 1973). In 1985, Knox County, Tenn., had at least four large, active limestone quarries, Blount and Sevier Counties two each, and Cocke County one (Hershey and Maher, 1985). These quarries supplied mostly crushed rock but also produced limestone for agricultural lime, cement, glass, whiting, and various other uses. The resources of the Valley and Ridge area by formation and a description of the quarries and industry are given by Hershey and Maher (1985). Large volumes of various qualities of limestone and dolomite are available in the Valley and Ridge part of the quadrangle. Limiting factors are environmental concerns and zoning regulations.

Resources of limestone in the Blue Ridge and Piedmont parts of the quadrangle are restricted to the Murphy Marble belt of the central Blue Ridge in Cherokee, Clay, Macon, and Swain Counties, N.C. (Van Horn, 1948); the Brevard belt at the western edge of the Inner Piedmont in McDowell, Buncombe, Henderson, and Transylvania Counties, N.C., and Ocoee County, S.C. (Conrad, 1960); a few scattered marble occurrences in the east flank of the Blue Ridge; and some Proterozoic marble lenses and Paleozoic carbonates in and around the Hot Springs window in the west flank of the Blue Ridge in Madison County, N.C. (Oriel, 1950). No significant carbonate units are reported from most of the Inner Piedmont part of the quadrangle (Loughlin and others, 1921; Conrad, 1960).

Detailed geologic mapping at scales of 1:24,000 or larger in the east flank of the Blue Ridge and Piedmont combined with geochemical studies might delineate other scattered marble lenses, but none of those currently known have economic potential, except as noted above.

Sand and Gravel

All the counties in the Blue Ridge and Piedmont and some of those in the Valley and Ridge have produced sand and gravel (table 3). Recent mapping by various geologists in the Blue Ridge of North Carolina (fig. 5) generally shows areas of alluvium along major rivers. Some of these alluvial areas are large, especially along the French Broad in Transylvania, Henderson, and Buncombe Counties, N.C. (Butler, 1972b; Hoi-ton, 1982; Lemmon and Dunn, 1973a and 1973b; McDaniel and Dabbagh, 1981; Nelson, 1972), and along the Catawba River in McDowell County, N.C. (Conley and Drummond, 1981). Resources of sand and gravel are adequate for local use in much of the quadrangle (Maxwell and others, 1968; p. 254). For many years the Knoxville metropolitan area has imported sand dredged from TVA lakes, mostly outside the quadrangle.

Fine-grained quartz sand is produced as a byproduct of clay, feldspar, and mica mining in the Spruce Pine district of the east flank of the Blue Ridge in Avery, Mitchell, and Yancey Counties, N.C. For decades this sand was used for sanding roads and as concrete and plaster sand, or it was discarded into the Toe River. Improved processing techniques now permit production of ultraclean quartz that is classified as an industrial sand.

Industrial Minerals

Mineral Commodities Related to Mafic and Ultramafic Rocks

Mineral resources that are related to mafic and ultramafic rocks in the east flank of the Blue Ridge (pi. 1) in the Knoxville quadrangle and have been mined or might be present include asbestos, chromite, corundum, nickel, olivine, platinum-group elements (PGE's), soapstone-serpentinite, talc, and vermiculite. Of these, chromite, olivine, and the PGE's are generally considered to be primary minerals; the others are related to secondary processes, either metamorphism or weathering, or both. The only recent mining for any of these commodities has been by Applied Industrial Minerals Corp., which mined olivine at Day Book and the Addie mine as of 1988. The Addie mine, however, was reported closed by August 1988 (Griffiths, 1989, p. 28).

Asbestos, chromite, corundum, soapstone, talc, and vermiculite have been mined in the east flank of the Blue Ridge in the past in the Knoxville l°x2° quadrangle (table 3), but generally on a small scale. It is doubtful that any of these commodities will again be of economic importance in the quadrangle.

Information is available on 106 named deposits in high-magnesium and ultramafic rocks (table 5). The more important deposits are in dunite, a few are in metapyroxenite, and even some small soapstone bodies have been used locally. The principal talc deposits are metasomatic deposits in marble in the Murphy belt of the Central Blue Ridge and are not related to ultramafic rocks. They are, however, included in the section on talc.

The mafic and ultramafic rocks of the Blue Ridge have been the subject of extensive study by many geologists. The early and very complete study of these rocks by Pratt and Lewis (1905) is still the definitive work. Later studies by Hunter (1941), Hadley (1949), Miller (1953), Kulp and Brobst (1954), Hartley (1973), Conrad and others (1963), and other investigators mentioned in table 5 are generally concerned with only one deposit or one commodity. In the past 15 years renewed study by several university professors and their students has focused on various aspects of the origin of these mafic and ultramafic rocks in the Blue Ridge. Summary articles by Misra and Keller (1978) and Misra and McSween (1984) are useful guides to the problems concerning origin and history **of** these rocks.

The most common ultramafic bodies are peridotites; these are composed mostly of olivine but may contain varying amounts of pyroxene, amphibole, or mica. The larger and more abundant of these are dunites, consisting of 90 percent or more olivine and having an average composition of 92 percent forsterite (Carpenter and Phyfer, 1975). Enstatite and chromite are the other common primary accessory minerals. In most bodies the chromite constitutes less than 1 percent of the rock and is generally disseminated in small crystals. In a few bodies, chromite occurs in small lenses, thin veins, or pods, but these are not common.

Olivine is susceptible to alteration and weathering, and most of the dunites contain olivine that is partly altered to serpentine, talc, vermiculite, chlorite, or anthophyllite, especially in the outer parts of the bodies along contacts with country rock, along internal fractures, and adjacent to pegmatite or quartz veins cutting the dunite. Other minerals commonly associated with the dunites include magnetite, actinolite, phlogopite, gamierite, magnesite, corundum, spinel, antigorite, limonite, chalcedony, sepiolite(?), and occasionally tourmaline (Conrad and others, 1963, p. 8; Pratt and Lewis, 1905, p. 270-333).

Most of the dunite bodies are small, covering only a few acres of surface exposure. The Buck Creek body, which is one of the larger, covers a little more than 300 acres (Hadley, 1949, p. 109). Most of the dunite bodies are lens-shaped, with a major axis 2 to 3 times the minor axes. Drilling and geophysical studies show that the bodies are ellipsoid or irregular pod-like masses with well-defined bottoms (Honeycutt and others, 1981; Hirt and others, 1987; Chatman, 1985). Most of them are roughly concordant to the regional foliation of the enclosing gneiss and schist, but some may be discordant locally.

Harzburgite (peridotite containing olivine and significant amounts oforthopyroxenes, enstatite, or bronzite) occurs as individual bodies or more commonly as parts of a larger dunite body. The harzburgite may be in contact with or completely enclosed by dunite (Conrad and others, 1963, p. 9). Wehrlite (peridotite containing clinopyroxene) has been reported by Hartley (1973, p. 31-32) but is not a common rock type in the area.

Pyroxenite is not as common as peridotite in the Knoxville quadrangle but occurs as two types: enstatolite, composed of enstatite, and websterite, composed of diopside and bronzite. Websterite is restricted to parts of the Webster-Addie dunite body. The enstatolite bodies, which are smaller than most of the dunites, commonly occur in groups of small separate bodies. These are more common in the Toxaway area of Jackson and Transylvania Counties and in the Spruce Pine pegmatite area of Avery, Mitchell, and Yancey Counties, N.C. (Conrad and others, 1963, p. 9). The enstatolite bodies are commonly enclosed by an envelope of altered rock consisting of talc, chlorite, vermiculite, and anthophyllite.

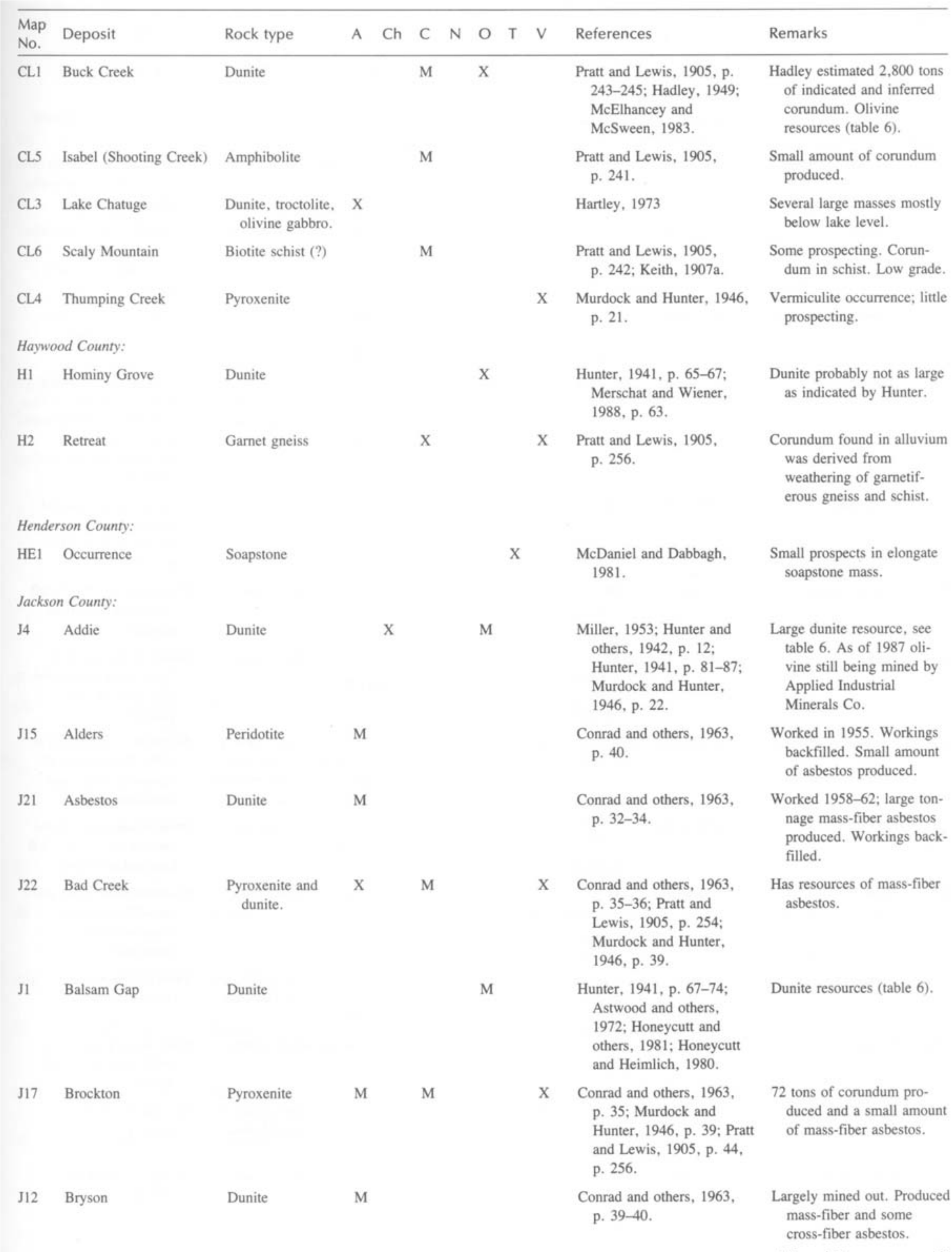
Many of the smaller ultramafic bodies are completely altered to soapstone, talc schist, chlorite schist, or serpentinite and in general seem to have been mostly pyroxenite or harzburgite; a few may have been dunite. Many of the soapstone or chlorite schist bodies are closely associated with larger masses of amphibolite and may represent cumulate zones in mafic intrusions.

Table 5. Summary of high-magnesium and ultramafic rock deposits that have been mined or prospected for various mineral commodities (cont.)

[Map number refers to localities shown on pl. 1. Symbols used: A, asbestos; Ch, chromite; C, corundum; N, nickel; O, olivine; T, talc and soapstone; V, vermiculite; X, commodity present; M, commodity mined; ?, possible resource but data lacking]

Map No.	Deposit	Rock type	A	Ch	C	N	O	T	V	References	Remarks
North Carolina											
Buncombe County:											
B5	Bee Tree	Pyroxenite							M	Murdock and Hunter, 1946, p. 17.	Two large open cuts on separate deposits.
B1	Democrat	Dunite		M	M	X	X			Carpenter and Hale, 1967; Pratt and Lewis, 1905, p. 257; Hunter, 1941, p. 61–63; Hunter and others, 1942, p. 5–7.	North end of long narrow mass of dunite. Has olivine resources (table 6). Small resources of residual placer chromite. Some vein and disseminated chromite.
B3	Juno	Serpentinite						X		Hunter, 1941, p. 63–64	Hunter (1941, p. 64) estimates 95,000 tons of "quarrable" serpentinite.
B6	Lake Eden	Pyroxenite							X	Murdock and Hunter, 1946, p. 17.	Some prospecting on small deposit.
B2	Morgan Hill	Dunite		M			X			Hunter and others, 1942, p. 7.	South end of Democrat dunite body. Olivine resources (table 6). Vein, disseminated, and placer chromite.
B4	Newfound Gap	Dunite					X			Hunter, 1941, p. 65; Hirt and others, 1987.	One large and at least two small dunite masses. Olivine resources large (table 6).
Cherokee County:											
C6	Columbia Marble Co.	Talc in marble						M		Van Horn, 1948, p. 48, nos. 25–27.	Little talc found in drilling.
C2	Hayes	Talc in marble						M		Pratt, 1900; Van Horn, 1948, p. 46, no. 20.	1,000 tons of talc prior to 1900.
C8	Nantahala Talc and Limestone Co.	Talc in marble						M		Pratt, 1900; Van Horn, 1948, p. 49, nos. 29–30.	Shallow pits and inclines. Minor production.
C5	Prospect	Talc in marble						X		Pratt, 1900; Van Horn, 1948, p. 48, no. 24.	Shafts of unknown date.
C1	Regal Talc mines	Talc in marble						M		Pratt, 1900; Van Horn, 1948, p. 46, nos. 17–19.	Numerous prospect pits and shafts. Little production.
C3	Southern Mineral Co.	Talc in marble						M		Pratt, 1900; Van Horn, 1948, p. 46, no. 21.	Talc contains too much tremolite. 1,000 tons talc produced before 1900.
C4	Valley Town Mineral Co. and Biltmore Talc Co.	Talc in marble						M		Pratt, 1900; Van Horn, 1948, p. 46–48, nos. 22–23.	Minor production. Some tremolitic talc.
C7	Weber Co.	Talc in marble								Pratt, 1900; Van Horn, 1948, p. 48, no. 28.	Sericitic slate, little or no talc found.
Clay County:											
CL2	Behr	Peridotite			M					Pratt and Lewis, 1905, p. 240; Hartley, 1973, p. 50.	Two shafts, visible at low lake level; closed 1890; shipped several carloads of clean corundum.

Table 5. Summary of high-magnesium and ultramafic rock deposits that have been mined or prospected for various mineral commodities *(cont.)*



Map No.	Deposit	Rock type	A	Ch	C	N	O	T	V	References	Remarks
CL1	Buck Creek	Dunite			M		X			Pratt and Lewis, 1905, p. 243–245; Hadley, 1949; McElhancey and McSween, 1983.	Hadley estimated 2,800 tons of indicated and inferred corundum. Olivine resources (table 6).
CL5	Isabel (Shooting Creek)	Amphibolite			M					Pratt and Lewis, 1905, p. 241.	Small amount of corundum produced.
CL3	Lake Chatuge	Dunite, troctolite, olivine gabbro.	X							Hartley, 1973	Several large masses mostly below lake level.
CL6	Scaly Mountain	Biotite schist (?)			M					Pratt and Lewis, 1905, p. 242; Keith, 1907a.	Some prospecting. Corundum in schist. Low grade.
CL4	Thumping Creek	Pyroxenite							X	Murdock and Hunter, 1946, p. 21.	Vermiculite occurrence; little prospecting.
Haywood County:											
H1	Hominy Grove	Dunite					X			Hunter, 1941, p. 65–67; Merschat and Wiener, 1988, p. 63.	Dunite probably not as large as indicated by Hunter.
H2	Retreat	Garnet gneiss			X				X	Pratt and Lewis, 1905, p. 256.	Corundum found in alluvium was derived from weathering of garnetiferous gneiss and schist.
Henderson County:											
HE1	Occurrence	Soapstone						X		McDaniel and Dabbagh, 1981.	Small prospects in elongate soapstone mass.
Jackson County:											
J4	Addie	Dunite		X			M			Miller, 1953; Hunter and others, 1942, p. 12; Hunter, 1941, p. 81–87; Murdock and Hunter, 1946, p. 22.	Large dunite resource, see table 6. As of 1987 olivine still being mined by Applied Industrial Minerals Co.
J15	Alders	Peridotite	M							Conrad and others, 1963, p. 40.	Worked in 1955. Workings backfilled. Small amount of asbestos produced.
J21	Asbestos	Dunite	M							Conrad and others, 1963, p. 32–34.	Worked 1958–62; large tonnage mass-fiber asbestos produced. Workings backfilled.
J22	Bad Creek	Pyroxenite and dunite.	X		M				X	Conrad and others, 1963, p. 35–36; Pratt and Lewis, 1905, p. 254; Murdock and Hunter, 1946, p. 39.	Has resources of mass-fiber asbestos.
J1	Balsam Gap	Dunite					M			Hunter, 1941, p. 67–74; Astwood and others, 1972; Honeycutt and others, 1981; Honeycutt and Heimlich, 1980.	Dunite resources (table 6).
J17	Brockton	Pyroxenite	M		M				X	Conrad and others, 1963, p. 35; Murdock and Hunter, 1946, p. 39; Pratt and Lewis, 1905, p. 44, p. 256.	72 tons of corundum produced and a small amount of mass-fiber asbestos.
J12	Bryson	Dunite	M							Conrad and others, 1963, p. 39–40.	Largely mined out. Produced mass-fiber and some cross-fiber asbestos.

Table 5. Summary of high-magnesium and ultramafic rock deposits that have been mined or prospected for various mineral commodities *(cont.)*

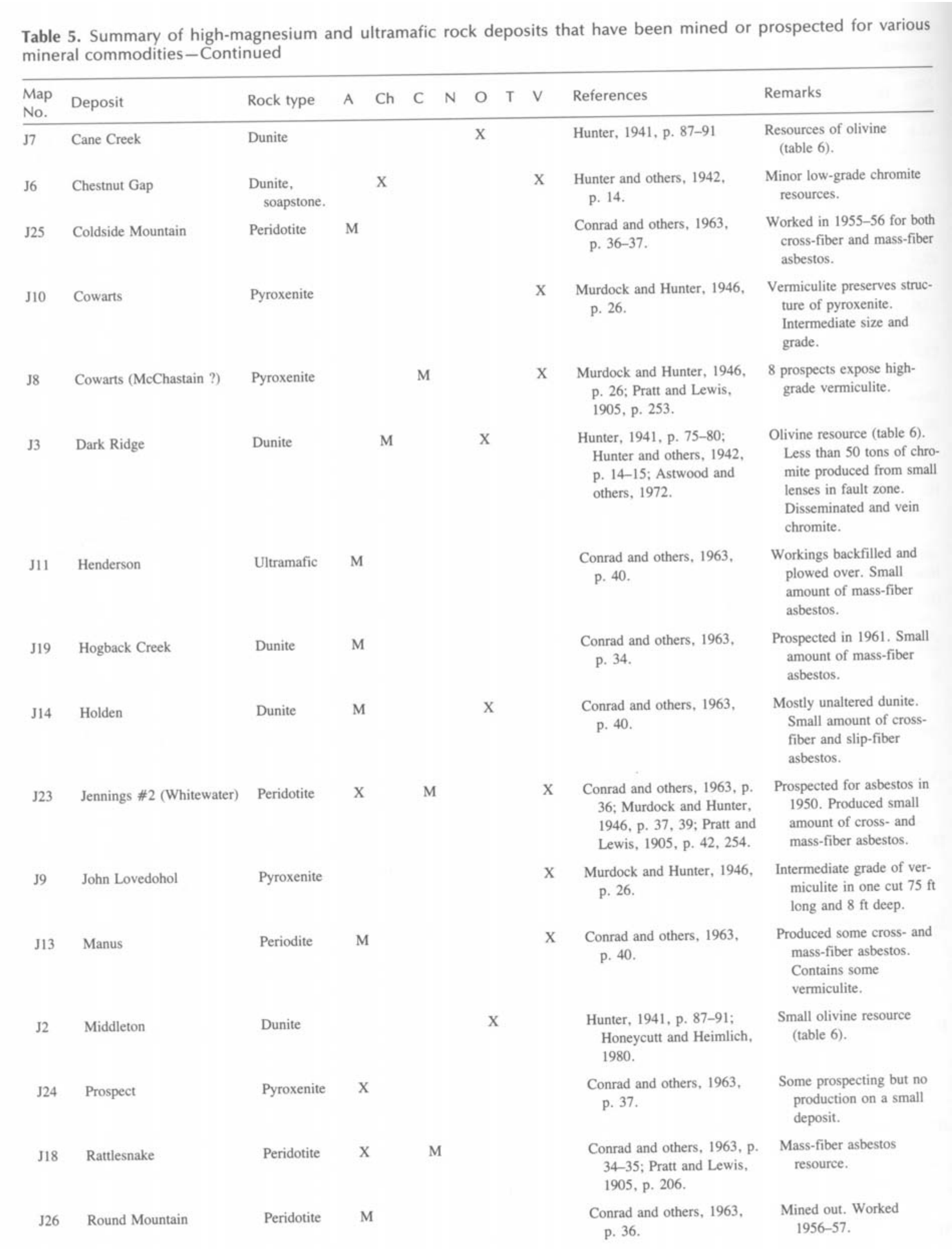


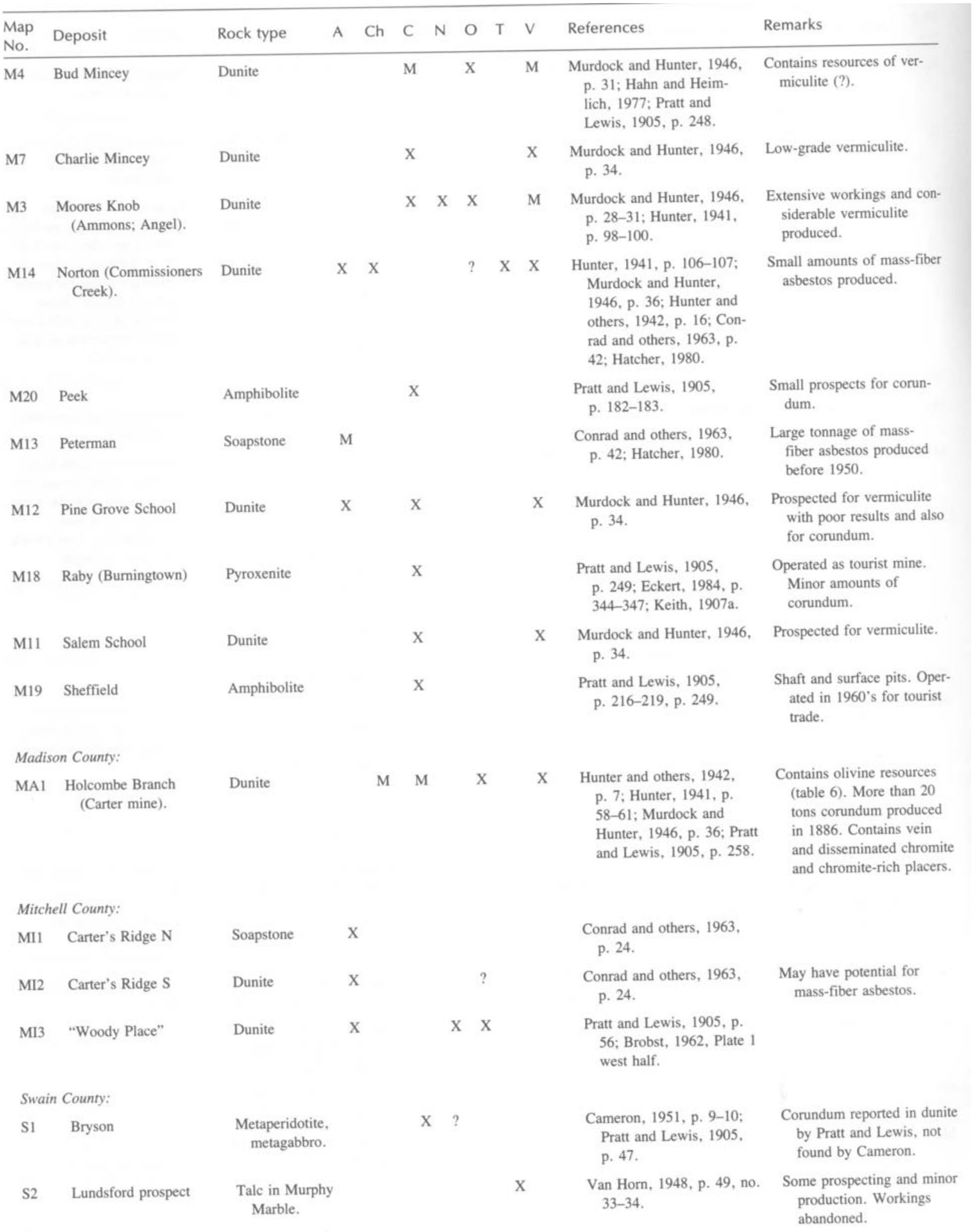
Table 5. Summary of high-magnesium and ultramafic rock deposits that have been mined or prospected for various mineral commodities—Continued

Map No.	Deposit	Rock type	A	Ch	C	N	O	T	V	References	Remarks
J7	Cane Creek	Dunite					X			Hunter, 1941, p. 87–91	Resources of olivine (table 6).
J6	Chestnut Gap	Dunite, soapstone.		X					X	Hunter and others, 1942, p. 14.	Minor low-grade chromite resources.
J25	Coldside Mountain	Peridotite	M							Conrad and others, 1963, p. 36–37.	Worked in 1955–56 for both cross-fiber and mass-fiber asbestos.
J10	Cowarts	Pyroxenite							X	Murdock and Hunter, 1946, p. 26.	Vermiculite preserves structure of pyroxenite. Intermediate size and grade.
J8	Cowarts (McChastain ?)	Pyroxenite			M				X	Murdock and Hunter, 1946, p. 26; Pratt and Lewis, 1905, p. 253.	8 prospects expose high-grade vermiculite.
J3	Dark Ridge	Dunite		M			X			Hunter, 1941, p. 75–80; Hunter and others, 1942, p. 14–15; Astwood and others, 1972.	Olivine resource (table 6). Less than 50 tons of chromite produced from small lenses in fault zone. Disseminated and vein chromite.
J11	Henderson	Ultramafic	M							Conrad and others, 1963, p. 40.	Workings backfilled and plowed over. Small amount of mass-fiber asbestos.
J19	Hogback Creek	Dunite	M							Conrad and others, 1963, p. 34.	Prospected in 1961. Small amount of mass-fiber asbestos.
J14	Holden	Dunite	M				X			Conrad and others, 1963, p. 40.	Mostly unaltered dunite. Small amount of cross-fiber and slip-fiber asbestos.
J23	Jennings #2 (Whitewater)	Peridotite	X		M				X	Conrad and others, 1963, p. 36; Murdock and Hunter, 1946, p. 37, 39; Pratt and Lewis, 1905, p. 42, 254.	Prospected for asbestos in 1950. Produced small amount of cross- and mass-fiber asbestos.
J9	John Lovedohol	Pyroxenite							X	Murdock and Hunter, 1946, p. 26.	Intermediate grade of vermiculite in one cut 75 ft long and 8 ft deep.
J13	Manus	Periodite	M						X	Conrad and others, 1963, p. 40.	Produced some cross- and mass-fiber asbestos. Contains some vermiculite.
J2	Middleton	Dunite					X			Hunter, 1941, p. 87–91; Honeycutt and Heimlich, 1980.	Small olivine resource (table 6).
J24	Prospect	Pyroxenite	X							Conrad and others, 1963, p. 37.	Some prospecting but no production on a small deposit.
J18	Rattlesnake	Peridotite	X		M					Conrad and others, 1963, p. 34–35; Pratt and Lewis, 1905, p. 206.	Mass-fiber asbestos resource.
J26	Round Mountain	Peridotite	M							Conrad and others, 1963, p. 36.	Mined out. Worked 1956–57.

Table 5. Summary of high-magnesium and ultramafic rock deposits that have been mined or prospected for various mineral commodities *(cont.)*

Map No.	Deposit	Rock type	A	Ch	C	N	O	T	V	References	Remarks
J20	Sapphire	Dunite	M		M					Conrad and others, 1963, p. 34; Pratt and Lewis, 1905, p. 254.	Worked for both asbestos and corundum.
J16	Sheep Cliff Mountain.	Dunite							X	Murdock and Hunter, 1946, p. 39.	Large exposures of dunite north of Sheep Cliff Mountain.
J5	Webster	Dunite, websterite.		M		X	X		X	Hunter, 1941, p. 91–97; Hunter and others, 1942, p. 9–12; Murdock and Hunter, 1946, p. 27; Pratt and Lewis, 1905, p. 92–97; Pawel, 1939; Ross and others, 1928; Hunter and Mattocks, 1938; Miller, 1953.	Large olivine resources (table 6); prospected for nickel and chromite. Less than 600 tons of chromite produced. Small chromite placers present. Some prospecting for nickel and minor production on trial basis in 1910.
Macon County:											
M1	Adams Place	Soapstone						X	X	Murdock and Hunter, 1946, p. 36.	Small deposit of poor-quality vermiculite.
M10	Corundum Hill (Cullasaja).	Dunite		X	M		X		M	Hunter, 1941, p. 103–106; Murdock and Hunter, 1946, p. 31, 34; Prindle and others, 1935, p. 43; Hunter and others, 1942, p. 15; Pratt and Lewis, 1905, p. 246–248; Yurkovich, 1977; Ballard, 1947a; Larson and Lesure, 1965, p. 62–66; Lewis, 1896, p. 34–35.	Olivine resources (table 6). Corundum production may be as much as 6,700 tons. Vermiculite mined intermittently. Latest work has been as tourist attraction for gem corundum.
M15	Cunningham	Soapstone	X					X		Hatcher, 1980	
M6	Deposit #9 (Ellijay; Higdon; McGuire).	Dunite	M	M	M		X		X	Hunter, 1941, p. 100–102; Hunter and others, 1942, p. 16; Murdock and Hunter, 1946, p. 31; Conrad and others, 1963, p. 41–42; Dribus and others, 1982; Pratt and Lewis, 1905, p. 247–248.	Olivine resources (table 6). Limited amount of good-quality asbestos produced.
M17	Dobson Mountain	Pyroxenite			X (emery)					Friedman, 1952, 1956; Pratt and Lewis, 1905, p. 251.	Minor amount of emery produced.
M5	Ellijay Creek	Dunite					X		M	Hunter, 1941, p. 100; Murdock and Hunter, 1946, p. 31.	Small olivine resources (table 6). Small production of vermiculite.
M16	Fairview Ridge	Pyroxenite			X (emery)					Friedman, 1952, 1956; Pratt and Lewis, 1905, p. 249.	Minor amount of emery produced.
M8	Higdon Mountain	Dunite			M				X	Murdock and Hunter, 1946, p. 36; Pratt and Lewis, 1905, p. 249.	
M9	Jacob Knob	Dunite (?)	X		M				X	Conrad and others, 1963, p. 41.	
M2	Vance Jennings	Soapstone							X	Murdock and Hunter, 1946, p. 36.	Small deposit of good-quality vermiculite.

Table 5. Summary of high-magnesium and ultramafic rock deposits that have been mined or prospected for various mineral commodities *(cont.)*

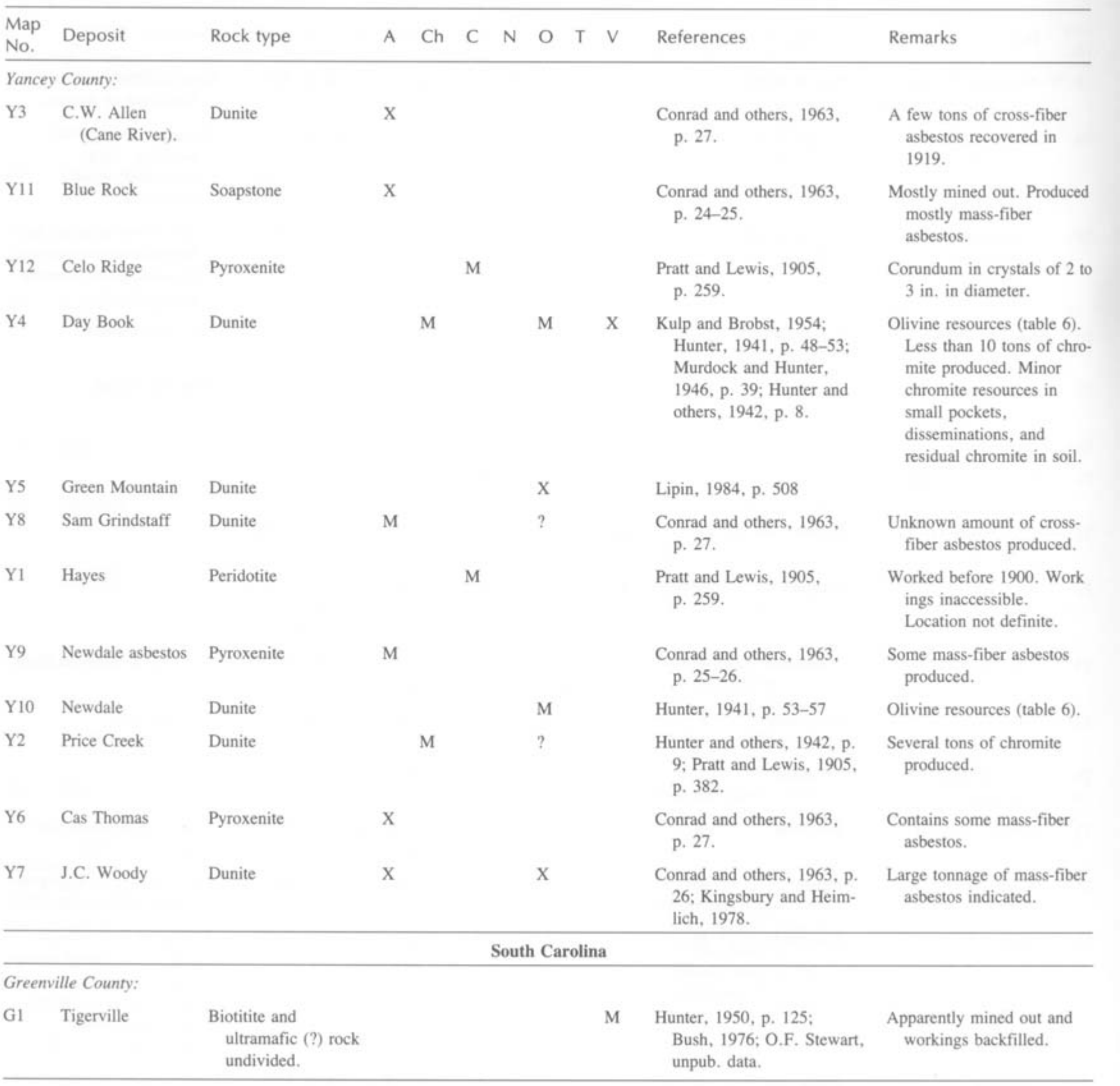


Map No.	Deposit	Rock type	A	Ch	C	N	O	T	V	References	Remarks
M4	Bud Mincey	Dunite			M		X		M	Murdock and Hunter, 1946, p. 31; Hahn and Heimlich, 1977; Pratt and Lewis, 1905, p. 248.	Contains resources of vermiculite (?).
M7	Charlie Mincey	Dunite			X				X	Murdock and Hunter, 1946, p. 34.	Low-grade vermiculite.
M3	Moores Knob (Ammons; Angel).	Dunite			X	X	X		M	Murdock and Hunter, 1946, p. 28–31; Hunter, 1941, p. 98–100.	Extensive workings and considerable vermiculite produced.
M14	Norton (Commissioners Creek).	Dunite	X	X			?	X	X	Hunter, 1941, p. 106–107; Murdock and Hunter, 1946, p. 36; Hunter and others, 1942, p. 16; Conrad and others, 1963, p. 42; Hatcher, 1980.	Small amounts of mass-fiber asbestos produced.
M20	Peek	Amphibolite			X					Pratt and Lewis, 1905, p. 182–183.	Small prospects for corundum.
M13	Peterman	Soapstone	M							Conrad and others, 1963, p. 42; Hatcher, 1980.	Large tonnage of mass-fiber asbestos produced before 1950.
M12	Pine Grove School	Dunite	X		X				X	Murdock and Hunter, 1946, p. 34.	Prospected for vermiculite with poor results and also for corundum.
M18	Raby (Burningtown)	Pyroxenite			X					Pratt and Lewis, 1905, p. 249; Eckert, 1984, p. 344–347; Keith, 1907a.	Operated as tourist mine. Minor amounts of corundum.
M11	Salem School	Dunite			X				X	Murdock and Hunter, 1946, p. 34.	Prospected for vermiculite.
M19	Sheffield	Amphibolite			X					Pratt and Lewis, 1905, p. 216–219, p. 249.	Shaft and surface pits. Operated in 1960's for tourist trade.
Madison County:											
MA1	Holcombe Branch (Carter mine).	Dunite		M	M		X		X	Hunter and others, 1942, p. 7; Hunter, 1941, p. 58–61; Murdock and Hunter, 1946, p. 36; Pratt and Lewis, 1905, p. 258.	Contains olivine resources (table 6). More than 20 tons corundum produced in 1886. Contains vein and disseminated chromite and chromite-rich placers.
Mitchell County:											
MI1	Carter's Ridge N	Soapstone	X							Conrad and others, 1963, p. 24.	
MI2	Carter's Ridge S	Dunite	X				?			Conrad and others, 1963, p. 24.	May have potential for mass-fiber asbestos.
MI3	"Woody Place"	Dunite	X			X	X			Pratt and Lewis, 1905, p. 56; Brobst, 1962, Plate 1 west half.	
Swain County:											
S1	Bryson	Metaperidotite, metagabbro.			X	?				Cameron, 1951, p. 9–10; Pratt and Lewis, 1905, p. 47.	Corundum reported in dunite by Pratt and Lewis, not found by Cameron.
S2	Lundsford prospect	Talc in Murphy Marble.						X		Van Horn, 1948, p. 49, no. 33–34.	Some prospecting and minor production. Workings abandoned.

Table 5. Summary of high-magnesium and ultramafic rock deposits that have been mined or prospected for various mineral commodities *(cont.)*

Map No.	Deposit	Rock type	A	Ch	C	N	O	T	V	References	Remarks
S3	Nantahala Talc and Limestone Company.	Talc in Murphy Marble.						X		Van Horn, 1948, p. 49, no. 35.	Some drilling and an adit. Minor talc in pockets.
S4	Hewitt Shaft, Nantahala Talc and Marble Co.	Talc in Murphy Marble.						X		Van Horn, 1948, p. 50, no. 36–37.	Extensive underground workings. Large production. Now abandoned.
S5	North Carolina Talc and Mining Company.	Talc in Murphy Marble.						X		Van Horn, 1948, p. 50, no. 38.	Extensive workings on Talc Mountain now abandoned. Reported many thousand tons production.
S6	Blowing Spring prospect.	Talc in Murphy Marble.						X		Van Horn, 1948, p. 51, no 39.	Some talc found.
S7	Prospects							X		Van Horn, 1948, p. 51, no. 40–41.	Minor talc found.
Transylvania County:											
T6	Bearwallow Creek	Peridotite							X	Murdock and Hunter, 1946, p. 38.	
T1	Buck Mountain	Dunite			M					Murdock and Hunter, 1946, p. 39.	
T9	Burnt Rock	Peridotite			M					Murdock and Hunter, 1946, p. 39; Pratt and Lewis, 1905, p. 255–256.	
T7	L.E. Cash	Pyroxenite	X							Conrad and others, 1963, p. 32.	Slip-fiber asbestos on dump.
T11	Fisher	Pyroxenite	X							Conrad and others, 1963, p. 32.	Small deposit.
T8	Great Hogback Mountain.	Peridotite							X	Murdock and Hunter, 1946, p. 39.	
T2	Jennings No. 1	Peridotite	M							Conrad and others, 1963, p. 31–32.	Small tonnage mass-fiber asbestos in 1957.
T13	Kilpatrick	Dunite	M							Conrad and others, 1963, p. 29.	Large tonnage of high-grade anthophyllite produced.
T4	Miller	Pyroxenite	M						X	Conrad and others, 1963, p. 30–31.	Prospected by Powhatan Mining Co. Small tonnage mass-fiber asbestos produced; may contain large resources of asbestos.
T5	Oakland	Pyroxenite	M							Conrad and others, 1963, p. 29–30.	Small amount of mass-fiber asbestos produced.
T3	Socrates	Peridotite	X		M				X	Murdock and Hunter, 1946, p. 39; Conrad and others, 1963, p. 32; Pratt and Lewis, 1905, p. 44, 254.	Contains asbestos resources. Produced some corundum in 1890's.
T10	Toxaway Lake	Pyroxenite	X		X					Conrad and others, 1963, p. 32.	Prospected for asbestos and corundum. Small deposit.
T12	Walnut Cove	Peridotite	M							Conrad and others, 1963, p. 30.	Abandoned in 1950's. Small amount of mass-fiber asbestos produced. Workings backfilled.

Table 5. Summary of high-magnesium and ultramafic rock deposits that have been mined or prospected for various mineral commodities (cont.)



Map No.	Deposit	Rock type	A	Ch	C	N	O	T	V	References	Remarks
Yancey County:											
Y3	C.W. Allen (Cane River).	Dunite	X							Conrad and others, 1963, p. 27.	A few tons of cross-fiber asbestos recovered in 1919.
Y11	Blue Rock	Soapstone	X							Conrad and others, 1963, p. 24–25.	Mostly mined out. Produced mostly mass-fiber asbestos.
Y12	Celo Ridge	Pyroxenite			M					Pratt and Lewis, 1905, p. 259.	Corundum in crystals of 2 to 3 in. in diameter.
Y4	Day Book	Dunite		M			M		X	Kulp and Brobst, 1954; Hunter, 1941, p. 48–53; Murdock and Hunter, 1946, p. 39; Hunter and others, 1942, p. 8.	Olivine resources (table 6). Less than 10 tons of chromite produced. Minor chromite resources in small pockets, disseminations, and residual chromite in soil.
Y5	Green Mountain	Dunite					X			Lipin, 1984, p. 508	
Y8	Sam Grindstaff	Dunite	M				?			Conrad and others, 1963, p. 27.	Unknown amount of cross-fiber asbestos produced.
Y1	Hayes	Peridotite			M					Pratt and Lewis, 1905, p. 259.	Worked before 1900. Workings inaccessible. Location not definite.
Y9	Newdale asbestos	Pyroxenite	M							Conrad and others, 1963, p. 25–26.	Some mass-fiber asbestos produced.
Y10	Newdale	Dunite					M			Hunter, 1941, p. 53–57	Olivine resources (table 6).
Y2	Price Creek	Dunite		M			?			Hunter and others, 1942, p. 9; Pratt and Lewis, 1905, p. 382.	Several tons of chromite produced.
Y6	Cas Thomas	Pyroxenite	X							Conrad and others, 1963, p. 27.	Contains some mass-fiber asbestos.
Y7	J.C. Woody	Dunite	X				X			Conrad and others, 1963, p. 26; Kingsbury and Heimlich, 1978.	Large tonnage of mass-fiber asbestos indicated.
							South Carolina				
Greenville County:											
G1	Tigerville	Biotitite and ultramafic (?) rock undivided.							M	Hunter, 1950, p. 125; Bush, 1976; O.F. Stewart, unpub. data.	Apparently mined out and workings backfilled.

The origin of the Blue Ridge mafic and associated ultramafic rocks has been the subject of much speculation. Several writers have proposed that these rocks represent parts of ophiolites, complex plutons, or melange terranes (Misra and Keller, 1978; McElhaney and McSween, 1983; Misra and McSween, 1984; Hatcher and others, 1984; Abbott and Raymond, 1984). Shaw and Wasserburg (1984), using isotopic data, pointed out that, although some of the large dunites and associated mafic complexes like Lake Chatuge and Chunky Gal have a depleted mantle signature and may be fragments of oceanic crust, others like Webster-Addie are not isotopically similar to oceanic crust or to other Blue Ridge ultramafic bodies analyzed. They inferred diverse origins for the Appalachian mafic rocks. Lipin (1984), studying the chromite in the dunites in North Carolina, concluded that the Blue Ridge dunites are probably remnants of ophiolites emplaced before or during peak metamorphism. Later metamorphism dehydrated the serpentine-bearing rocks to form olivine and altered the chromite compositions and textures.

Asbestos

Asbestos deposits in the Blue Ridge of North Carolina are associated with metaperidotite and metapyroxenite bodies (table 5). The recorded production (J.H. DeYoung, Jr., 1984, written commun.) in the Knoxville 1°x2° quadrangle is as follows for three counties:

Jackson County........	1,742 tons (1970-72)
Transylvania County ..	1,900 tons (1950-71)
Yancey County	22,548 tons (1919-77)

Conrad and others (1963, p. 21) estimated past production for North Carolina as at least 100,000 tons from Avery, Jackson, Macon, Mitchell, and Transylvania Counties in the Blue Ridge and Caldwell County in the Piedmont.

Conrad and others (1963) studied many of the more promising deposits. They reported that all of the asbestos of commercial value in North Carolina is fibrous anthophyllite that has characteristically short and only slightly flexible fibers of low tensile strength. It has been used extensively in fireproofing, roofing shingles, pipe covering, wall board, and floor tile. It has better resistance to heat and acid than chrysotile.

Anthophyllite occurs in three principal forms: cross-fiber veins, slip-fiber veins, and mass-fiber deposits. Most of the production is from mass-fiber deposits. All the North Carolina deposits are generally small because the ultramafic bodies are small. Development of fibrous or asbestos forms of anthophyllite seems largely dependent on the degree of weathering (Conrad and others, 1963, p. 20), and most deposits cannot be expected to go very far underground.

Demand for asbestos is down because of environmental concerns. Resources of asbestos in the Knoxville quadrangle are probably equal to past production or 100,000 tons of mass-fiber anthophyllite (Conrad and others, 1963, p. 21).

Chromite

Chromite, which is present in small quantities in most of the peridotites in the Knoxville 1°x2° quadrangle, occurs in three forms: massive or segregated chromite, sand or disseminated chromite, and chromite sand in colluvium or alluvium (Hunter, 1938; Hunter and others, 1942, p. 4; Lipin, 1984, p. 510-511). Massive chromite forms small lenses and irregular seams, pods, and veins, commonly near the contact of the peridotite and the country rock (Lewis, 1922, p. 114-115; Hunter, 1938, p. 18). Sand chromite is the name applied to disseminated but more thickly spaced chromite crystals in peridotite, generally in layers separated by peridotite containing much less chromite. Chromite sand, on the other hand, consists of crystals and fragments of chromite in clay derived from weathered peridotite. Minor production of chromite has come from Democrat and Morgan Hill in Buncombe County, Dark Ridge and Webster in Jackson County, Holcombe Branch in Madison County, Deposit No. 9 in Macon County, and Day Book and Price Creek in Yancey County (table 5). Recorded production (J.H. DeYoung, Jr., 1984, written commun.) is as follows for three counties:

Buncombe County.....	38 tons (1918)
Jackson County........	229 tons (1918)
Yancey County........	150 tons (1909-18)

Total production according to Hunter and others (1942, p. 1) is less than 1,000 tons. Resources of chromite are small. Residual placers and alluvial resources are present at Democrat, Webster, and Corundum Hill, vein and lens chromite at Day Book and Dark Ridge, and disseminated chromite at Webster (Hunter and others, 1942, p. 1-2). Unexposed dunite bodies are probably present in the metamorphic rocks of the Blue Ridge but significant effort would be required to locate them. The known bodies are generally small and have no known geochemical halo except for a few feet of alteration at the contact with country rock. Detailed ground geophysical methods have been used to determine the shape and size of known bodies (Hunter and others, 1942, p. 18-28; Hirt and others, 1987; Honeycutt and others, 1981) and might be useful in the search for unexposed bodies. The rewards, however, are probably not worth the cost of such exploration.

Corundum

Systematic mining of corundum for abrasive use began at the Corundum Hill deposit, Macon County, N.C., in the fall of 1871 (table 5), and from then until 1898 the deposits in North Carolina and adjacent Georgia supplied most of the U.S. demand (Pratt and Lewis, 1905, p. 361-362). Corundum mining in the United States ceased in 1905 but was reactivated in 1917-19. During World War II some additional prospecting was done (Ballard, 1947a and b), but little or no mining was done. Total production figures are not available, but the mines in the Knoxville quadrangle (table 5) probably produced a total of more than 7,000 tons of cleaned corundum. The largest recorded production is from the Corundum Hill mine, 6,700 tons (French and Eilertson, 1968, p. 265), which is followed by Buck Creek, 230 tons, Joe Mincey, 150 tons, and the McChastain (Cowarts?), more than 20 tons.

Corundum is generally found associated with alteration zones along the margins of peridotite or pyroxenite bodies or along internal fractures, especially where the bodies have been cut by granite or pegmatite. Corundum also occurs in lesser amounts in amphibolite at the Sheffield mine, Macon County, N.C., and in mica gneiss or schist on Scaly Mountain in Clay County and near Retreat in Haywood County, N.C. (table 5).

Emery, a mixture of corundum and magnetite or corundum and spinel (spinel emery), has been produced from several small deposits in amphibolite and metapyroxenite south of Franklin, N.C. (table 5). The Fairview mine, Macon County, N.C., produced about 100 tons in 1898 (Pratt and Lewis, 1905, p. 251), and some emery was also produced from the Day Book deposit in Yancey County in 1918 (Stuckey, 1965, p. 351).

Because of deep weathering, only saprolite is exposed around the old workings of the Fairview and Dobson Mountain emery mines south of Franklin. Fresh amphibolite on the dump of a caved adit near the Fairview mine may be a metapyroxenite. No emery was found on the dumps in 1963 (Lesure, unpub. data).

During the past three decades several of the corundum deposits in Macon County have been opened to the public for mineral collecting. These include the Corundum Hill, Mincey, Raby, and Sheffield mines, and the corundum-bearing gravels along Caler Fork of Cowee Creek, which have yielded many fine rubies.

Because most of the abrasive needs are now supplied by artificial materials, there is little or no commercial demand for the North Carolina corundum. Continued demand for ruby and sapphire collecting by mineral collectors and tourists can be anticipated.

Nickel

The dunite bodies in the Blue Ridge contain from 0.1 to 0.4 percent nickel, mostly in olivine (Ross and others, 1928, p. 545). During weathering this nickel is released and forms the hydrous nickel silicate minerals collectively called gamierite. The nickel silicates tend to migrate through the soil and saprolite and to concentrate near the base of the saprolite or weathered material. Analyses of soils over some of the dunites in the Knoxville quadrangle show nickel contents ranging from 0.47 to 3.1 percent and concentration ratios of 2:1 to 4:1 (Worthington, 1964, p. 106). One of the largest of these nickeliferous zones is along the northeastern edge of the Webster-Addie dunite, south and east of Webster, N.C. This zone is 500 ft wide and 2 mi long (Stuckey, 1965, p. 329) and has an average NiO content of 1.5 percent (Pawel, 1939, p. 36). This area has been extensively explored since 1887 (Barlow, 1906, p. 304-305). Thomas Edison, who became interested in nickel sources, visited the deposit in 1905, and C.T. Henning erected an electric-furnace reduction plant in 1910 (Pawel, 1939, p. 36). The Consolidated Nickel Co. attempted to work the deposit in 1912 but reported no production. Worthington (1964) made a geochemical survey of ultramafic rock in the Blue Ridge looking for areas that might have lateritic nickel ore similar to deposits in Cuba. His minimum target for development was a square mile of nickeliferous ultramafic rock overlaid by at least 25 ft of lateritic soil having a nickel content averaging more than 1 percent nickel, which would contain 25,000,000 tons of usable material. Estimates of the nickel resources at Webster are 2,500,000 tons of soil and saprolite containing 1 percent nickel (Stuckey, 1965, p. 329), well below the minimum requirement. Because the Webster deposit is the largest known in the Knoxville quadrangle, the potential for additional nickel deposits that might be economic are nil. Even if larger dunite deposits are found that are not fully exposed or not exposed, the only hope for nickel deposits is in weathered material or just below deeply weathered rock. The less surface area that is available for weathering, the smaller the potential deposit will be.

Olivine

Olivine, for use in refractories, foundry sand, and even sandblasting, has been produced for many years from several of the dunites in the Blue Ridge (table 5); however, production records are poor. The U.S. Bureau of Mines listed a production of 65,000 tons of olivine from Jackson County, N.C., under "sands" from 1960 to 1969 (J.H. DeYoung, Jr., 1984, written commun.). Stuckey (1965, p. 425) reports an annual production in excess of 10,000 tons of olivine from 1954 through 1963. Much of this production was probably from the Addie deposit and the rest from Day Book and Newdale (table 5) and from the Frank deposit in Avery County outside the Knoxville quadrangle. The Addie and Day Book deposits were being worked in 1988, but the Addie is reported to have been closed in August 1988 (Griffiths, 1989, p. 28).

Resources of olivine (table 6) were estimated for 22 of the larger deposits by Hunter (1941). These resource estimates indicate sufficient material for the foreseeable future and do not encourage prospecting for additional concealed deposits.

Platinum-Group Elements (PGE's)

No deposits of PGE's are known in the Knoxville quadrangle. A few grains of native platinum have been reported in stream-sediment samples from Habersham and White Counties, Ga., in the Greenville quadrangle just south of the Knoxville quadrangle (Hurst and Crawford, 1964, p. 17; Hurst and Otwell, 1964, p. 14), and sperrylite, a platinum arsenide, has been reported as a few minute grains in the gravels from Cowee Creek, Macon County, N.C. (Hidden, 1898; Pratt and Lewis, 1905, p. 333). PGE analyses of samples of dunite, amphibolite, and metapyroxenite from the Knoxville quadrangle (fig. 15) show uniformly low values for platinum, palladium, and rhodium (table 7). The higher values are in metapyroxenite, and the highest values are in saprolite developed on metapyroxenite. These values are 1 or 2 orders of magnitude lower than minimum ore grade.

Soapstone and Talc

Soapstone in the Blue Ridge part of the Knoxville quadrangle was probably one of the earliest used rock types. Indian quarry sites in small impure soapstone deposits were

Table 6. Olivine resources (in short tons) in the Knoxville 1°x2° **quadrangle**

[Data from Hunter, 1941. Locations shown on pi. 1]

Map No	Deposit	Dunite	Serpentinized dunite
J4	Addie	28,350,000	102,400,000
Jl	Balsam	17,330,000	32,860,000
CL1	Buck Creek	52,820,000	300,000,000
J7	Cane Creek	1,800,000	3,100,000
M10	Corundum Hill	700,000	6,970,000
J3	Dark Ridge	16,550,000	24,500,000
Y4	Day Book	3,180,000	6,710,000
Bl	Democrat	2,000,000	25,000,000
M6	Deposit No. 9	5,020,000	7,020,000
M5	Ellijay Creek	315,000	300,000
MA1	Holcombe Branch	3,530,000	17,500,000
HI	Hominy Grove'	1,000,000	20,000,000
J2	Middleton	500,000	100,000
M3	Moores Knob	14,000	42,000,000
Y10	Newdale	1,560,000	5,090,000
B4	Newfound Gap	1,310,000	6,640,000
M14	Norton		10,000,000
J5	Webster	58,150,000	167,890,000

'Recent work suggests this deposit is much smaller (Merschat and **Wiener,** 1988).

the source for soapstone vessels commonly used by Late Archaic to Early Woodland cultures, 500-2000 B.C. (Coe. 1964). Later, European pioneers used the same rock types as sources of easily cut dimension stone for making door lintels and sills and fireplace hearths. In 1868 a deposit on Walnut Creek in Madison County, near Marshall, N.C., was worked for blocks 15-20 ft across to be used as liners for iron-smelting furnaces (Stuckey, 1965, p. 456). Minor use in this manner has continued into the present. Most of the deposits are too small to have other than local use. The Juno deposit, east of Leicester, N.C. (table 5, B3), was estimated by Hunter (1941, p. 64) to contain 95,000 tons of "quarrable" serpentine. Production of ground soapstone and talc crayons from at least five of the better soapstone deposits associated with ultramafic deposits in the area around Marshall and Mars Hill, Madison County, N.C., began about 1920 and continued until the late 1940's (Stuckey. 1965, p. 457). Production of 11,600 tons has been reported for the county, 1903 to 1945 (J.H. DeYoung, 1984, written commun.).

The most important talc deposits in the quadrangle, however, are metamorphic deposits in dolomitic units of the Murphy Marble (Van Horn, 1948). These deposits are not related to ultramafic rocks but may be in part related to metadiorite sills that intrude the metasedimentary rocks 300-450 ft stratigraphically above or below the marble (Van Horn, 1948, p. 15-18, 29). The talc-producing area extends for more than 35 mi in Clay, Macon, and Swain Counties, N.C. From 1898 to 1977 more than 120,000 tons of ground talc and talc crayons were produced in this area (J.H. DeYoung, Jr., 1984, written commun.). Recent production has been from several large deposits near Murphy, N.C., just southwest of the Knoxville quadrangle.

Vermiculite

Vermiculite, a micaceous mineral produced by weathering of biotite, chlorite, or phlogopite, is used to make lightweight aggregate, soil conditioners, insulation, and mineral filler (Bush, 1976). Two different types of deposits are present in the quadrangle: the Blue Ridge type and the Piedmont type (Hunter, 1950). Most of the ultramafic bodies of the Blue Ridge part of the quadrangle contain some vermiculite along the serpentinized contacts of the ultramafic body and enclosing country rock and along fractures within the ultramafic body where intruded by granite and pegmatite (Murdock and Hunter, 1946, p. 9; Hunter, 1950; Bush and Sweeney, 1968, p. 222; Bush, 1976, p. 148-152). These deposits are generally only a few inches to a few feet thick and a hundred to a thousand or so feet long. At most, they contain only a few thousand tons of ore and are generally worked by pick and shovel in narrow trenches or small open cuts.

In contrast, the Piedmont-type deposit is a product of deep weathering of a large lenticular mass of biotite-rich schist or biotitite covering many acres. These deposits may have developed by metamorphic or metasomatic alteration of pyroxenite or other mafic rock by granitic or syenitic intrusions (Bush, 1976, p. 152-153) or by metamorphism of K-rich ultramafic rocks related to lamproite (Libby, 1975; Bergman, 1987; Butler, 1989). A Piedmont-type deposit was mined at Tigerville, Greenville County, S.C., and several such deposits are being mined in Laurens and Spartanburg Counties, S.C., southeast of the Knoxville quadrangle. These deposits, which can contain 20,000 to 100,000 or more tons of ore (Bush, 1976, p. 153), are mined in large open cuts using large earth-moving equipment.

Production of vermiculite from the Blue Ridge-type deposits began in 1933 from the Bee Tree mine. Buncombe County, N.C., and was followed shortly after by production from the Corundum Hill, Moores Knob, Bud Mincey, and Ellijay Creek deposits, Macon County, N.C. (table 5). Murdock and Hunter (1946, p. 3-4) list production of vermiculite for North Carolina, 1939^1-2, as 4,052 tons and estimate resources of about 380,000 tons in more than 30 deposits in Buncombe, Clay, Jackson, and Macon Counties. Annual production from these small Blue Ridge deposits was probably a few thousand tons between 1946 and 1955, the date of the last production in North Carolina (Bush and Sweeney, 1968, p. 224). Total production is probably about 25,000 tons.

Production of vermiculite from the Piedmont-type deposits is much larger. Greenville County, S.C., has a recorded production of nearly 20,000 tons of vermiculite for 3 years between 1956 and 1969, most of which must have

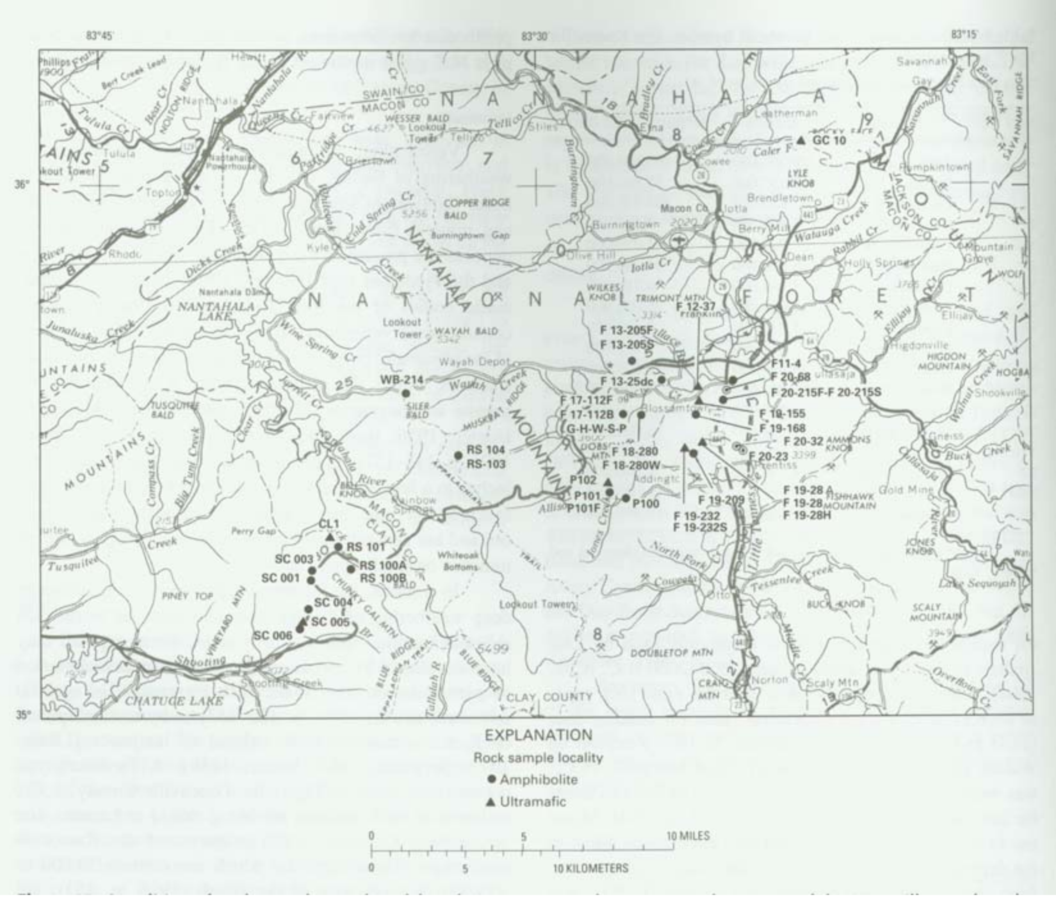


Figure 15. Localities of rock samples analyzed for platinum-group elements, southern part of the Knoxville quadrangle.

come from Tigerville, S.C. (J.H. DeYoung, 1984, written commun.). The deposit at Tigerville has been mined out and the pits backfilled and grassed over, but several deposits in Lauren and Spartanburg Counties, S.C., are now being worked. Resources of the Piedmont-type deposits in the Spartanburg 1°x2° quadrangle south east of the Knoxville quadrangle are large. There is low to moderate potential for additional resources in this type of deposit in the Knoxville quadrangle. Geologic mapping in the Tigerville area is not detailed enough to make resource estimates.

Some lamproites contain diamonds. The biotitites of Laurens and Spartanburg Counties, S.C., have whole-rock chemistry that falls within the range of the diamond-bearing lamproites (Bergman, 1987, p. 118-120). Only one diamond has been reported from South Carolina (Kunz, 1885, p. 730), but this find has been tentatively located in Spartanburg County (McCauley, 1964, p. 22), possibly downstream from the area of the Tigerville vermiculite deposit.

Mineral Commodities Related to Granite and Pegmatite

Mineral commodities related to granite and pegmatite in the Knoxville quadrangle include feldspar, kaolin, mica, quartz, and zircon. Other economically important minerals, such as beryl, columbite-tantalite, spodumene, and uranium and rare-earth minerals, are commonly found in complex, zoned pegmatites but are uncommon, rare, or nonexistent in the Blue Ridge mica pegmatites. The Blue Ridge pegmatites appear to belong in the "ceramic class" muscovite pegmatites of Cemy and Meintzer (1985, p. 171) that form as synmetamorphic segregations in medium- to high-grade

Table 7. Palladium, platinum, and rhodium contents (in parts per billion) of various rock types from the Blue Ridge in the Knoxville 1°x2° quadrangle

[Data from Lipin (1984) marked with asterisk (*), data from Bentzen (1971) marked **, the rest are from David Gottfried and F.G. Lesure (unpub. data). Analyses in USGS Laboratory, Reston, Va., by P.J. Aruscavage, Norma Rait, and Hezekiah Smith, using fire assay and atomic absorption methods. Locality numbers refer to plate 1, figure 15, and table 5]

Map No.	Dunite				Amphibolite					Metapyroxenite and soapstone				
	Locality	Pd	Pt	Rh	Locality	Sample No.	Pd	Pt	Rh	Locality	Sample No.	Pd	Pt	Rh
Y5	*Green Mountain	<0.1	<1	<0.1	Carrol Knob	P100	1.6	3.1	—	Carrol Knob	P102	8.2	150	1
Y4	*Day Book	.3	2	.6		P101	<.5	<1	—	Franklin quad.	F 12–37	1.6	8	<1
Y10	*Newdale	<.1	3	.6		P101F	<.5	<1	—	(Fresh rock)	F 17–112H	12	15	<1
MA1	*Holcombe Branch	.4	<1	<.1	Franklin	F11–4	4	6.4	<1	(Saprolite)	F 17–112W	49	290	1.2
B1	*Democrat	12	8	.7	quad.	F 13–25dc	13	6.8	1		F 17–112S	38	83	2.1
B4	*Newfound Gap	.5	5	1.3	(Fresh rock)	F 13–205F	36	7	1		F 17–112P	14	9.6	—
J1	*Balsam Gap	10	<1	.3	(Saprolite)	F 13–205S	<.5	<1	.5		F 19–28	13	20	<1
J3	*Dark Ridge	3	5	1.3		F 17–112F	10	24	<1		F 19–28H	50	13	<1
J4	*Addie	21	5	1.3		F 17–112B	5.6	19	—		F 19–155	14	27	<1
J4	Addie	3.1	4	.5		F 17–112G	24	4.7	—		F 19–168	18	15	<1
J6	*Chestnut	.2	4	.9	(Fresh rock)	F 18–280	3.6	9	<1	(Fresh rock)	F 19–232	31	30	<1
J5	*Webster	39	24	1.7	(Saprolite)	F 18–280W	<.5	<1	<.5	(Saprolite)	F 19–232S	36	55	5.5
M3	*Moores Knob	.4	3	.8		F 19–28A	<.5	<1	—	Winding Stair	RS–103	4.8	4.2	—
M6	*Deposit #9	11	12	1.5		F 19–209	<1	3	<1	Chunky Gal	SC 005	8.4	6.7	—
M10	*Corundum Hill	<.1	<1	.4	(Fresh rock)	F 20–215F	2	4	<1	Caler Fork	GC 10	4.5	6.8	—
CL1	*Buck Creek	11	5	.7	(Saprolite)	F 20–215S	6.1	5.5	.7	Average (13)[1]		16.5	30	.3
CL1	Buck Creek	<.5	<1	—	Wayah Bald	WB–214	3	1.3	<1	Median (13)[1]		13	15	<1
	Average (17)	6.6	4.7	.7	Chunky Gal	RS 100A	8.4	5.8	—					
	Median (17)	.4	3	.7		RS 100B	7	5	—					
						RS 101	2.4	7.3	—					
	Chromite Concentrate									*Aluminous Schist*				
						SC 001	<.5	<1	—	Franklin quad	F 20–23	2.6	5	<1
	**Addie	13	36	<20		SC 003	1.1	4	—		F 20–32	4	7.2	<1
	**Addie	200	470	76		SC 004	5.2	<	—		F 20–68	4.6	2.4	<1
	**Dark Ridge	<35	<35	<20		SC 006	6.3	2.1	—					
	**Balsam Gap	<45	<45	63	Winding Stair	RS 104	<.5	<1	—					
	**Democrat	<30	<30	43										
					Average (22)[1]	6.1	5.1	.3						
					Median (22)[1]	3.3	4	<1						

[1] Does not include saprolite.

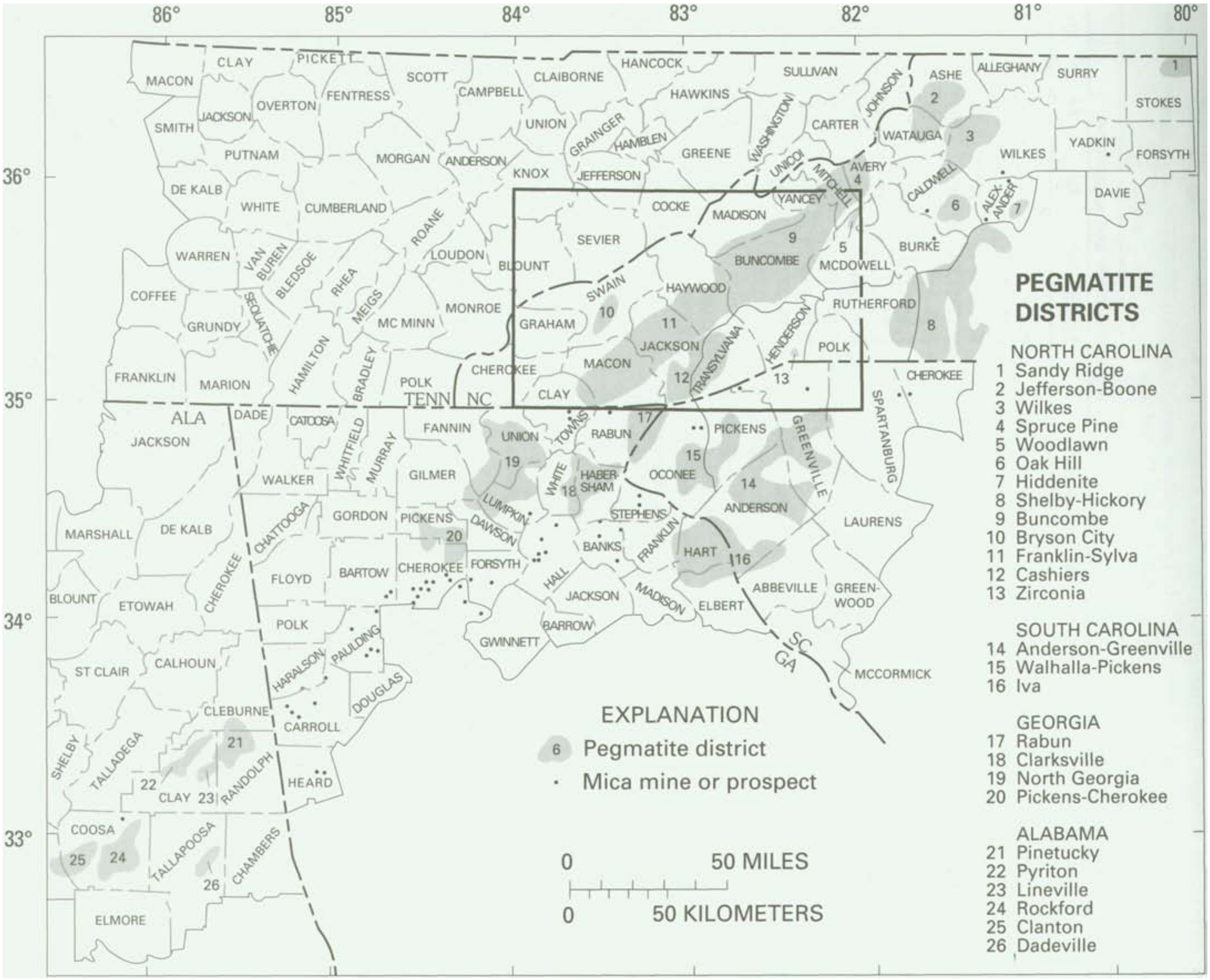


Figure 16. Pegmatite districts and outlying pegmatites in the Southern Appalachians (from Lesure and Shirley, 1968, fig. 84, p. 317).

(Barrovian series) metamorphic belts containing eugeosynclinal sediments.

Seven out of 26 described mica-pegmatite districts in the southeastern United States are wholly or partly in the Knoxville quadrangle (fig. 16), mostly in the east flank of the Blue Ridge. Of these, the Spruce Pine district, which is mostly in the Knoxville quadrangle (fig. 16), is the principal source of feldspar and much of the scrap or flake mica produced in the United States. The Spruce Pine and Franklin-Sylva districts have supplied much of the sheet mica produced in the Blue Ridge in the past, but little sheet mica has been mined in the United States since the end of the U.S. Government buying program in 1962. A complete summary of the pegmatite deposits and the resources of feldspar and mica in the Blue Ridge of North Carolina is given by Lesure (1968), Lesure and Shirley (1968), and Lesure and others (1968). Only minor amounts of geologic work have been done on these deposits since the World War II USGS pegmatite studies (Kesler and Olson, 1942; Cameron, 1951; Olson, 1944 and 1952; Olson and others, 1946; Brobst, 1962; and Parker, 1946 and 1952). The Mineral Research Laboratory of the North Carolina State University, School of Engineering, Asheville, N.C., in cooperation with the North Carolina Division of Mineral Resources, has evaluated feldspar resources in granite, feldspathic gneiss, and pegmatite in North Carolina (Neal and others, 1973) and flake mica resources in mica schist (Lewis and others, 1971). The structure of the feldspar and mica industries has changed rapidly in the past few years (Robbins, 1986; Benbow, 1988). The recovery of a high-purity quartz product containing less than 25 parts per million (ppm) total impurities from the tailings of the feldspar flotation plants in Spruce Pine is the most interesting innovation in the industry in the past decade.

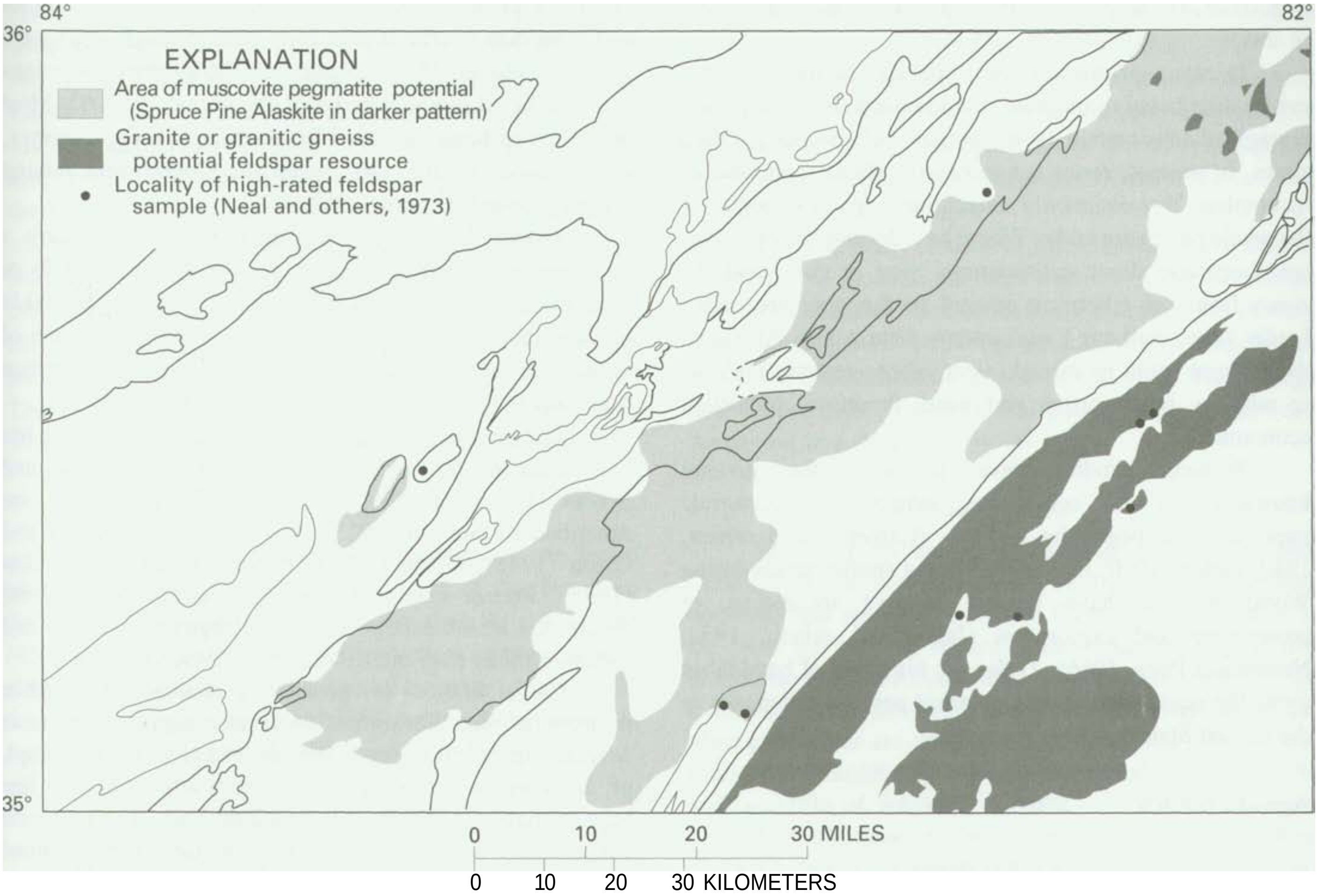


Figure 17. Areas containing pegmatite resources and granite suitable for feldspar production in the Knoxville quadrangle.

Pegmatite Deposits

Deposits of mica-pegmatite in the Knoxville quadrangle occur mostly in the east flank of the Blue Ridge in the Richard Russell and Tallulah Falls thrust sheets (fig. 17, pi. 2). Some feldspar-rich pegmatite bodies occur in the central Blue Ridge around the Bryson City window. The pegmatite bodies are generally restricted to areas having metamorphic conditions of staurolite grade or higher (pi. 2); however, their distribution throughout this high-grade metamorphic belt is uneven, and most large pegmatite districts occur in areas of interlayered amphibolite and mica schist and gneiss sequences. The amphibolite units may provide rheology contrast relative to the schist and gneiss during deformation localizing segregations of synmetamorphic pegmatite melt (Lesure, 1968).

Mica-pegmatites are light-colored, coarsely crystalline igneous rocks, commonly found as dikes or sills in metamorphic rocks or in large granitic intrusions. Individual mineral grains and crystals range in length from an inch or less to many feet, and a large variation in grain size **within** a single pegmatite body is common. Pegmatites range from small pods and thin seams to large masses hundreds of feet thick and thousands of feet long. In general they are tabular or lenticular bodies and may pinch and swell either along strike, down-dip, or both. Where pinch and swell are pronounced, the pegmatite body may appear to be a series of lenses following a narrow zone in the metamorphic country rock. Most lenticular bodies are discoidal, having one axis shorter than the other two, but some have one axis much longer and are best described as pipelike.

Mica-pegmatites are composed mostly of feldspar, quartz, and mica but may contain accessory minerals such as garnet, tourmaline, apatite, and beryl and unusual or rare minerals of many types. Many rare pegmatite minerals are rich in cesium, lithium, molybdenum, niobium, rubidium, scandium, tantalum, thorium, tin, tungsten, uranium, yttrium, zirconium, and the rare earths. The many and unusual minerals found in some pegmatites make them favorite collecting sites for mineralogists and rockhounds.

Plagioclase is generally the most common feldspar in muscovite-rich pegmatite. Perthite or perthitic microcline is generally present and may be abundant in some pegmatites.

In pegmatite mined commercially, the book mica generally constitutes 2-6 percent of the rock mined. Local rich shoots or pockets might have as much as 40 percent muscovite, but large volumes of pegmatite have 2 percent or less.

In many pegmatites the minerals are more or less evenly distributed throughout, but in others the minerals are segregated into certain layers or parts of the body called zones. In general, zones are successive shells, complete or incomplete, that commonly reflect the shape or structure of the whole pegmatite body. Where best developed, the zones are concentric about an innermost zone or core, and the zones from the outermost inward to the core are called border zone, wall zone, and intermediate zones. At places these zones could be mined selectively to recover feldspar **or** mica by hand sorting and were, therefore, important economically.

Previous studies have increased the general knowledge of the occurrence, origin, and economic importance of pegmatite deposits (Cameron and others, 1949; Parker, 1950; Jahns, 1955), and studies made during World War II have helped improve techniques of prospecting and exploration (Jahns and others, 1952; Norton and Page, 1956). Today the high cost of hand labor limits the economic potential of most pegmatite deposits in the United States.

Pegmatite Districts

Spruce Pine District

The Spruce Pine district covers about 300 sq mi in Avery, Mitchell, and Yancey Counties, N.C. (fig. 16). The district has been active for many years and has consistently been the principal producer of mica and feldspar in North Carolina. Mica was mined by the Indians before arrival of the white settlers; traces of their pits and trenches found by the first white settlers were considered to be the workings of old Spanish silver mines (Kerr, 1881; Phillips, 1888; Simonds, 1896). In 1868, T.L. Clingman prospected the Sinkhole mine area in Mitchell County, which had been the site of extensive Indian diggings. The prospect was abandoned, but the following year the Sinkhole mine was opened by the firm of Heap and Clapp of Knoxville, Tenn. Shortly thereafter the Ray mine was opened in Yancey County by G.D. Ray (Sterrett, 1923, p. 168), and within a few years there were more than 20 active mines.

Several thousand pegmatites are exposed in the district, but only a fraction contain minable deposits of sheet or scrap mica. Large masses of alaskite (muscovite granodiorite) in the area are also mined for scrap mica and feldspar.

Some information is available concerning 714 mines and prospects in the Spruce Pine district (Lesure, 1968), of which 472 are within the Knoxville quadrangle. Production data for the district prior to World War I are sparse. Incomplete production records for 130 mines for the period 1917-40 are given by Kesler and Olson (1942, table 4), and fairly complete records for the production from 703 mines and prospects for the period June 1942 through 1945 were kept by Colonial Mica Corporation. More than 100 mines had significant production during the period 1952-62. Most of the mines being operated for sheet mica only, however, were closed in June 1962 when the Government buying program ended (Lesure, 1968).

Within the Spruce Pine district, 67 mines have a recorded individual production greater than 10,000 lb of sheet mica, and 146 mines have produced more than 500 lb but less than 10,000 lb of sheet mica. Total production of sheet mica for the district from 1917 to 1962 was more than 6 million lb.

The general geology of the Spruce Pine district has been described by Olson (1944), Parker (1952), Kulp and Brobst (1956), and Brobst (1962). The pegmatites are described by Sterrett (1923), Maurice (1940), Kesler and Olson (1942), Olson (1944), Parker (1952), and Brobst (1962). Recent mapping along the eastern edge of the district has added details concerning regional structure and metamorphism (Bryant, 1962; Reed, 1964a,b).

Large bodies or groups of bodies of alaskite (muscovite granodiorite) or fine-grained pegmatite occur in several parts of the Spruce Pine district (fig. 16; unit Dqd, pl. 1). These bodies range in size from a few hundred feet long to masses 4,000 ft wide and 2 mi long. Their mineral composition is the same as that of the coarse-grained pegmatites and consists principally of plagioclase, quartz, perthitic microcline, and muscovite. Biotite and garnet are the principal accessory minerals. The average grain size is about half an inch. Inclusions of country rock and masses of coarse-grained pegmatite are common in most alaskite bodies. These alaskite masses are the source of feldspar, flake mica, and quartz where fresh and produce kaolin, mica, and quartz where weathered.

Woodlawn District

The Woodlawn district in McDowell County contains at least 12 small mines in an area about 10 mi long and several miles wide. It is separated from the Spruce Pine district by an area 1-3 mi wide that contains few or no pegmatites (fig. 16). Very little is known about the deposits of this district or other deposits in McDowell County. The principal mining activity was apparently from 1894 to 1918, although no production records exist. Production came from 18 mines in McDowell County during 1942^5, some outside the Woodlawn district, and about 15 mines and prospects have been worked in the county since 1952. The quality of the sheet mica is poor and much is stained; the quantity is small.

Buncombe District

The Buncombe district is an area of widely scattered pegmatites that lies between the Spruce Pine and the

Franklin-Sylva districts (fig. 16). The district is about 24 mi wide and 30 mi long in Buncombe, McDowell, Madison, and Yancey Counties. Ninety mines and prospects are known, but many more small prospects may have been lost and forgotten (Lesure, 1968). Sterrett (1923, p. 184-188) described 11 deposits in Buncombe County. According to the Colonial Mica Corporation records, about 50 deposits were worked during the period 1942-45. At least 20 mines were active at various times from 1952 to 1962. Complete production records are not available, but probably no mine has had production greater than 10,000 Ib of sheet and punch mica. Most of the mines produced less than 500 Ib. Total production for the district may be no more than 50,000 Ib. The average size of the sheet mica is small.

Bryson City District

More than 150 feldspar-rich pegmatites are found near Bryson City, Swain County, west of the Franklin-Sylva district (Cameron, 1951). More than 30 mines have produced feldspar, but only a few prospects on the southeast side of the district have yielded small amounts of sheet mica and some scrap mica. The mica ranges from green to reddish brown, and the quality is generally poor.

Franklin-Sylva District

The Franklin-Sylva district is second to the Spruce Pine district in number of mines and in total production of sheet mica. The district is about 12 mi wide and 50 mi long in Haywood, Jackson, and Macon Counties and extends a short distance into Clay County (fig. 16). Most of the mica mines are located about Franklin, Macon County, and Sylva, Jackson County. Although the number of mines and pegmatites decreases sharply away from the center of the district, the largest single producer is the Big Ridge mine in Haywood County, well away from the center of the district. This mine was opened in 1867 and is one of the first mica mines to be operated in North Carolina. As in the districts to the northeast, several of the large deposits were originally worked by Indians for mica (Smith, 1877, p. 441-443) and clay (Watts, 1913, p. 10; Griffiths, 1929). Clay mining in the district was started in 1888 near Webster (Watts, 1913, p. 10), but little clay has been mined in the district since the 1920's. Some feldspar has been produced sporadically, generally as a byproduct of mica mining.

Information has been assembled on 433 mica deposits in the district (Lesure, 1968), but several hundred others probably have been mined or prospected. Sterrett (1923) described more than 100 deposits in Haywood, Jackson, and Macon Counties. Records of the Colonial Mica Corporation show that from 1942 to 1945 some work was done at 24 mines in Haywood County, 189 in Jackson County, and 157 in Macon County. Olson and others (1946) show the locations of 326 mines and describe in detail 20 mines worked during World War II. More than 150 mines were active in the district from 1952 to 1962.

Production records for the district are not complete. During each major period of production about 10 percent of the mines produced 65-85 percent of the sheet and punch mica. Total production of sheet mica from 1922 to 1962 was more than 3 million Ib.

The pegmatite bodies in the Franklin-Sylva district are similar to those in the other districts in the Blue Ridge of North Carolina. Most of them are tabular dikes that cut quartz-mica gneiss. A few cut the interlayered mica gneiss and schist and hornblende gneiss country rock. The average dike is less than 10 ft thick and 200 ft long and has been weathered to a depth of 10-100 ft.

Cashiers District

The Cashiers district in Jackson and Transylvania Counties is an elongate area, 11 by 30 mi, trending northeast and separated from the Franklin-Sylva district to the west by an area several miles wide containing few prospects. Some 60 mines and propsects are known in the Cashiers district (Olson, 1952), but there may be others. Most pegmatites are tabular sills intruded into mica gneiss, schist, and amphibolite and are associated with large sills and laccoliths of Whiteside Granite.

About 30 deposits were prospected during World War II, and a few mines produced good-quality mica (Olson, 1952, p. 9). Only a few mines and prospects were worked sporadically in the 1950's; production may have been as much as 1,000 Ib of sheet mica.

Feldspar

Feldspar is the general name for a group of anhydrous aluminum silicate minerals that contain varying amounts of potassium, sodium, and calcium. Producers and consumers know feldspar as a beneficiated mixture composed of feldspar minerals with less than 5 percent to more than 20 percent quartz and very small amounts of other minerals. Perthitic microcline ("potash spar"), albite ("soda spar"), and oligoclase ("soda-lime spar") are the principal types of feldspar mined in the Knoxville quadrangle.

From 1960 to 1964 about 54 percent of the feldspar sold in the United States was used in glass, 31 percent in pottery, 4 percent in enamel, and 11 percent in soap, abrasives, mineral fillers, welding-rod coatings, and other miscellaneous uses (Wells, 1965). In 1986 nearly 54 percent was used in glass, 46 percent in pottery, and less than 1 percent in other uses (Potter, 1988, p. 367). The delivered cost per unit of alumina plus alkalies is the basis for determining relative value of competing feldspar products used in the glass industry (Feitler, 1967, p. 20-26). The transportation cost is, therefore, an important element in marketing feldspar for glass. The ceramic industry, however, is more concerned with a particular feldspar and its effect on the delicate balance of ceramic mix, plant operation, and product quality. In general, one feldspar product cannot be substituted for another in a ceramic mix without extensive tests. A ceramic feldspar sometimes is shipped past other producing plants to consumers who would rather pay more freight than change their raw materials.

Feldspar was first mined in the United States in 1825 from pegmatite bodies in Connecticut and shipped to England for use in ceramics (DuBois, 1940, p. 207). Although it has been said that the Native Americans mined and sold partly kaolinized feldspar from western North Carolina before 1744, the first recorded shipment from that State was made in 1911 when W.E. Dibbell recovered feldspar from the dump of the Flat Rock mica mine in Mitchell County and shipped it to the Golding Sons plant in East Liverpool, Ohio. Within several years, North Carolina became a major producer and for many years has produced about half of the annual United States total. In recent years California, Connecticut, Georgia, South Carolina, and South Dakota have been the other important feldspar producers.

Potential resources of feldspar in intrusive rocks of the east flank of the Blue Ridge are very large. In the Spruce Pine district alone, the reserves of feldspar, in alaskite bodies within 50 ft of the surface and recoverable by flotation, exceed 200 million tons (Brobst, 1962, p. A15). No quantitative data exist on reserves or resources of feldspar in zoned pegmatites; many deposits of high-grade potassium feldspar have been worked out. Deposits in most of the pegmatite districts other than Spruce Pine are, in general, too small or too far from a grinding plant to be of economic importance at the present market value of feldspar.

The study of North Carolina feldspar resources by the Asheville Minerals Research Laboratory (Neal and others, 1973) shows that commercial feldspar products can be produced from at least seven areas in the Knoxville quadrangle from granite, granitic gneiss, or feldspathic pegmatite deposits in the east flank of the Blue Ridge and the Inner Piedmont. Resources of feldspar in these areas are large. Any additional detailed geologic mapping could undoubtedly supply additional samples for testing and add details needed for quantitative estimates of the feldspar resource potential.

Kaolin

Deeply weathered pegmatite, granite, and alaskite (muscovite granodiorite) in the east flank of the Blue Ridge in the Knoxville quadrangle contain white clay that is generally kaolinite, halloysite, metahaloysite, or mixtures of all three. This clay has been produced in the Franklin-Sylva and Spruce Pine districts since 1888, but only the Spruce Pine district has current production. This current production is mostly from Avery County, N.C., just east of the Knoxville quadrangle.

Resources of kaolin have been estimated by Hunter (1940) and Parker (1946) to range between 3 and 7 million tons of washed kaolin in the Spruce Pine district. Resources of halloysite are estimated to be greater than 150,000 tons in some of the larger pegmatite deposits in the Spruce Pine, Buncombe, and Franklin-Sylva districts (Hunter and Hash, 1949, p. 9). Because these residual clay deposits are present only where the pegmatite or granite has been in the zone of weathering long enough to form saprolite, the deposits are surficial and are not present at any great depth. For this reason most of the deposits are probably known, but a few may be found in areas not mapped in adequate detail.

Mica

Mica is the general name for several complex hydrous aluminum silicate minerals. The principal mica minerals are muscovite (white mica), biotite (black mica), and phlogopite (amber mica). All have a perfect basal cleavage and form crystals that can be split into thin sheets having various degrees of transparency, toughness, flexibility, and elasticity. Muscovite is the most important commercially in the United States, but some biotite has been mined. Commercial phlogopite comes from Canada and the Malagasy Republic.

Two types of mica are sold: sheet and scrap or flake. Sheet mica must be relatively flat, free from most defects, and large enough that it can be cut in pieces of 1 sq in with a minimum dimension on one side of 3/4 in. Scrap and flake mica include all mica that does not meet sheet mica specifications and is generally ground to a powder. Small sheets of untrimmed mica of poorer quality that can be punched or trimmed into disks 1 in or larger in diameter are classified as punch mica and are included in the general term "sheet mica." Built-up mica made from very thin sheets ("splittings") and reconstituted mica made from delaminated scrap can be substituted for larger sheet mica for some uses.

Although mica was mined by Native Americans more than a thousand years before the whites arrived (Prufer, 1964, p. 90), modem mica mining began in New Hampshire in 1803 and in North Carolina in 1867. The grinding of scrap mica began in a small way in North Carolina about 1870 (Broadhurst and Hash, 1953, p. 13) and grew rapidly after 1890.

North Carolina is the principal mica-producing state in the Appalachians and the nation and has produced more than 90 percent of the total sheet mica and 78 percent of the total scrap mica in Appalachia. Although sheet mica has been produced in 20 counties and scrap mica in 18, the principal sheet-mica-producing counties have been Mitchell, Avery, Yancey, and Macon, listed in order of output;

the principal scrap-producing counties have been Yancey, Mitchell, Avery, and Macon. In 1983 and 1984 North Carolina annually produced about 80,000 tons of scrap and flake mica, much of it from the Spruce Pine district.

Reserves of sheet mica in the Blue Ridge province of the Knoxville quadrangle cannot be calculated from the data available because no development work has preceded mining and no mica-bearing rock is blocked out. An appraisal of the probable amount of sheet mica remaining in the ground, based on the premise that the abundance of pegmatite bodies at depth is almost certain to be almost the same as at the surface, indicates that at least as much mica remains as has been mined. Whether this mica will be found within a few hundred feet of the surface and mined depends largely on such economic factors as domestic market and prices, which influence the amount of prospecting. Under normal market conditions domestic sheet mica cannot compete with foreign imports.

During the last period of Government mica buying, 1952-62, most of the larger producing sheet-mica mines were ones that had been big producers in the past, and many of these were worked out or were left in a condition that will make further mining difficult. The rate of new discoveries was small during both World War II and the 1950's, even though exploration was encouraged by financial assistance from the Federal Government. The deposits exposed at the surface have generally been prospected, and the difficulty and cost of finding unexposed deposits are great. Detailed geologic studies of structural control and country-rock alteration, geochemistry, and geophysics should help locate additional pegmatites with recoverable sheet mica.

The scrap-mica resources in North Carolina are better known than sheet-mica resources. Scrap-mica reserves in the Spruce Pine district are 25,000,000 tons of ore containing 12-18 percent mica (Broadhurst and Hash, 1953, p. 15). In addition, reserves of scrap mica in kaolin deposits in the same district have been estimated as 7.5 million tons, and the amount of scrap mica that can be recovered as a byproduct from feldspar flotation is more than 38 million tons (Brobst, 1962, p. A15-A16). The scrap-mica reserves of the Franklin-Sylva district are confined to a few large pegmatites containing more than 1 million tons of high-grade ore (Broadhurst and Hash, 1953, p. 15).

Resources of flake mica in mica schist in the Blue Ridge and Piedmont provinces are large and will become more important with the increasing use of new methods of recovery (Lewis and others, 1971).

Quartz

Nearly pure quartz is an important component in pegmatite and granite. In 1933, quartz from the core of the Chestnut Flats mine in the Spruce Pine District was used in making the 200-in mirror for the telescope at Mount Palomar Observatory, Calif. (Stuckey, 1965, p. 442-443). In the early 1960's quartz from pegmatites in the Blue Ridge was being mined for use as aggregate in prestressed concrete.

Until recently much of the quartz separated from the feldspar and flake mica by flotation was sold for plaster sand or road sand or was released into the Toe River. In recent years increased pressure from environmental concerns has led to the development of a pure quartz product containing 30 ppm or less of elements other than Si02 from the byproduct from feldspar and mica mining. The demands of the fiber-optic and synthetic quartz crystal industry are for such high-purity quartz, and this market may grow. Resources of this type of silica are large.

Other sources of quartz are also present in the Blue Ridge. Resources of high-silica sandstone in Swain, Madison, and Cherokee Counties, N.C., are large (Broadhurst, 1949; Stuckey, 1965, p. 442), and a large quartz vein in the Shining Rock Wilderness, Haywood County, N.C. (fig. 18), contains more than half a million tons of nearly pure SiO^ (Lesure and Dunn, 1982).

Zircon

Two syenite or quartz-syenite pegmatites near Zirconia, Henderson County, N.C. (fig. 18), produced about 35 tons of zircon between 1888 and 1915 (Olson, 1952, p. 17). Only three deposits have been studied, but there are numerous other pegmatites in an area of a large pendant in the Caesars Head Granite in the Inner Piedmont. Some of the pegmatites are in granite gneiss and some in sillimanite-bearing mica gneiss and schist of the pendant (Olson, 1952, p. 19). The pegmatites are mostly microcline and have vermiculite-rich border and wall zones. In view of the increased demand for zircon, these pegmatites and the district as a whole are a likely target for renewed exploration. The amount ofdetrital zircon in stream gravels near these deposits is unknown but could be large. The area, however, contains numerous vacation homes and may not be receptive to prospecting or mining.

Other Industrial Minerals

Barite

Barite (BaS04) is an abundant and widespread mineral used primarily as an additive because it is heavy, nonabrasive, and inert chemically (Brobst and Hobbs, 1968, p. 270). About 90 percent of the barite consumed in the United States is ground to -325 mesh and added to the fluids used in rotary drilling for oil and gas. Barite mining in the United States began about 1845 in Virginia. In the latter half of the 19th century, many residual and vein deposits in the Appalachian States were mined on a small scale. Much of this barite was used as an adulterant to increase the weight of foods until Federal laws governing

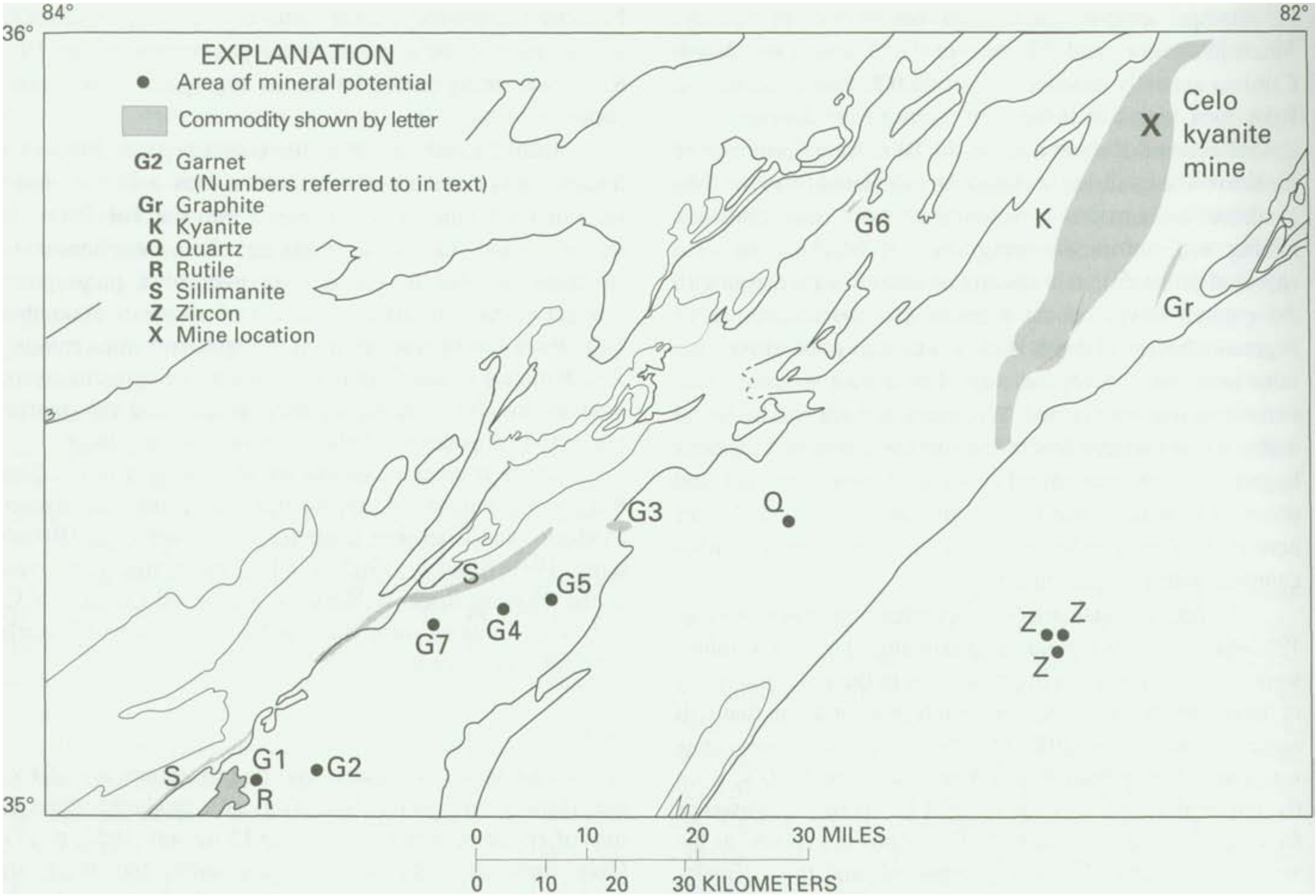


Figure 18. Areas containing resources of garnet, graphite, kyanite, quartz, rutile, sillimanite, and zircon in the Knoxville quadrangle.

food purity were passed. The use of barite in fluid for rotary drilling in petroleum exploration and development began in 1926. This single need increased the demand for barite, and domestic production and imports reached a peak in 1981 but have declined since then.

Two types of barite deposits occur in the Knoxville quadrangle: vein and cavity fillings, and residual. Vein and cavity-filling deposits are those in which barite and associated minerals occur along faults, gashes, joints, bedding and foliation planes, breccia zones, solution channels, and sinkholes. Most barite deposits in bedrock are in the Lower Ordovician and Upper Cambrian Knox Group or in the Late Proterozoic Ocoee Supergroup adjacent to the Proterozoic basement gneisses and are apparently associated with faults and fractures resulting from folding. However, the breccia zones in some areas may have resulted from collapse related to solution of carbonate rocks (Hoagland and others, 1965). Only a few vein deposits like those in the Del Rio district of Tennessee and the Hot Springs district of North Carolina have any potential for commercial value now (fig. 19).

Prospecting in the future might well require the coordinated study and application of methods of economic geology, geochemistry, geophysics, and geomorphology (Laurence, 1960, p. 178). Thrust faults are the keys to locating barite deposits of the Del Rio district of Tennessee (Stuckey, 1928; Ferguson and Jewell, 1951; Maher, 1970) and the adjacent Hot Springs district of North Carolina (Oriel, 1950). In the Del Rio district, most deposits of the Moccasin Gap type are directly beneath a prominent quartzite ledge about 50 ft thick. The veins, commonly containing abundant ankerite, crop out as brown-stained ledges or weather to a distinctive reddish-brown soil. Locally, this type of vein is capped on the surface by silicified or jasperoid-limonite material that sticks up like a backbone (Ferguson and Jewell, 1951, p. 96).

The barite resources in the zone of thrust faults in the Del Rio district of Tennessee and the adjacent Hot Springs district of North Carolina offer good possibilities for additional production, particularly with some favorable changes in the economic conditions. Most of these deposits would have to be mined by underground methods and thus

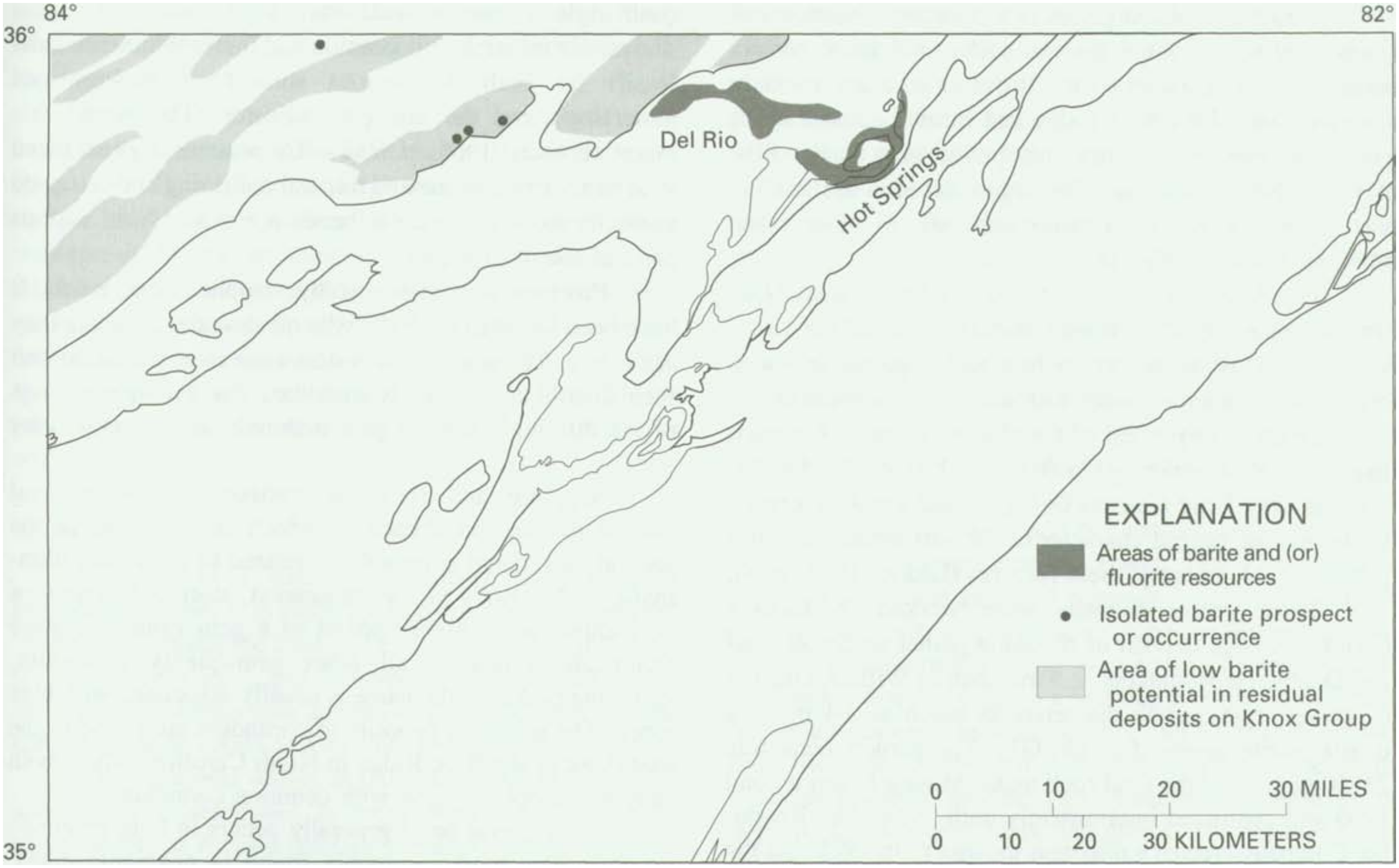


Figure 19. Areas of barite and fluorite resources in the Knoxville quadrangle.

are not competitive with nearby residual deposits that can be mined in open pits. The Del Rio district has an estimated 3 million tons of barite resources, and the Hot Springs district is a "moderate" barite resource (Brobst and Hobbs, 1968, p. 276).

Fluorspar

Fluorspar, a mineral product **of** considerable importance in the national economy, is used mainly (1) in the manufacture of artificial cryolite and aluminum fluoride for the aluminum industry, (2) in the production of hydrofluoric acid used for the manufacture of most fluorine chemicals, (3) as a flux in steelmaking, and (4) in the manufacture of glass and enameled products. Fluorspar is marketed in acid (^97 percent **CaF^),** ceramic (93-95 percent CaF^), and metallurgical grades (>60 percent CaF^) (Van Alstine and Sweeney, 1968, p. 280-287).

Some fluorspar could be recovered from the Del Rio district of North Carolina (Oriel, 1950), where barite and fluorite have replaced granulated and mylonitized rocks along and near thrust faults (fig. 19). The relative quantities of barite, fluorite, and calcite in the deposits vary widely. Fluorite rarely constitutes more than one-third of any given deposit.

Fluorspar deposits in the Del Rio district could merit further attention when the large supply of low-cost imports is no longer available and economic conditions in the domestic fluorspar industry once again favor exploration and development. Newer methods of exploration, mining, and beneficiation also should help make the barite-fluorite-calcite deposits in carbonate rocks more economic. In particular, sink-float processes that separate fluorspar from vein calcite or carbonate wall rock have made the use of lower grade deposits profitable elsewhere in the United States. By this means, some low-grade ores can be upgraded to a metallurgical-grade material, and others become a feed for flotation plants. Methods for making commercial-grade flotation concentrates of fluorite and barite from mixed ores have been described by Eddy and Browning (1964), Browning and others (1963), and Bloom and others (1963).

Garnet

The chief use of garnet is as an abrasive, although the clear, transparent crystals (particularly the deep red ones) have long been used as semiprecious gems. More than 90 percent of production is fabricated into garnet-coated paper and cloth, and the remainder is used as loose grains.

Garnet as isolated grains is a common constituent of gneiss and schist, some igneous rocks, and some contact metasomatic calcareous rocks. It occurs in many rocks in the east flank of the Blue Ridge and Inner Piedmont but is present in minable quantity and quality only in the Blue Ridge of North Carolina. The largest deposits are in Clay and Jackson Counties; smaller ones are in Macon and Madison Counties (fig. 18).

Two large garnet deposits are in Clay County, N.C. **One** at Penland Bald on Buck Creek (fig. 18, G2) is a very large deposit of garnetiferous hornblende gneiss in which crystals of almandite garnet with diameters as much as 2.5 in. make up 3-25 percent of the total rock mass. A similar large deposit on Shooting Creek east ofHayesville (fig. 18, Gl) has very large reserves of high-grade abrasive garnet. However, the rugged character of the surrounding country hinders development of these reserves (Ladoo, 1922, p. 4).

Three garnet deposits were worked in Jackson County. A large deposit of rhodolite garnet on Sugar Loaf and Doubletop Mountains, 2.5 mi south ofWillets, consists of garnet crystals with diameters as much as 3/4 in, in a quartz biotite gniess (fig. 18, G3). The garnets constitute 25-50 percent of the total rock mass. Mining began around 1900 and continued intermittently until 1926. The Rhodolite Company erected a mill near the quarry in 1925, but the operation closed down in 1926 because of the limited market for its product. Nevertheless, large reserves of high-quality, readily accessible abrasive garnet remain. The two other deposits in Jackson County, the Savannah at the head of Betty Creek (fig. 18, G4) and the Presley near Speedwell (fig. 18, G5), were worked intermittently for a number of years around 1900. No information is available about reserves in these two deposits (French and Eilertson, 1968, p. 266).

Deposits elsewhere in North Carolina are small. Southwest of Marshall near Little Pine Creek, Madison County, garnet crystals with diameters of 1-2 in were mined from a zone 8-10 ft thick in a chlorite schist (fig. 18, G6). This mining occurred about 1900 or 1905, and total production was very small. In 1944, garnets were produced as a byproduct of the kyanite concentrating mill of the Celo Mines Company in Yancey County (Stuckey, 1965, p. 351-352).

Garnet abrasives are still widely used in industry, and it is possible that in the future the high-grade deposits in North Carolina may be utilized (French and Eilertson, 1968, p. 265-266).

Gem Stones

The collecting of minerals, rocks, and fossils has become a hobby for an increasingly large number of people. Many "rockhound" clubs exist throughout the country, as well as numerous professional and semiprofessional societies of student and amateur collectors. The Knoxville quadrangle affords a wide variety of rock types, gem stones, ore minerals, uncommon and unusual minerals, and fossils for both the serious student of geology and mineralogy and the amateur collector. The Appalachia report (French, 1968, p. 288-302) presents a generalized treatment of gem-stone and mineral collecting and is a good guide in showing which minerals are available in various parts of the quadrangle.

Precious gem stones (ruby, sapphire, and emerald) have been found in the Knoxville quadrangle, although they are scarce. The semiprecious stones are more abundant, but their distribution is highly irregular. The geologic settings of the different kinds of gem materials and minerals vary widely.

Sapphire and ruby are varieties of the mineral corundum, the occurrence of which is described in the section on mineral commodities related to mafic and ultramafic rocks. Ruby is the transparent, deep-red variety of corundum and is highly prized as a gem stone. Sapphire technically refers to all other gem-quality corundum, including pink, but the name is usually associated with blue tones. The principal deposits of corundum are found in the east flank of the Blue Ridge in North Carolina, where both ruby and sapphire occur with common corundum.

The mineral beryl generally occurs in long prismatic crystals; it is most commonly found in pegmatite dikes. Three important varieties of beryl, used as gem stones, are found sparingly in the Knoxville quadrangle. Emerald is a precious gem with an emerald-green color and is the most valuable gem stone today in its value per carat. Only a few gem-quality stones have been found in the Blue Ridge, but many interesting mineral specimens have been collected. Most of those collected come from the Crabtree Mountain Emerald Mine in the Spruce Pine District (fig. 16). The geologic setting of the Spruce Pine district and other pegmatites in the east flank of the Blue Ridge is similar to that of the emerald-bearing pegmatites in Pakistan (Kazmi and Snee, 1989). Two semiprecious varieties of beryl that are found sparingly in the pegmatite deposits are aquamarine (blue to green) and heliodor (golden yellow).

Of the semiprecious gem stones, the largest group is in the quartz family. Quartz is a very common mineral and is an important constituent of many rock types, although the semiprecious gem varieties are found mostly in veins and pegmatites. The crystalline varieties of quartz provide the following gem stones: rock crystal, which is transparent, crystal clear, and colorless; amethyst, the transparent purple- to violet-colored crystal form; rose quartz, usually massive, transparent to translucent, pink to rose red; smoky quartz, smoky yellow through brown and black, crystals and massive; citrine—clear, transparent yellow; and sagenite, which is the general name for crystals containing inclusions of various other minerals, the most common of which are rutile, hornblende, actinolite, and mica. The cryptocrystalline varieties of quartz are chalcedony, agate, jasper, bloodstone, chert, flint, and petrified wood. Many of these varieties of quartz are present in the Knoxville quadrangle.

Transparent varieties of garnet are considered to be semiprecious gem stones and have been produced in the east flank of the Blue Ridge, although second-class, flawed, or opaque material for mineral collection is much more widespread. Of special interest is the pale lavendar garnet, rhodolite, described from Mason Branch a few miles north of Franklin, Macon County, N.C. (Hidden and Pratt, 1898), in the east flank of the Blue Ridge (fig. 18, G7). Several small open cuts have been opened on Mason Mountain to mine gem-quality garnet, mainly for the tourist trade.

Graphite

Graphite is a naturally occurring form of pure crystalline carbon. It is marketed in three categories termed "flake" (or "crystalline flake"), "amorphous lump and chip" (or "lump and chip"), and "amorphous." The terms reflect the distinctive appearance and physical characteristics of the natural graphite (Weis and Feitler, 1968, p. 303).

Flake graphite occurs as flat, flakelike grains more or less evenly disseminated in metamorphosed sedimentary rocks, where it formed through the alteration of carbonaceous material that was part of an original sediment. Lump and chip graphite occurs as the major constituent of veins that may be found cutting rocks of all kinds. Amorphous graphite is extremely fine-grained, earthy-looking graphite that may make up either a minor or a major part of a slightly metamorphosed sedimentary rock, but the highest quality, and the type most widely used, is formed through the graphitization of coal beds.

Graphite occurs as a minor constituent in some of the mica schists in the east flank of the Blue Ridge (fig. 18). Low-grade amorphous graphite was mined from the Brevard Schist of Early Cambrian age at Graphiteville, McDowell County, N.C. (Keith, 1905, p. 8), where the graphite content is said to reach 25 percent locally (Pratt, 1905, p. 1159). Attempts to produce a refined product in 1911 apparently met with little success.

None of the North Carolina deposits are believed to be of sufficiently high quality and tenor to be of commercial value at present.

Kyanite Group of Minerals

The kyanite or sillimanite group of minerals consists of kyanite, sillimanite, and andalusite—all with the same chemical composition (Al^-SiO^), and the rare mineral mullite (Al^Si^O^). Topaz and dumortierite, which are closely related aluminosilicate minerals containing fluorine (topaz) and boron (dumortierite), are also included in the group. When heated to high temperatures, these minerals convert to the composition of mullite plus silica glass. Refractories made from these materials are commonly known as mullite refractories. Owing to their high alumina content, mullite refractories will withstand high temperatures, abrupt temperature change, and corrosive action, such as occur in metallurgical and glass furnaces and certain types of kilns and boilers (Espenshade and Eilersten, 1968, p. 307). The United States is self-sufficient in the production of kyanite, most of which is mined from deposits in Virginia.

Kyanite, sillimanite, and andalusite are relatively common minerals that are widespread in certain types of metamorphic rocks in many parts of the world; topaz and dumortierite are much less common. In the Southeastern United States, members of the kyanite group occur in several types of deposits: quartzose rock, micaceous schist and gneiss, quartz veins and pegmatites, and stream and beach placers (Espenshade and Potter, 1960; Espenshade, 1962). The kyanite group of minerals is most abundant in quartzose deposits and in some micaceous schist and gneiss. All except dumortierite occur in quartzose deposits east of the Knoxville quadrangle in a belt that extends from central Virginia to eastern Georgia. Kyanite and sillimanite are the only members of the group that are known to occur in abundance within the Knoxville quadrangle, principally as deposits in micaceous schist and gneiss. The deposits lie in several belts.

Kyanite-bearing schist and gneiss are known at various places in the east flank of the Blue Ridge, the major deposits being those of the Bumsville-Swannanoa area in Buncombe, Yancey, and Mitchell Counties, N.C. (fig. 18), where kyanite schist and gneiss occur in a belt several miles wide and about 30 mi long (Espenshade and Potter, 1960, p. 60-62; Brobst, 1962, p. 23-24, Lesure and others, 1982). Kyanite was mined here by the Yancey Cyanite Company (fig. 18) from 1934 to 1944 from surface and underground workings in kyanite-gamet-mica gneiss on the north slope of Bowlens Pyramid at the north end of the Black Mountains in the northern part of the belt (Chute, 1944). Kyanite content of ore mined was 10-11 percent in the early days of operation and 7.0-7.5 percent in July 1943. Brobst (1962, p. A23-A24) estimated a kyanite resource of 40 million tons in rock averaging about 15 percent kyanite in an area about 3 km wide and 16 km long centered on the Celo mine.

Sillimanite schist occurs in the Wame-Sylva belt in southwestern North Carolina (Hash and Van Horn, 1951), and both kyanite and sillimanite have been found together at several places in the Wame-Sylva belt (fig. 18). Investigation of the sillimanite deposits of the Southeastern United States was stimulated during World War II and afterward by difficulties in maintaining adequate supplies of kyanite from domestic production and imports (Teague, 1950). No sillimanite has been mined in the area.

The productive kyanite mines of the Piedmont province east and northeast of the Knoxville quadrangle are

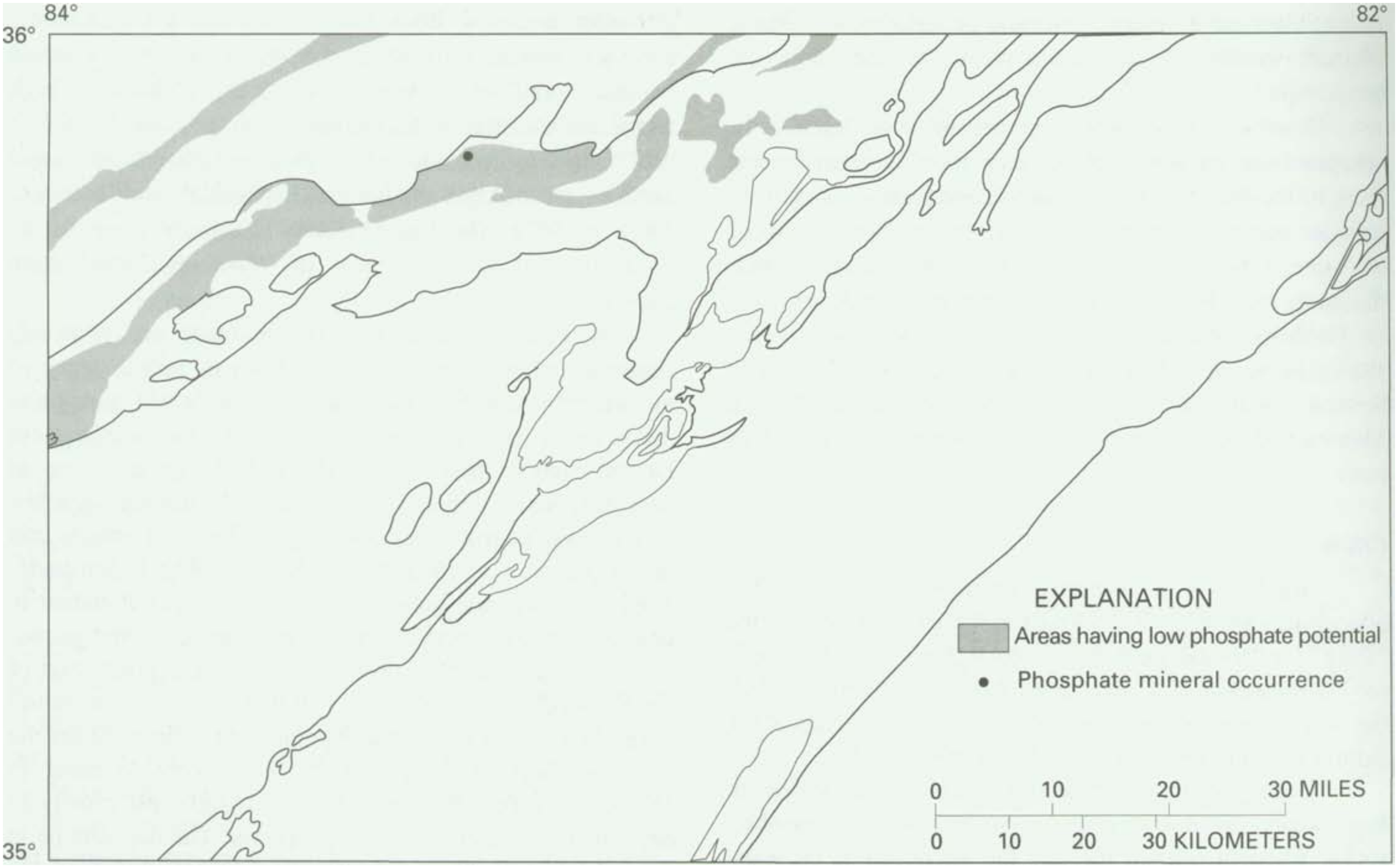


Figure 20. Areas having a low potential for phosphate deposits.

all in quartzose deposits that contain as much as 25-30 percent kyanite. Within the Knoxville quadrangle the amount of metamorphic rock containing kyanite or sillimanite is probably much larger, but the content of kyanite or sillimanite is only about half that of the productive quartzose ores. The resources of kyanite and sillimanite in the Knoxville quadrangle are enormous, and, although at present they cannot compete with deposits outside the quadrangle, they constitute a potential resource for the future.

Phosphate

Phosphate minerals occur in several deposits in the Valley and Ridge and west flank of the Blue Ridge parts of the Knoxville quadrangle, but only two basic types of deposits are of any potential economic importance: (1) bedded phosphate rock containing phosphate nodules, oolites, or grains, or their reworked clastic equivalents, incorporated in Proterozoic and Paleozoic sedimentary rocks; and (2) lateritic or residual accumulations in the sand, clay, or other residuum derived by the weathering of bedrock (Wedow and Stansfield, 1968). The phosphorus content of most of these deposits is much too low for fertilizer raw material.

At Dunn Creek near the East Fork manganese mine about 14 mi northeast of Sevierville, Sevier County, Tenn. (fig. 20), minor amounts of carbonate-fluorapatite occur associated with manganese oxides and pyrite in rocks of the Ocoee Supergroup (Hamilton, 1961, p. A50). In Cooke County, wavellite in small quanitities is associated with manganese oxides in residual material from the Lower and Middle Cambrian Shady Dolomite and Lower Cambrian Rome Formation (Stose and Schrader, 1923). In Blount County, phosphatic nodules and pellets occur in Middle Ordovician shale and limestone (Wedow and Stansfield, 1968, p. 284).

Bedded arkosic phosphorite in the Late Proterozoic Wilhite Formation in Sevier County, Tenn., was first noted by P.B. Stockdale in 1946 (unpublished data). Because of the generally poor exposures in the area, its extent, thickness, and grade have not yet been determined. Information available through 1965 on the occurrence of Proterozoic phosphorite in eastern Tennessee has been summarized by Wedow and others (1966), who demonstrated that phosphorite occurs at many localities in the Late Proterozoic Ocoee Supergroup both as nodules and thin lenses in several black slate units and as pebbles in associated coarser clastic beds. These occurrences indicate the possibility of finding minable phosphate rock in the

Proterozoic sedimentary sequence in the western flank of the Blue Ridge.

Exploration for residual or lateritic deposits should also be made. The wavellite occurrences in the east Tennessee manganese mines, and the abnormally high phosphorus content of the residual manganese and iron ores on the Lower and Middle Cambrian carbonate rocks (Rome Formation and Shady Dolomite) indicate that secondary phosphate is widespread in the Valley and Ridge. Further search and exploration may find minable concentrations. Phosphatic material may have been overlooked, for much residual phosphorite resembles the chert and clay derived from weathering of the parent rock.

Rutile

Rutile and other sources of TiO^ are used primarily for white pigment (96 percent) and other uses including titanium metal (4 percent). Force (1976, p. B2-B30) showed the distribution of rutile in rocks in the east flank of the Blue Ridge in the Knoxville quadrangle. The known rutile resources are in placer deposits in alluvium along the lower reaches of Shooting Creek (fig. 18) and some of its smaller tributaries in Clay County, N.C. (Van Horn, 1945). Seven areas mapped by Van Horn covering an area of more than 700 acres contain several million cubic yards of alluvium containing as much as 12 Ib of rutile to the cubic yard. Williams (1964, table 2) estimated from these data a resource of about 68,000 tons of rutile. The rutile-bearing rocks are in a gamet-mica schist unit that appears to be localized within the Shooting Creek window (Hartley, 1973, p. 46-48) in rocks that have been correlated with the Ocoee Supergroup (Nelson and others, 1987). This area is being developed for vacation homes and a tourist industry. Mining alluvium might encounter environmental or zoning problems. More detailed mapping and petrologic study of the source rock are needed to establish an accurate picture of its distribution.

Other titanium minerals found in the Knoxville quadrangle include titaniferous magnetite, ilmenite, and brookite, which are associated with metamorphic rocks such as gneiss and schist (Herz and Eilertsen, 1968). Weathering of the primary deposits has resulted in saprolite deposits that are slightly richer in titanium. Erosion of the saprolite has produced small alluvial deposis along many streams in the Blue Ridge and Piedmont in North and South Carolina that contain minor concentrations of ilmenite (Williams, 1964).

Small fossil placer deposits of ilmenite and rutile in sandstone of the Snowbird Group are also widespread in Cocke County, Tenn. (Carpenter and others, 1966). These may represent a minor resource but have not been evaluated.

Oil and Gas Potential

The rocks of the Knoxville quadrangle contain no coal and there is no history of commercial hydrocarbon production in the quadrangle. Lacking known resources of organic fuels, the probability of finding commercially exploitable volumes of oil or gas must be estimated from available information on the presence or absence of appropriate hydrocarbon source rocks, reservoir rocks, hydrocarbon traps, seals for the traps, and the degree of thermal alteration of the source rocks. The data on thermal maturation will be discussed first, followed by source rocks and hydrocarbon traps.

Oil occurs in the Appalachian basin and elsewhere at thermal maturation temperatures less than 120 °C, and deposits of dry natural gas tend to occur at maturation temperatures lower than 300 °C. All rocks in the Knoxville quadrangle at chlorite and higher grades of metamorphism (pi. 2) are beyond the temperature windows for hydrocarbon formation; therefore, only the "unmetamorphosed" Paleozoic strata in the northwestern portion of the quadrangle and their subsurface equivalents that dip eastward under the crystalline metamorphic thrust sheets of the Blue Ridge have any potential for hydrocarbon resources.

The 120 °C isograd approximately correlates with the conodont alteration index (CAI) of 2 (Epstein and others, 1977), and in the Appalachian basin no large oil deposits are found above or east of the CAI 2 isograd for Paleozoic rocks (Wallace deWitt, Jr., written commun., 1989). All of the Paleozoic sedimentary rocks in the Knoxville quadrangle lie east of the CAI 2 isograd (Omdorff and others, 1988; Epstein and others, 1977), and the quadrangle is interpreted as having no potential for commercially exploitable oil.

Most of the "unmetamorphosed" Paleozoic rocks in the Knoxville quadrangle (pi. 2) are between CAI 2 (west) and CAI 4.5 (east) and are in the thermal maturation zone for dry natural gas (Epstein and others, 1977). Windows through metamorphosed Blue Ridge rocks reveal unmetamorphosed Valley and Ridge rocks in the Cades Cove and Tuckaleechee Cove areas having CAPs of 3.5 or less (Omdorff and others, 1988) and indicate that "unmetamorphosed" Paleozoic strata with a thermal maturity appropriate for the formation of natural gas occur beneath postmetamorphic thrust sheets of late Paleozoic age (probably Permian) containing metamorphic rocks (pi. 1 and 2). This isograd pattern indicates that a limited area of Paleozoic sedimentary rock adjacent to and beneath the Blue Ridge may have potential for natural gas resources.

Organic-matter-rich dark-gray to black shales that may be good source rocks for hydrocarbons in the unmetamorphosed portion of the Valley and Ridge of the Knoxville quadrangle occur in the lower part of the Chickamauga Group (unit Oc, pi. 1) and in the Chattanooga Shale (lower part of unit MDu, pi. 1). Most of the porosity and permeability in the unmetamorphosed Paleozoic section of the Knoxville quadrangle is fracture-induced porosity and permeability in broken formation zones associated with decollement, imbricate thrusts, and splay faults in the Valley and Ridge and the Blue Ridge (Harris and others, 1981). Therefore, almost all hydrocarbon traps will be structural traps associated with thrust fault structures, such as horses, duplex structures, and lateral ramps. Shaly strata and massive dolomite in the Paleozoic sequence and metamorphic rocks in the Blue Ridge thrust sheet may be effective seals for hydrocarbon traps (Wallace deWitt, Jr., written commun., 1989), although high-angle faults and joint sets may breach seals and allow hydrocarbons (and other fluids) to escape. In fact, the extensive vein-hosted barite and base-metal mineralization associated with faults in the Hot Springs and Del Rio areas (fig. 19; deposits 38-62, pi. 1) may be evidence of this fluid migration.

In summary, the "unmetamorphosed" Paleozoic sequence in the Valley and Ridge and underlying the adjacent part of the Blue Ridge in the Knoxville quadrangle appears to have some potential for natural gas resources. Source beds existed and were capable of generating hydrocarbons at the time when structural traps formed during the Alleghanian orogeny. The lack of exploratory drilling for oil and gas in the area, the difficulty of defining subsurface structural traps in this complexly faulted area, and the probability of hydrocarbon leakage along high-angle faults suggest that the northwestern portion of the Knoxville quadrangle is a high-risk frontier area for natural gas exploration (Wallace deWitt, Jr., written commun., 1989).

Metallic Resources

The distribution, geologic setting, and classification of deposit types of the larger metal mines and occurrences in the Knoxville quadrangle are shown on plate 1 and table 8. The most important metallic resources are stratabound massive sulfide deposits containing base and precious metals. Of somewhat lesser significance are stratabound manganese deposits, Mississippi Valley-type and vein-type lead-zinc deposits, barite and fluorite vein deposits, and lode and placer gold deposits. Placer occurrences of rutile, monazite, and scheelite may be associated with bedrock mineralization of a nature, extent, and distribution that require further evaluation. The Knoxville quadrangle has significant potential for additional metallic resources of the types identified in table 8 and discussed below. The metallic resources are discussed by commodity.

Base Metals (Copper, Lead, Zinc, and Iron)

Copper, the dominant base metal produced in the quadrangle, occurs in stratabound massive sulfide deposits in three different lithotectonic belts (Espenshade, 1944, 1963; Hadley and Nelson, 1971; Ross, 1935; Weed, 1911). The Fontana district contains several small metamorphosed massive sulfide deposits of probable Besshi type (deposits 1-8, table 8). The deposits are mostly iron sulfides containing copper and zinc as minor constituents and traces of lead, silver, and gold. These deposits are located within a sulfidic and graphitic metasedimentary unit of the Copperhill Formation of the Late Proterozoic Great Smoky Group. The Fontana district includes the Fontana and Hazel Creek mines and the Welch, Calhoun, and Westfeldt prospects (pi. 1). Average ore grades for the Fontana mine were 7.37 percent copper, 2.11 percent zinc, 0.007 oz/ton gold, and 0.385 oz/ton silver. Production from the Fontana Mine was 583,505 tons of ore between 1926 and 1944; production from the Hazel Creek mine was about 5,000 tons from 1900 to 1944 (Espenshade, 1963, p. 128-131). Prior to 1975 the property was owned for a number of years by the Cities Service Corporation as an inholding at the edge of the Great Smoky Mountains National Park but has since been acquired by the National Park Service.

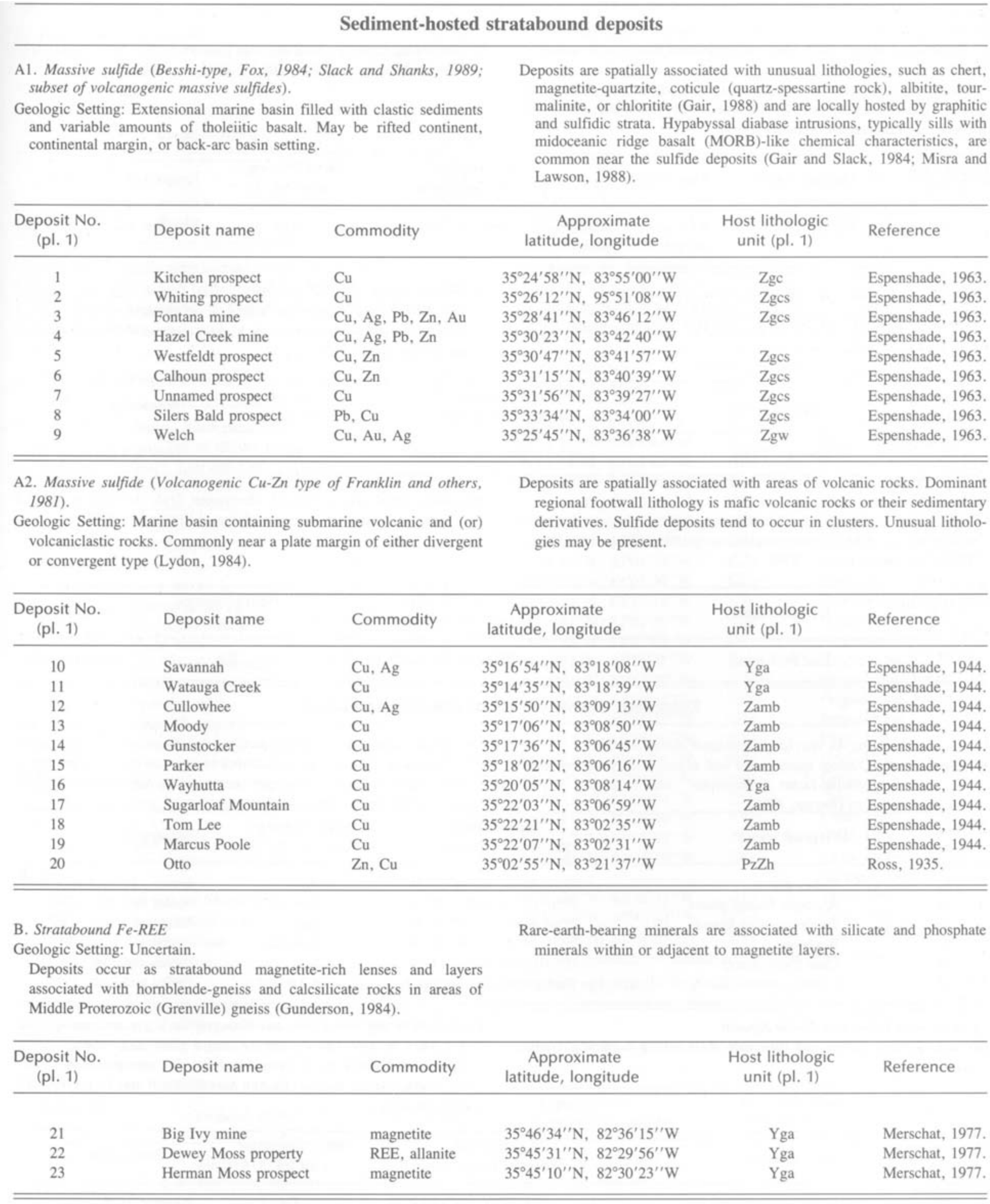
The Savannah and Cullowhee copper mines, in Jackson County, N.C., developed stratabound massive sulfide deposits that occur in interbedded mica schist, hornblende gneiss, and amphibolite (unit Yga, pi. 1) of the Richard Russell tectonic sheet. These deposits are interpreted as metamorphosed, deformed, and remobilized volcanogenic massive sulfide deposits (copper-zinc type as described by Lydon, 1984). Eight other iron sulfide and copper occurrences are reported in this area (Watauga Creek, Moody, Gunstocker, Parker, Wayhutta, Sugarloaf Mountain, Tom Lee, and Marcus Poole prospects). Deposits at the Otto mine, situated within rocks of the Helen belt, may be of similar origin.

Zinc, besides a minor presence in massive sulfide deposits, is limited to small shows as Mississippi Valley-type mineralization within carbonate rocks of the Valley and Ridge province (Trotter prospect, deposit 34), and to a vein occurrence in a shear zone at the contact of Proterozoic orthogneiss (Max Patch Granite) with rocks of the Snowbird Group (Redmond mine, deposit 36; Hadley and Goldsmith, 1963; Espenshade and others, 1947).

Lead mineralization occurs in small Mississippi Valley-type and vein-type deposits at a few localities in the quadrangle and is present as a minor constituent in the massive sulfide deposits of the Fontana district. Galena is found in the Mississippi Valley-type ores of the Kimberlin mine (Ramsey, 1926) in a dolomite horizon within the Rome Formation and in fault-controlled vein deposits at the Redmond mine (deposit 36) and the Pardo mine (deposit 37, circa 1572, Davis and Hale, 1966).

Iron is abundant throughout the quadrangle (Wright and others, 1968). It occurs as (1) pyrite and pyrrhotite in sulfidic schists of the Great Smoky Group and in stratabound massive sulfide bodies; (2) hydroxides and oxides in

Table 8. Deposit types, location, and geologic setting of the larger mines and metal occurrences in the Knoxville 1°x2° quadrangle



Sediment-hosted stratabound deposits

A1. *Massive sulfide* (*Besshi-type, Fox, 1984; Slack and Shanks, 1989; subset of volcanogenic massive sulfides*).

Geologic Setting: Extensional marine basin filled with clastic sediments and variable amounts of tholeiitic basalt. May be rifted continent, continental margin, or back-arc basin setting.

Deposits are spatially associated with unusual lithologies, such as chert, magnetite-quartzite, coticule (quartz-spessartine rock), albitite, tourmalinite, or chloritite (Gair, 1988) and are locally hosted by graphitic and sulfidic strata. Hypabyssal diabase intrusions, typically sills with midoceanic ridge basalt (MORB)-like chemical characteristics, are common near the sulfide deposits (Gair and Slack, 1984; Misra and Lawson, 1988).

Deposit No. (pl. 1)	Deposit name	Commodity	Approximate latitude, longitude	Host lithologic unit (pl. 1)	Reference
1	Kitchen prospect	Cu	35°24′58″N, 83°55′00″W	Zgc	Espenshade, 1963.
2	Whiting prospect	Cu	35°26′12″N, 95°51′08″W	Zgcs	Espenshade, 1963.
3	Fontana mine	Cu, Ag, Pb, Zn, Au	35°28′41″N, 83°46′12″W	Zgcs	Espenshade, 1963.
4	Hazel Creek mine	Cu, Ag, Pb, Zn	35°30′23″N, 83°42′40″W		Espenshade, 1963.
5	Westfeldt prospect	Cu, Zn	35°30′47″N, 83°41′57″W	Zgcs	Espenshade, 1963.
6	Calhoun prospect	Cu, Zn	35°31′15″N, 83°40′39″W	Zgcs	Espenshade, 1963.
7	Unnamed prospect	Cu	35°31′56″N, 83°39′27″W	Zgcs	Espenshade, 1963.
8	Silers Bald prospect	Pb, Cu	35°33′34″N, 83°34′00″W	Zgcs	Espenshade, 1963.
9	Welch	Cu, Au, Ag	35°25′45″N, 83°36′38″W	Zgw	Espenshade, 1963.

A2. *Massive sulfide* (*Volcanogenic Cu-Zn type of Franklin and others, 1981*).

Geologic Setting: Marine basin containing submarine volcanic and (or) volcaniclastic rocks. Commonly near a plate margin of either divergent or convergent type (Lydon, 1984).

Deposits are spatially associated with areas of volcanic rocks. Dominant regional footwall lithology is mafic volcanic rocks or their sedimentary derivatives. Sulfide deposits tend to occur in clusters. Unusual lithologies may be present.

Deposit No. (pl. 1)	Deposit name	Commodity	Approximate latitude, longitude	Host lithologic unit (pl. 1)	Reference
10	Savannah	Cu, Ag	35°16′54″N, 83°18′08″W	Yga	Espenshade, 1944.
11	Watauga Creek	Cu	35°14′35″N, 83°18′39″W	Yga	Espenshade, 1944.
12	Cullowhee	Cu, Ag	35°15′50″N, 83°09′13″W	Zamb	Espenshade, 1944.
13	Moody	Cu	35°17′06″N, 83°08′50″W	Zamb	Espenshade, 1944.
14	Gunstocker	Cu	35°17′36″N, 83°06′45″W	Zamb	Espenshade, 1944.
15	Parker	Cu	35°18′02″N, 83°06′16″W	Zamb	Espenshade, 1944.
16	Wayhutta	Cu	35°20′05″N, 83°08′14″W	Yga	Espenshade, 1944.
17	Sugarloaf Mountain	Cu	35°22′03″N, 83°06′59″W	Zamb	Espenshade, 1944.
18	Tom Lee	Cu	35°22′21″N, 83°02′35″W	Zamb	Espenshade, 1944.
19	Marcus Poole	Cu	35°22′07″N, 83°02′31″W	Zamb	Espenshade, 1944.
20	Otto	Zn, Cu	35°02′55″N, 83°21′37″W	PzZh	Ross, 1935.

B. *Stratabound Fe-REE*

Geologic Setting: Uncertain.

Deposits occur as stratabound magnetite-rich lenses and layers associated with hornblende-gneiss and calcsilicate rocks in areas of Middle Proterozoic (Grenville) gneiss (Gunderson, 1984).

Rare-earth-bearing minerals are associated with silicate and phosphate minerals within or adjacent to magnetite layers.

Deposit No. (pl. 1)	Deposit name	Commodity	Approximate latitude, longitude	Host lithologic unit (pl. 1)	Reference
21	Big Ivy mine	magnetite	35°46′34″N, 82°36′15″W	Yga	Merschat, 1977.
22	Dewey Moss property	REE, allanite	35°45′31″N, 82°29′56″W	Yga	Merschat, 1977.
23	Herman Moss prospect	magnetite	35°45′10″N, 82°30′23″W	Yga	Merschat, 1977.

Table 8. Deposit types, location, and geologic setting of the larger mines and metal occurrences in the Knoxville 1°x2° quadrangle (cont.)

C. *Stratabound W (scheelite) - Sn (and associated placer occurrences)*
Geologic Setting: Uncertain.
Similar deposits occur in metamorphosed eugeosynclinal sedimentary belts containing volcanics and calcsilicate rocks (Holl and others, 1987; Barnes, 1983; Fulp and Renshaw, 1985). Marine setting probable. Volcanogenic massive sulfide deposits may also occur in the same belt (Moench and Erickson, 1980).

Deposit No. (pl. 1)	Deposit name	Commodity	Approximate latitude, longitude	Host lithologic unit (pl. 1)	Reference
24	Sandymush	trace scheelite occurrences in stream sediment samples from numerous sites		Yga	Merschat and Wiener, 1988.

D. *Stratabound rutile (and associated placer occurrences)*
Geologic Setting: Deeply weathered metamorphic belts of sillimanite grade or higher. Eugeosynclinal belts favorable as sources of high-titanium volcanic rocks (Force, 1976). Rutile-rich strata may be associated with altered rock and unusual lithologies in the vicinity of volcanogenic massive sulfide deposits metamorphosed to amphibolite (or higher) metamorphic grade (Nesbitt and Kelley, 1980).

Deposit No. (pl. 1)	Deposit name	Approximate latitude, longitude	Host lithologic unit (pl. 1)	Reference
25	Shooting Creek	numerous placer occurrences	Zg	Herz and Eilertsen, 1968.

E. *Stratabound Mn (carbonate)*
Geologic Setting: Shallow marine carbonate and shale sequence deposited around the rim of anoxic basins during transgression (Cannon and Force, 1986; Force and Cannon, 1988). Phosphatic strata may be present. Manganese oxide develops as residual deposits on weathered carbonate (Stose and Schrader, 1923).

Deposit No. (pl. 1)	Deposit name	Approximate latitude, longitude	Host lithologic unit (pl. 1)	Reference
26	East Fork mine	35°49′33′′N, 83°24′04′′W	Zw	Reichert, 1942.

Epigenetic deposits without igneous association

F. *Low-sulfide quartz-Au vein (and associated placer deposits)*
Geologic Setting: Dilatent quartz veins and segregations in greenschist- and lower amphibolite-facies metamorphic belts containing eugeosynclinal sequences (Berger, 1986). Sericite and carbonate alteration typically accompanies gold mineralization in shear zones. Weathering of host rock to saprolite may be important to concentrate gold in the supergene environment. Gold placer deposits occur where fluvial gradients flatten.

Deposit No. (pl. 1)	Deposit name	Approximate latitude, longitude	Host lithologic unit (pl. 1)	Reference
27	Valley placer	35°10′26′′N, 83°54′55′′W	Zmb	Bryson, 1936; Blake, 1860.
28	Ammons Branch placer	35°01′17′′N, 83°07′52′′W	Zab	Pardee and Park, 1948.
29	Fairfield Valley placer	35°08′48′′N, 82°57′03′′W	Zab	Nitze and Hanna, 1896.
30	Boylston	35°21′10′′N, 82°37′36′′W	Zamb/bz	Pardee and Park, 1948.
31	Cane Creek placer	35°31′12′′N, 82°24′12′′W	bz	Pardee and Park, 1948.
32	Cureton placers	(five placer occurrences)	ЄZpg/sb(?)	Pardee and Park, 1948.

G. *Mississippi Valley-type Pb-Zn deposits*
Geologic Setting: Continental carbonate shelf setting bordering marine basins. Deposits typically occur near paleotopographic highs and stratigraphic pinchouts in dolomitic carbonate strata (Hill and others, 1971). Paleokarst features are a favorable locus for mineralization. Trace base-metal, barite, and (or) fluorite mineralization may be present on a regional scale.

Deposit No. (pl. 1)	Deposit name	Approximate latitude, longitude	Host lithologic unit (pl. 1)	Reference
33	Kimberlin	35°54′43′′N, 83°44′43′′W	Єu	Ramsey, 1926
34	Trotter	35°57′22′′N, 83°32′22′′W	Єk	Carpenter and others, 1971.

Table 8. Deposit types, location, and geologic setting of the larger mines and metal occurrences in the Knoxville 1°x2° quadrangle (cont.)

H. *Base-metal ± barite vein*

Geologic Setting: Deposits hosted by faults and fractures cutting continental platform or continental shelf sediments and crystalline quartzo-feldspathic rocks.

Fluids causing mineralization may have a source in nearby sedimentary basins. Tectonic deformation may drive fluid transport (Robinson, in press).

Deposit No. (pl. 1)	Deposit name	Approximate latitude, longitude	Host lithologic unit (pl. 1)	Reference
35	Willis	35°53′19″N, 83°02′35″W	Zw	Ferguson and Jewell, 1951.
36	Redmond	35°41′10″N, 83°00′09″W	Ybg/ZYs	Hadley and Goldsmith, 1963.
37	Pardo	35°21′40″N, 83°18′45″W	ꞒZgs	Davis and Hale, 1966.

I. *Barite±base-metal, fluorite vein*

Geologic Setting: Deposits hosted by faults and fractures cutting continental platform or continental shelf sediments overlying crystalline quartzo-feldspathic rocks.

Proximity to stratigraphic contact between crystalline basement and sedimentary cover may be a favorable location for mineralization. Fluids causing mineralization may have a source in nearby sedimentary basins. Tectonic deformation may drive fluid transport (Robinson, in press).

Deposit No. (pl. 1)	Deposit name	Approximate latitude, longitude	Host lithologic unit (pl. 1)	Reference
38	Beetree Knob prospect	35°54′35″N, 83°06′19″W	ꞒZc	Ferguson and Jewell, 1951.
39	Mud Tunnel Hollow mine	35°55′33″N, 83°05′44″W	ꞒZc	Ferguson and Jewell, 1951.
40	Darky Tom and Spence mines	35°55′53″N, 83°05′08″W	ꞒZc	Ferguson and Jewell, 1951.
41	West Meyer mine	35°55′58″N, 83°04′49″W	ꞒZc	Ferguson and Jewell, 1951.
42	East Meyer mine	35°56′08″N, 83°03′54″W	ꞒZc	Ferguson and Jewell, 1951.
43	Whiterock Hollow mine	35°55′18″N, 83°04′37″W	ꞒZc	Ferguson and Jewell, 1951.
44	Huff prospects	35°56′27″N, 83°02′12″W	ꞒZc	Ferguson and Jewell, 1951.
45	Oliver mine	35°56′47″N, 83°01′36″W	ꞒZc	Ferguson and Jewell, 1951.
46	Stone mine	35°56′12″N, 83°01′30″W	ꞒZc	Ferguson and Jewell, 1951.
47	Moccasin Gap mine	35°56′19″N, 82°59′14″W	ꞒZc	Ferguson and Jewell, 1951.
48	Mooneyham mine	35°55′43″N, 82°59′00″W	ꞒZc	Ferguson and Jewell, 1951.
49	Krebs mine	35°53′43″N, 82°57′08″W	Zw	Ferguson and Jewell, 1951.
50	Bee Branch prospect	35°54′02″N, 82°56′38″W	Zw	Ferguson and Jewell, 1951.
51	Dry Fork prospect	35°53′03″N, 82°57′07″W	ZYs	Ferguson and Jewell, 1951.
52	Williams mine	35°53′19″N, 82°56′44″W	ZYs	Ferguson and Jewell, 1951.
53	Cross Mountain prospect	35°55′18″N, 82°55′27″W	ꞒZc	Ferguson and Jewell, 1951.
54	Mine Ridge prospect	35°55′13″N, 82°54′19″W	ꞒZc	Oriel, 1950.
55	Unnamed prospect	35°54′51″N, 82°52′04″W	ꞒZc	Oriel, 1950.
56	Long Mountain mine	35°50′30″N, 82°51′13″W	ZYs	Oriel, 1950.
57	Dry Pond Ridge prospects	35°51′33″N, 82°48′04″W	ZYs	Oriel, 1950.
		35°51′01″N, 82°48′49″W	ZYs	Oriel, 1950.
58	Doe Branch prospect	35°51′02″N, 82°47′03″W	ZYs	Oriel, 1950.
59	Stackhouse and Defender mines	35°52′41″N, 82°45′19″W	ZYs	Oriel, 1950. Dahners, 1949.
60	Nettie and Martha mines	35°52′24″N, 82°45′13″W	ZYs	Oriel, 1950.
61	Sandybottom mines	35°52′03″N, 82°45′23″W	ZYs	Oriel, 1950.
62	Gahagan mine	35°54′08″N, 82°44′39″W	ZYs	Oriel, 1950.

Magmatic and igneous-associated epigenetic deposits

J. *Syenite pegmatite with Zr ± REE (and associated placer deposits)*

Geologic Setting: Syenitic pegmatoid segregations associated with alkaline igneous intrusions

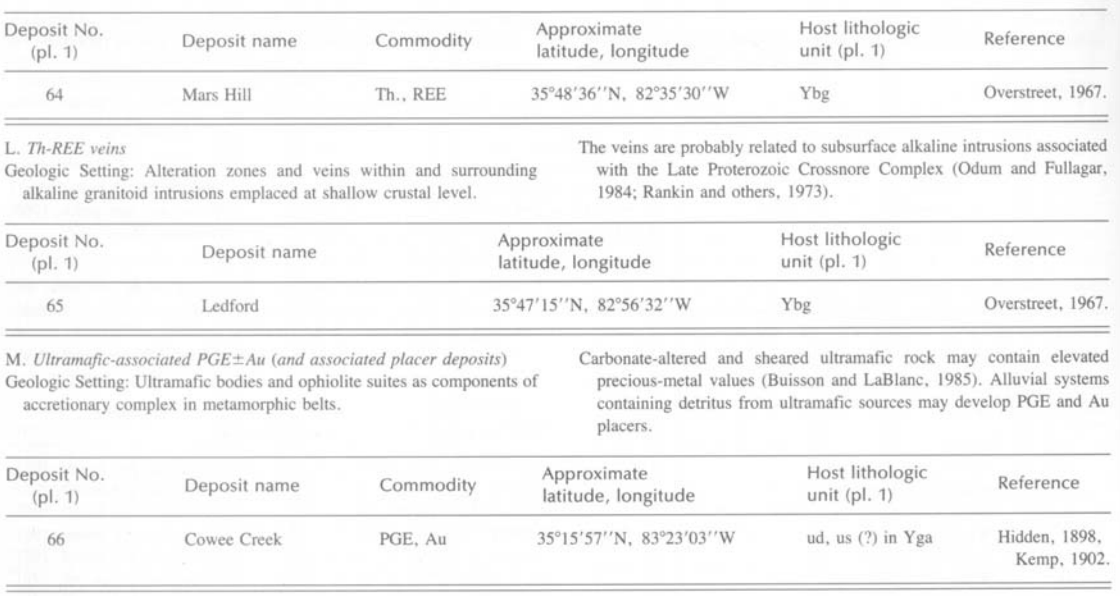
Deposit No. (pl. 1)	Deposit name	Commodity	Approximate latitude, longitude	Host lithologic unit (pl. 1)	Reference
63	Zirconia	zircon	(three occurrences)	syenite	Olson, 1952.

K. *Rare-earth Pegmatite (and associated placer deposits)*

Geologic Setting: Synmetamorphic pegmatites in medium grade metamorphic belts containing eugeosynclinal sediments. Rare metal contents enhanced in pegmatites associated with crustal extension (Cerny and Meintzer, 1985).

Deep weathering provides detrital monazite for placer concentration (Overstreet, 1967).

Table 8. Deposit types, location, and geologic setting of the larger mines and metal occurrences in the Knoxville 1°x2° quadrangle (cont.)



Deposit No. (pl. 1)	Deposit name	Commodity	Approximate latitude, longitude	Host lithologic unit (pl. 1)	Reference
64	Mars Hill	Th., REE	35°48′36″N, 82°35′30″W	Ybg	Overstreet, 1967.

L. *Th-REE veins*
Geologic Setting: Alteration zones and veins within and surrounding alkaline granitoid intrusions emplaced at shallow crustal level.

The veins are probably related to subsurface alkaline intrusions associated with the Late Proterozoic Crossnore Complex (Odum and Fullagar, 1984; Rankin and others, 1973).

Deposit No. (pl. 1)	Deposit name	Approximate latitude, longitude	Host lithologic unit (pl. 1)	Reference
65	Ledford	35°47′15″N, 82°56′32″W	Ybg	Overstreet, 1967.

M. *Ultramafic-associated PGE±Au (and associated placer deposits)*
Geologic Setting: Ultramafic bodies and ophiolite suites as components of accretionary complex in metamorphic belts.

Carbonate-altered and sheared ultramafic rock may contain elevated precious-metal values (Buisson and LaBlanc, 1985). Alluvial systems containing detritus from ultramafic sources may develop PGE and Au placers.

Deposit No. (pl. 1)	Deposit name	Commodity	Approximate latitude, longitude	Host lithologic unit (pl. 1)	Reference
66	Cowee Creek	PGE, Au	35°15′57″N, 83°23′03″W	ud, us (?) in Yga	Hidden, 1898, Kemp, 1902.

residual ore, the product of weathering, in the Valley and Ridge and the Murphy belt; (3) hematite in oolites of Ordovician age in the Valley and Ridge (Bay ley, 1923 a); and (4) magnetite in lenses and veins within gneiss (unit Yga, pi. 1) of the amphibolitic basement complex (Bayley, 1923b). The larger iron occurrences in the Knoxville quadrangle are of the latter type and appear to be associated with concentrations of rare-earth, uranium, and thorium minerals. Similar magnetite occurrences in Middle Proterozoic Grenville basement rocks in southern New York and northern New Jersey (Sims, 1958; Klemic and others, 1959; Vassilou, 1980) are interpreted as stratabound sediments rich in iron, rare-earths, and thorium (Palmer, 1970; Gunderson, 1984). However, some of the magnetite is titaniferous and cannot be smelted economically in a blast furnace and as a result has little value as iron ore. Some may have value as ores of rare-earths, thorium, or uranium if sufficiently enriched in these elements.

Iron ores formed by weathering processes were mined throughout the Valley and Ridge. The irregular nature and limited volume of these deposits make them presently unattractive as iron resources.

Precious Metals (Gold, Silver, and PGE's)

The distribution of precious-metal occurrences in the Knoxville quadrangle is shown in plate 1 and table 8. Gold in placer and vein deposits, PGE's in one placer deposit, and silver as an accessory commodity in vein and massive sulfide deposits all are reported from the quadrangle, although the occurrences tend to be small (tables 4 and 7).

Gold has been mined by small-scale operations in a number of locations in the Knoxville quadrangle. The gold is mainly found in small placers including the Valley placers, the Fairfield Valley placers (more than 15,000 oz gold), and the Cureton mine area (Nitze and Hanna, 1896; Pardee and Park, 1948), where it results from the weathering of gold-bearing, low-sulfide quartz veins. Most of the gold in the placers is in solid solution in electrum (table 4). Gold also occurs as a trace constituent in the massive sulfide deposit at the Fontana mine (deposit 3), is associated with PGE's at the Cowee Creek placer occurrence (Hidden, 1898; Kemp, 1902; Shepard, 1847), and is present in quartz veins in the Brevard zone at the Boylston mine (Nitze and Hanna, 1896, Bryson, 1936). Traces of gold, however, are widely disseminated in bedrock of both the east flank and central Blue Ridge as shown by USGS mineral assessment studies of wilderness and roadless areas. Gold was found in amounts as much as 0.18 ppm in samples of mica schist and gneiss, amphibolite, or vein quartz in the Craggy Mountain Wilderness Study Area, Buncombe County, N.C. (Lesure and others, 1982, p. 18-19); from 0.1 to 0.6 ppm in 10 samples of meta-arkose, slate, or vein quartz in the Joyce Kilmer-Slickrock Wilderness, N.C.-Tenn. (Lesure and others, 1977, p. 23); as much as 0.024 ppm in samples of mica schist and gneiss in the Shining Rock Wilderness, Haywood County, N.C. (Lesure, 1981a); and 0.15 ppm in one sample.

of mica-garnet schist in the Snowbird Roadless Area, Graham County, N.C. (Lesure, 1986a). In addition, four samples from the southern part of the Franklin 7 1/2-min quadrangle, Macon County, N.C., analyzed during the 1960's as part of the USGS Heavy Metals Program, were found to contain gold: one sample of mica-garnet gneiss had 0.03 ppm gold, one sample of calcsilicate gneiss had 0.11 ppm gold, and two samples of amphibolite had 0.07 ppm gold. In addition, one sample of quartzite from the Wildacres Tunnel on the Blue Ridge Parkway, in McDowell County, N.C., was found to have 0.07 ppm gold (F.G. Lesure, unpub. data). During deep weathering and formation of saprolite, such disseminated gold could be concentrated into larger grains by supergene processes, later forming small placer deposits in primary or secondary drainages. Such placers, however, would not necessarily be an indication of significant gold mineralization in the drainage basin.

Silver is largely absent in the Knoxville quadrangle, with one important exception. It was recovered as a byproduct from copper ore mined in the Fontana district (171,000 oz) and is present in other small metamorphosed massive sulfide bodies (for example, at Savannah mine). Galena from the Hot Springs barite district, North Carolina, is also argentiferous (Oriel, 1950).

Sperrylite (PtAs^) has been reported with traces of gold at Cowee Creek, Macon County, N.C. (Hidden, 1898; Kemp, 1902). Platinum and palladium are somewhat enriched relative to background values in small ultramafic bodies and amphibolites in Proterozoic paragneiss (table 7). Similar bodies are the probable PGE source for the Cowee Creek placer occurrence (Yeend, 1986).

Manganese

Manganese occurrences are distributed over a large area of Tennessee and North Carolina, although no significant production has come from the Knoxville quadrangle (Van Dorr and Sweeney, 1968). The most significant occurrence in the quadrangle is bedded manganese carbonate at the East Fork mine (Reichert, 1942) in Sevier County, Tenn. A 4-m-thick interval there of bedded rhodochrosite, partly altered by weathering to manganese oxides, occurs at a vertical stratigraphic contact of slate and dolomite in strata of the Walden Creek Group of the Late Proterozoic Ocoee Supergroup.

Other occurrences of manganese in the Knoxville quadrangle are primarily small residual oxide bodies formed by supergene weathering and ground-water movement. These manganese oxide occurrences are mainly in the Shady Dolomite and in carbonate lenses of the Rome Formation that crop out in the far northwestern corner of the quadrangle.

Manganiferous rock as concentrations of stratabound manganese silicate minerals in schist occur near Shooting Creek in Clay County, N.C., and in Surry County, N.C., northeast of the Knoxville quadrangle. These manganese silicates have never been mined but in some areas may be one of the unusual lithologies associated with stratabound massive sulfide deposits (table 8).

Vanadium

Vanadium ore has never been mined in the Knoxville quadrangle or in any part of Appalachia (Fischer and Ohi, 1970), although the element has been reported as a few tenths of a percent V^ in several samples of titaniferous magnetite from North Carolina and Tennessee (Fischer and Feitler, 1968, p. 450). The magnetite occurs as small lenses in mafic and ultramafic gneiss and schist (Bayley, 1923b, p. 198-207), and the grades of vanadium are too low for these occurrences to have resource potential.

Thorium and Rare-Earth Elements

Thorium and rare-earth-bearing minerals are found in the Knoxville quadrangle (pl. 1) in two main types of occurrences: as accessory minerals and local concentrations in igneous and metamorphic rocks, and in heavy mineral concentrates in placer deposits (Overstreet, 1967). Pegmatites containing minor amounts of thorium and rare-earth minerals are numerous in western North Carolina. These include Mars Hill in Madison County, the Zirconia district in Henderson County, and the Spruce Pine district in Avery, Mitchell, and Yancey Counties. Although the minerals are abundant locally, they are generally of too sporadic occurrence to constitute minable ore in their own right. Monazite is actually an uncommon mineral in the Spruce Pine district, but crystals weighing 2-3 lb have been found (Overstreet, 1967), some of which contain up to 8.2 percent ThO^ and 58 percent total RE203. The Mars Hill occurrence contains large crystals (6.5-12 lb) of monazite with 5.1 to 7.0 percent ThO^ and about 63.3 percent total RE^. These monazite-bearing pegmatites constitute a portion of the Blue Ridge monazite belt. An unevaluated potential for significant thorium and rare-earth mineralization also exists with the stratabound iron deposits discussed above.

The Zirconia district in Henderson County is east of the other monazite occurrences and contains a variety of heavy minerals in decomposed syenitic pegmatite (Olson, 1952, p. 17-22). These include zircon, xenotime, magnetite, and monazite. The syenite pegmatites are possibly members of an alkalic suite of small intrusive bodies (including lamproites) that intrude the Piedmont.

Thorium and rare-earth minerals (primarily monazite) also occur in saprolite in Macon County, especially along Masons Branch and Caler Fork of Cowee Creek, tributaries of the Little Tennessee River, and in Jackson and Clay Counties, comprising the Mountain monazite belt (fig. 21) of Mertie (1979). Analyses of small yellow crystals, thought to be monazite, from Masons Branch yielded values

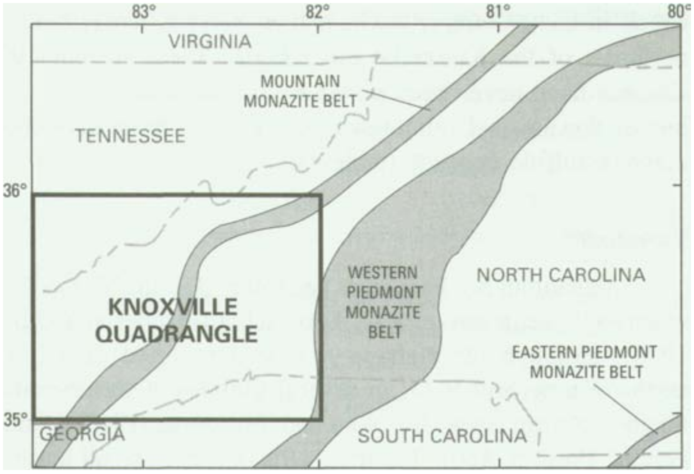


Figure 21. Location of detrital monazite belts in the Knoxville quadrangle and vicinity (after Mertie, 1979).

of only 0.03 percent ThO^, and the material may have been xenotime (Overstreet, 1967, p. 193). Monazite from the Whiteside granite(?) near Cashiers in Jackson County may contain as much as 5.7 percent ThO^ and relatively high values of lanthanum, cerium, and praseodymium (Overstreet, 1967, p. 194). The monazite placers in Clay County, although rich, are small and are generally regarded as having little economic value at the present time (Pratt and Sterret, 1908, p. 315).

Uranium

Although no uranium is being produced in the Knoxville quadrangle, there are a number of possible sources, including low-grade uranium-bearing shales, U-bearing veinlets in crystalline rocks, U-bearing pegmatites (Butler and Stansfield, 1968), and U-bearing stratabound deposits of iron and rare-earth minerals. The Chattanooga Shale contains an average of 0.007 percent L^Og in the upper member (Conant and Swanson, 1961), but only a small portion of this unit crops out in the quadrangle. The Chattanooga Shale is thought to be of too low a grade to mine profitably. Uranium-bearing veinlets in crystalline rocks of Proterozoic age are known in Avery County, N.C., northeast of the Knoxville quadrangle (Bryant and Reed, 1966, p. 5-7; Crandell and others, 1982). Uraninite and other less abundant uranium minerals fill joints in sheared pegmatites, which may contain as much as 1.0 percent U^Og. Uranium-bearing pegmatites are sparse in Appalachia except in the Knoxville quadrangle, which contains the Spruce Pine district in Avery, Mitchell, Yancey Counties, N.C. In that district, uraninite and other uranium-bearing minerals are rare trace constituents and are not sufficiently abundant to economically recover (Lesure, 1968, p. 20-21).

Tungsten

An occurrence of scheelite, an important ore of tungsten, has been found in medium grained calcsilicate rock and amphibolite in rocks of the amphibolitic basement complex (unit Yga, pi. 1) in the southeastern part of the Sandymush quadrangle, N.C. (Merschat and Wiener, 1988, p. 49; see fig. 4 for location of the Sandymush quadrangle). In this area, scheelite has also been found to be a trace component of many stream-sediment samples in areas where streams drain rocks of the amphibolitic basement complex (Merschat and Wiener, 1988, appendix 2). The location of their stream-sediment sites reported to contain trace scheelite are shown on plate 1.

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This report was developed as part of a planning document for the National Mineral Resource Assessment Program at USGS. Our work involved library research and reinterpretation of existing data and did not involve field investigations or new mapping; therefore, the maps and interpretations contained in this report should be regarded as preliminary. However, the geologic interpretations contained in this report differ significantly from other published maps (for example, Hadley and Nelson, 1971) and incorporate the results of recent mapping in the area. In addition, this report is a detailed information and citation source for the mineral deposits of the area.

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