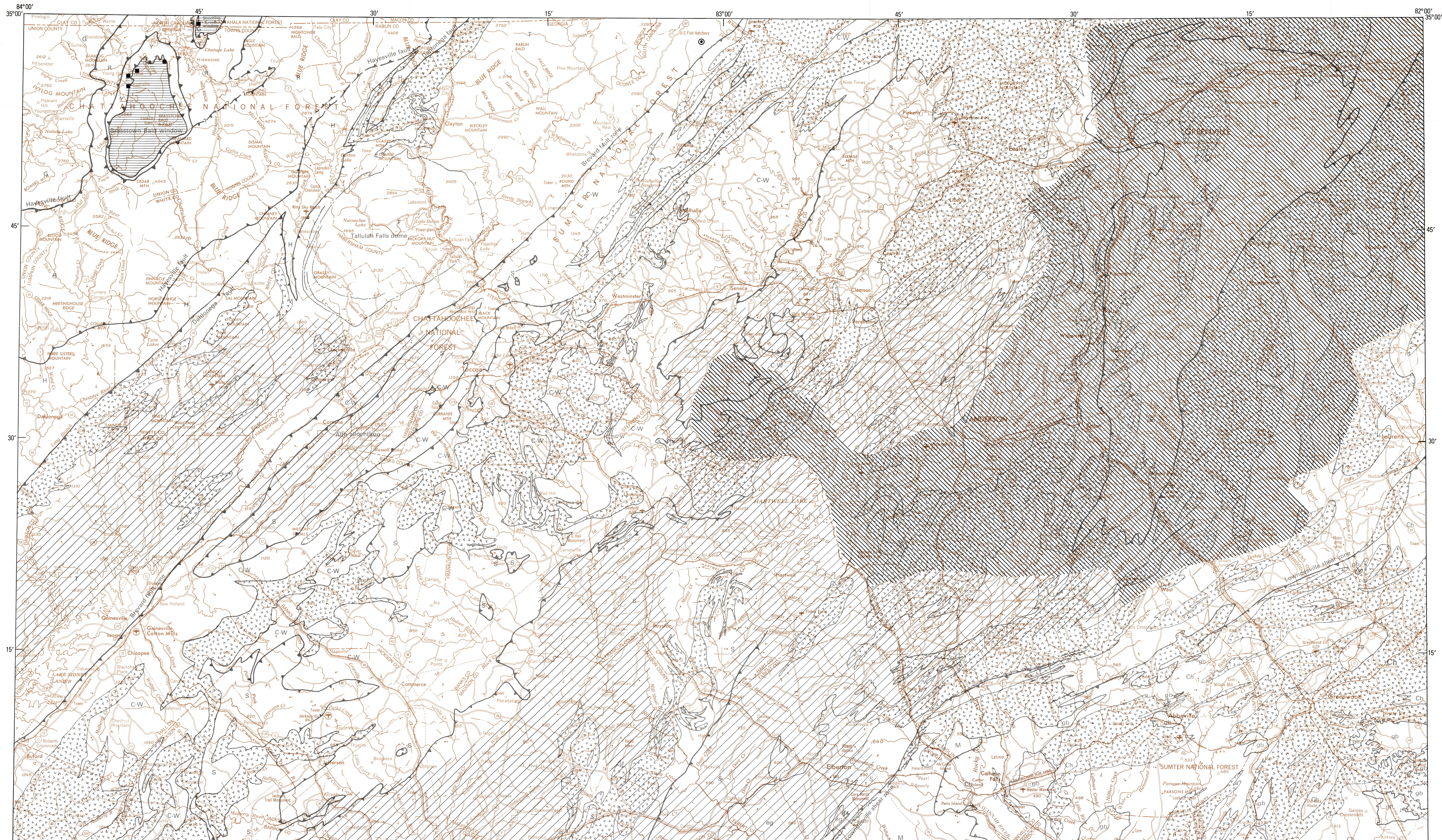
MISCELLANEOUS FIELD STUDIES
MAP MF–2198–E



Base from U.S. Geological Survey, 1954 (limited revision, 1964)
Transverse Mercator projection

Geology modified from Nelson and others (1987, 1989)
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SCALE 1:250 000

DATUM IS MEAN SEA LEVEL

MAP SHOWING DISTRIBUTION OF KNOWN AND POSSIBLE AREAS THAT CONTAIN MONAZITE- AND RUTILE-BEARING STREAMS IN THE GREENVILLE 1° × 2° QUADRANGLE

EXPLANATION

Area of known monazite-bearing streams—From Overstreet and others (1968, pl. 7)

Area of possible monazite-bearing streams

Area of possible rutile-bearing streams

Uranium–thorium prospect—From Luce and others (1983)

Rutile placer deposit—From Van Horn (1945)

LIST OF MAP UNITS AND SYMBOLS
[Stacking order of thrust sheets]

Blue Ridge thrust stack

T **Tallulah Falls thrust sheet**

R **Richard Russell thrust sheet**

Y **Young Harris thrust sheet**

H **Helen thrust sheet**

G **Great Smoky thrust sheet**

Inner Piedmont thrust stack

L **Laurens thrust sheet**

P **Paris Mountain thrust sheet**

S **Six Mile thrust sheet**—Includes the metagabbro at Anderson (Paleozoic?) (ag) and the Elberton Granite (Mississippian) (eg)

C-W **Chauga–Walhalla thrust complex**

Southeast of Lowndesville shear zone

Ch **Charlotte thrust sheet**—Includes the Concord Plutonic Suite (Silurian and Devonian) (gb) and the granitic rocks at Coronaca (as used by Fullagar and Butler, 1979; Permian) (cg)

M **Mafic–ultramafic thrust sheet**

Granite, granodiorite, quartz diorite, and diorite gneiss, undivided (Pennsylvanian to Cambrian)—Shown mostly where rocks cover large areas or where tectonic boundaries are obscured

Contact

Thrust fault—Dashed where inferred; queried where uncertain. Sawteeth on upper plate

Shear zone

Kyanite schist—Queried where uncertain. Shown around Tallulah Falls dome

DISCUSSION

INTRODUCTION

Mineral resources of the Greenville 1° × 2° quadrangle, South Carolina, Georgia, and North Carolina, were assessed between 1984 and 1990 under the Conterminous United States Mineral Assessment Program (CUSMAP) of the U.S. Geological Survey (USGS). The mineral resource assessments were made on the basis of geologic, geochemical, and geophysical investigations and the presence of mines, prospects, and mineral occurrences from the literature.

This report is an assessment of the rare-earth elements (REE), thorium, titanium, and uranium resources in the Greenville quadrangle and is based on heavy-mineral concentrates collected in 1951–54 by the USGS (Overstreet and others, 1968; Caldwell and White, 1973; Cuppels and White, 1973); on the results of the U.S. Department of Energy, National Uranium Resource Evaluation (NURE) sampling program (Ferguson, 1978, 1979); on analyses of stream-sediment and heavy-mineral-concentrate samples (Jackson and Moore, 1992; G.C. Curtin, USGS, unpub. data, 1992) on maps showing aerial gamma radiation in the Greenville quadrangle (D.L. Daniels, USGS, unpub. data, 1992); and on the geology as mapped by Nelson and others (1987, 1989).

GEOLOGIC SETTING

The Greenville 1° × 2° quadrangle extends from the Blue Ridge province in the northwest corner to the Piedmont province in the southeast corner (fig. 1*A*). In the Valley and Ridge province of the southern Appalachians west of the Greenville quadrangle, it has long been known that westward-transported thrust sheets are the dominant structural elements (Rodgers, 1970, p. 39–59). Recent work has shown, however, that the same structural style also dominates the crystalline rocks east of the Valley and Ridge (Cook and others, 1979; Harris and others, 1981). Previously, the rocks of the Greenville quadrangle were described as parts of the Blue Ridge, Inner Piedmont, Kings Mountain, Charlotte, and the Carolina slate belts (fig. 1*B*; King, 1955; Overstreet and Bell, 1965a, b; Hatcher, 1972).

The Greenville quadrangle contains metamorphosed crystalline rocks of mostly Late Proterozoic to Paleozoic age in 11 westward-transported thrust sheets (fig. 2), each having a characteristic rock assemblage (Nelson and others, 1989). In ascending stacking order, the Great Smoky, Helen, Young Harris, Richard Russell, and Tallulah Falls thrust sheets form the Blue Ridge thrust stack northwest of the Brevard fault zone. The Inner Piedmont thrust stack, southeast of the Brevard fault zone, contains, in ascending order, the Chauga–Walhalla thrust complex and the Six Mile, Paris Mountain, and Laurens thrust sheets. The Lowndesville shear zone separates the Inner Piedmont thrust stack from the Charlotte thrust sheet and a separate mafic–ultramafic thrust sheet.

Rocks of all the thrust sheets are polydeformed and polymetamorphic (Nelson, 1988, p. 11). Many rocks of the Blue Ridge and Inner Piedmont thrust stacks are at medium to high metamorphic grade in the kyanite or sillimanite zone (fig. 3). The Charlotte and mafic–ultramafic thrust sheets are generally of lower grade. Nelson (1988, p. 9–11), in summarizing the timing of regional metamorphism, recognized separate metamorphic events at 470 to 430 million years ago (Ma) for the thrust sheets west of the Dahlonega thrust fault, about 365 Ma for the Tallulah Falls and Six Mile thrust sheets, about 365 or possibly 430 to 410 Ma for the Chauga–Walhalla thrust complex, about 344 Ma for the Paris Mountain and Laurens thrust sheets, and 338 to 312 Ma for the Charlotte and mafic–ultramafic thrust sheets. Granitic masses in most of these thrust sheets appear to be generally pre- or synmetamorphic. Exceptions include the Elberton Granite in the Six Mile thrust sheet, which is 350 to 320 Ma (Ross and Bickford, 1980, p. 52; Whitney and others, 1980, p. 63), and the granite at Coronaca in the Charlotte thrust sheet, which is 278 Ma (Fullagar and Butler, 1979, p. 169).

Rocks of the Blue Ridge Thrust Stack

Great Smoky Thrust Sheet

The Great Smoky thrust sheet in the northwest corner of the Greenville quadrangle consists chiefly of metamorphosed conglomerate, sandstone, and shale of the Great Smoky Group, which is part of the Ocoee Supergroup of Late Proterozoic age (Nelson and others, 1989). These rocks are overlain in a small area of a few acres in the northwest corner of the quadrangle by the Nantahala Slate of Cambrian age. Farther southeast, rocks of the Great Smoky thrust sheet are also exposed below the Hayesville fault in the Brasstown Bald and Shooting Creek windows, which are areas eroded through the Richard Russell and Young Harris thrust sheets (fig. 2). Unlike the other thrust sheets to the southeast, the Great Smoky thrust sheet contains no recognizable igneous or metaigneous rocks in the Greenville quadrangle other than a few small mica-pegmatite bodies of metamorphic origin that are found where the rocks have reached kyanite or sillimanite metamorphic grade.

Helen Thrust Sheet

The Helen thrust sheet comprises a variety of metamorphosed interlayered sedimentary and volcanic rocks of Late Proterozoic and (or) early Paleozoic age (Nelson and others, 1989). These rocks include siltstone, sandstone, shale, and chemically deposited sedimentary rocks and mafic to felsic tuffs, flows, and intrusive bodies, which are now micaceous and quartzofeldspathic gneiss and schist, quartzite, iron- and manganese-rich quartz schist, amphibolite, metagabbro, granitic to dioritic gneiss, and metatrondhjemite (Cook and Burnell, 1986). Rocks of the Helen thrust sheet overlie rocks of the Great Smoky thrust sheet along an unnamed fault zone southwest of the Greenville quadrangle (Nelson, 1991). The Dahlonega fault forms the boundary between the Helen thrust sheet and the Tallulah Falls thrust sheet to the southeast.

Young Harris Thrust Sheet

A complex of mafic and ultramafic rocks makes up the relatively small Young Harris thrust sheet, which lies between the Great Smoky and the Richard Russell thrust sheets and is exposed in narrow belts around the Brasstown Bald and Shooting Creek windows (fig. 2) in the northwestern part of the quadrangle (Nelson and others, 1989). The complex includes masses of gabbro, troctolite, pyroxenite, talc schist, eclogite, wehrlite, and amphibolite; it may, in part, represent a tectonic melange. The age of these rocks, which may be Late Proterozoic or early Paleozoic, is not well established. All the other thrust sheets above the Great Smoky thrust sheet also contain a variety of rare ultramafic and mafic rocks, commonly as small discontinuous pods but locally as larger mappable units.

Richard Russell Thrust Sheet

Metasandstone, quartzofeldspathic gneiss, metagraywacke, biotite gneiss, mica schist, and lesser amounts of amphibolite, together with granitic gneiss, granodiorite gneiss, and granitic pegmatite, make up most of the Richard Russell thrust sheet (Nelson and Gillon, 1985). The metamorphic rocks are mostly Middle Proterozoic in age, but some metagabbro and quartz dioritic to tonalitic gneiss in this thrust sheet may be of early Paleozoic age (Nelson, 1988; Nelson and others, 1989). This thrust sheet overlies parts of the Helen and Great Smoky thrust sheets along the Hayesville thrust fault.

Tallulah Falls Thrust Sheet

The Tallulah Falls thrust sheet comprises interlayered and folded metagraywacke, mica schist, amphibolite, aluminous schist, quartzite, biotite gneiss, biotite schist, quartzofeldspathic gneiss, and amphibolite, together with several types of granitoid rock (Nelson and others, 1989). Most of the rocks are of Late Proterozoic to early Paleozoic age except for two masses of granitic gneiss of Middle Proterozoic age. This thrust sheet is bounded to the southeast by the Brevard fault zone.

Rocks of the Inner Piedmont Thrust Stack

Chauga–Walhalla Thrust Complex

The 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 across the quadrangle immediately southeast of the Brevard fault zone. This thrust complex includes rocks assigned by Hatcher (1972) to the Chauga belt and by Griffin (1969) to his Walhalla nappe. Abundant amphibolite, especially in the Walhalla nappe, is interlayered with various types of quartzofeldspathic and micaceous gneiss and schist, metasandstone, metasiltstone, carbonate rocks, quartzite, phyllonitic schist, and pegmatite of Late Proterozoic to early Paleozoic age in the complex.

Six Mile Thrust Sheet

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 of Late Proterozoic to early Paleozoic age are widespread in the Six Mile thrust sheet (Nelson and others, 1989). A distinctive quartz-garnet rock (gondite) and various types of mostly Paleozoic plutonic gneiss, pegmatite, and quartz veins also are found in this thrust sheet, which structurally overlies the Chauga–Walhalla thrust complex.

Paris Mountain Thrust Sheet

The Paris Mountain thrust sheet consists chiefly of sillimanite schist, quartzite, and amphibolite of Late Proterozoic to early Paleozoic age, and granitic gneiss of Paleozoic age (Nelson and others, 1989). It has been thrust over the Six Mile thrust sheet.

Laurens Thrust Sheet

The principal rock types of the Laurens thrust sheet are layered biotite gneiss, amphibolite, hornblende gneiss, mica schist, sillimanite schist, marble, and magnetite-bearing quartzite, all of Late Proterozoic to early Paleozoic age (Nelson and others, 1989). Also included are Paleozoic granitic and granodioritic gneiss. The Laurens thrust sheet structurally overlies the Six Mile and Paris Mountain thrust sheets (Art Nelson, USGS, written commun., 1990).

Rocks Southeast of the Lowndesville Shear Zone

Mafic–Ultramafic Thrust Sheet

A melange of probable Late Proterozoic to early Paleozoic age that contains fragmental ultramafic and mafic rocks in a quartzofeldspathic matrix and several different-sized granitic bodies of Paleozoic age is near the south border of the Greenville quadrangle southeast of the Lowndesville shear zone (Nelson and others, 1989). This melange, which is at least partly equivalent to the Juliette melange of Higgins and others (1989), may represent a separate thrust sheet. To the northeast, these rocks are bordered by the volcanic-arc assemblage of the Charlotte thrust sheet. The boundary between the melange and the volcanic arc has not been observed but is inferred to be a thrust fault.

Charlotte Thrust Sheet

Metamorphosed volcanic and related sedimentary rocks of Late Proterozoic to early Paleozoic age, together with plutonic rocks of Paleozoic age, make up a volcanic-arc assemblage, which may or may not represent a distinct thrust sheet or thrust complex (Nelson and others, 1989). These rocks have been traditionally included in the Kings Mountain belt, Charlotte belt, and Carolina slate belt (fig. 1*B*; King, 1955; Overstreet and Bell, 1965a, b). The rocks include metatuff, amphibolite, phyllite, quartzite, greenstone, biotite gneiss, biotite schist, quartzofeldspathic gneiss, mica schist, and various types of granitoid gneiss. The Charlotte thrust sheet also has relatively unmetamorphosed mafic igneous complexes of Paleozoic age that range in composition from gabbro to syenite and diorite (Butler and Ragland, 1969). The Charlotte volcanic-arc assemblage and the adjacent melange complex overlie rocks of the Six Mile and Laurens thrust sheets along the Lowndesville shear zone.

RARE-EARTH ELEMENTS

The rare-earth elements (REE), commonly called the lanthanides, are the 15 geochemically related elements that have atomic numbers 57 through 71. In consecutive order, these elements are lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu). Yttrium (Y), atomic number 39, is generally included within the group because of its chemical similarities. The REE's are generally subdivided into the cerium group, or light rare-earth elements, which includes the first seven lanthanide elements (lanthanum through europium), and the yttrium group, or heavy rare-earth elements, which includes yttrium plus gadolinium through lutetium. According to estimates by Turekian (1977, p. 629) the cerium group ranges in abundance in the Earth's crust from a low of 2 parts per million (ppm) for Eu to a high of 83 ppm for Ce; Pm does not occur naturally in the crust. The yttrium group ranges in abundance in the Earth's crust from a low of 0.5 ppm for Tm to 8 ppm for Dy; the abundance of Y is 35 ppm. Both groups have become increasingly important economically because of their physical rather than their chemical properties (Adams and Staatz, 1973, p. 547–556). They are used as catalysts in petroleum cracking, and as minor ingredients in glass and ceramic manufacture, in ironmaking and steelmaking, and in the manufacture of electronic and illumination devices, high-strength magnets, and nuclear-reactor components. Although some of these elements (Ce, La, Nd, and Y) are relatively abundant in the Earth's crust, minable concentrations are uncommon. Trace amounts are found in many minerals but only bastnaesite, a rare-earth fluorocarbonate, and monazite, a rare-earth phosphate, are important ore minerals of the cerium group. The less common minerals in which the yttrium-group elements predominate are xenotime, samarskite, and fergusonite. Only monazite, however, is found in measurable amounts in rocks of the Greenville quadrangle, where it is generally a trace mineral in some granite, granitic gneiss, biotite gneiss, and sillimanite schist (Mertie, 1953, 1979; Overstreet and others, 1968). Monazite is also found as a stable heavy mineral in placer deposits along many streams in the Blue Ridge (Lesure and others, 1987a, b) and Inner Piedmont provinces of North and South Carolina (Overstreet and others, 1968), which include the Greenville quadrangle.

THORIUM

Thorium is a heavy, ductile, silver-gray metal that has a crustal abundance of 6 ppm. It is the parent of a series of radioactive-decay products that end in a stable isotope of lead (Staatz and Olson, 1973). Thorium is used in refractories, incandescent lamp mantles, aerospace alloys, nuclear fuel, and welding electrodes (Hedrick, 1985). The chief ore minerals of thorium are monazite [$(Ce,La,Nd,Th)PO_4$], thorite ($ThSiO_4$), uranothorite [$(Th,U)SiO_4$], and brannerite (mutiple oxide of Ti, U, Ca, Fe, Th, and Y). Thorium has been recovered principally from monazite that has been concentrated in beach and fluviatile placer deposits. It has also been obtained as a byproduct from uranium deposits rich in uranothorianite [$(Th,U)O_2$] in Madagascar and uranium-bearing Precambrian conglomerate in Canada (Staatz and Olson, 1973). Thorite associated with allanite was reported by Luce and others (1983, p. 10) from a small uranium–thorium prospect in northeastern Oconee County, S.C. (map).

TITANIUM

Titanium, the ninth most abundant element, has a crustal abundance of as much as 0.8 percent. It is found in nature as an oxide, generally in combination with iron, and in small amounts in many silicate minerals. Because of the high strength-to-weight ratio of titanium alloys, the metal is important for the aerospace, electrical, and chemical industries (Lynd, 1985, p. 859–861). Fully 95 percent of the titanium mined, however, is used to make white titanium-oxide pigment used in paint, paper, rubber, plastic, and other materials. The common ore minerals of titanium are rutile (TiO_2), ilmenite ($FeTiO_3$), and leucoxene, which is a general term for a mixture of the end products of the alteration or weathering of ilmenite (Force, 1976a, p. A2). Economic concentrations of ilmenite and rutile in rock, or primary deposits, are associated with anorthosite or gabbro–anorthosite complexes (Herz, 1976, p. D1). Much of the current production of ilmenite and rutile, however, comes from secondary deposits in alluvial or beach placers.

The Greenville quadrangle contains no primary sources of titanium ore. Although at least one of the gabbro bodies in the Charlotte thrust sheet is rich in titanium, the element is dispersed throughout the rock in the silicate minerals, especially titanaugite, and in the oxide, titaniferous magnetite, neither of which is useful economically (Lesure and others, in press).

Many of the rocks in the quadrangle contain small amounts of rutile and ilmenite because progressive regional metamorphism shifts titanium from silicate minerals to the oxide minerals, ilmenite and rutile (Force, 1976b, p. B1). These oxides are heavy, weathering-resistant minerals easily concentrated in soil or stream sediments. Extensive resources of ilmenite and rutile in low-grade alluvial placers are present in many streams throughout the quadrangle. An unusual example is the coarse-grained rutile in small-stream placer deposits in the Brasstown Bald and Shooting Creek windows in the northwest corner of the quadrangle. These deposits have developed from the deep weathering of rutile-bearing garnet-mica schist in the Great Smoky thrust sheet. Van Horn (1945) has outlined about 300 acres of rutile-bearing alluvium in five areas. The alluvium ranges in thickness from 5 to 6 ft. If the average rutile content is assumed to be 12 lb/yd^3 (Van Horn, 1945, p. 1), then the indicated resources are 16,000 tons of rutile.

URANIUM

Uranium is a silvery white metal that consists of three semistable radioactive isotopes—U^{238}, U^{235}, and U^{234}—of which U^{235} is an important energy source (Finch and others, 1973). The uranium content of the crust of the Earth is about 2 ppm and that of granitic rocks is about 4 ppm (Finch and others, 1973, p. 459). In unoxidized black ores, uranium is found in uraninite (UO_2), coffinite [$U(SiO_4)_{1-x}(OH)_{4x}$], and multiple oxides like brannerite and davidite. Tetravalent uranium substitutes for thorium and other elements in minerals such as monazite and uranothorite and for calcium in carbonate fluorapatite. Under oxidizing conditions, tetravalent uranium changes to hexavalent uranium and forms many complex compounds. The principal domestic resources are found in continental and marginal marine sandstone and related rocks; less than 2 percent of domestic resources are in vein deposits (Finch and others, 1973, p. 460). Although traces of uranium are found in many rock types in the Greenville quadrangle, no concentrations of ore grade are known, and the geology is not favorable for the occurrence of significant deposits. The aerial gamma-ray map showing distribution of radiation related to uranium correlates closely with the map for thorium in the southeastern and eastern parts of the quadrangle, which suggests the presence of both elements in resistant minerals in the soil, most probably in monazite (figs. 4 and 5).

DISTRIBUTION OF MONAZITE IN ROCK

Mertie (1953, 1979) proposed several monazite belts in the southeastern United States on the basis of the analyses of panned accessory minerals in bedrock, principally saprolite, and some samples of crushed fresh rock. Two of his belts, the western Piedmont belt and the less well defined mountain belt, cross the Greenville quadrangle (fig. 6). Distribution of anomalous concentrations of Ce, Th, U, and La in stream sediments and heavy-mineral concentrates from stream sediments (Curtin and others, in press) suggests that monazite is more widely disseminated than in just these belts. Overstreet (1967, p. 11) reported that monazite is widely distributed as a minor accessory mineral in intermediate- and high-rank metamorphic rocks derived from argillaceous sediments and is less common in those derived from arenaceous sediments. Argillaceous rocks of the Great Smoky Group north of the quadrangle contain very fine grained metamorphic monazite (Mohr, 1984) where the metamorphic grade is staurolite to kyanite or greater. Monazite is also found in magmatic rocks ranging in composition from diorite to granite, but it is rarely found in syenite. It is not known to occur in plutonic mafic rocks or their metamorphic equivalents. The areas in the quadrangle of the greatest thorium content as indicated by the aerial gamma-ray data (fig. 5) are mostly underlain by sillimanite schist or various types of granitic gneiss in the Paris Mountain, Six Mile, and Laurens thrust sheets and by a variety of metamorphic rocks in the sillimanite zone in the southwestern part of the Tallulah Falls thrust sheet (figs. 3 and 5).

REE, THORIUM, TITANIUM, AND URANIUM RESOURCES

REE, thorium, titanium, and uranium resources in the Greenville quadrangle are restricted to natural, secondary accumulations of monazite, ilmenite, and rutile. These minerals have been found as placer deposits in small streams, especially in parts of the Six Mile and Paris Mountain thrust sheets (see map). Overstreet and others (1968) outlined in the South Carolina part of the quadrangle (fig. 7) the monazite placers, all of which contain various amounts of rutile and ilmenite. Overstreet and others (1959) estimated a resource of more than 430 million lb of monazite containing 4 to 5 percent ThO_2 and 0.4 to 0.7 percent U_3O_8. This monazite would also contain 55 to 65 percent REE's, generally cerium and lanthanum (Overstreet, 1967, p. 235). The same placers may also contain about 2.9 million tons of ilmenite and 27,000 tons of rutile (Overstreet and others, 1968, p. 65–67). Williams (1967, table 3) estimated reserves of 31.2 million lb of monazite, 161,000 tons of ilmenite, and 7,800 tons of rutile in four of the better placer deposits described by Overstreet and others (1968). The only reported mining of monazite in the quadrangle was in 1900, when about 500 lb of monazite was produced in Spartanburg County, S.C., and between 1905 and 1909, when about 480,000 lb of monazite was recorded from Greenville County, S.C. (J.H. DeYoung, USGS, written commun., 1983). There is no recorded production of ilmenite or rutile from the quadrangle.

Used together, the geology as mapped by Nelson and others (1989) and the aerial gamma-ray map for thorium (fig. 5) suggest that the area of monazite placer deposits outlined by Overstreet and others (1968) probably extends into Georgia and follows rocks rich in sillimanite in the Six Mile thrust sheet (map). Similarly, rocks of the Six Mile thrust sheet that form a klippe called the Alto allochthon (Hatcher, 1978) just east of the Brevard fault zone (fig. 2) may also be source rocks for small monazite placer deposits in that area (map; figs. 4 and 5). The southwestern part of the Tallulah Falls thrust sheet is also considered a likely source of small monazite placer deposits (fig. 6). All of these placer deposits also contain various amounts of ilmenite and rutile.

Most of the placer deposits outlined by Overstreet and others (1968) have not been worked for their heavy-mineral content. Sand and gravel operators in this area should consider the possibility of recovering the heavy minerals as valuable byproducts when washing their products; these heavy minerals would include various amounts of monazite, rutile, zircon, ilmenite, and possibly gold.

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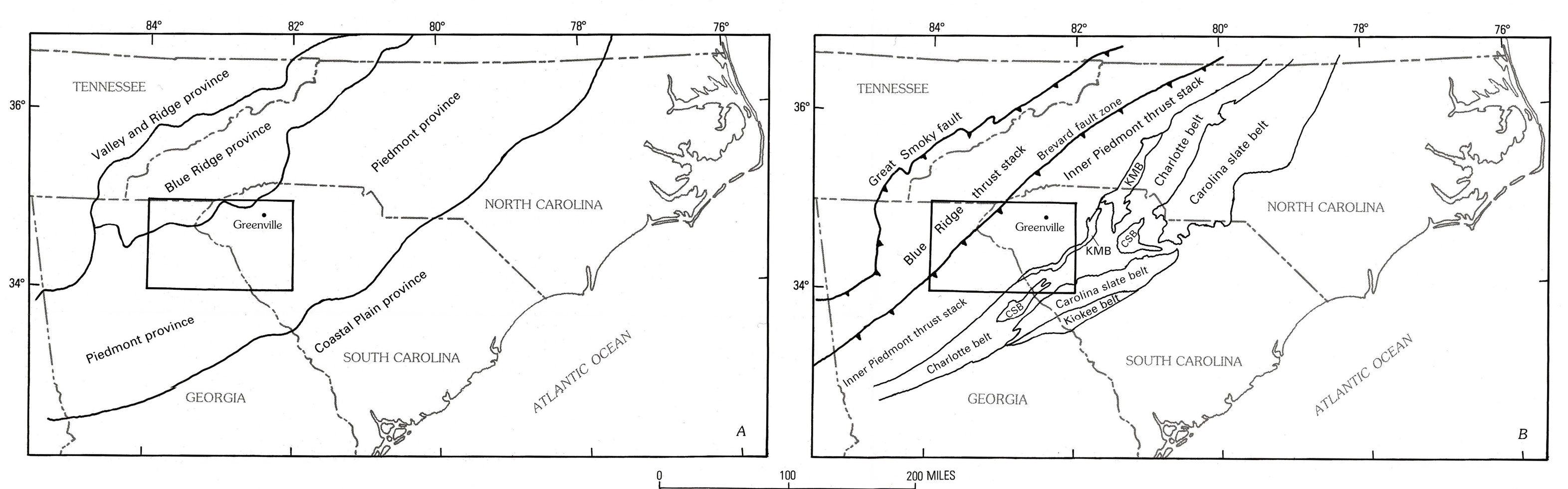

Figure 1.—Maps showing location and setting of the Greenville 1° x 2° quadrangle (box). *A*, Physiographic provinces modified from Fenneman and Johnson (1946). *B*, Previous interpretations of geologic terranes, modified from King (1955), Overstreet and Bell (1965a), and Nelson (1988); CSB, Carolina slate belt; KMB, Kings Mountain belt.

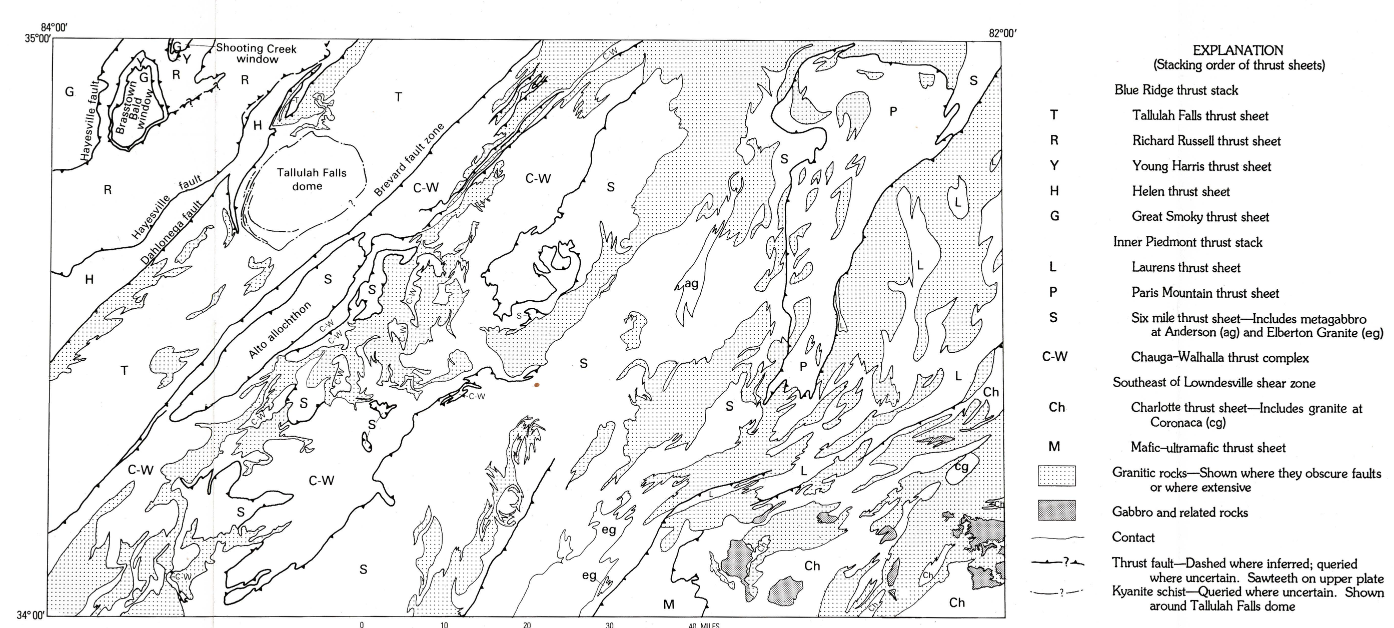

Figure 2.—Generalized tectonic map of the Greenville 1° x 2° quadrangle (modified from Nelson and others, 1990).

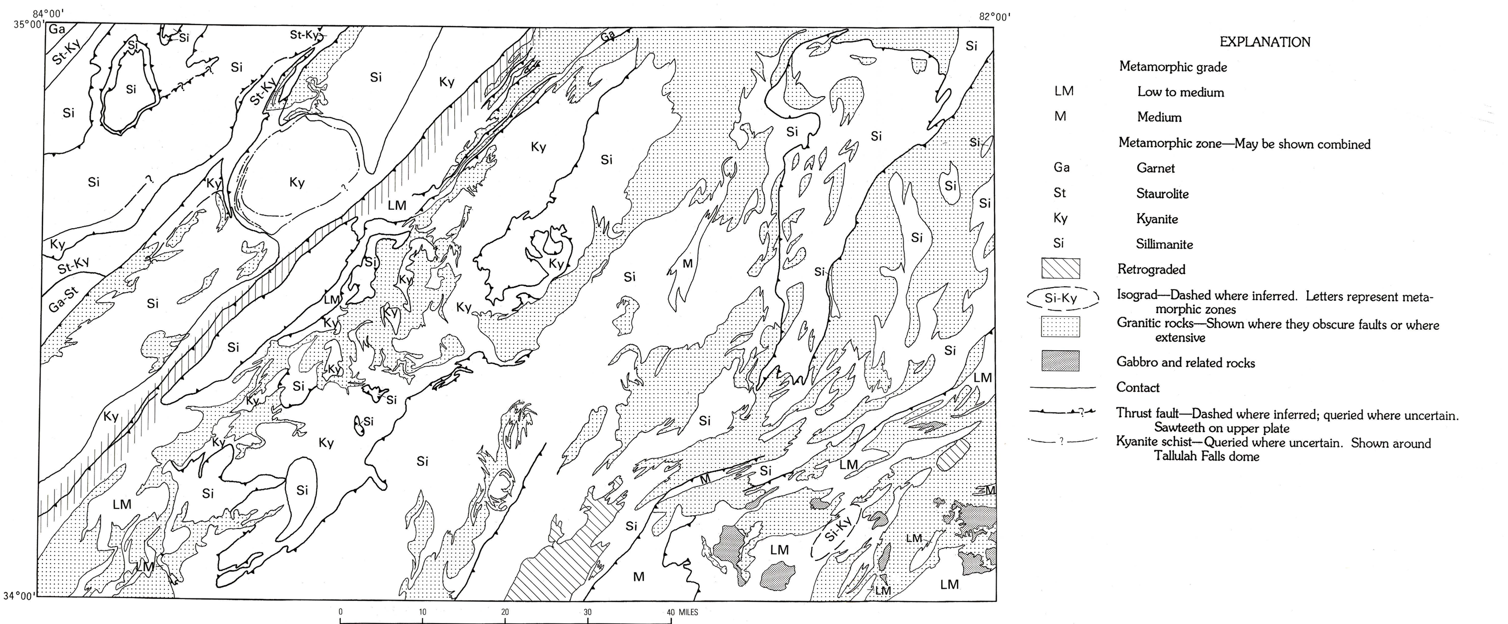

Figure 3.—Generalized tectonic map of the Greenville 1° x 2° quadrangle showing metamorphic grade and metamorphic zones (modified from Nelson, 1988). See figure 2 for explanation of geologic map units.

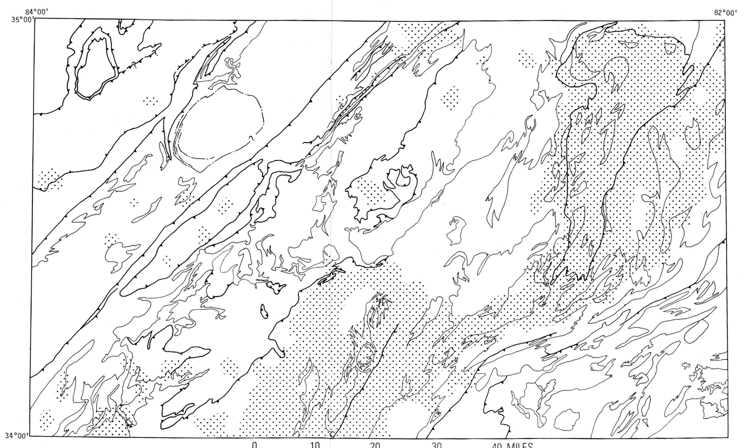

Figure 4.—Areas of greater uranium content (stipple) in surface materials in the Greenville 1° x 2° quadrangle based on spectral gamma-ray data (D.L. Daniels, unpub. data, 1992). See figure 2 for explanation of geology.

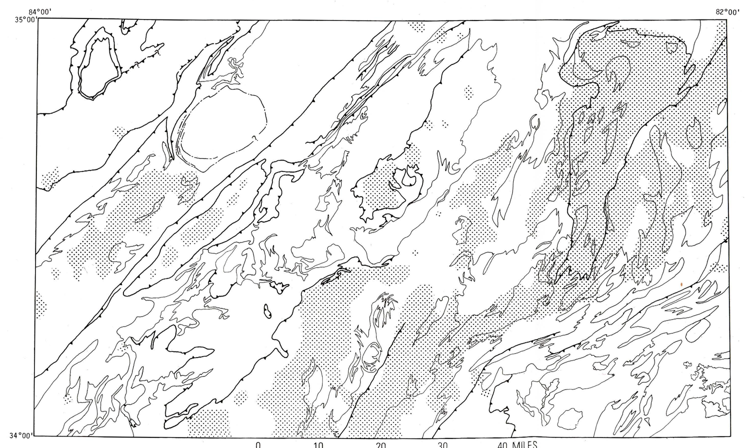

Figure 5.—Areas of greater thorium content (stipple) in surface materials in the Greenville 1° x 2° quadrangle based on spectral gamma-ray data (D.L. Daniels, unpub. data, 1992). See figure 2 for explanation of geology.

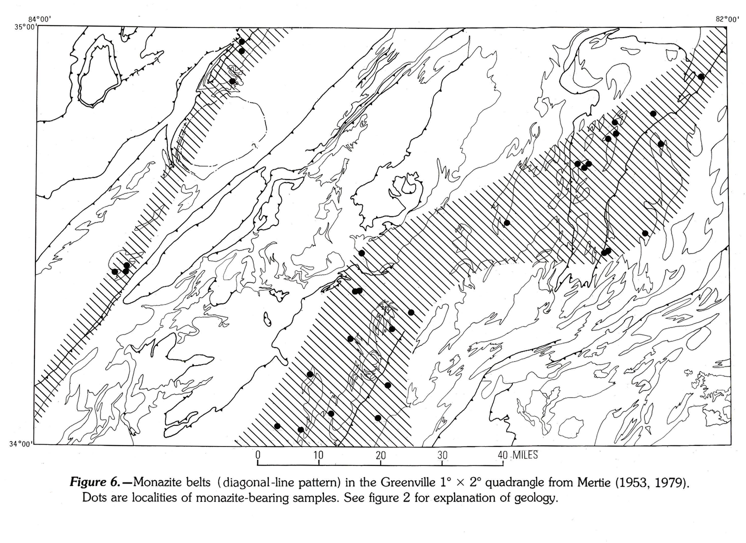

Figure 6.—Monazite belts (diagonal-line pattern) in the Greenville 1° x 2° quadrangle from Mertie (1953, 1979). Dots are localities of monazite-bearing samples. See figure 2 for explanation of geology.

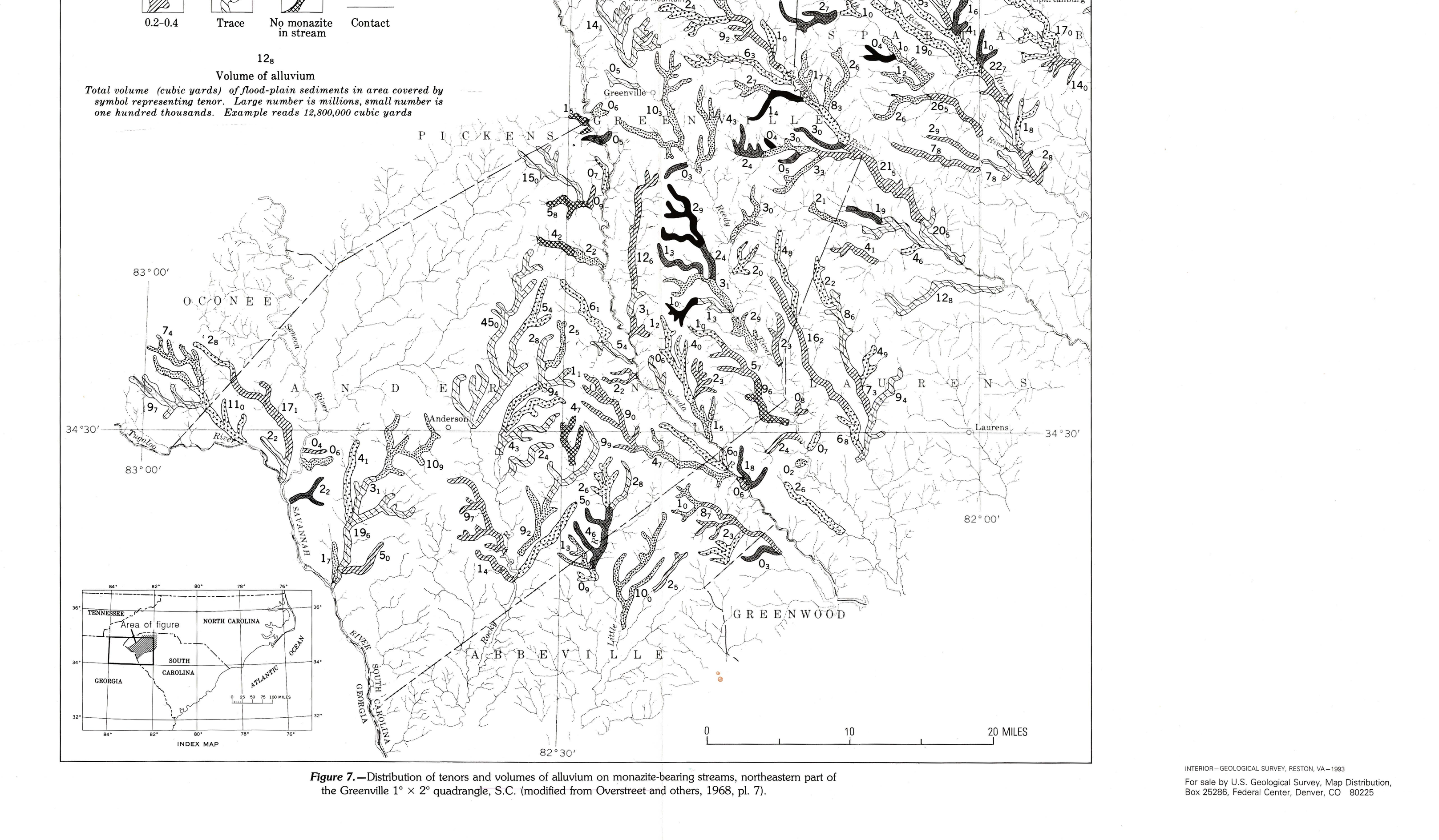

Figure 7.—Distribution of tenors and volumes of alluvium on monazite-bearing streams, northeastern part of the Greenville 1° x 2° quadrangle, S.C. (modified from Overstreet and others, 1968, pl. 7).

MINERAL RESOURCE ASSESSMENT OF RARE-EARTH ELEMENTS, THORIUM, TITANIUM, AND URANIUM IN THE GREENVILLE 1° × 2° QUADRANGLE, SOUTH CAROLINA, GEORGIA, AND NORTH CAROLINA

By
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