Geology and Mineral Resource Potential of the Chattanooga 1°×2° Quadrangle, Tennessee and North Carolina—A Preliminary Assessment

U.S. GEOLOGICAL SURVEY BULLETIN 2005

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By SANDRA H.B. CLARK, GREGORY T. SPANSKI, DONALD G. HADLEY, and ALBERT H. HOFSTRA

On the basis of geology and known mineral deposits, five tracts are delineated that are favorable for the occurrence of mineral resources, including metals, industrial minerals, and fuels

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METRIC CONVERSION FACTORS

For readers who wish to convert measurements from the inch-pound system of units to the metric system of units, the conversion factors are listed below:

Multiply inch-pound units	By	To obtain metric units
Foot (ft)	0.3048	Meter (m)
Cubic foot (ft^3)	.02832	Cubic meter (m^2)
Mile (mi)	1.609	Kilometer (km)
Square mile (mi^2)	2.59	Square kilometer (km^2)
Ounce (oz)	28.349	Gram (g)
Ton, short	.907	Megagram (Mg)

ALTITUDE DATUM

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Geology and Mineral Resource Potential of the Chattanooga 1°×2° Quadrangle, Tennessee and North Carolina—A Preliminary Assessment

By Sandra H.B. Clark, Gregory T. Spanski, Donald G. Hadley, *and* Albert H. Hofstra

Abstract

The Chattanooga 1°×2° quadrangle is the westernmost of four adjacent quadrangles that transect the southern Appalachians. It includes, from east to west, parts of five physiographic provinces or sections—Blue Ridge, Valley and Ridge, Cumberland Plateau, Highland Rim, and Nashville Basin. These provinces or sections reflect differences in the underlying bedrock. In the Blue Ridge province, the bedrock is derived primarily from a thick sequence of clastic sediments of Proterozoic age that were repeatedly deformed and metamorphosed. West of the Blue Ridge, the bedrock is primarily a Cambrian to Pennsylvanian sedimentary sequence that formed in the Appalachian basin and was folded and faulted during the Alleghanian orogeny. In the Valley and Ridge province, deformation is predominantly thin-skinned thrust faulting. At depth, the thrust faults join a master décollement near the sedimentary rock-basement contact. The intensity of deformation decreases to the west. In the Cumberland Plateau section, the thickness of the sedimentary sequence is less than in the Valley and Ridge, and deformation decreases to nearly zero. The Highland Rim section is a transitional zone between the Cumberland Plateau and the Nashville Basin sections. In the area of the Nashville Basin, the sedimentary sequences of the western part of the Appalachian basin are upwarped into the Nashville dome, which is part of the Cincinnati arch.

The major mineral resources in the Chattanooga 1°×2° quadrangle and their geologic settings are listed below:

- Metals, barite, and fluorite
  1. Massive sulfide (copper-iron-sulfur-zinc) deposits of the Ducktown massive sulfide district in Late Proterozoic metasedimentary rocks of the Blue Ridge province;
  2. The Coker Creek vein, metasedimentary- rock- hosted gold, and placer deposits in Late Proterozoic metasedimentary rocks of the Blue Ridge;
  3. Barite, fluorite, lead, and zinc in residual deposits and veins in carbonate rocks of the Upper Cambrian and Lower Ordovician Knox Group in the Sweetwater barite district and elsewhere in the Valley and Ridge province;
  4. Fluorite, barite, lead, and zinc in veins in the Nashville Basin;
  5. Sedimentary iron deposits in the Lower and Middle Silurian Rockwood Formation exposed near the base of the Cumberland Plateau escarpment, on the eastern side of the Sequatchie Valley, and in the Valley and Ridge; and
  6. Secondary iron and manganese deposits that developed over certain favorable rock layers in the Valley and Ridge and Blue Ridge.
- Industrial and construction minerals
  1. Talc and marble from the Murphy belt of the Blue Ridge;
  2. Marble, limestone (including agricultural limestone), and dolomite from the Valley and Ridge;
  3. Limestone (including cement and agricultural limestone), high-silica sand, and ornamental sandstone from the Cumberland Plateau section;
  4. Limestone (including agricultural limestone) from the Highland Rim section; and
  5. Sand, gravel, clay, and material for use as crushed stone or dimension stone or in lightweight aggregate in all provinces or sections.
- Fuels
  1. Gas fields underlying the Highland Rim and western Cumberland Plateau and
  2. Coal in the Pennsylvanian rocks exposed in the Cumberland Plateau.

Other actual or potential mineral resources in the quadrangle include low-grade sinkhole bauxite deposits (for aluminum) near the city of Chattanooga and low-grade uranium deposits and oil shale in the Chattanooga Shale.

Hydrocarbon production has been mainly gas from six small fields in the western Cumberland Plateau-Highland Rim area and a small amount of oil from one field near the eastern escarpment of the Cumberland Plateau. Oil shale in the Chatta-

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nooga Shale is estimated to contain 10 million to 20 million barrels of oil and 60 billion to 80 billion cubic feet of gas per square mile. Most of the Pennsylvanian section of the Cumberland Plateau contains coal seams. The total coal resource is about 500 million tons.

On the basis of the present interpretation of the geology of the region and the distribution of known deposits, the following five tracts have been identified as being permissive (favorable) for the presence of the described types of mineral deposits:

Tract 1. A thick Late Proterozoic metaclastic sequence of the Ocoee Supergroup, exposed in the Blue Ridge, has potential for massive sulfide and sedimentary exhalative copper, iron, sulfur, zinc, gold, and silver and for sedimentary-rock-hosted, vein, and placer gold.

Tract 2. The Cambrian(?) metaclastic and carbonate sequences of the Murphy belt in the Blue Ridge province have potential for supergene and residual iron and manganese deposits, placer gold, talc, and marble.

Tract 3. The Lower Cambrian through Middle Silurian sedimentary sequence of the Appalachian basin, which is exposed mainly in the Valley and Ridge province, has potential for Mississippi Valley-type barite, zinc, lead, and fluorite deposits; sedimentary iron; residual-weathering barite and secondary iron and manganese; karst-type bauxite; clay; marble; limestone; and dolomite.

Tract 4. The Upper Devonian through Upper Mississippian sedimentary sequence of the Appalachian basin, which is exposed primarily in the Highland Rim section, has potential for deposits of secondary manganese, phosphate, limestone, sand, ornamental sandstone, uranium, and oil and gas from oil shale.

Tract 5. The Lower Pennsylvanian terrigenous clastic sequence of the Appalachian basin, which is exposed primarily in the Cumberland Plateau section, has potential for coal, high-silica sand, and dimension stone (sandstone).

GEOLOGY OF THE AREA

The Chattanooga 1°×2° quadrangle includes parts of the Blue Ridge and Valley and Ridge physiographic provinces, the Cumberland Plateau section of the Appalachian Plateaus province, and the Highland Rim and Nashville Basin sections of the Interior Low Plateaus province (fig. 1). The portion of the quadrangle in the Blue Ridge physiographic province includes predominantly rocks of the Ocoee Supergroup and Murphy lithotectonic belt. At the western border of the Blue Ridge, rocks that were deposited during the Late Proterozoic and the Cambrian are juxtaposed. The rocks in the quadrangle west of the Blue Ridge are part of the Paleozoic Appalachian basin sedimentary sequence.

The geology of the area has been studied and described by many workers, and many areas of uncertainty in interpretation remain, especially in the Blue Ridge. For this paper, a brief and generalized overview of the geologic setting is presented, based primarily on published descriptions, with no attempt to resolve differences in interpretation. The major sources of summary materials used in this paper are cited; for more detailed information and references to the original field studies upon which the summaries are based, the reader is referred to lists of references in the literature cited herein. The geologic map of the quadrangle (pl. 1) was generalized from more detailed geologic maps of the east-central part of Tennessee (Swingle and others, 1966) and the southwestern portion of North Carolina (North Carolina Geological Survey, 1985) and provisional maps of the Blue Ridge area of Tennessee by Merschat and Wiener (1973; unpub. data). A geophysical study of the Chattanooga 1°×2° quadrangle, which was done in conjunction with the mineral resource appraisal, has been published separately as a companion document (King, 1991).

Ocoee Supergroup

The Late Proterozoic Ocoee Supergroup, which includes the oldest rocks in the Chattanooga 1°×2° quadrangle, is the predominant unit exposed in the Blue Ridge province. The Ocoee Supergroup consists of a thick sequence of mainly terrigenous, clastic sediments that is unconformable or in fault contact with Grenville basement and has been subjected to Barrovian-type metamorphism. The metasediments are thought to thicken eastward and mark a hinge of major downwarping of the continental margin in Late Proterozoic time (Hadley, 1970). In Tennessee and North Carolina, the Ocoee Supergroup has been divided into three major groups, the Snowbird, Great Smoky, and Walden Creek Groups, which occur in thrust slices (King and others, 1958). Several formations have been mapped in these groups (table 1), but because of the repetitive nature of sequences, structural complexity, lack of marker beds, and apparent lack of lateral continuity of mapped units, stratigraphic subdivision and correlation of map units from one area to another are difficult and not always possible (Wiener and Merschat, 1978; Slack and others, 1984). Distinct differences in stratigraphy have been recognized east and west of the Greenbrier fault (table 1). The Late Proterozoic sequence and units shown on plate 1 are based on provisional data and mapping compiled by Merschat and Wiener (1973; unpub. data) and are believed to be a rational interpretation of the stratigraphic sequence.

The discovery of a Paleozoic fossil assemblage in the Wilhite Formation of the Walden Creek Group in the vicinity of Chilhowee Lake (near the east-central border of the Chattanooga 1°×2° quadrangle) brings into question

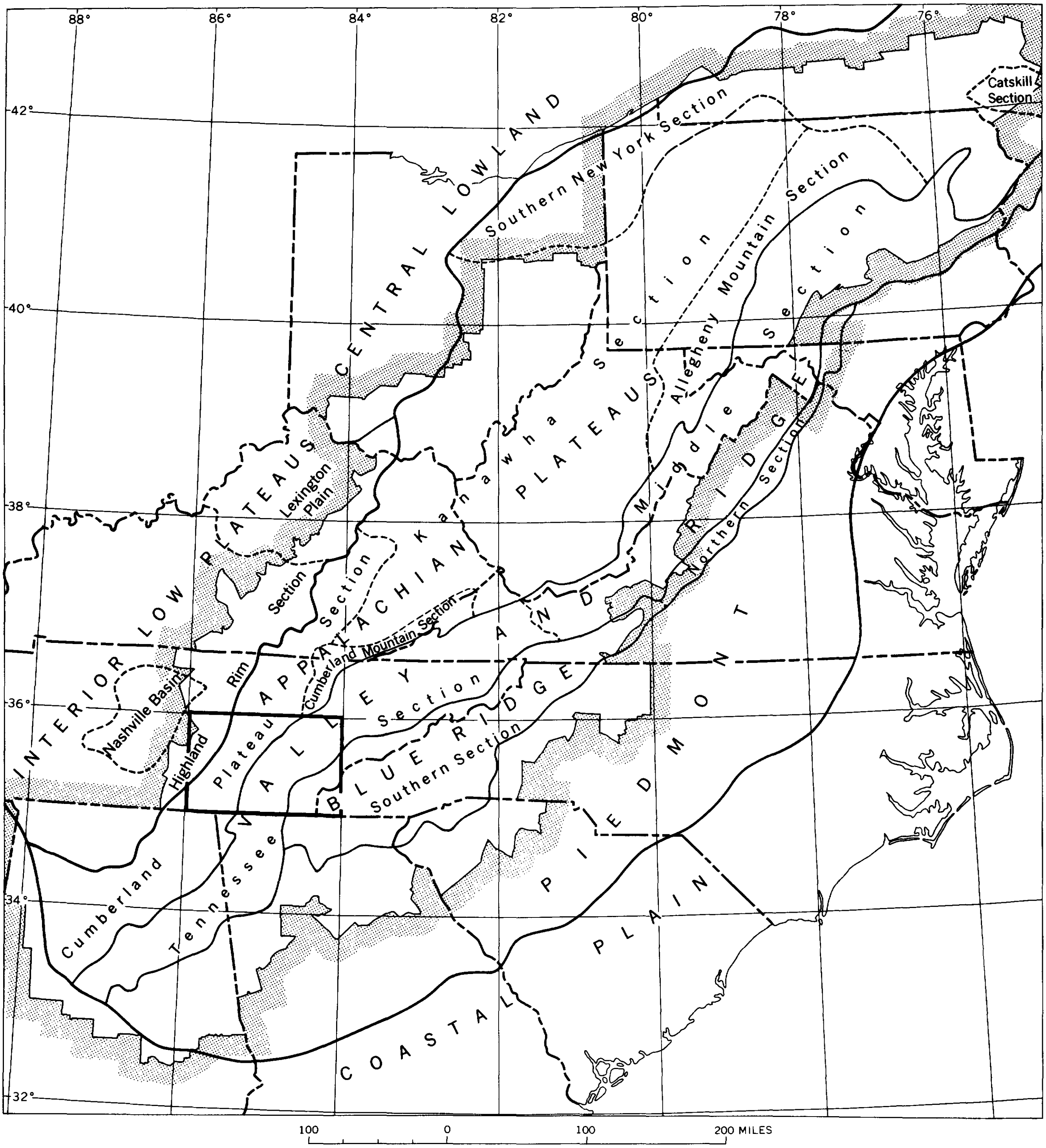


Figure 1. Physiographic provinces and sections of the East-Central United States and the location of the Chattanooga 1°×2° quadrangle (heavy lines) (from Davies, 1968).

conventional views of ages, stratigraphic sequences, and structural relations (Tull and Groszos, 1990; Unrug and Unrug, 1990). Because many questions remain unresolved, the previously used designations of age and stratigraphy are retained in this report, pending further study.

The Snowbird Group is a sequence of phyllite, metasiltstone, and feldspathic metasandstone, which conformably overlies Grenvillian gneisses. In the area of the Great Smoky Mountains, the Snowbird Group was divided into several intertonguing formations by King and others

Table 1. Interpretations of relationships of rock units of the Tennessee-North Carolina Blue Ridge belt in the Chattanooga 1°×2° quadrangle

[Correlation between regions is not implied]

From Hatcher and Butler (1979); based on mapping by Hurst (1955) and Hernon (1968) in the Ducktown area

	Northwest of and below the Greenbrier fault		Southeast of and above the Greenbrier fault
	Rome Formation	Murphy belt sequence	Mineral Bluff Formation
Chilhowee Group	Shady Dolomite	Murphy belt sequence	Nottely Quartzite
Chilhowee Group	Hesse Sandstone	Murphy belt sequence	Andrews Formation
Chilhowee Group	Murray Shale	Murphy belt sequence	Murphy Marble
Chilhowee Group	Nebo Sandstone	Murphy belt sequence	Brasstown Formation
Chilhowee Group	Nichols Shale	Murphy belt sequence	Tusquitee Quartzite
Chilhowee Group	Cochran Conglomerate	Murphy belt sequence	Nantahala Formation
	Sandsuck Formation	Great Smoky Group	Dean Formation
		Great Smoky Group	Hothouse Formation
		Great Smoky Group	Hughes Gap Formation
Walden Creek Group	Wilhite Formation	Great Smoky Group	Boyd Gap Formation
		Great Smoky Group	Wehutty Formation
		Great Smoky Group	Copperhill Formation
	Snowbird Group		–Nonconformity–
			Grenville basement

From Rast and Kohles (1986); based on the work of King and others (1958) in the Great Smoky Mountains

Age			Northwest of and below the Greenbrier fault			Southeast of and above the Greenbrier fault
Middle Ordovician to Middle Cambrian			Knox Group Conasauga Group Rome Formation			Murphy Group
Early Cambrian			Chilhowee Group			
late Precambrian	Ocoee Supergroup	Walden Creek Group	Sandsuck Formation Wilhite Formation Shields Formation Licklog Formation	Ocoee Supergroup	Great Smoky Group	Anakeesta Formation Thunderhead Sandstone Elkmont Sandstone
late Precambrian	Ocoee Supergroup		Sandstones of Webb Mountain and Big Ridge	Ocoee Supergroup	Great Smoky Group	
late Precambrian	Ocoee Supergroup		Cades Sandstone	Ocoee Supergroup	Snowbird Group	Roaring Fork Sandstone Longarm Quartzite Wading Branch Formation
late Precambrian	Ocoee Supergroup		Rich Butt Sandstone	Ocoee Supergroup	Snowbird Group	
late Precambrian	Ocoee Supergroup	Snowbird Group	Metcalf Phyllite Pigeon Siltstone Roaring Fork Sandstone Longarm Quartzite Wading Branch Formation	Ocoee Supergroup	Snowbird Group	
earlier Precambrian			Grenville basement			Grenville basement

(1958). The formations of this group thin stratigraphically eastward, successively overlapping one another (DeWindt, 1975). Although rocks of the Snowbird Group were not recognized in the Chattanooga 1°×2° quadrangle at the time of the compilation of the Geologic Map of Tennessee (Swingle and others, 1966), the work of Wiener and Merschat (1978; unpub. mapping) suggests that the Snowbird is present west of the Great Smoky Group (pl. 1).

The Great Smoky Group is estimated to be about 25,000 feet thick (Wiener and Merschat, 1978) and includes the host rocks of the massive sulfide deposits of the Ducktown district. Most of the rocks are metagraywacke or feldspathic metasandstone, slate, phyllite, and schists and are composed of poorly sorted, coarse- to fine-grained quartz, feldspar and micas, and chlorite. The original sediments were deposited commonly under reducing conditions, and graphitic schist and iron sulfides recur repeatedly in the section. Graded bedding and other diagnostic primary features of cyclic sedimentation are present widely in the rocks. At least part of the sequence probably originated as submarine fans and turbidites in a deep, elongated marine rift basin (Lesure and others, 1977; Force and Gazdik, 1983; Rast and Kohles, 1986).

The Walden Creek Group consists mainly of metasiltstone, slate having dolomitic layers, metaconglomerate, and feldspathic metasandstone locally. The original sediments of the Walden Creek Group were predominantly turbidites and are lithologically the most heterogeneous of the three groups of the Ocoee Supergroup. Exposures of the Walden Creek Group are in isolated thrust sheets of the western Blue Ridge of Tennessee (Kish and others, 1975).

The Ocoee Supergroup is thought to have formed during the Late Proterozoic continental rifting event associated with the opening of Iapetus to the east (Rankin, 1975). On the basis of an analysis of sedimentology and structure in the Ocoee Supergroup, as described by previous workers, Rast and Kohles (1986) proposed a model of deposition in which the Snowbird Group and the Great Smoky Group formed in distinct basins, most likely grabens, separated by a ridge, probably a horst; the provenances of the two groups apparently were away from the ridge (respectively to the southeast and the northwest). An alternative interpretation is that the Walden Creek Group formed as part of a successor basin sequence that postdated the Middle Ordovician Taconic orogeny (Tull and Groszos, 1990).

The rocks of the Blue Ridge province were deformed several times during the Paleozoic. Superposition of structures is a major aspect of the deformation in the central and eastern Blue Ridge (Hatcher, 1978). Premetamorphic, as well as Alleghanian, thrusts have been recognized (Hatcher, 1978). Several thrusts are related to the Taconic orogeny, and Alleghanian thrusts are prominently exposed along the western edge of the Blue Ridge (Hatcher and Butler, 1979). Low-angle thrust faults and passive-slip folds that have axial-plane slaty cleavage are important structures in the western portion of the Blue Ridge (Hatcher, 1978). Farther east, large folds are the dominant structures. At the western border of the Blue Ridge province, a major dislocation, the Great Smoky fault system, has juxtaposed Proterozoic and Cambrian rocks with other Paleozoic strata (Wiener and Merschat, 1978).

The structure of the Blue Ridge is obscured by Barrovian metamorphism, which generally increases from west to east across the belt. Garnet and staurolite are present in the southeastern part of the Great Smoky Group in the Chattanooga $1° \times 2°$ quadrangle, and kyanite and sillimanite are present farther to the east (Hernon, 1968; Wiener and Merschat, 1978). The Murphy belt is an anomaly in this pattern; there, metamorphism is in the greenschist facies (North Carolina Geological Survey, 1985). The major metamorphic mineral assemblages are thought to have formed in a single event during the Taconic orogeny about 440 to 480 Ma (Butler, 1972; Dallmeyer, 1975), followed by one or more retrograde events.

Murphy Belt

The Murphy belt is a sinuous, northeast-trending lithotectonic feature that extends nearly 100 miles from Cartersville, Ga., to Bryson City, N.C. (Keith, 1907; Hurst 1955; Fairley, 1965; Power and Forrest, 1971, 1973; Fritz and LaTour, 1988). The rocks of the Murphy belt include metamorphosed thin-bedded argillaceous siltstone, shale, and fine-grained sandstone (Hadley, 1970) and, in the southeastern corner of the Chattanooga $1° \times 2°$ quadrangle, schist, quartzite, marble, and rare amphibolite (North Carolina Geological Survey, 1985). The Murphy belt is distinct from the surrounding rocks of the Great Smoky Group in that the Murphy-belt sequence includes graphitic phyllite, clean metaquartzite, and marble. The Murphy belt includes three distinct sedimentary sequences (Groszos and Tull, 1987; Tull and Groszos, 1988). The lowest units are in a clastic sequence that fines and thins upward. The middle unit is dominated by carbonate units (a carbonate bank?) and includes the Murphy Marble. The upper sequence is a diverse package of clastic units.

The Murphy belt generally is considered to be a synformal structure that has at least one major fault near the center of the belt (Hatcher, 1978), but recent work in Georgia suggests that the belt had a complex history and is extensively thrust faulted (Higgins and others, 1988, 1989). Murphy belt rocks have been correlated with the Walden Creek Group (Hadley, 1970) and, alternatively, with the Lower Cambrian Chilhowee Group, Shady, and Rome Formations (Power and Forrest, 1973). A more recent interpretation (based on newly discovered fossil assemblages) is that the Mineral Bluff Formation, as well as the Walden Creek Group, was deposited in Taconic (Middle Ordovician) successor basins (Tull and Groszos, 1990). Because of the uncertainty regarding age, structural relations, and stratigraphic order of the Murphy belt rocks, the age designations and sequences as used by Hurst (1955) are retained for this report.

Appalachian Basin Sedimentary Sequence

The Appalachian basin was an elongate miogeoclinal depositional trough along the eastern passive margin of the North American Continent. The basin began to develop after Late Proterozoic rifting and the formation of the

Iapetus Ocean, and its development continued until the beginning of the Late Pennsylvanian and Early Permian Alleghanian orogeny. A generalized restored-basin model (Harris and Milici, 1977) shows major characteristics of the basin (fig. 2), including Paleozoic rocks ranging in age from Cambrian to Pennsylvanian in a wedge-shaped sequence that thins markedly from east to west. These rocks represent three major depositional episodes separated by regional unconformities between the Lower and Middle Ordovician, Lower and Upper Devonian, and above the Pennsylvanian. The stratigraphic sequence of Harris and Milici (1977) is used as a basis of discussion in this report (fig. 3) but has been modified to include more recent work.

Late Proterozoic to Silurian

The Cambrian-to-Silurian Appalachian basin sequence is well exposed mainly in the Valley and Ridge physiographic province. The lower part of the sequence (mostly Cambrian and Ordovician rocks) and the underlying Late Proterozoic Sandsuck Formation underlie the western portion of the Blue Ridge province in the Chattanooga 1°×2° quadrangle; middle Paleozoic rocks are exposed mainly in the Sequatchie Valley and near the northwest corner of the quadrangle in the Nashville Basin.

The Sandsuck Formation, which is unconformably below the Cambrian Chilhowee Group, is generally considered to be latest Proterozoic in age. Opinions differ as to whether the Sandsuck Formation is part of the Walden Creek Group. The Sandsuck Formation may have had a history similar to that of the Chilhowee Group but formed in a less stable depositional environment, as suggested by poorer sorting, a greater range in size of detritus, and more discontinuous sandstone units in the Sandsuck than in the Chilhowee (Wiener and Merschat, 1978). The Sandsuck Formation is included with the Appalachian basin sequences in this report.

The Cambrian and Lower Ordovician sediments that were deposited in the miogeoclinal Appalachian basin during the first depositional episode are a westward-transgressive sequence, which gradually changes upward from dominantly clastic to dominantly carbonate (Harris and Milici, 1977). Basal Cambrian clastic rocks (Chilhowee Group) and an overlying carbonate-shale sequence (Lower to Middle Cambrian Shady and Rome Formations; Middle to Upper Cambrian Conasauga Group) are exposed near the western border of the Blue Ridge in the Valley and Ridge province (Miller and others, 1968) (pl. 1). The Chilhowee Group sandstones formed in nearshore, shallow marine environments and interfinger with deeper water shales and siltstones (Whisonant, 1974). Most of the sediment was eroded from a craton to the west (Colton, 1970).

The Shady Formation is a carbonate-shelf rim sequence and was the first result of the formation of a carbonate bank following the earlier clastic sedimentation. The Shady Formation thins westward in Tennessee and interfingers with the Rome Formation, which 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 Rome Formation (Early and Middle Cambrian), the floor of the Appalachian basin gradually subsided so that deeper water marine environments prevailed throughout the area (Hatcher and Butler, 1979). The Conasauga Group, deposited in a regional intrashelf basin, consisted of shallow marine carbonate-shelf units that interfingered 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, however, 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 intrashelf basinal setting of the Conasauga includes the following depositional environments: (1) shallow water, shale-dominated, peritidal to the northwest; (2) mixed carbonate-shale intrashelf; and (3) shelf-margin carbonate-dominated shoal and peritidal complex (Hasson and Hasse, 1988). Lithofacies and isopach maps and stratigraphic cross sections define regional depositional patterns of the Conasauga Group and show that there was a subbasin within the regional intrashelf basin (Hasson and Hasse, 1988). The subbasin was elongated northwestward, perpendicular to the regional trend of the shelf and Appalachian structure. The boundaries of the subbasin are generally coincident with structures interpreted as major basement faults and with zinc and barite deposits in dolomite of the overlying Knox Group, and so at least some of the mineralizing fluids are likely to have originated by dewatering of shales in the subbasin and then to have migrated upward along boundary faults (Hasson and Hasse, 1988).

During the Late Cambrian, shallow-water carbonate shelf deposits that form the lower part of the Knox Group transgressed westward and eventually spread across the entire Appalachian basin (Harris and Milici, 1977). The Knox Group is mainly limestone in the eastern part of the Valley and Ridge province and mainly dolomite in the central and western parts. The regional distribution of limestone and dolomite is believed to be related to a westward-increasing salinity gradient in epicontinental seas that covered the continental shelf during Late Cambrian and Early Ordovician time (Harris, 1973). Regional uplift in Early Ordovician time resulted in a widespread erosion surface and development of karst topography, now a paleokarst. The paleokarst in the upper part of the Knox Group, which occurs below the regional unconformity between the Knox and the Chickamauga Groups, has been important in localizing the zinc and barite deposits in the

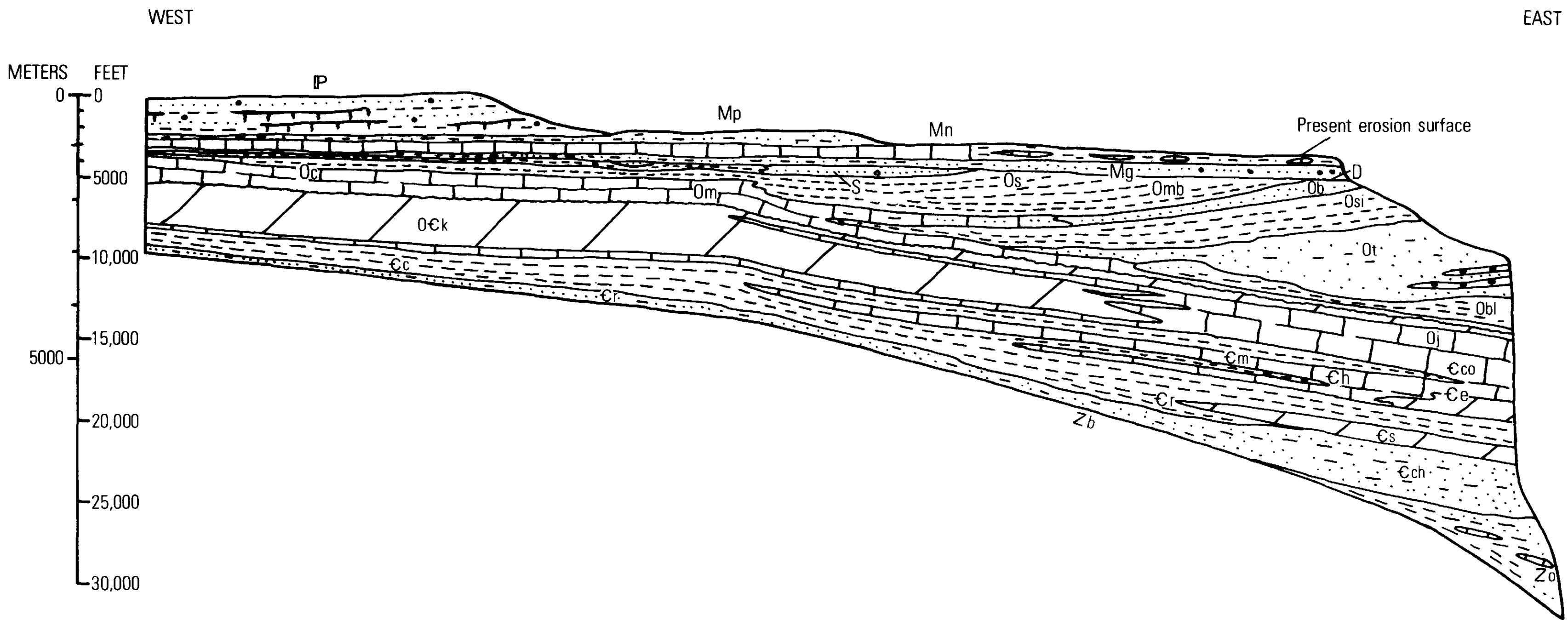
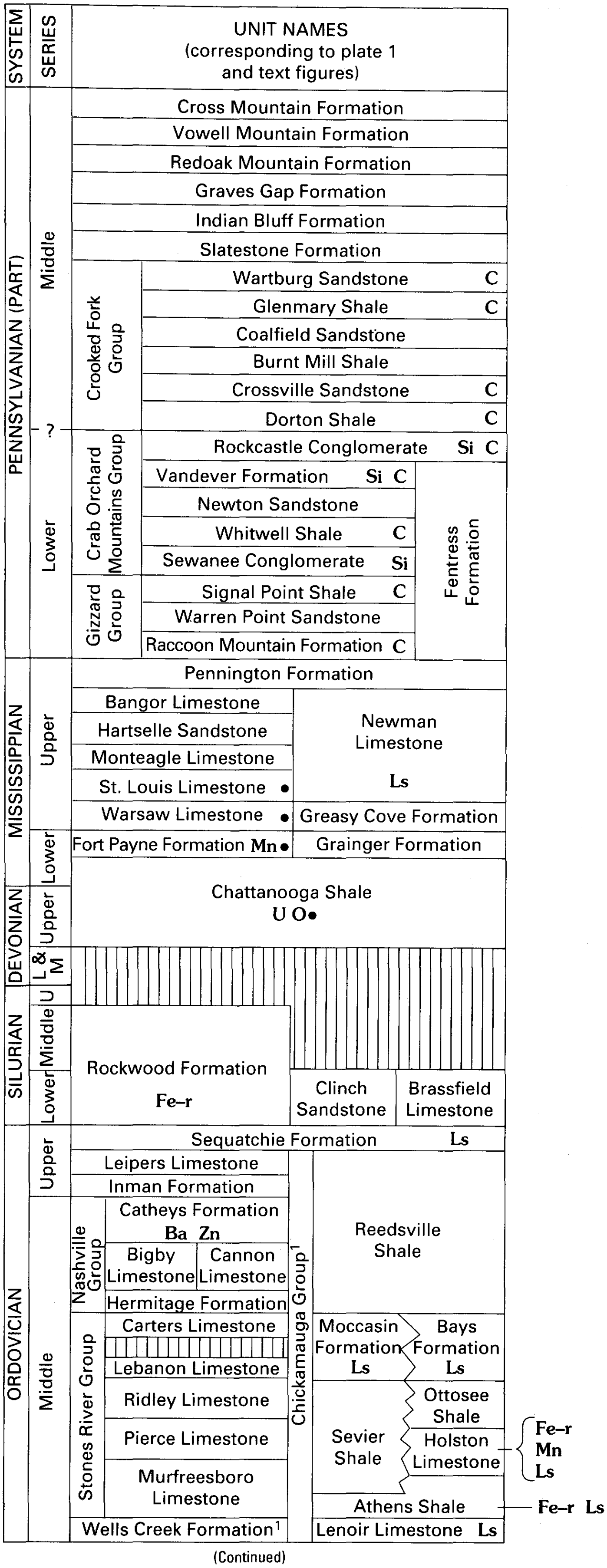
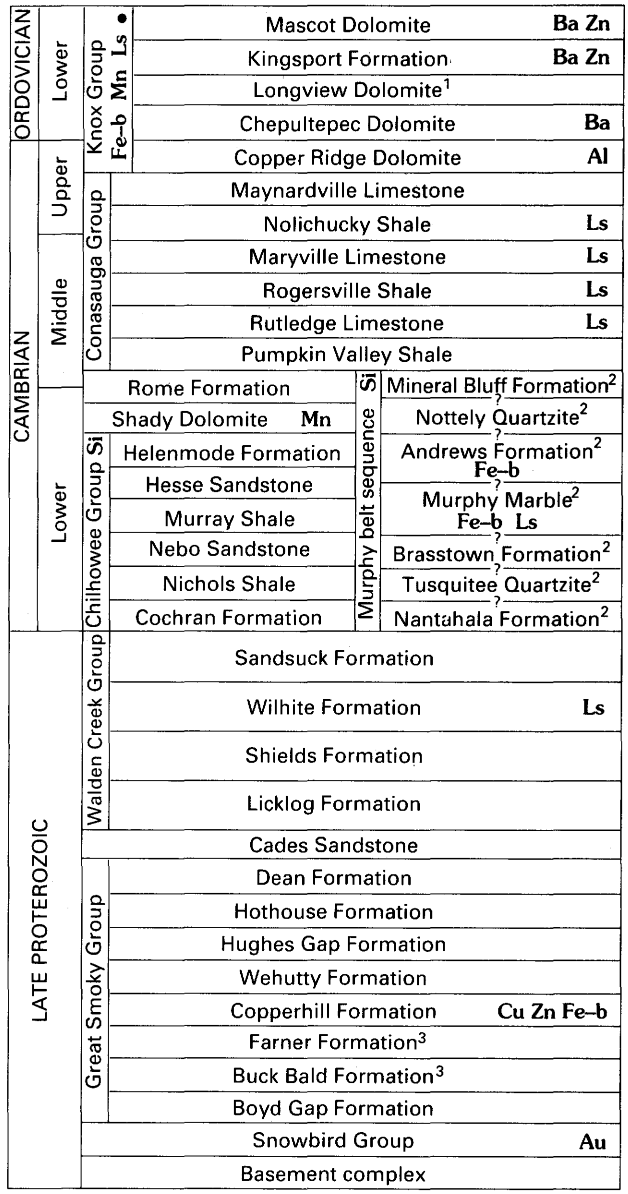


Figure 2. Generalized restored-basin model of the Paleozoic Appalachian basin in eastern Tennessee (from Harris and Milici, 1977). IP, Pennsylvanian rocks, undivided; Mp, Pennington Formation; Mn, Newman Limestone; Mg, Grainger Formation; D, Devonian rocks, undivided; S, Rockwood Formation, Clinch Sandstone, and Brassfield Limestone, undivided; Os, Sequatchie Formation; Omb, Martinsburg Shale; Oc, Chickamauga Group as used by Swingle and others (1966); Om, lower and middle parts of Martinsburg Shale; Ob, Bays Formation; Osi, Sevier Shale; Ot, Tellico Sandstone; Obl, Blockhouse Shale; Oj, Jonesboro Limestone; OЄk, Knox Group, undivided; Єco, Conococheague Limestone; Єc, Conasauga Group, undivided; Єm, Maryville Limestone; Єh, Honaker Dolomite; Єe, Elbrook Dolomite; Єr, Rome Formation; Єs, Shady Dolomite; Єch, Chilhowee Group, undivided; Zo, Ocoee Supergroup, undivided; Zb, basement rocks.





1 As used by Swingle and others (1966).
2 Of Hurst (1955).
3 Informal formation of Wiener and Merschat (1978).

Figure 3. Stratigraphic nomenclature used in eastern Tennessee and western North Carolina (modified from Harris and Milici, 1977, and Milici and others, 1979; stratigraphic sequence of Hurst (1955) used for Murphy belt rocks, with queries to reflect uncertainty in age, correlation, and stratigraphy based on recent work (Higgins and others, 1988; Unrug and Unrug, 1990; Tull and Groszos, 1990)). The major formations from which zinc, barite, copper, and gold have been produced are indicated by Zn, Ba, Cu, and Au, respectively. The major formations from which sedimentary (red) iron ore has been produced are indicated by Fe-r. The major formations upon which secondary concentrations of iron (brown), aluminum (bauxite), and manganese have developed are indicated by Fe-b, Al, and Mn, respectively. High uranium concentrations and oil shale resources in a formation are indicated by U and O, respectively. Rock units containing high-silica sand are indicated by Si; those containing limestone, dolomite, or marble resources are indicated by Ls. Coal-bearing formations are indicated by C. Oil-producing formations are indicated by a dot.

Valley and Ridge province of eastern Tennessee (Harris, 1969).

Middle Ordovician deep-water limestones and shales of the Chickamauga Group were deposited above the erosion surface as carbonate-shelf deposits. The Holston Formation, in the lower part of the Chickamauga Group, is a coarsely crystalline limestone that has been quarried for dimension stone (locally called the Holston Marble) (Gordon, 1924; Maher and Walters, 1960; Hershey and Maher, 1963, 1985). In many areas, the upper part of the Holston is sandy ferruginous limestone and calcareous shale (the Tellico Sandstone). Sedimentary iron ores and residually enriched iron and manganese deposits commonly are associated with the Holston Formation, especially the upper part.

Later, as the basin was filled, Upper Ordovician shaly limestones and shales of the Sequatchie Formation were overlain by a westwardly prograding sequence composed of shallow-water (beach or sand bar) orthoquartzite of the Lower Silurian Clinch Sandstone on the east, which grades into deep-water shales and siltstones of the Lower and Middle Silurian Rockwood Formation and then, in turn, into dominantly carbonate beds of the Lower Silurian Brassfield Limestone (Harris and Milici, 1977). The Rockwood Formation is the host rock for sedimentary iron ores in both the Valley and Ridge province and the Cumberland Plateau section. A major provenance of the clastic rocks was present east or southeast of the Appalachian basin from Middle Ordovician time onward (Hatcher and Butler, 1979).

Late Devonian to Pennsylvanian

Erosion following uplift, 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). Then, beginning in Late Devonian time, the Chattanooga Shale was deposited widely; the thickest accumulations were in the central part of the Valley and Ridge, and thinner ones to the east and west (Harris and Milici, 1977). The Chattanooga Shale is typically a dark-gray to black, carbonaceous, finely laminated shale having pyrite lamellae and nodules (Rheams and Neatherly, 1988). The formation locally contains small lenses and interbeds of sandstone, siltstone, and carbonate rocks. Calcite streaks, phosphate nodules, and cherty layers occur locally. The Chattanooga Shale is part of a very extensive Upper Devonian and Lower Mississippian black shale deposit that extends over large areas of the eastern and central parts of the United States and probably accumulated in an anaerobic sea (Rheams and Neatherly, 1988). Although the Chattanooga has been used commercially only as a source of pigment, it has been evaluated as a potential source of oil shale, phosphate, and uranium (Conant and Swanson, 1961).

The Chattanooga Shale is overlain, in different areas, by the Mississippian clastic Grainger Formation and the cherty Fort Payne Formation, succeeded by a wedging carbonate shelf sequence (Newman Limestone) that thickens eastward (Harris and Milici, 1977; Milici and others, 1979) (figs. 2 and 3). Certain Upper Mississippian and Pennsylvanian littoral, deltaic, and alluvial deposits in the Cumberland Plateau completed the filling of the southern Appalachian basin, in association with a westward advance of the shoreline (Ferm and others, 1972; Milici, 1974). The Pennsylvanian section includes the Gizzard Group at the base, the Crab Orchard Mountains Group, and the Crooked Fork Group at the top. Coal occurs in most of the Pennsylvanian rocks (fig. 3), mostly in thin and unminable seams.

Structure West of the Blue Ridge Province

The Valley and Ridge province in Tennessee is in a westward bulge of the Appalachian orogen, characterized by gently to steeply dipping thrust faults alternating with rootless synclines (fig. 4) (Harris and Milici, 1977). There are 11 major Valley and Ridge thrust faults west of the Blue Ridge province in the Chattanooga 1°×2° quadrangle (fig. 5). Such faults generally are parallel to bedding in incompetent units and refract sharply across competent units. The faults join a master décollement, which is a low-angle thrust near the sedimentary rock-basement contact. The décollement extends westward from beneath the Blue Ridge as a major detachment zone under the Valley and Ridge and Cumberland Plateau and dies out in the plateau (Harris and Milici, 1977). The Valley and Ridge province is divisible into a western belt characterized by thrust faults and an eastern belt characterized by folds (Rodgers, 1953). The dominant fold style is flexural slip (Hatcher, 1978). Major deformation in the Valley and Ridge province is of Alleghanian age (Hatcher, 1978).

Rocks of the Cumberland Plateau are less deformed than those of the Valley and Ridge province. Deformation in the plateau is Alleghanian, involves the Pennsylvanian and younger rocks, and is characterized by low-angle overthrusts and flexural-slip folds that may be related to overthrusts (fig. 4) (Hatcher, 1978). Thrusts generally follow coal or shale layers and refract across competent sandstone or carbonate beds. The western border of the Cumberland Plateau adjoins less deformed rocks of the Highland Rim section, which is in a transitional zone between the Cumberland Plateau and the Nashville Basin.

The northwest corner of the Chattanooga 1°×2° quadrangle is in the Nashville Basin physiographic section and is near the eastern edge of the Nashville dome, a southern extension of the Cincinnati arch. The Cincinnati

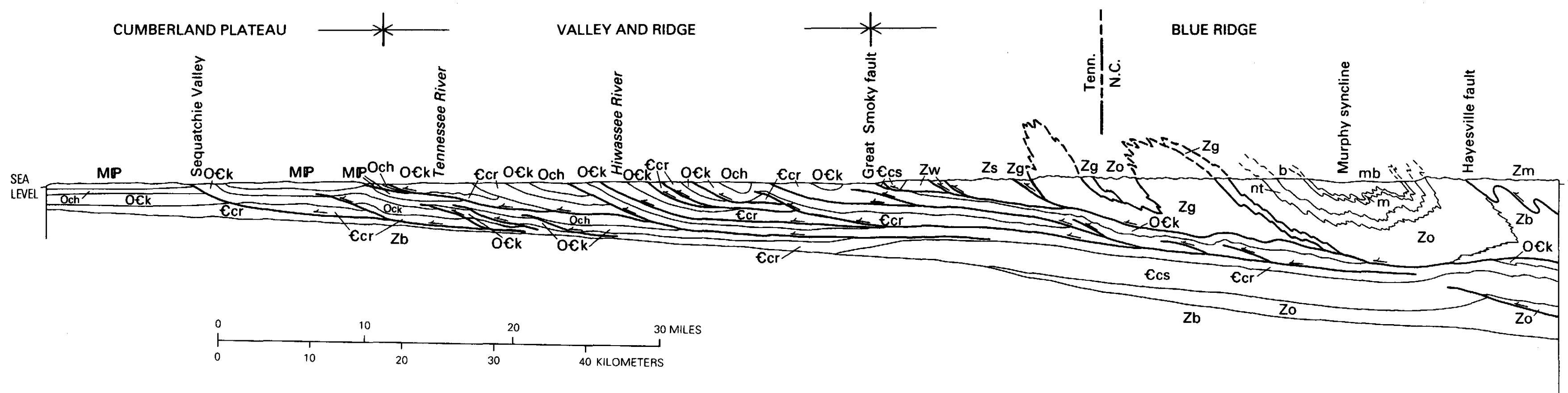


Figure 4. Geologic cross section from the Cumberland Plateau in Tennessee to the central Blue Ridge at the North Carolina-Georgia border (modified from Hatcher, 1978). Zm, late Proterozoic paragneisses, schists, and mafic and ultramafic rocks; Zb, Grenvillian orthogneisses; Zo, Ocoee Supergroup, undivided; Zg, Great Smoky Group, undivided; Zs, Snowbird Group, undivided; Zw, Walden Creek Group, undivided; nt, Nantahala Formation; b, Brasstown Schist; m, Murphy Marble and Andrews Formation; mb, Mineral Bluff Formation of Hurst (1955); Ꞓcs, Chilhowee Group and Shady Dolomite, undivided; Ꞓcr, Conasauga Group and Rome Formation, undivided; OꞒk, Knox Group undivided; Och, Chickamauga Group, undivided; MIP, Pennsylvanian and Mississippian rocks. Arrows show relative movement direction on thrust faults; dashed lines show structural trends or projections above the surface.

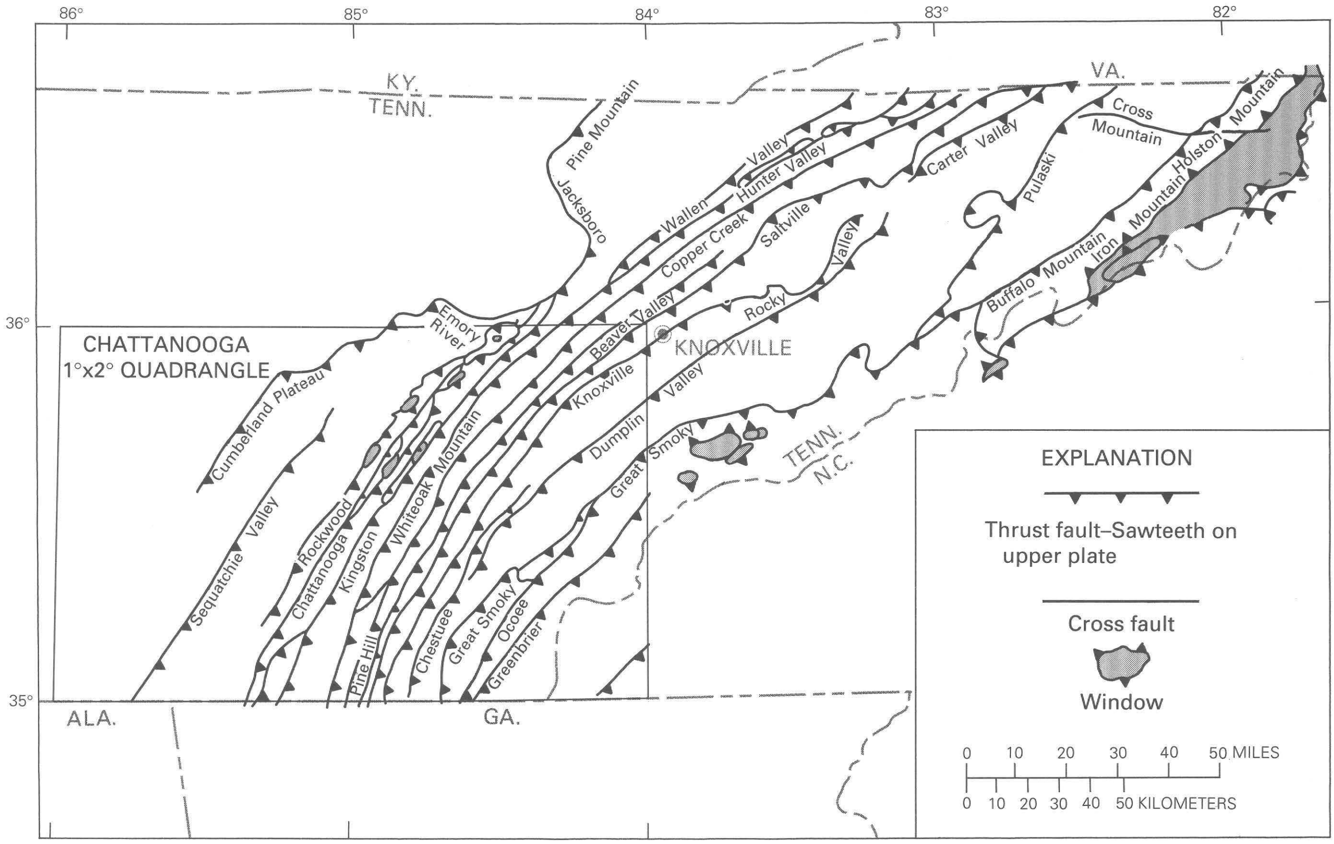


Figure 5. Major faults of the Chattanooga 1°×2° quadrangle (from Hatcher and Butler, 1979).

arch is a broad, northeast-trending, gentle, regional uplift that extends from north-central Ohio through Kentucky to central and western Tennessee.

MINERAL RESOURCES

Known Mineral Deposits

Mineral Resource Data

The locations of 402 metallic and nonmetallic mines and mineral occurrences and 158 deposits of industrial minerals, coal, and oil shale were confirmed through a review of relevant literature and a search of the records in the Mineral Resource Data System of the U.S. Geological Survey. A map compilation of these deposits has been made at a scale of 1:500,000 for this report (pl. 2); in addition, names and other information on the major commodities, anomalous elements, or mineral concentrations reported as present have been compiled, along with the geologic character or type of deposit (tables 1–3 on plate 2).

The metallic mineral occurrences are grouped as either surficial or bedrock deposits. Barite and fluorite have been included because of their close genetic association with zinc and lead mineralization. The surficial occurrences are in unconsolidated or poorly consolidated surficial materials and arise directly from surficial geologic processes. The bedrock group originated principally by nonsurficial processes, such as hydrothermal, metamorphic, and tectonic processes, or by primary sedimentary processes, all of which occur in well-indurated rocks. The occurrences in bedrock are further differentiated into hypogene veins, supergene veins, breccia fill and replacements, stratabound concordant, and massive sulfide replacement deposits. The industrial minerals, coal, and oil shale deposits are displayed on plate 2 by commodity type without regard to the nature of the occurrence. Productive deposits are indicated by enlarged location symbols.

Most of the metallic occurrences were known by the end of the 19th century. The productive occurrences were worked mainly before the early 1900's and then only sporadically. Production records are few and incomplete. Metallic mineral production in the Chattanooga 1°×2° quadrangle characteristically has been only marginally economic owing either to the small size or low grade of the deposits and has been responsive mainly to short-lived market aberrations. The only exceptions are the Ducktown and Sweetwater mining districts, which have had sustained production from the time of discovery almost to the present. The last operating mines in the Ducktown district closed in 1987. Although there was no mining in 1989 in the

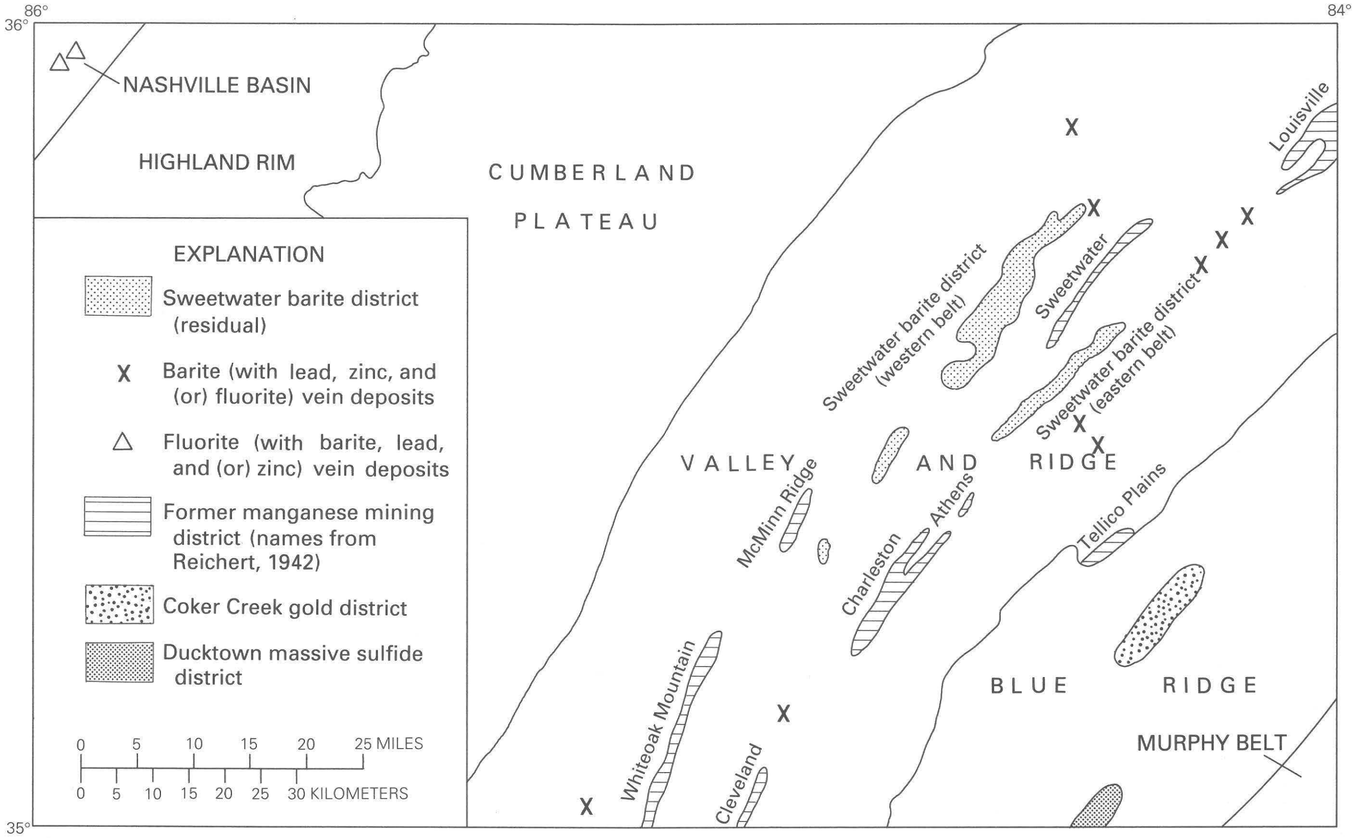


Figure 6. Major metallic mineral deposits (except iron) in the Chattanooga 1°×2° quadrangle (compiled from Reichert, 1942; Jewell, 1947; Magee, 1968; Maher, 1970; and Hale, 1974).

Sweetwater district, plans for mining reserves were announced by New Riverside Ochre Company, Inc. Two other major metal-mining districts, Jefferson City-Mascot (East Tennessee) and Central Tennessee, are just outside the quadrangle and are given consideration in this assessment of mineral potential.

Historically, industrial mineral production has met the needs of the construction industry in the area. Now, there is some indication that the area may have potential for more exotic industrial minerals, such as high-purity silica, specialty clays, talc, and abrasives. Known seams of coal in the quadrangle are generally thin, and production has been small. Oil shales have been identified but are of very low grade.

Metals, Barite, and Fluorite

The major deposits of metallic minerals, barite, and fluorite in the Chattanooga 1°×2° quadrangle (figs. 6 and 7) are (1) massive sulfide deposits (copper, iron, sulfur, and zinc) of the Ducktown district; (2) vein, sedimentary-rock-hosted, and placer gold of the Coker Creek district; (3) residual concentrations of barite in the Sweetwater barite district; (4) bedrock deposits of barite, lead, zinc, and fluorite in the Sweetwater barite district and elsewhere; (5) fluorite-barite-galena-sphalerite veins near the periphery of the Central Tennessee zinc-lead-barite-fluorite district in the Nashville Basin; (6) sedimentary (red) and secondary (brown) iron deposits; and (7) secondary concentrations of manganese.

Ducktown Massive Sulfide District

The massive sulfide deposits of the Ducktown district are principally in eight, highly folded orebodies. They have been mined for copper, iron, sulfur, and zinc, and small amounts of gold and silver have been produced as smelting byproducts. The deposits have been described by Emmons and Laney (1926), Magee (1968), Addy and Ypma (1977), Stephens and others (1984), Abrams (1987), and many other workers. The deposits are in a thick, clastic, metasedimentary sequence of the Late Proterozoic Great Smoky Group in the Ocoee Supergroup in the Blue Ridge province. The host rocks are in the Copperhill Formation (table 1), a unit of interbedded metagraywackes, metagraywacke conglomerates, and schists (metapelite). The schists vary

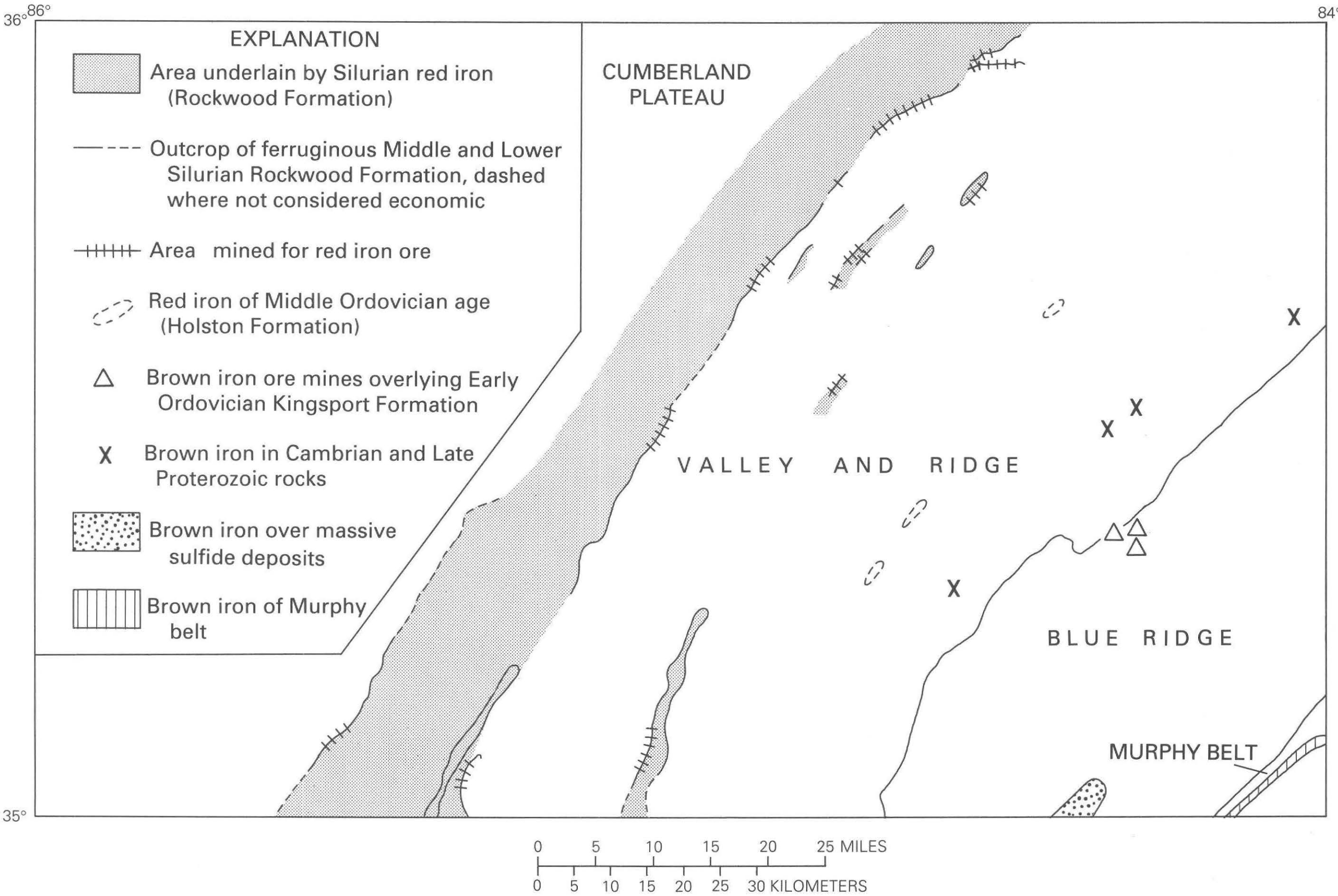


Figure 7. Iron deposits of the Chattanooga 1°×2° quadrangle (compiled from Burchard, 1913; Bayley, 1925; Maher, 1964a,b; and Whitlow, 1962).

from graphitic to nongraphitic muscovite-biotite schist± garnet and staurolite (Abrams, 1987). Garnet and staurolite coarsen near the ore zone, and chlorite and sericite alteration is common adjacent to or on strike with the ore horizons (Abrams, 1987). Minor bodies of amphibolite, interpreted as metamorphosed sills or flows (Magee, 1968; Gair and Slack, 1980; Abrams, 1987), are associated with the deposits at Ducktown.

The country rocks have been intricately folded in multiple stages. Major structures are northeastward-plunging tight isoclinal folds, younger superimposed smaller folds, and three fault systems. Some structures are preore, and some are postore (Magee, 1968). The orebodies are generally tabular in shape and conformable with the enclosing host rocks (stratiform). The orebodies generally plunge to the southwest, opposite to the plunge of the major folds. Metamorphism includes (1) Taconian (480–440 Ma) prograde, syntectonic, Barrovian metamorphism that reached garnet grade in the ore zone and (2) posttectonic Acadian (390–350 Ma) prograde and retrograde metamorphisms (Addy and Ypma, 1977).

The ore minerals, in order of abundance, are pyrrhotite (60 percent), pyrite (30 percent), chalcopyrite (4 percent), sphalerite (4 percent), magnetite (2 percent), and trace amounts of silver and gold (Addy and Ypma, 1977). About 15,000 ounces of gold were recovered from 1831 through 1959 (Koschmann and Bergendahl, 1968).

The origin of the ore deposits has been controversial but generally is thought to be either syngenetic, metamorphic, or postmetamorphic hydrothermal. Data from the study of oxygen, carbon, and hydrogen isotopes suggest that the sulfides were deposited syngenetically, folded along with the host rocks during the Taconian orogeny, and remobilized during metamorphism (Addy and Ypma, 1977). The paleotectonic setting in which the Ducktown deposits formed has been interpreted as an intracratonic rift formed along the eastern margin of the North American Continent during the incipient divergence and development of the Iapetus Ocean (Stephens and others, 1984).

Coker Creek Gold District

More than a hundred gold occurrences and deposits are in the Coker Creek gold district in the Blue Ridge portion of the Chattanooga 1°×2° quadrangle (Ashley, 1911; Koschmann and Bergendahl, 1968; Hale, 1974; Merschat and Hale, 1983a,b). Production from the district occurred mostly between 1831 and 1954 and is estimated to have totaled 7,500 to 10,000 ounces.

Gold occurs in quartz veins, in metasedimentary rocks, and as detrital grains in weathered residuum (alluvial placers). The gold-bearing quartz veins characteristically occur in ankeritic, banded metasiltstones and very fine grained metasandstones of the Proterozoic Snowbird Group of the Ocoee Supergroup, along joints and sheeting or shear surfaces (Merschat and Hale, 1983a,b). Quartz veins along joints in coarse- to very coarse grained arkosic sandstones within the same unit appear to be devoid of gold (Hale, 1974). Quartz is the principal vein mineral; ankerite, chlorite, muscovite, and gold are subordinate, and locally there are trace amounts of rutile and base-metal sulfides. The quartz-vein gold is thought to have been derived from the country rocks and transported in alkaline solutions during early deformation that may have been associated with regional metamorphism (Hale, 1974). Most of the quartz-vein gold was deposited as auriferous sulfides and native gold. Coarse gold in veins was formed by supergene enrichment (Hale, 1974).

Gold in detectable amounts (greater than 0.02 part per million, but generally less than 0.5 part per million) is widespread in clastic metasedimentary rocks of the Coker Creek gold district (Hale, 1974). The gold is finely particulate, locally occurs in fossil placers, and is thought to have been deposited contemporaneously with the Ocoee sediments (Hale, 1974). Therefore, such bedrock gold may be similar to the Late Proterozoic and Paleozoic graywacke- or turbidite-hosted gold deposits described by Hutchinson (1987).

Placer deposits of gold, which are mainly along Coker Creek and its tributaries, are recent alluvial deposits and remnants of ancient high-level terraces (Hale, 1974). The placer deposits have been mined extensively and produced most of the gold in the district.

Sweetwater Barite District and Other Locations

The most productive barite mines in Tennessee are those of the Sweetwater barite district in the Valley and Ridge province of the Chattanooga 1°×2° quadrangle (fig. 6) (Laurence, 1939, 1960; Dunlap, 1945, 1955a,b; Maher, 1970; Zimmerman and Kesler, 1981). Mining for barite in the Sweetwater district began in about 1870, and by 1970, production from the district was about 1.5 million tons (Maher, 1970). All commercial production has been from open-pit mines in barite-bearing clays. Most of the deposits are residual concentrations of barite in soils that overlie limestones and dolomites of the Kingsport Formation of the Knox Group, but some overlie the Mascot and Chepultepec Dolomites. The bedrock beneath the commercial concentrations of barite contains veins and breccia masses of dolomite, cemented by barite, fluorite, and pyrite, and some local concentrations of sphalerite and galena. The minerals in bedrock have not been mined but have been evaluated for fluorite potential. Veins containing barite, lead, zinc, and (or) fluorite are known in the Sweetwater district and elsewhere in the Valley and Ridge province (fig. 6).

A similarity of the mineralized bedrock in the Sweetwater district and zinc deposits in the eastern Tennessee zinc district and in other locations throughout the Valley and Ridge province has long been recognized (Laurence, 1960; Zimmerman and Kesler, 1981). These deposits are all thought to be localized mainly by the dissolution of carbonate rocks below the Middle Ordovician unconformity. Mineralization generally has been thought to be of pre-Middle Ordovician age; however, recent studies of $^{40}Ar/^{39}Ar$ ratios in overgrowths on detrital potassium feldspar suggest that the regional migration of basinal brines in response to the Late Pennsylvanian Alleghanian orogeny may have been responsible for mineralization (Oliver, 1986; Hearn and others, 1987).

Central Tennessee Zinc-Lead-Barite-Fluorite District

The northwest corner of the Chattanooga 1°×2° quadrangle is within the Central Tennessee zinc-lead-barite-fluorite district (Jewell, 1947; Clark, 1987). Major zinc deposits near the towns of Alexandria and Gordonsville, Tenn., are approximately 6 miles northwest and 12 miles north, respectively, of the northwest corner of the quadrangle.

Near-surface barite, fluorite, galena, and sphalerite fissure veins in the Nashville Basin and adjacent areas of the Highland Rim sections were first worked by the Indians before the arrival of white settlers in the area and at various times since then (Jewell, 1947). The veins are mainly in Middle Ordovician carbonate rocks but also are known in rocks as young as the Lower Mississippian Warsaw Limestone. Their average strike is about N. 40° to 45° E., and nearly all are steeply dipping. The veins are composed predominantly of barite, fluorite, and calcite, with small amounts of galena and sphalerite. In the Chattanooga 1°×2° quadrangle, veins of fluorite, barite, and calcite containing small amounts of lead and zinc in the Middle Ordovician Catheys Formation of the Nashville Group have been worked mostly in the Dry Creek area of DeKalb County (Jewell, 1947).

In 1964, Mississippi-Valley type (MVT) deposits were discovered in the subsurface in central Tennessee by exploratory drilling. Subsequent work has shown that the Central Tennessee zinc district is one of the largest MVT deposits in the United States (Hoagland, 1976; Kyle, 1976; Gaylord and Briskey, 1983; Briskey and others, 1986). Most of the ore in the Central Tennessee zinc district occurs in altered limestone interbeds in the lower to middle members of the Mascot Dolomite, the uppermost formation of the Upper Cambrian and Lower Ordovician Knox Group (Gaylord and Briskey, 1983). Small amounts of ore are present

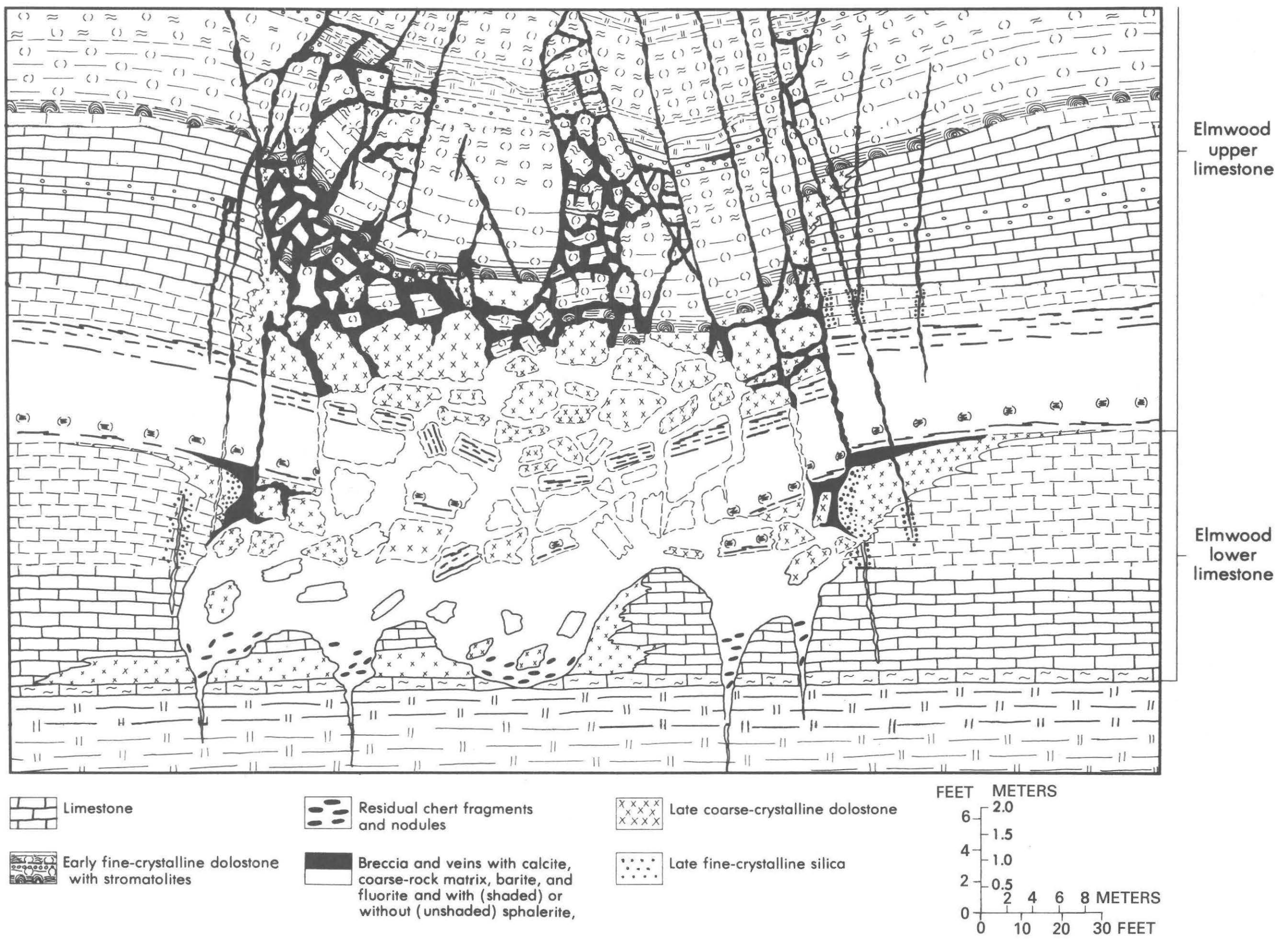


Figure 8. Cross section of a mineralized collapse breccia in the Elmwood mine, Central Tennessee district. Figure (from Gaylord and Briskey, 1983; Briskey and others, 1986) used with permission of the Irish Association for Economic Geology.

also in the underlying Kingsport Formation. Both the Mascot Dolomite and Kingsport Formation are shallow-water marine dolomite and limestone. Ore occurs mainly in dissolution collapse breccias (fig. 8) and caverns in a paleoaquifer system developed in soluble limestone beds below the regional unconformity that truncates the Knox Group. Joints were important in channeling ground-water movement in the paleoaquifer. Ore-bearing breccias generally trend about N. 65° E. and N. 25° W. in the Elmwood mine, approximately coincident with the dominant trends of joints in the Mascot Dolomite but discordant with joints in Middle Ordovician rocks (Gaylord and Briskey, 1983).

Limestone beds throughout the district have been partly to completely replaced by dolomite and fine-grained crystalline quartz, especially in areas where porosity and permeability were enhanced by dissolution in the paleoaquifer system. Dolomitization, which preceded ore deposition, increased porosity and permeability of the limestones (Gaylord and Briskey, 1983). Silicification, which also preceded ore deposition, typically forms selvages adjacent to fractures.

Sphalerite is the principal ore mineral and commonly is intergrown with calcite, fluorite, barite, and galena. Bituminous material and liquid hydrocarbons are associated locally with the ore. The ore occurs mainly as open-space fillings and always with brecciated and altered rock, but there are extensive areas of brecciated and altered rock that do not contain ore. Concentrations of barite and fluorite generally overlie concentrations of sphalerite. A relationship between paleostructure and ore deposition has been recognized in the Central Tennessee district, in which major deposits, such as near Elmwood, Gordonsville, and South Carthage, are along the flanks or crests of broad, gentle, ancient structural highs in the Mascot Dolomite (Gaylord and Briskey, 1983). The ancient structural highs may be the result either of limestone buildups in the shallow Knox seas, differential compaction, or both. The main ore deposits also are located on the flanks and crests of present structural highs; their position suggests that post-Knox deformation emphasized and steepened preexisting structures (Gaylord and Briskey, 1983).

A Mississippian or younger age has been proposed for mineralization in the Central Tennessee district on the basis of similarities between the MVT deposits in the Knox Group and the fissure vein deposits that cut the overlying Middle Ordovician to Mississippian beds (Gaylord and Briskey, 1983). The East Tennessee and Central Tennessee zinc deposits commonly are attributed to metal-bearing connate brines derived from the compaction and dewatering of thick shale sequences of the Appalachian basin (for example, Hoagland, 1971, 1976). Expulsion of metal-bearing basinal brines during compaction or tectonism could have driven the brines into the Knox paleoaquifer system. Ore was deposited where the metal-bearing fluids rose into broad crestal areas of the Nashville dome and into local structural highs (Gaylord and Briskey, 1983; Briskey and others, 1986).

Iron

Two types of iron ores occur in the Chattanooga 1°×2° quadrangle (fig. 7). The greater production has been from sedimentary ores, which are often called Clinton or red iron ores. Less production has been from secondary supergene or brown ores concentrated by weathering processes. These brown ore deposits probably are similar to the Oriskany iron ores of Virginia. Also, some iron has been recovered in the Ducktown district from magnetite associated with massive sulfides and from supergene concentrations of limonite derived from and overlying the massive sulfides.

Sedimentary iron-bearing beds were deposited intermittently from Early Cambrian to Pennsylvanian time in elongated lenses near and roughly parallel to northeast-trending shorelines of the Appalachian basin (Wright and others, 1968). Most of the iron is thought to have been transported to the sea in solution and either to have precipitated directly as oxides or hydroxides or to have replaced layers of calcium carbonate. The most extensive iron deposition was in Middle Silurian time; this deposition gave rise to the distinctive red hematitic ores of the Clinton Group in New York State and equivalent deposits from New York to Alabama. The maximum development of these iron ores is in the Birmingham district, Alabama. A 20- to 40-mile-wide belt that contains the ores continues across northeastern Alabama, northwestern Georgia, and eastern Tennessee (Whitlow, 1962; Wright and others, 1968). The sedimentary red iron ores crop out along ridges and dip under younger rocks, which in general are coal bearing.

In Tennessee, the Silurian sedimentary iron ores are in the Rockwood Formation, which is composed predominantly of green and brown shales, some calcareous and some silty with sandstone lenses, thin lenses of siltstone, limestone beds in places, and nonpersistent red beds that contain the iron ore. Outcrops of such iron ores in the Chattanooga 1°×2° quadrangle are primarily at the foot of the eastern escarpment of the Cumberland Plateau, on the eastern side of the Sequatchie Valley, and in parts of the Valley and Ridge province (Burchard, 1913; Whitlow, 1962; Wright and others, 1968). Thin beds of sedimentary iron ores in the Chattanooga 1°×2° quadrangle also occur in the Middle Ordovician Holston Formation and underlying Athens Shale.

Secondary brown iron ores that were concentrated during weathering processes consist principally of limonite (Wright and others, 1968). In the Chattanooga 1°×2° quadrangle, these secondary iron ores occur in the Blue Ridge and Valley and Ridge provinces in Tennessee and in the Murphy belt in North Carolina. In the Valley and Ridge province, most such deposits occur at the surface, generally overlying the Kingsport Formation of the Knox Group (Wilson, 1958; Maher, 1964a,b). In the Ducktown district, brown iron ore was mined from gossan overlying the sulfide deposits (Emmons and Laney, 1926; Wright and others, 1968). In the Murphy belt, most of the secondary deposits overlie the Andrews Formation and the Murphy Marble (Bayley, 1925; Robertson, 1946).

Manganese

Manganese oxides and hydrous oxides were mined extensively in the Valley and Ridge province of the Chattanooga 1°×2° quadrangle in the early part of the 20th century, especially during World War I (Reichert, 1942). The deposits are surficial and formed during weathering. They are most commonly enclosed in blanketlike secondary clay deposits derived from dissolution of impure dolomite and limestone. The manganese oxides occur in pockets and streaks as lumps, nodules, or masses. Some of the deposits also contain iron oxides, either within the manganese nodules or as separate nodules, and close to the surface some manganese deposits are overlain by an "iron cap."

Manganese deposits in the Chattanooga 1°×2° quadrangle occur in the Whiteoak Mountain, McMinn Ridge, Charleston, Cleveland, Athens, Sweetwater, Louisville, and Tellico Plains districts (Reichert, 1942). The secondary (supergene) deposits overlie the Lower Cambrian Shady Dolomite in the Tellico Plains district; the Upper Cambrian and Lower Ordovician Knox Group in the McMinn Ridge and Sweetwater districts; the Middle Ordovician Holston Formation in the Charleston, Athens, and Louisville districts; and the Lower Mississippian Fort Payne Formation in the Whiteoak Mountain district (Reichert, 1942).

Two possible sources of the manganese have been suggested in the literature. One is low concentrations of manganese carbonate disseminated in the bedrock (Stose and others, 1919; King and others, 1944; King, 1950); the other, hydrothermal sources along lines of structural weakness (Kesler, 1950). The concentration of manganese oxides is thought to have taken place during the formation of the residual clay, especially in association with the formation of the older valley floors (King and others, 1944).

Manganese, evidently dissolved as bicarbonate during weathering, was transported along favorable channels and was deposited in clays that had formed by weathering of carbonate rocks or shales where the bicarbonate waters contacted more oxygenated waters (Stose and others, 1919). Hack (1965) explained concentrations of manganese and iron at the foot of the Blue Ridge in Virginia and West Virginia by mechanical and chemical trapping processes. A mechanical trap is formed by a gravel cover over residual clays, and a chemical trap by reactions as limestone is dissolved and the pH of ground and surface waters increases to prevent iron and manganese from escaping in solution.

Uranium

The uranium potential of the Chattanooga Shale was evaluated in several studies between 1947 and 1954 (Conant and Swanson, 1961). The most uraniferous parts of the formation are the most massive, the darkest in color, and the most pyritic. The Gassaway Member of the Chattanooga Shale is consistently the richest, with only small variations, in uranium content (Conant and Swanson, 1961; Rheams and Neatherly, 1988). The average uranium grade of a 15-foot-thick shale unit that extends for approximately 50 miles along the eastern Highland Rim from DeKalb County, near the northwest corner of the Chattanooga $1°\times2°$ quadrangle, to Coffee County, west of the Chattanooga $1°\times2°$ quadrangle, is an estimated 60 parts per million. This grade is equivalent to about 1,800 tons of metallic uranium per square mile (Conant and Swanson, 1961).

Aluminum

Bauxite deposits are known in the Missionary Ridge and the Summit Knobs areas near the city of Chattanooga (McIntosh, 1949; Dunlap and others, 1965). The bauxite in most of the deposits is low-grade material that is suitable only for chemical use or for metallurgical purposes other than the extraction of aluminum (Dunlap and others, 1965). The bauxite deposits have shapes that resemble those of modern sinks and are thought to be sinkhole fillings developed in the Copper Ridge Dolomite, probably after the Alleghanian orogenic event (Dunlap and others, 1965). The bauxite either was transported to the sinkholes in Tertiary time (Dunlap and others, 1965) or developed in place as described by Knechtel (1963).

Industrial and Construction Minerals

Talc

Talc occurs sporadically in localized lenticular bodies within the Murphy Marble. This formation is in the Murphy belt of north-central Georgia and southwestern North Carolina. A small segment of the Murphy belt crosses the extreme southeastern corner of the Chattanooga quadrangle, and high-grade talc has been produced in the quadrangle from lens-shaped bodies in the Murphy Marble. Forty-one prospects or quarries have been identified in the Murphy belt; of these, 12 to 14 are in the Chattanooga quadrangle in the Blue Ridge province, including three mines near Murphy, N.C., from which talc has been produced (Wedow and Sweeney, 1968).

Carbonate Rocks

Carbonate rocks consist of limestone, dolomite, and marble. They are among the most widely used mineral commodities in the United States. In relatively pure form, they are composed of the carbonate minerals calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$). In most field occurrences, however, pure limestone (high calcium) and pure dolomite (high magnesium) are rare. Most carbonate rocks are mixtures of calcite and the mineral dolomite and commonly are contaminated by quartz and clays, as well as by other substances.

Carbonate rocks of Cambrian, Ordovician, and Mississippian ages crop out over large areas of the Chattanooga $1°\times2°$ quadrangle (fig. 9) and have been quarried at numerous localities, in the past as well as today (Born, 1936; Hardeman and Miller, 1959; Maher and Walters, 1960; Hershey and Maher, 1963, 1985; Ericksen and Cox, 1968; Ericksen and Thomson, 1968); specific localities are shown on plate *2C*, and geologic and economic characteristics of the limestones and dolomites are summarized on table 2. Most production, particularly for commodities other than riprap and crushed stone, has been in the Valley and Ridge province.

Limestone and dolomite.—Limestone and dolomite rocks are quarried for general-purpose crushed stone at numerous localities throughout the Chattanooga $1°\times2°$ quadrangle (pl. *2C*). Portland cement limestone has been produced from quarries in Marion, Hamilton, and Franklin Counties in the Cumberland Plateau (Ericksen and Thomson, 1968). Agricultural limestone has been produced from quarries in Bradley, McMinn, Monroe, and Meigs Counties in the Valley and Ridge province; from Cumberland and Sequatchie Counties in the Cumberland Plateau; and from White, Warren, and Grundy Counties in the Highland Rim section (Hershey and Maher, 1963, 1985).

Marble.—Marble produced in the Chattanooga $1°\times2°$ quadrangle includes metamorphosed (recrystallized) limestone like the Murphy Marble in the Murphy belt of the Blue Ridge province and crystalline limestone and dolomite, such as the so-called "Tennessee marble." Tennessee has been one of the leading marble-producing States. One of the main marble-producing rock units in Tennessee is the Holston Formation. Substantial production in North Carolina has come from the Murphy Marble (Newman and others, 1968). Other formations suitable for commercial marble production in the quadrangle are the Lenoir Limestone and limestone lenses within the Athens Shale.

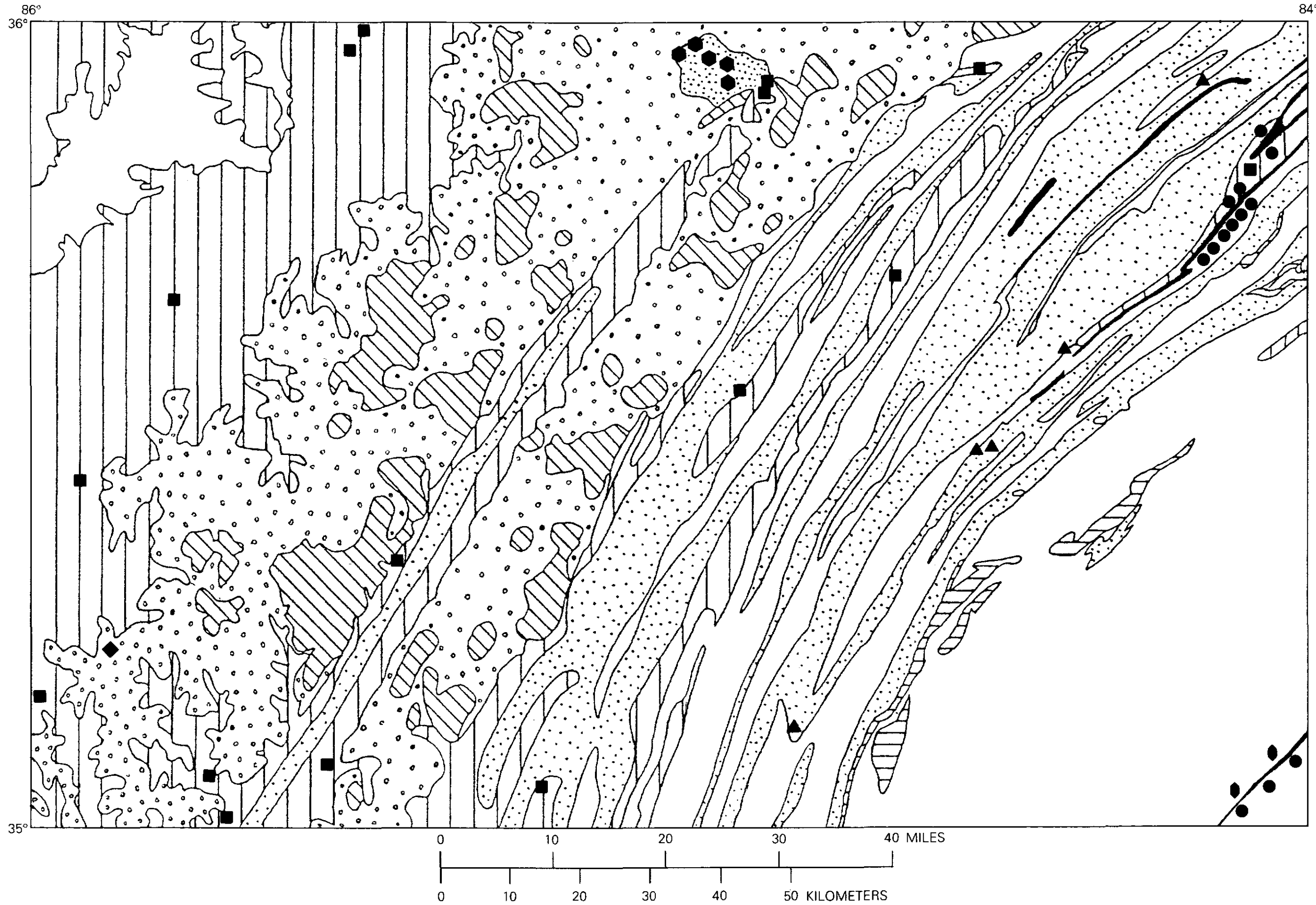


Figure 9. Industrial mineral localities, geologic units, and mining areas in the Chattanooga 1°×2° quadrangle. Data are from Van Horn (1948); Hardeman and Miller (1959); Hershey (1960); Hershey and Maher (1963, 1985); and North Carolina Geological Survey (1985). Additional plots of industrial mineral localities in the quadrangle are shown on plate 2.

Commercial marble formations in the Chattanooga quadrangle are far more restricted than limestone and dolomite formations. "Tennessee marble," which is a very pure limestone in the Holston Formation, is confined principally to a narrow belt in the Valley and Ridge province extending northeastward from near Sweetwater to within a few miles of the Virginia border (Gordon, 1924; Hardeman and Miller, 1959). The principal producing quarries in Tennessee are between Sweetwater and Knoxville, and some of these lie in the Chattanooga quadrangle.

Silica

Sandstones and quartzites having more than 95 percent silica (SiO_2) constitute the raw materials for the production of glasses of various kinds. The higher the silica content and, correspondingly, the lower the content of the oxides Fe_2O_3, Al_2O_3, CaO+MgO, other coloring agents, and refractory minerals, the more valuable and specialized the silica source. Tennessee has large quantities of high-silica sand available for a wide variety of industrial uses. High-quality sandstone or quartzite, containing 93–99.8 percent SiO_2 or more, is used for optical glass, plate glass, container glass, and other nonoptical glasses (Hershey, 1960). Many sandstones and quartzites require some beneficiation to attain a minimum grade of 95 percent silica to be usable.

High-silica rocks in the Cumberland Plateau are mainly in the Sewanee Conglomerate and, to a lesser degree, the Rockcastle Conglomerate and Vandever Formation (fig. 3). All three formations belong to the widely exposed Crab Orchard Mountains Group of Early Pennsylvanian age. The silica content of the Sewanee Conglomerate ranges from 95 to 98 percent, averages around 95 percent, and is similar to that of the other two formations of the group. The Sewanee also contains 0.03 to 1.16 percent Fe_2O_3 (0.30 percent average) and 0.62 to 4.06 percent Al_2O_3 (clay) (average about 1.80 percent) (Hershey, 1960, table 4).

Glass sand of lower quality (no analysis published) is mined from the Sewanee Conglomerate near Monteagle (Hershey, 1960). The sand is used for soft-drink bottles.

EXPLANATION

- Area of minor industrial mineral potential
- Area of limestone outcrop; rocks are Mississippian through Ordovician
- Area of magnesian limestone
- Area of dolomite outcrop; rocks are primarily Ordovician
- Area of marble outcrop; rocks are Ordovician in Tennessee and Cambrian(?) in North Carolina
- Area of coal-bearing rocks; rocks are Middle and Lower Pennsylvanian
- Area of known coal resources, past mining, and (or) current mining
- Area of ornamental sandstone outcrops

Approximate locations of past and present mining sites

- ■ Limestone
- ▲ Dolomite
- ● Marble
- Sandstone
- ◆ High-silica sand
- Talc

Figure 9. Continued.

In the Blue Ridge province, quartzites from the Chilhowee Group and the Murphy belt sequence are potential sources of high-silica sand (Broadhurst, 1949; Carter, 1968; Wiener and others, 1990). Evaluation of upper Chilhowee Group quartzites east of the Chattanooga quadrangle (McDowell County, N.C.) showed that samples could be processed to yield a concentrate that meets industry specifications for high-silica materials (Wiener and others, 1990).

Phosphate

The two principal types of phosphorus-bearing rocks in the region are (1) sedimentary rocks containing phosphate nodules, oolites, or small clasts in primary or reworked form and (2) either lateritic or residual deposits derived from the weathering of primary bedrock. However, most of the phosphorus-bearing rocks in Appalachia, including the Chattanooga quadrangle, are too small in size and too low in P_2O_5 to be mined for fertilizer (Wedow and Stansfield, 1968).

Three types of phosphate deposits occur in different parts of the Chattanooga quadrangle (Wedow and Stansfield, 1968): (1) residual concentrations of fluorapatite from phosphatic limestones of Middle and Late Ordovician age located in Dekalb County, (2) phosphatic nodules in the Upper Devonian and Lower Mississippian Chattanooga Shale of the Highland Rim area, and (3) globular masses and pellets in basal Middle Cambrian pyritic sandstones of Rhea and Meigs Counties. At the present time, these sources are noncompetitive commercially but are a potential resource.

Sandstone

Sandstone for building stone is found in the Chattanooga 1°×2° quadrangle primarily in Pennsylvanian rocks of the Cumberland Plateau. The rock is being, and has been, quarried from several areas. The Crossville Sandstone, also known by the trade names "Crab Orchard stone" and "Tennessee variegated stone," is the most prominent sandstone quarried in Tennessee (Floyd, 1965). It is valued because of its uniform bedding, durability due to tight cementation, and attractive variable color. Sandstone from the Crossville has been shipped throughout the United States and to some places abroad (Floyd, 1965).

Abrasives

A small amount of tripoli has been produced near Cleveland in the Valley and Ridge province in Bradley County from a deposit in the Copper Ridge Dolomite. The tripoli is thought to be derived from weathering of chert (Swingle, 1959; French and Eilertsen, 1968).

Clay

Resources of clay are widely scattered throughout the Chattanooga 1°×2° quadrangle; however, the suitability for commercial use depends on physical properties controlled by mineral and chemical composition (Hosterman and others, 1968). Clay for use in fired products has been mined in Loudon and Hamilton Counties in the Valley and Ridge province. Many small deposits of kaolin are known in prospect pits and associated with bauxite in sinkholes and other depressions in Copper Ridge Dolomite in Hamilton County (Swingle, 1959; Dunlap and others, 1965; Hosterman and others, 1968). A small deposit of halloysite occurs in a pocketlike depression in Fort Payne Chert on Whiteoak Mountain in the Valley and Ridge province in Bradley County, but no halloysite has been produced (Swingle, 1959; Hosterman and others, 1968). Other clay resources include fire clay, particularly from underclay beds that underlie coal beds of Pennsylvanian age in the Cumberland Plateau. A small amount of potassium-bentonite that occurs as a bed in Ordovician limestone has been mined near Dayton in Rhea County (Gildersleeve, 1946; Hosterman and others, 1968).

Table 2. Geologic and economic characteristics of formations containing limestone and dolomite in the Chattanooga 1°×2° quadrangle

[Data from Hershey and Maher, 1963.—, no data]

Unit	Main rock types	Thickness (feet)	Quality[1]	Remarks
Mississippian				
Newman Limestone	Limestone	600–2,800	HCL[2]	Shaly; cherty locally. Lower part dolomitic. Excellent as a low MgO source and as lime flux. Has broad commercial use.
Ordovician				
Sequatchie Formation.	Calcareous siltstone.	200–300	Low $CaCO_3$	Restricted distribution. Siliceous.
Moccasin Formation	Shale	800–1,000	Poor	Interbedded shale and limestone. Siliceous. Generally poor commercial limestone.
Bays Formation	Shale	700–1,000	Shaly	Low $CaCO_3$; high silica. Probably used mainly for aggregate.
Holston Limestone	Marble	200–400	HCL	High purity locally. Lower part crystalline and used as marble. $CaCO_3$ over 97 percent locally. Red Fe and Mn ores produced in local weathered zones. Excellent for commercial use.
Athens Shale	Shale	800–1,000	Low $CaCO_3$	Limestone generally impure and thin. Mostly used for aggregate and riprap.
Lenoir Limestone	Limestone	200–500	Poor	Variable quality. Cherty, dolomitic, and shaly. Low $CaCO_3$ generally. Minor economic importance.
Ordovician and Cambrian				
Knox Group	Limestone and dolomite.	3,000	Low $CaCO_3$	Most widely used rock unit in Tennessee. Broad use for aggregate and road base material, building stone, and agricultural lime and as a magnesium source.
Cambrian				
Nolichucky Shale	Shale and limestone.	400–750	Poor	Good for crushed stone and aggregate.
Maryville Limestone	Limestone	0–250	—	Crushed stone.
Rogersville Shale	Shale	0–250	Poor	Brick, dimension stone, and interior trim.
Rutledge Limestone	Limestone[3,4]	100–500	Poor	Crushed stone.
Late Proterozoic				
Wilhite Formation	Limestone	up to 100	Poor	Crushed stone.

[1]For cement, chemical, and agricultural purposes.
[2]HCL, high-calcium limestone.
[3]Contains interbeds of dolomite in places.
[4]Locally has interbedded shale and dolomite.

Other Construction Materials

Construction materials are one of the most important and widely distributed mineral commodities in the Chattanooga 1°×2° quadrangle. However, their utilization is largely dependent on the proper physical properties and proximity to market. Sand and gravel resources are adequate for local use in the Blue Ridge and most of the Cumberland Plateau (Maxwell and others, 1968). In much of the Valley and Ridge province and the Sequatchie Valley, in which carbonate bedrock predominates, sand and gravel resources are limited and locally scarce; however, abundant alluvial deposits are available locally along stream channels. In the Highland Rim section, gravel is locally abundant, but resources of sand and gravel are limited.

Carbonate rocks are the primary source of crushed stone and dimension stone in the Chattanooga 1°×2° quadrangle. However, sandstone, especially in the Cumberland Plateau area, is an important source of crushed stone, and other rocks that are suitable for crushed stone are abundant and widespread. In addition to marble and sandstone, other resources of building stone and flagstone are (1) slate of the Ocoee Supergroup from the Blue Ridge province and near the eastern border of the Valley and Ridge province and (2) Nottely and Tusquitee Quartzites from the Murphy belt of the Blue Ridge province (Amick, 1939; Newman and others, 1968). Production from these rock units has been limited and mainly for local use.

Many kinds of argillaceous sediments and sedimentary rocks can be used as materials for lightweight aggregate. Rock units in the Chattanooga 1°×2° quadrangle that are known or potential sources of clay or shale for lightweight aggregate are the Cambrian Rome Formation, Pumpkin Valley Shale, and Nolichucky Shale; the Ordovician Reedsville Shale and Sequatchie Formation; the Upper Devonian to Lower Mississippian Chattanooga Shale; the Upper Mississippian Pennington Formation; and the Pennsylvanian Whitwell Shale, Slatestone Formation, and Indian Bluff Formation (Bush and Sweeney, 1968).

Table 3. Principal oil- and gas-producing pay zones (formation or group) in Tennessee

[Modified from Miller, 1975. Names in quotation marks are local usage or drillers' terms]

Period	Series	Producing formation or group
Mississippian	Upper	Unnamed sedimentary rocks Glen Dean Limestone "Gasper formation" St. Louis Limestone Warsaw Limestone
	Lower	Fort Payne Formation Borden Formation Chattanooga Shale
Devonian		
Silurian	Upper	
	Middle	
	Lower	"Lockport dolomite"
Ordovician	Upper	
	Middle	Trenton Limestone "Black River limestone" Stones River Limestone
	Lower	Knox Group

Table 4. Cumulative oil (barrels) and gas (million cubic feet) production to 1986 by county in the Chattanooga 1°×2° quadrangle

[Data from the unpublished Tennessee Division of Geology Oil and Gas Well Computer Printout. —, no recorded production]

County	Oil	Gas
Coffee	—	0.023
Cumberland	17,539	.069
Grundy	—	.169
Rhea	81	—
Warren	—	13.4
White	169	.011
Total	17,789	13.67

Energy Resources

Oil and Gas

North of the Chattanooga 1°×2° quadrangle in Tennessee and Virginia, commercial oil and gas reserves have been discovered in the flat-lying beds of the Appalachian Plateaus immediately adjacent to the Pine Mountain thrust (Harris and Milici, 1977). The producing section in Tennessee includes several formations of Ordovician, Silurian, and Mississippian age (Miller, 1975). Within the Chattanooga quadrangle, however, only the Upper Cambrian and Lower Ordovician Knox Group, the Upper Devonian and Lower Mississippian Chattanooga Shale, the Lower Mississippian Fort Payne Formation, and the Upper Mississippian Warsaw and St. Louis Limestones are producing formations (table 3).

Oil production has been very limited in the quadrangle. Most production has come from small oil and gas fields in the Cumberland Plateau in Cumberland and White Counties (table 4) and a very small amount of oil from the Dayton field. The Dayton field is located near the eastern escarpment of the Cumberland Plateau section and has produced only about 81 barrels of oil to 1986.

Most of the hydrocarbon production has been gas in the Highland Rim and Cumberland Plateau sections. Six small gas fields are located in Warren and Grundy Counties (fig. 10), but gas also has been produced in small amounts from Coffee, Cumberland, and White Counties (table 4). From these fields, a total of 13.67 million cubic feet of gas has been produced as of 1986. However, relative to the rest of the Appalachian Mountains and Eastern United States, the oil and gas resources and potential of the Chattanooga quadrangle are of minor importance.

Most of the exploratory wells for oil and gas in the quadrangle have been drilled in the northern part adjacent to the higher producing areas of Tennessee, which are located northeast of the Chattanooga 1°×2° quadrangle. Of a total of 22 wells in the quadrangle, 11 have been drilled in the Cumberland Plateau of Cumberland County (fig. 10). A majority of these wells have bottomed in the Upper Cambrian and Lower Ordovician Knox Group at depths of about 1,900 to 8,365 feet (table 5). Three wells, Ladd Kemmer, Continental Tennessee No. 1, and Amoco No. 1 Driver, were drilled to the basement; Ladd Kemmer bottomed at a depth of 10,141 feet.

Oil Shale

Pennsylvanian and older black shales crop out or underlie younger rocks throughout most of the Cumberland Plateau, Highland Rim, and Nashville Basin sections of the Chattanooga 1°×2° quadrangle (Swingle and others, 1966; Conant and Stansfield, 1968). Such shales are a potential source of oil and gas and may have yields of oil ranging from a few gallons per ton in the less carbonaceous layers to more than 100 gallons per ton where the shales grade into impure coal. A detailed analysis of the total oil and gas resources of the shales (and impure coals) has not been made to date because these rocks are not now competitive with other energy sources.

In the Chattanooga quadrangle, the Upper Devonian to Lower Mississippian Chattanooga Shale is the principal oil-shale formation. This formation and formations correlative with it crop out or are found in the subsurface from Alabama to New York. In addition to a potential for oil and gas production, the Chattanooga Shale is a potential resource for uranium (see "Uranium" section of this report). The Chattanooga Shale is estimated to contain as much as 10 million to 20 million barrels of oil, 60 billion to 80

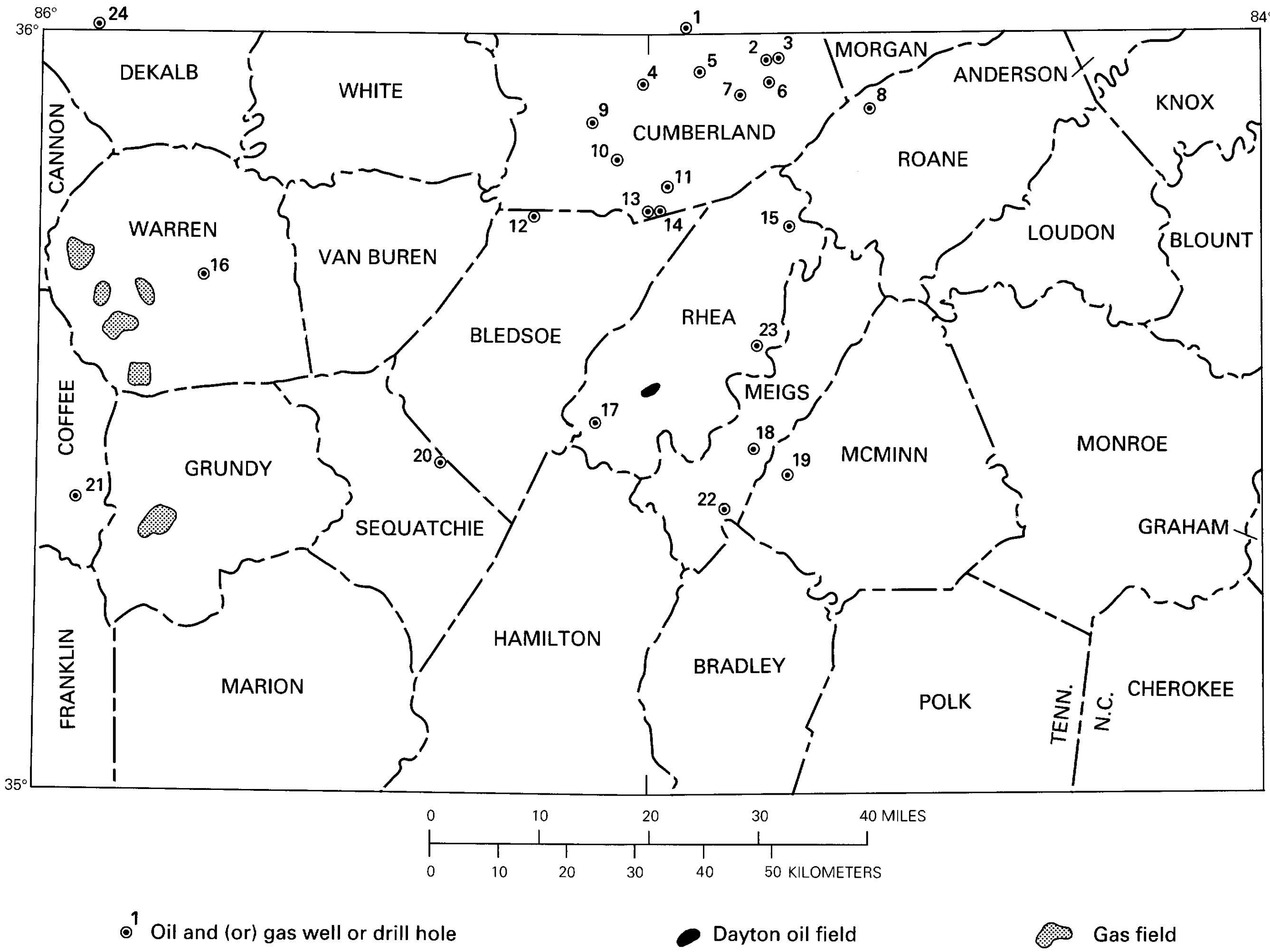


Figure 10. Oil and gas fields and selected oil or gas wells or drill holes in the Chattanooga 1°×2° quadrangle drilled to the Knox Group or deeper. Selected data for the wells and drill holes are given in table 5 and are from the Geological Sample Log Company, Pittsburgh, Pa. (R.T. Ryder, U.S. Geological Survey, written commun., 1988), and the Oil and Gas Computer Printout (Tennessee Division of Geology, unpub. data). The gas fields are from Petroleum Information Corporation (1976). The Dayton oil field is reported in Harris and Milici (1977). Oil and gas fields in Cumberland and White Counties are not shown because the configuration of the fields has not been published. For additional data on oil and gas wells in the Chattanooga quadrangle, see the Oil and Gas Computer Printout noted above and oil and gas maps and charts available from the Tennessee Division of Geology.

billion cubic feet of gas, and 1,800 tons of metallic uranium per square mile (Conant and Stansfield, 1968).

Coal

The coal-bearing formations of the Chattanooga 1°×2° quadrangle are of Pennsylvanian age and are located in the Cumberland Plateau. The plateau is divided by the Sequatchie Valley and the Sequatchie Valley fault, but minable coal seams are found on both sides of the structure (fig. 11). The Pennsylvanian rocks in the quadrangle consist of three groups, the Gizzard Group at the base of the section, the Crab Orchard Mountains Group in the middle, and the Crooked Fork Group at the top (fig. 12). Upper Pennsylvanian rocks immediately north of the Chattanooga quadrangle are not discussed in this report.

The Gizzard Group crops out principally in a narrow belt around the periphery of the Cumberland Plateau and is overlain there by the Crab Orchard Mountains Group. In the southwestern part of the quadrangle, large areas of the Gizzard Group have been exposed by erosion of the overlying Crab Orchard Mountains Group. The Crab Orchard Mountains Group has the largest outcrop area of any Pennsylvanian group in the quadrangle. This group is exposed across the bulk of the plateau west of the Sequatchie Valley and is the most abundantly exposed unit in much of Walden Ridge, particularly south of about latitude 35°30′ N. The Crooked Fork Group in the quadrangle is exposed in the northeastern part of the plateau and as several outlying buttes in the central and southwestern parts of the plateau.

Table 5. Selected data for oil and gas wells and drill holes in and immediately adjacent to the Chattanooga 1°×2° quadrangle

[Map numbers correspond to wells and drill holes shown in figure 10; however, oil and gas fields in Cumberland and White Counties are not shown on figure 10 because the configuration of the fields has not been published or determined to date. Data from Geological Sample Log Company, Pittsburgh, Pa. (R.T. Ryder, U.S. Geological Survey, written commun., 1988), and Oil and Gas Computer Printout (Tennessee Division of Geology, unpub. data)]

Map no.	Well name	Depth (feet)	Bottom formation	County
1............	Harrison #6	3,981	Knox Group	Cumberland.
2............	Ladd Kemmer	10,141	Proterozoic	Do.
3............	Unknown	3,527	Knox Group	Do.
4............	Rattiff No. 1	3,612	Knox Group	Do.
5............	Unknown	3,892	Knox Group	Do.
6............	Ladd No. 2 Yang	3,500	Knox Group	Do.
7............	Shell No. 1	5,405	Knox Group	Do.
8............	United American Energy No. 1	6,000	Unknown	Roane.
9............	Kingwood No. 1	3,707	Knox Group	Cumberland.
10............	Arco No. 1 Simonton	7,400	Conasauga Group	Do.
11............	Arco-Ladd No. 1	8,500	Rome Formation	Do.
12............	Sun No. 1	3,380	Knox Group	Bledsoe.
13............	Unknown	3,109	Knox Group	Cumberland.
14............	Unknown	3,555	Knox Group	Do.
15............	Arco No. 1 Wright	7,187	Conasauga Group	Rhea.
16............	Continental Tennessee No. 1	6,565	Proterozoic	Warren.
17............	Burgin No. 1	3,978	Knox Group	Rhea.
18............	Unknown	2,051	Knox Group	Meigs.
19............	Arco No. 1 Hiwassee	8,365	Knox Group	McMinn.
20............	Weaver Oil No. 1	7,401	Rome Formation	Sequatchie.
21............	Amoco No. 1 Brothers	5,756	Rome Formation(?) Granite gneiss.	Coffee.
22............	Unknown	1,900	Knox Group	Meigs.
23............	Unknown	2,505	Knox Group	Rhea.
24............	Amoco No. 1 Driver	6,334	Proterozoic	DeKalb.

The Pennsylvanian rocks in Tennessee have a total thickness of about 4,000 feet and consist of coal and the clastic lithologies—conglomerate, sandstone, siltstone, and shale. Most coal seams are enclosed entirely within shale units. The upper portion of the Pennsylvanian rocks is truncated by erosion over most of the Cumberland Plateau; this truncation reduces the thickness of the section in the quadrangle to no more than 1,500 feet.

The Gizzard Group rests disconformably on the calcareous, thick-bedded Pennington Formation of Late Mississippian age along the western edge of the plateau. Eastward, the disconformity is obscured as the Gizzard Group thickens and the Pennington becomes less calcareous and more clastic.

The Gizzard Group includes the Raccoon Mountain Formation, Warren Point Sandstone, and Signal Point Shale. The Warren Point Sandstone is widely distributed and thus provides a stratigraphic marker for subdividing the group. The thickness of the group varies from 0 to 700 feet and averages 250 feet (Luther, 1959). Eight coal seams are found in the Gizzard Group, six in the Raccoon Mountain Formation, and two in the Signal Point Shale (Swingle and others, 1966).

The Crab Orchard Mountains Group consists of five formations. Within these there are seven coal seams. The group thins from about 900 feet along Walden Ridge to about 300 feet along the southwestern and northwestern edges of the Cumberland Plateau. The most important coal-bearing formation in the group is the Whitwell Shale. The Whitwell contains the Richland and Sewanee coals and an overlying unnamed coal.

The Crooked Fork Group consists of six formations and five coal seams; the Dorton Shale is at the base, and the Wartburg Sandstone is at the top (fig. 12). The group ranges in thickness from about 320 to 455 feet.

Nine of 14 Pennsylvanian formations in the quadrangle are coal bearing and contain a total of 20 seams. Most of the coal seams, however, are thin and unminable. Some coal seams are abnormally thickened structurally; this thickening greatly enhances the economic recovery of coal from them.

Identified coal resources for counties in or partly in the Chattanooga quadrangle total 892.6 million short tons (table 6). This value is artificially high for the strict confines of the quadrangle, however, because two of the counties having large reserves, Anderson and Morgan, are mostly outside the quadrangle. Total resources within the quadrangle are probably close to 500 million short tons.

Coals in the Chattanooga quadrangle are dominantly of high-volatile A bituminous rank, but some coals are of high-volatile B and C and medium volatile rank (Luther, 1959). Attrital layers range from dull to bright in luster and are interlaminated with thin and thick vitrain bands. Cannel coal is common locally. Representative analyses of coals

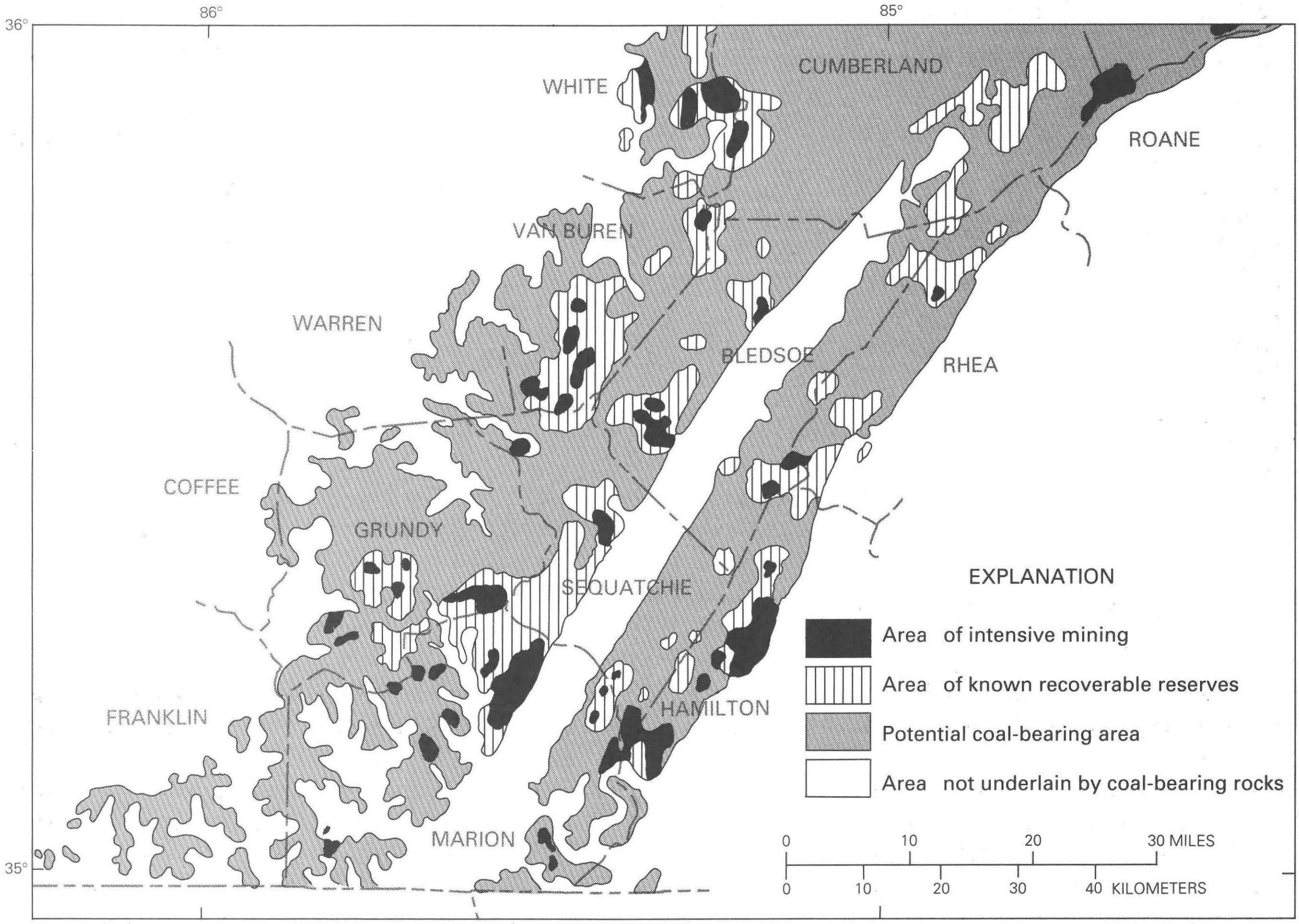


Figure 11. Distribution of Pennsylvanian coal-bearing rocks in the Chattanooga 1°×2° quadrangle showing resources and mining characteristics (modified from Keystone Coal Industry Manual, 1987).

from the quadrangle are shown in table 7. These analyses should be used with caution because the samples sites, methods of collection, and reliability of analyses are not known.

Mineral Resource Potential

Method of Assessment

In the preliminary assessment, characterization of the resource potential was limited to the first step of a three-step process described by Singer (1984)—the identification of areas (tracts) that are determined to be geologically permissive (favorable) for the occurrence of a specified type of mineral deposit. Wherever possible, mineral deposit models, as described in Cox and Singer (1986), were used for the delineation to add consistency to the procedure and to provide a basis for future studies. In the first step of the assessment process, geologic information about the region, including records and descriptions of known mineral occurrences, and petrological, geochemical, structural, and geophysical data were used to establish a geologic history for the region and to characterize the known mineral deposits. This information gathering was followed by a comparison of the known deposits with mineral deposit models and the selection of additional models that included other geologic environments that may be represented in the geologic history of the region. Finally, the environmental and descriptive characteristics of the selected deposit models were used to define favorable geologic terrain and delineate tracts.

The second and third steps of the Singer (1984) assessment process are, respectively, the estimation of the number of deposits and the integration of grade-tonnage information. Because of the limited amount of production data for the commodities of interest and the preliminary nature of the study, steps 2 and 3 were not attempted in this study.

Stratigraphic factors play a dominant role in localization of many of the mineral deposits in the Chattanooga

Table 6. Coal data for the Chattanooga 1°×2° quadrangle

[Data for Anderson and Morgan Counties greatly exaggerated because only about 10 percent of these counties is in the Chattanooga quadrangle. —, none reported]

County	Mines		Resources[1]	Production[2]	
	Deep	Surface		Deep	Surface
Anderson	9	3	236.4	1,090	109
Bledsoe	—	—	44.5	—	—
Cumberland	—	—	88.2	—	—
Grundy	—	1	12.0	—	63
Hamilton	—	—	81.8	—	—
Marion	3	1	78.8	414	61
Morgan	1	2	168.0	14	88
Rhea	2	—	31.9	74	—
Roane	—	—	6.4	—	—
Sequatchie	16	2	88.9	1,162	367
Van Buren	—	1	38.4	—	19
White	—	—	17.3	—	—
Subtotals	31	10	892.6	2,754	707
Totals	41		892.6	3,461	

[1]Measured, indicated, and inferred coal in seams 28 inches or thicker in short tons. Data from Luther (1959).

[2]Production figures in thousands of short tons from 1986 data (Energy Information Administration, 1986).

1°×2° quadrangle and were, therefore, a primary feature used to delineate tracts. Five tracts were identified that are favorable for a multiplicity of types of mineral deposit models (pl. 1). In selecting models (pl. 1), an effort was made to include as many types as possible, rather than limiting selections to the most likely types, to provide a broad range of possibilities for consideration in future work. Twenty-eight deposit types, 18 of which are formally defined deposit models (following Cox and Singer, 1986), are identified in the assessment. With the exception of the Ducktown models, all of the deposit types are interpreted as permissive in two or more tracts. A four-level ranking code (A–D) is used to reflect the relative probability of a deposit type occurring within a tract (pl. 1).

Preliminary Assessment

Tract 1

Tract 1 encompasses the area southeast of the trace of the Great Smoky thrust fault, an area underlain by Late Proterozoic rocks of the Ocoee Supergroup (pl. 1). A long and complex history of geologic events is recorded and preserved in the rocks of this tract. The complexity of the history must be considered in analysis of mineral resource potential. The great thickness and variable mineral composition of the rocks in the Ocoee Supergroup are typical of clastic deposition under marine conditions at the continental margin of a rapidly subsiding basin. This thick clastic wedge was subsequently subjected to moderately deep burial, followed by a minimum of three periods of Paleozoic tectonism during which the rocks were deformed and intensely metamorphosed. Mineral deposits in the tract reflect the effects of this complex history, which commonly obscure primary features.

The Cu-Fe-S-Zn-Au-Ag deposits of the Ducktown massive sulfide district and the gold deposits of the Coker Creek gold district are the major known deposits in this tract. Massive sulfide deposits similar to those in Ducktown occur elsewhere in the oceanward extension (Iapetus) of the continental margin to the east. Deposits in the Gossan Lead district, Virginia, Ore Knob, N.C., and Chestatee, Ga., are similar to the Ducktown deposits except that the host rocks contain more amphibolite than the Ducktown deposits; this difference suggests that mafic volcanism was associated with ore deposition (Stephens and others, 1984).

The Ducktown deposits appear to be examples of mineralization that has been affected by a multiplicity of events (Addy and Ypma, 1977). Pretectonic, probable syngenetic sulfides may have been remobilized during three episodes of regional metamorphism accompanying the Taconic, Acadian, and Alleghanian orogenic events. The hypothesized syngenetic accumulation of sulfides and metals may be explained by the Besshi massive sulfide model (Gair and Slack, 1980; Hutchinson, 1980; Fox, 1984) or the sedimentary exhalative model (Sangster, 1980; Slater and others, 1985). A model that includes characteristics of both the Besshi and the sedimentary exhalative models also has been suggested for the Ducktown district (Abrams, 1987) (fig. 13). The characteristics of the present orebodies, however, have been attributed to the remobilization of the preexisting sulfides in meteoric waters circulating through the sedimentary sequence during periods of metamorphism (Addy and Ypma, 1977). Metamorphic effects make a definitive choice highly speculative.

Table 7. Coal analyses from the Chattanooga 1°×2° quadrangle

[Maximum, top figure; minimum, middle figure; average, bottom figure. —, no data. Data from Luther, 1959]

Seam County	Poplar Creek Anderson	Morgan Springs Bledsoe	Wilder Cumberland	Sewanee Grundy	Richland Hamilton
		Proximate (percent)			
Moisture	2.4	2.2	1.3	15.8	3.3
	.9	.7	1.1	1.5	2.0
	1.7	1.45	1.25	3.04	2.6
Volatile matter	44.9	33.8	41.2	33.4	31.0
	37.2	32.8	39.0	24.4	28.6
	40.00	33.3	39.98	29.21	29.68
Fixed carbon	60.3	53.4	49.5	61.2	60.9
	51.1	51.6	48.5	51.8	51.6
	55.7	52.5	48.9	58.17	55.3
Ash	6.0	14.9	10.5	13.7	16.5
	3.1	10.6	9.2	7.3	7.8
	4.2	12.75	9.88	9.62	12.95
		Ultimate (percent)			
Sulfur	2.1	3.5	5.2	3.7	2.7
	1.2	—	4.0	.4	1.7
	1.7	3.5	4.3	.93	2.38
Hydrogen	5.7	—	5.4	5.1	—
	5.5	—	5.2	4.8	—
	5.6	4.9	5.3	4.96	4.9
Carbon	84.50	—	73.8	77.1	—
	79.45	—	72.2	73.3	—
	81.45	70.8	73.08	75.29	73.3
Nitrogen	2.30	—	1.3	1.5	—
	2.13	—	1.2	1.4	—
	2.21	1.4	1.25	1.48	1.4
Oxygen	7.00	—	6.6	9.8	—
	5.30	—	5.6	7.2	—
	6.06	4.5	6.2	8.16	5.6
Heat value (Btu)	15,550	13,250	13,570	13,750	14,150
	14,220	12,780	13,280	11,560	12,160
	14,341	13,015	13,445	13,099	12,995
A.S.T.[1] (°F)	2,230	2,310	2,020	2,750	2,560
	2,000	2,210	1,970	1,970	2,450
	2,112	2,260	2,003	2,532	2,497

Seam County	Sewanee Rhea	Sewanee Roane	Richland Sequatchie	Sewanee Van Buren	Wilder White
		Proximate (percent)			
Moisture	2.0	8.7	.8	3.5	3.4
	1.6	1.5	—	2.3	2.8
	1.75	3.2	.8	2.9	3.08
Volatile matter	29.3	33.1	26.6	33.6	40.5
	25.2	22.9	26.4	30.7	38.8
	27.53	29.01	26.5	32.6	39.64
Fixed carbon	54.8	64.1	52.4	55.9	47.7
	48.2	47.2	51.9	50.8	46.4
	52.28	56.98	52.15	53.4	46.84
Ash	2.48	23.1	21.0	16.0	11.2
	1.53	6.5	20.9	11.2	10.1
	1.85	10.81	20.95	13.23	10.44
		Ultimate (percent)			
Sulfur	1.2	2.0	3.5	6.0	5.1
	.9	.5	3.4	.8	3.3
	1.03	.68	3.45	2.8	4.08
Hydrogen	—	5.0	4.3	—	—
	—	4.8	4.2	—	—

Table 7. Coal analyses from the Chattanooga 1°×2° quadrangle—Continued

Seam County	Sewanee Rhea	Sewanee Roane	Richland Sequatchie	Sewanee Van Buren	Wilder White
Ultimate (percent)—Continued					
	4.7	4.9	4.25	5.0	5.3
Carbon	—	77.8	66.8	—	—
	—	73.1	66.3	—	—
	70.3	75.45	66.55	72.1	71.0
Nitrogen	—	1.5	1.3	—	—
	—	1.4	—	—	—
	1.5	1.45	1.3	1.4	1.4
Oxygen	—	11.6	3.8	—	—
	—	5.6	3.2	—	—
	7.0	8.6	3.5	8.3	7.8
Heat value (Btu)	12,510	13,890	11,840	13,500	13,160
	10,960	10,980	—	12,500	12,970
	11,993	13,050	11,840	12,925	13,038
A.S.T.[1] (°F)	—	2,490	2,390	—	2,210
	—	2,210	—	—	2,050
	2,430	2,347	2,390	2,510	2,135

Seam **County**	**Lantana** **Hamilton**	**Bon Air** **Marion**	**Rex** **Morgan**	**Hooper** **Morgan**	**Poplar Creek** **Morgan**
Proximate (percent)					
Moisture	—	5.7	—	4.5	4.3
	—	2.0	—	1.7	.7
	2.7	3.28	3.6	2.79	2.03
Volatile matter	—	39.4	—	39.6	40.5
	—	24.6	—	36.9	33.5
	28.9	33.08	36.4	38.31	38.59
Fixed carbon	—	67.4	—	57.2	57.3
	—	46.4	—	47.4	46.4
	53.7	54.47	54.7	54.47	52.69
Ash	—	23.8	—	11.1	16.9
	—	2.1	—	2.4	2.7
	14.7	9.75	5.3	4.44	6.78
Ultimate (percent)					
Sulfur	—	5.1	—	4.4	8.5
	—	.4	—	.7	.99
	1.4	2.39	.77	1.53	3.43
Hydrogen	—	5.4	—	5.6	5.6
	—	5.2	—	5.5	5.25
	—	5.35	—	5.55	5.39
Carbon	—	81.9	—	80.2	80.3
	—	75.0	—	78.0	65.6
	—	76.85	—	79.1	75.92
Nitrogen	—	1.5	—	2.1	2.2
	—	1.4	—	1.9	1.5
	—	1.45	—	2.0	1.84
Oxygen	—	8.2	—	9.5	8.42
	—	5.8	—	9.2	2.9
	—	7.3	—	9.35	5.49
Heat value (Btu)	—	14,620	—	14,440	14,690
	—	10,940	—	12,670	12,250
	12,610	13,182	13,910	14,051	13,937
A.S.T.[1] (°F)	—	2,710	—	—	2,480
	—	2,080	—	—	2,020
	2,870	2,327	—	—	2,183

[1]Ash softening temperature.

In the Coker Creek gold district, gold occurs in three forms—disseminated in metasedimentary rocks, concentrated in quartz veins, and as detrital grains in weathered residuum overlying metasedimentary and quartz vein deposits. Disseminated gold has been identified in what may be fossil placers in arkosic and conglomeratic metasedimentary beds in the Ocoee Supergroup (Hale, 1974). The gold-bearing quartz veins are interpreted to be the result of metamorphism and leaching of gold from the country rock.

In addition to the deposit models for the Ducktown and Coker Creek mineral districts, several other models are included in plate 1, on the basis of geologic environments and deposit characteristics that are compatible with the known geologic history and rocks of Tract 1. However, no mineralization within the tract is known to accord with these models; therefore, the tract can be considered to be only permissive for such deposit types.

Tract 2

Tract 2 occupies the extreme southeast corner of the Chattanooga quadrangle and corresponds to rocks of the Cambrian (?) Murphy belt. These rocks have been interpreted as a transgressive sequence laid down on rocks of the Great Smoky Group (Power and Forrest, 1973) and possibly in part coeval with uppermost Ocoee Supergroup rocks included in Tract 1. Recent work in Georgia (Higgins and others, 1988, 1989) suggests that the Murphy belt may not be a folded sedimentary sequence as earlier supposed (Hurst, 1955; Fairley, 1965; Power and Forrest, 1971, 1973) but may be the product of a complex series of faults.

Secondary or brown iron deposits and one residual manganese deposit are the only known metallic mineral occurrences in the part of the Murphy belt in the Chattanooga 1°×2° quadrangle. The iron occurs as veinlike masses, residual deposits, and replacements of enclosing schists. Older studies (Bayley, 1925) suggest that the veinlike iron masses were derived from the weathering of the country rock and downward transportation into fractures in the bedrock under oxidizing conditions. This interpretation is supported by the character of the mineralization and by the presence of detrital quartz grains within the ferruginous vein fillings. These deposits appear to be similar to the Oriskany-type iron ores mined extensively in Virginia.

Although no gold occurrences are known in Tract 2, placer gold has been recovered in small amounts from the Murphy belt about 10 miles east of the border of the Chattanooga 1°×2° quadrangle (Keith, 1907; Pardee and Park, 1948).

The tract may be considered as permissive for several of the same types of mineralization cited for Tract 1 (pl. 1). Nonmetallic resources in Tract 2 are talc and marble.

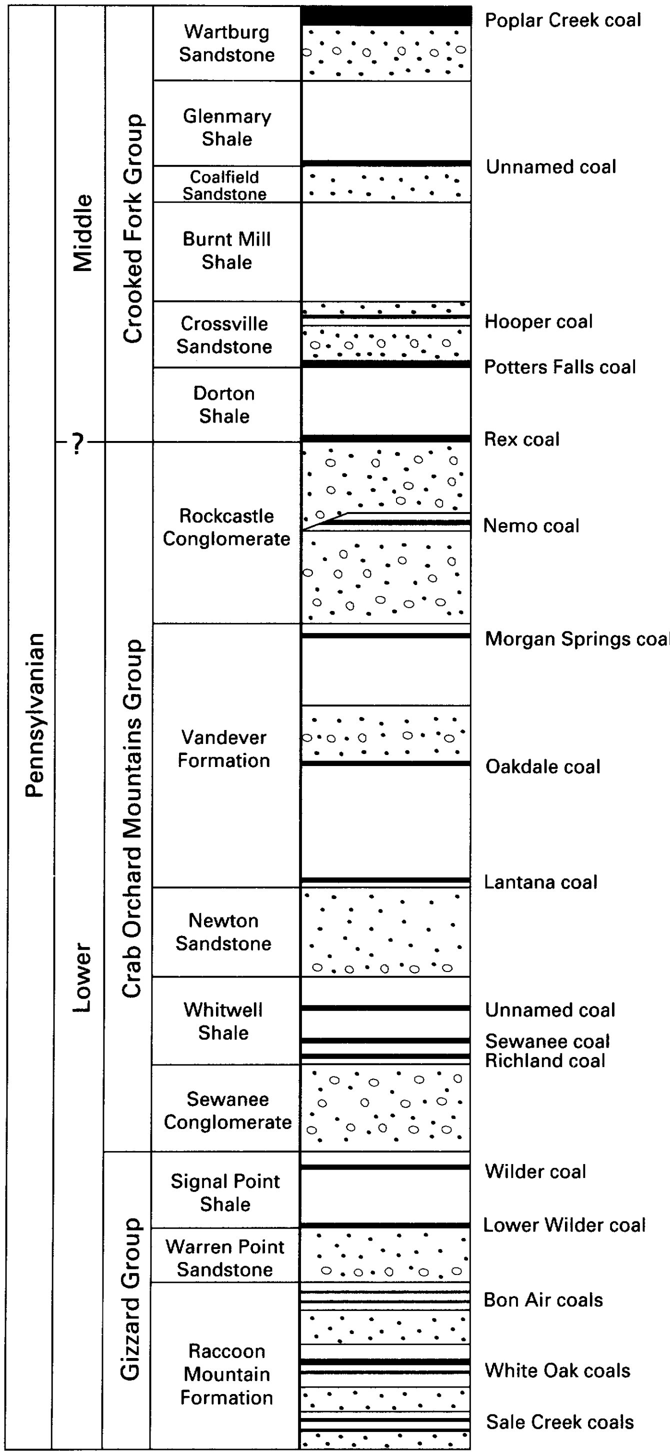


Figure 12. Stratigraphic column of Pennsylvanian coal-bearing rocks in the Chattanooga 1°×2° quadrangle showing coal beds and associated sedimentary lithologies (modified from Luther, 1959). Coal beds, solid pattern; sandstone and conglomerate units, stippled or small circles; shale units, unpatterned.

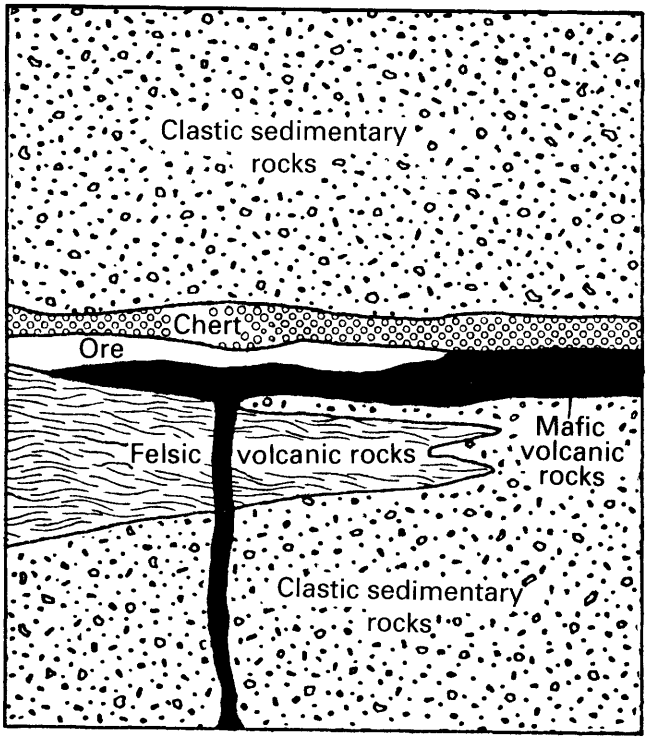


Figure 13. Generalized model for the Ducktown district; includes characteristics of both sedimentary exhalative and Besshi models (from Abrams, 1987).

Tract 3

Tract 3 consists of Lower Cambrian through Middle Silurian sedimentary rocks that were deposited in the Appalachian basin, now exposed in the Valley and Ridge province. This stratigraphic sequence is host to syngenetic sedimentary iron ores; epigenetic Mississippi Valley-type (MVT) deposits of barite, zinc, lead, and fluorite; residual-weathering deposits of barite; secondary iron and manganese deposits; and small deposits of bauxite. The syngenetic iron ores are mainly in the Lower and Middle Silurian Rockwood Formation; the MVT ores (barite, zinc, lead, and fluorite) are mainly in the permeable layers of the Upper Cambrian and Lower Ordovician Knox Group near unconformities; the residual deposits are weathered derivatives of the Knox Group, and the bauxite formed in clay pits associated with karst topography. In response to tectonic activity associated with the Taconic, Acadian, and Alleghanian orogenies, these sedimentary rocks have had a complex history of deformation and fluid migration. On the basis of this complex history and by comparison with analogous tracts of sedimentary rocks in the United States, a number of deposit types are postulated for Tract 3 (pl. 1). Included are the known types of mineralization in Tract 3 and types that may occur in the tract. Nonmetallic resources of Tract 3 include marble, limestone, dolomite, and clay.

Regional fluxes of hydrothermal brines can occur in cratonic basins in response to uplift, tilting, and deformation associated with orogenic activity (Erickson and others, 1981; Garven, 1985; Bethke, 1986; Leach and Rowan, 1986; Hearn and others, 1987). Such fluid fluxes provide the drive for MVT mineralization, regional dolomitization, and thermal maturation of organic matter. In cratonic basins, MVT mineralization typically is localized near basement highs, facies changes, karst features, and faults—features that focused the flow of regional hydrothermal brines and caused the brines to mix with local fluids. Mixing of different fluids that had contrasting chemistries may have resulted in mineral precipitation. Faults may have influenced sedimentation and later folding and faulting in the tract, which in turn may have influenced the migration and mixing of fluids responsible for MVT mineralization.

Parts of Tract 3 underlying the outcrop areas of Tracts 4 and 5 may contain MVT mineralization and very likely also contain sedimentary iron ores. Nevertheless, the mineral resource potential of such parts of Tract 3 is largely unknown. If mineralization exists in areas where the rocks of Tract 3 are below Tracts 4 and 5, at various depths as great as 1,200 feet below the surface, the depth of burial will greatly reduce their resource potential.

Tract 4

Tract 4 consists of marine Upper Devonian through Upper Mississippian sedimentary rocks that were deposited in the Appalachian basin after a long period of nondeposition and erosion (from the Late Silurian to Late Devonian) related to uplift associated with the Acadian orogeny. The Chattanooga Shale and overlying carbonate sequences were deposited during this interval. The rocks are exposed primarily in the Highland Rim section. Mineral resources in the tract are limestone and subeconomic occurrences of secondary manganese in the carbonate sequence; sand and ornamental sandstone; and unusual concentrations of trace elements, especially uranium and base metals, and phosphate and oil shale in the Chattanooga Shale. The Chattanooga Shale also has been considered a potential source rock for oil and gas.

The rocks in the tract may have been subjected to MVT mineralization associated with brine migration during the Acadian and (or) Alleghanian orogenies. Leventhal and others (1983) have shown that mineralization in the Chattanooga Shale is syngenetic, associated with the slow deposition of organic-rich sediments in an H_2S-rich anoxic environment. The source of the metals is thought to have been volcaniclastic sediments in upland areas marginal to the basin. Any MVT fluids that vented into such an environment would very likely have produced syngenetic base-metal mineralization. The Chattanooga Shale has many characteristics of the Zambian shale-hosted copper deposits. Plate 1 lists deposit types that may exist in Tract 4. The rocks of Tract 4 are largely overlain by rocks of

Tract 5, and the minerals for which such parts of Tract 4 may have potential are not known.

Tract 5

Tract 5 consists of Lower Pennsylvanian terrigenous clastic sedimentary rocks that were deposited in the Appalachian basin in response to uplift associated with the Alleghanian orogeny. The rocks are exposed mainly in the Cumberland Plateau section. This tract is considered permissive for coal, high-silica sand, and dimension stone (sandstone).

SUMMARY AND CONCLUSIONS

The Chattanooga 1°×2° quadrangle transects parts of the Blue Ridge, Valley and Ridge, Cumberland Plateau, Highland Rim, and Nashville Basin physiographic provinces or sections. Bedrock in the Blue Ridge province includes the Ocoee Supergroup, which consists of a thick sequence of clastic, marine metasediments that formed near a continental margin in a rapidly subsiding basin during Late Proterozoic rifting and were deformed several times during the Paleozoic. The Ocoee Supergroup rocks host massive sulfide (Cu-Fe-S-Zn-Au-Ag) deposits in the Ducktown district and gold deposits (vein, metasedimentary-rock-hosted, and placer) in the Coker Creek district. On the basis of known mineralization and geologic setting, the area of the quadrangle underlain by rocks of the Ocoee Supergroup (Tract 1) has moderate potential for discovery of Cu-Fe-S-Zn-Pb-Au-Ag mineral deposits in sedimentary-exhalative and Besshi massive sulfide, combined sedimentary-exhalative and Besshi massive sulfide, metamorphosed massive sulfide, sediment-hosted Cu-Co-Ag-Zn, bedded barite, secondary iron, quartz-pebble conglomerate gold, Homestake gold, low sulfide gold-quartz veins, and placer gold and platinum group elements (pl. 1).

Rocks of the Murphy belt underlie the Blue Ridge province in the extreme southeast corner of the Chattanooga quadrangle (Tract 2). The predominantly metasedimentary rocks of the Murphy belt, which include marble, metaquartzite, and graphitic phyllite, form a distinctive belt, but relations to the Ocoee Supergroup are complex and controversial. Marble and talc have been produced from rocks of the Murphy belt. Secondary iron and manganese deposits are the only known metallic occurrences in the part of the Murphy belt in the Chattanooga 1°×2° quadrangle, but the area (Tract 2) is considered to be permissive for many of the same types of mineral deposits as Tract 1.

The Valley and Ridge province and Cumberland Plateau, Highland Rim, and Nashville Basin portions of the Chattanooga 1°×2° quadrangle are underlain by rocks of the Cambrian to Pennsylvanian sedimentary sequence that formed in the Appalachian basin. Alleghanian deformation, which decreases in intensity to the west, is characterized by thin-skinned thrust faulting joining a master décollement near the sedimentary rock-basement contact.

Cambrian to Middle Silurian carbonate and clastic rocks (Tract 3) are the predominant bedrock in the Valley and Ridge province and are exposed also on the lower slopes of the eastern scarp of the Cumberland Plateau, in the Sequatchie Valley, and in the Nashville Basin. Known mineral deposits and occurrences in Tract 3 are sedimentary iron; residual-weathering barite and secondary iron and manganese; veins of MVT zinc-lead-barite-fluorite; and karst-type bauxite and clay. The carbonate rocks of Tract 3 are the source of commercially important deposits of marble, limestone (including agricultural limestone), and dolomite, especially in the Valley and Ridge province. A small amount of tripoli has been produced from a deposit near Cleveland.

Late Devonian through Upper Mississippian marine sedimentary rocks, which compose Tract 4, are exposed mainly in the Highland Rim section but also along the east scarp of the Cumberland Plateau and on both sides of the Sequatchie Valley. Known mineral resources are limestone (including cement and agricultural limestone), secondary manganese, high-silica sand, and ornamental sandstone. Tract 4 includes the Chattanooga Shale, which contains unusual concentrations of trace elements, phosphate, and oil shale and has been considered a potential source rock for oil and gas. Tract 4 has moderate potential for sedimentary phosphate or uranium deposits; sediment-hosted copper, cobalt, silver, and zinc; and MVT zinc-lead-barite-fluorite deposits in Cambrian to Middle Silurian rocks at depth (pl. 1).

Lower Pennsylvanian terrigenous clastic sedimentary rocks are exposed in the Cumberland Plateau (Tract 5) and contain numerous coal-bearing formations and deposits of high-silica sand and ornamental sandstone. Other resources of Tract 5 include fire clay from underclay beds that underlie coal seams.

Hydrocarbon production has been mainly gas from six small fields in the western Cumberland Plateau (Tract 5) and the Highland Rim (Tract 4). Sand, gravel, clay, and material for use as crushed stone, dimension stone, or lightweight aggregate occur in all tracts. Utilization of the construction materials, which form one of the most important resources of the quadrangle, is dependent upon proper physical properties and proximity to markets.

Industrial and construction materials, especially limestone, dolomite, sand, and gravel, have the greatest potential for development in the Chattanooga quadrangle to meet the requirements of population growth, industrial expansion, and new markets. The oil shale potential of the Chattanooga Shale represents a large potential resource that could be developed. Fluorite and barite in bedrock underlying residual barite deposits are resources that could be utilized. Discovery of additional gas or oil fields or of base-metal sulfide or precious metal deposits is possible on the basis of geologic setting and known resources within and near the Chattanooga 1°×2° quadrangle, but probability for major new discoveries is not considered to be high.

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