HISTORICAL OVERVIEW OF TENNESSEE'S MINERAL INDUSTRY: PAST AND PRESENT

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ABSTRACT--Even before the early days of the colonial settlers, the American Indians used several Tennessee minerals to their advantage. These original inhabitants used flint (chert) as arrowheads, scrapers, fire starters, and other items and the local clays for pottery. Galena and the iron ores were also used as war paint, native copper was used as jewelry, and salt from scattered licks was used in their cooking and preserving. Since the advent of the colonial settlers (circa 1768 through 1770) when Tennessee's carbonate rock and common clay were first used for the construction purposes as dimension stones and bricks, respectively, and quartzites served as grinding wheels in grist mills, the rocks and unconsolidated sediments of Tennessee have provided the State with the resources necessary to establish a very healthy and diverse minerals industry. The construction and industrial minerals such as dimension marble, limestone, and sandstone, crushed limestone, dolomite, and granite, sand and gravel, high silica sand, high calcium carbonate, phosphates, ball clay, fullers earth, brick clay and shale, barite, fluorite, sulfur, strontium, bauxite, tripoli, and mica have led the way towards Tennessee's strong economic and constructional growth. The metallic mineral industry of Tennessee has included production of limonite, magnetite, hematite, gold, silver, copper, zinc, lead, and manganese from four of the State's six easternmost geomorphic provinces. Even though Tennessee has never been a major producer of fuels, the State has produced sizable quantities of bituminous coal, oil, and gas, and possesses major lignite reserves. Without a doubt, Tennessee has sufficient reserves to ensure the existence of a healthy, diverse, and environmentally safe mineral industry for many decades to come.

Since the days of both the American Indians and early colonial settlers (circa 1768 through 1770; J. B. Jones, Tennessee Historical Commission, pers. comm.), the great abundance, accessibility, and variety in composition of Tennessee's sedimentary, metasedimentary, metamorphic, igneous, and unconsolidated formations have ensured the production and potential for production of at least one mineral commodity from each of the nine major geomorphic provinces (Table 1) and 10 geologic ages of rock (Table 2) found in Tennessee. By using these mineral resources wisely, the State of Tennessee has established a very healthy and diverse minerals industry as presented chronologically in Table 3.

Many bulletins and articles have been written about the 40 minerals that either have been mined or could be mined in Tennessee. The following chronological overview of Tennessee's mineral industry relies heavily on these sources.

HISTORICAL OVERVIEW

Dimension Limestone and Dolomite--The first minerals used by the early settlers of Tennessee were the bedded sandstones, limestones, and dolomites, known as fieldstone. As the original settlers prepared their fields for planting, these fieldstones were stacked in rows along field boundaries as stone fences. Other uses for such stones included foundations and chimneys of the settler's dwellings (Crouch and Claybrook, 1976). As Tennessee's population increased, more uses were found, such as street and road surfaces, bridges, dams, and reservoir components, liners for water wells and tunnels, and foundations and outer walls of buildings. A noteworthy example is Tennessee's State Capitol Building, completed in 1859 with exterior and retaining walls made from blocks quarried in Nashville from the Bigby Limestone of Ordovician age (Crouch and Claybrook, 1976).

During the early 1900s, dimension limestone was increasingly, but not altogether (e.g., marble) replaced by lighter weight brick and more easily formed precast concrete (Crouch and Claybrook, 1976). Examples of the use of limestones of Cambrian, Ordovician, Silurian, Devonian, and Mississippian age still remain throughout Middle and East Tennessee.

Common Clay and Shale--Common clay was used as a sealant between the logs of the very earliest settler's homes and structures. It was also used at the very outset of the iron industry to line the inside walls of pig and wrought iron furnaces (S. W. Maher, pers. comm.).

During the late 1700s slave labor and kilns were often used to shape and fire clay into hand-made bricks at the home site (S. W. Maher, pers. comm.). By the 1820s, there was enough urban development in most of Tennessee to support the establishment of several brick and tile manufacturing companies (Whitlatch, 1940). The use of brick was most prevalent in East and West Tennessee during the mid-1800s, but brick was widely used in Middle Tennessee by the early 1900s (Crouch and Claybrook, 1976).

Shales of Cambrian, Ordovician, Silurian, and Mississippian age have been the main sources of raw material for the many brick and tile plants of the Valley and Ridge province of East Tennessee. Unconsolidated clays found in the loess, alluvial deposits, Claiborne, Wilcox, Porters Creek, and Cretaceous formations provided the material for many small, soft-fired brick and tile plants in the West Tennessee region (Whitlatch, 1940).

The brick plants of West Tennessee were largely reduced in number due to the loss of local firewood, the brick industry's adoption

TABLE 1. Mineral commodities (active, inactive, and potential) by geologic provines.

Geologic province	Mineral commodities
Mississippi River Valley	Sand and gravel
Coastal Plain	Ball clay, common clay, fullers earth, heavy mineral sand, high silica sand, lignite, sand and gravel
Western Tennessee River Valley	Crushed limestone, dimension limestone
Western Highland Rim	Crushed limestone and dolomite, dimension limestone, limonite, manganese, tripoli
Central Basin	Barite, crushed limestone, dimension limestone, fluorite, lead, phosphate, zinc
Eastern Highland Rim	Barite, crude oil and natural gas, crushed limestone, dimension limestone, high calcium carbonate, strontium
Cumberland Plateau	Bituminous coal, crude oil and natural gas, dimension sandstone, lightweight aggregate, sand and gravel
Valley and Ridge	Barite, bauxite, common clay, crushed limestone and dolomite, dimension limestone, dimension marble, fluorite hematite, high calcium carbonate, high silica sand, lead, lightweight aggregate, limonite, manganese, uranium and oil shale, tripoli, zinc
Unaka Mountains	Copper, gold, granite, limestone, magnetite, mica, silver, slate, sulfur

of the hard-fired technique, and the great influx of cheaper brick from distant manufacturers (Whitlatch, 1940). Today, though, bricks are still made in large numbers by General Shale Incorporated in East Tennessee and to a lesser extent by other firms in West Tennessee. Revenues generated from the use of common clay and shale for manufacturing brick and tile ranked tenth among the Tennessee mineral commodities (United States Bureau of Mines, 1990*a*, 1990*b*, 1990*c*).

Quartzite--Although several rock formations saw use, East Tennessee's Erwin quartzite of Cambrian age was probably the first rock actually used as a millstone in grist mills to grind the different grains into flour (S. W. Maher, pers. comm.). Quartzites of Cambrian age in the Unaka Mountain province, chert found in the Knox Dolomite of Cambro-Ordovician age in the Valley and Ridge province, several sandstones and conglomerates of Pennsylvanian age in the Cumberland Plateau province, and Fort Payne chert of Mississippian age in the Western Highland Rim province were also used for this purpose (S. W. Maher, pers. comm.).

Salt--Like the American Indians, the early Tennesseans needed salt to season and preserve their foods. They were able to find salt (halite) licks in several counties in East and Middle Tennessee (Floyd, 1965) as early as the late 1700s.

Many shallow wells were subsequently drilled to acquire brine water for evaporation (Floyd, 1965). An early evaporator was established at Winters Gap, now Oliver Springs, during this period (S. W. Maher, pers. comm.). A well in Clay County had the highest annual yield of 226.8 metric tons (10,000 bushels) of salt (Floyd, 1965). As larger bedded salt deposits in the United States were developed and the transportation system improved, these small deposits and wells were gradually abandoned.

Bituminous Coal--As with many of the minerals mined in Tennessee, it is difficult to determine exactly when the use of bituminous coal actually began. Settler's living on or close to the Cumberland Plateau probably began using coal as a heating source in their dwellings during the late 1700s.

The first commercial use was by a blacksmith near Kingston in 1814. During the next 16 years, the coal mining industry grew in a very slow, sporadic, and unplanned manner until the 1830s. Then, the growth of the Industrial Revolution gave the burgeoning industry the impetus to generate enough production to have shipments barged to New Orleans (Luther, 1959). Expansion of the railroads into the Cumberland Plateau increased this new growth until the outbreak of the Civil War, at which time production fell (Luther, 1960).

TABLE 2. Mineral commodities (active, inactive, and potential) by geologic ages.

Geologic age	Mineral commodities
Precambrian	Copper, gold, granite, limonite, magnetite, mica, silver, sulfur
Cambrian	Barite, bauxite, common clay, crushed limestone and dolomite, dimension limestone, fluorite, lead, lightweight aggregate, limonite, manganese, slate, tripoli, zinc
Ordovician	Barite, common clay, crude oil and natural gas, crushed limestone and dolomite, dimension limestone, dimension marble, fluorite, high calcium carbonate, lead, phosphate, tripoli, zinc
Silurian	Common clay, crushed limestone and dolomite, dimension limestone, hematite, high silica sand, uranium and oil shale
Devonian	Crushed limestone and dolomite, dimension limestone, uranium and oil shale
Mississippian	Barite, common clay, crude oil and natural gas, crushed limestone and dolomite, dimension limestone, high calcium carbonate, limonite, manganese, strontium, tripoli
Pennsylvanian	Bituminous coal, dimension sandstone, lightweight aggregate, sand and gravel
Cretaceous	Common clay, heavy mineral sands
Tertiary	Ball clay, common clay, fullers earth, lignite
Quaternary	Common clay, high silica sand, mica, sand and gravel

TABLE 3. A chronicle of the mining industry in Tennessee.

Time period	Mining industry
1760	Dimension limestone
Late 1700s	Bituminous coal, limonite, magnetite, crushed limestone and dolomite
1800	Dimension marble
Early 1800s	Common brick clay
1821	Fluorite
Early 1820s	Ball clay
1826	Barite
1827	Gold
Early 1830s	Lead
Pre-1835	Hematite
1837	Manganese
1847	Copper
1856	Zinc
1866	Crude oil and natural gas
1893	Phosphate
1903	Silver
1907	Bauxite
Pre-1926	Dimension sandstone
1920s	Granite
1928	Tripoli
1930s	Sand and gravel, fullers earth
1942	Celestite
1949	Lightweight aggregate
1956	Mica
1960	Gem stones

During the post-war era railroads and coal production grew hand-in-hand. The 1930s depression era saw a decrease in production, but production then increased during World War II. The lowest annual production since World War II occurred in 1959 when production reached only 5 metric tons/year (Luther, 1960). Since then, production has increased, ranging from 7 to 11 metric tons/year between 1970 and 1981. Since 1981, though, production has decreased steadily to around 6 metric tons/year in 1989 (Division of Mines, 1970-1976; Energy Information Administration, 1977-1989).

In 1989, coal accounted for $173 million in revenue (Energy Information Administration, 1990) and is presently ranked second in value behind crushed stone among Tennessee's mineral commodities. Until the most recent decline in production, coal revenues led all mineral commodity revenues for many years.

Most of Tennessee's coal is classified as medium- to high-volatile A bituminous with varying abilities to coke. All of Tennessee's coal production comes from formations of Pennsylvanian age in the Cumberland Plateau province (Luther, 1959).

Limonite--Limonite, often referred to as brown iron ore, was first mined and smelted during the Revolutionary War in the Bumpass Cove (Embreeville) district of Unicoi and Washington counties within East Tennessee's Valley and Ridge geomorphic province. Eventually, the 1790s saw charcoal-fired bloomery forges for wrought and pig iron located in such places as Pigeon Forge and Mossy Creek (Jefferson City) and widely in northeastern Tennessee (Maher, 1964). Here, limonite was mined as residuum of the Shady, Knox, and Rome formations of Cambrian and Ordovician ages.

By 1797, Cumberland Furnace had been established west of Nashville in Dickson County on the Western Highland Rim. Ore for this and many future furnaces was obtained from iron-rich residuum of limestones of Mississippian age found in Stewart, Montgomery, Dickson, Hickman, Lewis, Lawrence, Wayne, and Hardin counties. Pig iron and the more ductile wrought iron, reheated and hammered pig iron, were both produced from charcoal- and eventually coke-fired furnaces. Cannon balls, used by General Andrew Jackson during the War of 1812, as well as steamboat boilers and the famous 'Kentucky rifle' were made of iron mined in this region (Burchard, 1934). Production from this region finally ceased by the end of 1930 (Maher, 1964).

Gossan limonite was first mined in 1850 from capping massive sulfide deposits of the Great Smoky Group of Precambrian age. This limonite was found in the Copper Basin of the Unaka Mountains southeastern Tennessee and led to the mining of the copper-iron sulfides (Maher, 1964).

Tennessee remained one of the leaders in the production of pig iron until 1900. Yet, several factors began to adversely affect the State's production as early as the 1860s when the open-hearth and Bessemer processes were invented in Germany and Great Britain. These processes allowed steel-making for the first time in large, high quality volumes. Steel-making pre-dates the 1860s, but volumes were small and uneven in quality.

Unfortunately, much of Tennessee's hematitic iron ore contained too much phosphorous for the production of steel. Even so, several furnaces were maintained using limonite (low phosphorous) as a blend with the hematite to make a pig iron which was ultimately shipped to the large steel forges in Pennsylvania (S. W. Maher, pers. comm.). During the 1870s, the Great Lakes iron ore districts opened and eventually captured much of Tennessee's pig and wrought iron markets (S. W. Maher, pers. comm.). Compounding the problem was the fact that Tennessee's iron ore reserves were also approaching depletion (S. W. Maher, pers. comm.). The final demise of Tennessee's iron industry came when several very small limonite mines ceased operating in Blount and Monroe counties in southeastern Tennessee during the early 1960s (Maher, 1964).

Magnetite--Magnetite, also known as black or magnetic iron ore, was first mined in the late 1700s for the production of high quality wrought iron (Floyd, 1965). The ore was obtained from the Cranberry and Beech granites of Precambrian age found in Carter County (Bayley, 1923). Production was always intermittent from this area of the Unaka Mountains in East Tennessee due to its inaccessibility and strong competition from the good quality, easily accessible ores of the Valley and Ridge province (S. W. Maher, pers. comm.). Production of magnetite for iron ore finally ceased in 1930 (Floyd, 1965).

Crushed Limestone and Dolomite--From the Revolutionary War period when iron ore was first produced in East Tennessee's Bumpass Cove (Embreeville) district until the final demise of Tennessee's iron industry in the early 1960s (Maher, 1964), the purer carbonate rocks of East and Middle Tennessee were crushed and used in the important role of flux (Burchard, 1913). This flux stone was used in all of the iron processes to remove silica and alumina from the ore and to carry it away into the resulting slag (Burchard, 1913).

Several of the high calcium limestone formations found throughout the eastern two-thirds of Tennessee have been used for the purpose of making hydraulic and Portland cement. Tennessee's first cement plants were established around 1850 along Cement Shoals by Esterbrook in eastern Knox County and at Clifton in Middle Tennessee's Wayne and Hardin counties (Safford, 1869). Before the turn of the century, the rotary kiln was implemented, which provided an even higher quality material eventually used in precast concrete (from speech on cement by C. W. Lewis in 1956 at the American Society of Civil Engineers meeting in Knoxville, Tennessee). Several of the high quality limestones were first used to make the more advanced Portland cement in Tennessee around World War I (S. W. Maher, pers. comm.) several years after the first plant in the United States was established at Coplay, Pennsylvania, in 1872 (Clausen, 1960).

Lower grade limestone formations were used as loose road metal (macadam) during the early 1800s after the Scotsman John McAdam invented its use, circa 1815 (S. W. Maher, pers. comm.). The use of many of these same limestones was greatly accelerated as concrete and asphalt aggregate and railroad ballast once the mechanical rock crusher was invented by the Englishman Eli W. Blake circa 1858 (S. W. Maher, pers. comm.).

Holston Limestone of Ordovician age and Monteagle Limestone of Mississippian age quarried in East Tennessee's Valley and Ridge and Crab Orchard Cove and Middle Tennessee's Eastern Highland Rim, respectively, have provided high calcium carbonate used in manufacturing paper, lime, cement, and glass (Hershey and Maher, 1985). Many of Tennessee's other limestone, dolomite, and granite formations of the Unaka Mountains, Valley and Ridge, Sequatchie Valley, Eastern and Western Highland rims, Central Basin, and Western Tennessee River Valley provinces have provided crushed stone products used in the agricultural stone, road aggregate, construction aggregate, and acid neutralization industries (Hershey and Maher, 1985).

Presently crushed stone, which includes lime, leads the State's mineral commodities in revenue. During 1989, over $252 million in revenue was realized from crushed stone production in Tennessee (United States Bureau of Mines, 1991).

Lead--The original site for mining galena for its lead content was probably at Watauga Shoals Settlement near Elizabethton in Carter County. The Honaker Dolomite of Cambrian age was the probable source (S. W. Maher, pers. comm.). The earliest district with significant production was actually Bumpass Cove where anglesite and cerusite and later galena were recovered from the Shady of Cambrian age during the Revolutionary War by John Sevier for eventual use as musket balls at the famous battle of King's Mountain (Rodgers, 1948). This district, also known as Embreeville, lies in both Unicoi and Washington counties. Production of lead was sporadic until mining ended in 1946 (Maher, 1958).

Lead was originally mined in Middle Tennessee during the 1830s at the National Cemetery in Madison, Davidson County. This mine, along with several others, including the Holt in Williamson County, consisted of small vein-type deposits found within jointed limestone formations of Ordovician age located in the Central Basin province (Jewell, 1947). The Powell River district of East Tennessee's Union and Claiborne counties also began producing minor amounts of lead in 1883 from fault-controlled deposits in Cambrian age formations (Brokaw et al., 1966). Lead is no longer mined as a primary metal in Tennessee, but is recovered in very minor amounts from the Knox Dolomite at Jersey Miniere's Elmwood-Gordonsville zinc mine in Middle Tennessee's Smith County.

Dimension Marble--The Holston Limestone of Ordovician age, commonly referred to as "East Tennessee marble," was first used as a headstone in the Knoxville area at the turn of the eighteenth century. In fact, the headstone of Tennessee's first United States Senator, William Blount, was made of Holston Limestone (Gordon et al., 1924).

It was not until 1838 that two blocks of this marble were shipped from Hawkins County near Rogersville to Washington, D.C. for use in the construction of the Washington Monument that "East Tennessee marble" became recognized as a very beautiful building stone. Members of the United States Capitol Building Committee decided to use "East Tennessee marble" for the Capitol's interior. This led to the establishment of the first marble district in Tennessee, which lasted from 1838 to 1912 (Gordon et al., 1924).

Quarrying began in the Knoxville and Friendsville areas of Knox and Blount counties during 1852. This soon became the leading district for quarrying of the Holston Formation of Ordovician age (Gordon et al., 1924).

More recently, marble has been developed in the 1940s just north of Thorn Hill in East Tennessee's Grainger County (Ayers, 1991). The marble from this quarry is dark gray to black and is extracted from the Maryville Formation of Cambrian age. This stone is known as Imperial Black marble and can also be found throughout the United States Capitol Building (Ayers, 1991).

Presently, two noteworthy marble operations exist near Friendsville and Thorn Hill. The Friendsville stone has been used in the construction of the recently completed Knoxville Art Museum on the grounds of the former World's Fair (R. E. Fulweiler, Tennessee Division of Geology, pers. comm.), while the Thorn Hill stone has recently been used as bases, pedestals, and plinths for museum quality sculpture and crystal throughout the United States (Ayers, 1991). These usages have enabled Tennessee's marble production to double in 1990 to 10,108 metric tons (United States Bureau of Mines, 1991).

Hematite--Hematite, also known as red iron ore, was first mined about 1810 along the escarpment between the Valley and Ridge and Cumberland Plateau provinces of East Tennessee's Campbell and Claiborne counties (S. W. Maher, pers. comm.) from thin, oolitic lenses of the Rockwood Formation of Silurian age (Burchard, 1913). The Rockwood Formation crops out close to the Cumberland Plateau escarpment in the Valley and Ridge province and in the Sequatchie Valley, though most of the mining activity occurred in the former.

Local limestone and dolomite formations were used as flux, while neighboring forests served as the source for charcoal fuel until 1868. It was during this year that the first coke-fired furnace west of the Appalachian Mountains was established in Rockwood. This event enabled the neighboring Cumberland Plateau coal seams to be used as a fuel and reductant.

Other pig iron furnaces and wrought iron bloomery forges were established in Cumberland Gap, LaFollette, Clinton, Daisy, and Chattanooga to use this 50 to 60% iron-rich ore (Burchard, 1913). Due to the high phosphorous content of the hematite, steel was never made in Tennessee (S. W. Maher, pers. comm.). Eventually, though, Tennessee pig iron blended from hematite and limonite was used in Pennsylvania's large steel-making industry (S. W. Maher, pers. comm.).

Fluorite--In 1821, fluorite, known in the minerals industry as fluorspar, was first discovered associated with barite, sphalerite, and galena as vein deposits in highly fractured limestones of Ordovician age in Middle Tennessee's Smith County. Fluorspar was not mined until 1902 when the Boatman and Alcorn mines of Smith and Trousdale counties produced minor amounts of industrial and optical grade spar. This production went into the manufacturing of hydrofluoric acid, glass, enamel, optics, and steel (Jewell, 1947). Production ceased during 1942 (Maher and Spencer, 1983). Specimen-grade fluorite is still being recovered from the Knox Dolomite as a by-product at the Elmwood-Gordonsville underground zinc mine in Smith County. Recent exploration in the Sweetwater district has indicated large resources occur in the upper Knox Group.

Ball Clay--Ball clay, a very pliable clay conducive to firing, was first used during the early 1820s to make pots and recepticles by settlers in Henry, Carroll, Weakley, and Gibson counties in West Tennessee. This same type of clay was also put to use as the main ingredient in manufacturing brick. Production of the clay was sporadic and unorganized until 1894 when a Missourian named Isadore Mandle established the first true clay company (Whitlatch, 1940).

The quality of West Tennessee's ball clay was not realized nationwide, though, until World War I when the United States' major supplies from Europe and Great Britain were terminated. Production of the clay in both Kentucky and Tennessee soared (Whitlatch, 1940). Tennessee has held the lion's share of production from the start. Presently, Tennessee provides between 70 and 75% of the United States' production, some of which is exported as far away as the Orient.

This very fine-grained to colloidal size, kaolinitic, deltaic clay is open-pit mined from Wilcox and Claiborne formations of Tertiary age and is used in the dinnerware, sanitary ware, pottery, and tile industries. During 1989, its $26 million in revenue ranked it sixth among Tennessee's mineral commodities (United States Bureau of Mines, 1990*a*, 1990*b*, 1990*c*).

Barite--Barite, sometimes referred to as white lead, was first surface mined in Tennessee near the town of Sweetwater in East Tennessee. Most of the United States' barite at that time was imported from Germany and was used as a food adulterant in sugar and flour and then as an ingredient in lithopone paint (Maher, 1970). During the Franco-Prussian War in 1870, all imports from Germany ceased; consequently, American production increased. Production from residual clay above the Knox Dolomite of Cambro-Ordovician age increased significantly in what would be the most prolific district, Sweetwater (Maher, 1970), while subsurface-mining began in the second most important district, Del Rio, a mylonite zone of the Brushy Mountain fault within the Unicoi Formation of Cambrian age in East Tennessee's Cocke County (Ferguson and Jewell, 1951), with some fault-controlled ore in the Ocoee rocks of Precambrian age.

Vein deposits found in limestones of Ordovician age in Middle Tennessee were mined during the late 1800s and early 1900s (Floyd, 1965). Mines near Fall Branch, Jearoldstown, Greeneville, and Lost Creek in East Tennessee's Valley and Ridge province were also present. Residuum and bedded deposits of limestones of Mississippian age near Pall Mall on the Eastern Highland Rim were mined from 1945 to 1949 (S. W. Maher, pers. comm.).

The Pure Food and Drug Law of 1911 halted the use of barite in foods, and titanium dioxide-based paints eventually replaced lithopone paints (S. W. Maher, pers. comm.). Yet, the production of barite received a boost during 1926 when the patented use of barite as a weighting agent in rotary drilling was introduced. The Depression Era took its toll on production, but, afterwards, production increased again as domestic petroleum exploration and production drilling escalated (Maher, 1970). Barite is also used in the pharmaceuticals, linoleum, and glass manufacturing industries (S. W. Maher, pers. comm.).

By the late 1940s, production ceased in all the districts except Sweetwater (Maher, 1970). Recently, A. J. Smith Company has been the sole producer of Sweetwater barite. Use of this barite has been for chemicals and fillers due to its low level of impurities (S. D. Bearden, pers. comm.).

Presently, A. J. Smith Company has contracted with New Riverside Ochre Company of Cartersville, Georgia, to mine properties formerly owned by National Lead-Baroid Company. Revenue from barite production during 1989 ranked eleventh among the active Tennessee mineral commodities (United States Bureau of Mines, 1990*a*, 1990*b*, 1990*c*).

Gold--The only gold district in Tennessee was found during 1827 in the Unaka Mountains of Monroe County. This district, Coker Creek, was mined for both placer and vein deposits on a very sporadic and low production basis until the early 1970s. Only 9,000 ounces were ever recovered from these Ocoee Series rocks of Precambrian age (Hale, 1974).

Gold prospectors continued southwestward in the Unaka Mountains to discover the copper-iron sulfides of the Copper Basin in Polk County during the 1840s. After many years of smelting these ores, refining techniques improved to the extent that minor amounts of gold were recovered from 1903 (Emmons and Laney, 1911). Even so, Tennessee still remained one of the smallest southeastern producers of gold (Hale, 1974).

Manganese--The first production of manganese in the United States occurred during 1837 from residuum of limestones of Mississippian age on the Western Highland Rim in Middle Tennessee's Hickman County (Reichert, 1942). Very little production of this indispensible component of steel occurred in Tennessee until 1915 when World War I spurred on the need for manganese production in the United States. Production from residuum of the Rome and Shady Formations of Cambrian age found chiefly in the Bumpass Cove (Embreeville) district in Unicoi and Washington counties and several districts in Carter, Johnson, Bradley, Monroe, Cocke, and Sevier counties (Reichert, 1942), oxides mined from the Holston Formation of Ordovician age in Bradley and Monroe counties, and manganese carbonates of the Wilhite Formation of Precambrian age found in Sevier County helped to satisfy some of this demand (S. W. Maher, pers. comm.).

The federal government initiated a manganese stockpiling program in the late 1930s. This, along with the advent of World War II, once again increased the United States' demand for manganese. Tennessee, the first state to produce manganese oxide minerals (pyrolusite, psilomelane, and manganite), responded by becoming a leading producer of manganese in the United States (S. W. Maher, pers. comm.). Production of manganese ceased in Tennessee in 1960 (United States Bureau of Mines, 1989*a*, 1989*b*) when the federal government terminated its stockpiling program (Floyd, 1965).

Copper and Sulfur--Gold prospectors discovered the copper-bearing, massive sulfide deposits of the Copper Basin within the Unaka Mountains in 1847 (Safford, 1869). The copper and iron-rich sulfide minerals (pyrite, chalcopyrite, pyrrhotite, and bornite) were found within highly folded and faulted Great Smoky Group schists and graywackes of Precambrian age. In 1850, the first mine began as a surface operation, and, by 1864, 14 mines were in operation (Safford, 1869). The Basin became the largest copper sulfide district in Appalachia and the southeastern United States. Gold and silver were first recovered in minor amounts during refining beginning in 1903.

During 1904, the technique of open-roasting and release of sulfur dioxide was replaced by the pyritic process, which enabled the recovery of the sulfuric gases, thereby allowing sulfuric acid production to commence in 1907 (Magee, 1968). Sulfuric acid production became the major reason for the Basin's existence from then on, even though zinc sulfides began to be recovered in 1927 and copper and iron continued to be recovered (Magee, 1968).

After producing copper and eventually sulfur over a 137-year period with only a 13-year hiatus from 1877 to 1890 (Emmons and Laney, 1911), Tennessee's only copper-producing district ceased production in July 1987. The Basin's last mine operator, Tennessee Chemical Company, believed that transporting sulfur from the Gulf Coast by rail would be cheaper than mining the ore from depths of 366 to 549 m just 3.2 km away. In 1990, the refining operation was sold to Boliden Mineral, A. B., a Swedish firm.

Zinc--In 1856, next to the town of Mossy Creek, now known as Jefferson City, in Jefferson County, zinc was mined for the first time in Tennessee. The Mossy Creek was an open-pit mine where the minerals calamine and smithsonite were recovered from the Knox Dolomite residuum for their zinc content and used in the paint industry (S. W. Maher, pers. comm.).

Mining for zinc and lead commenced in the Maynardville and Copper Ridge formations of Cambrian age within the Powell River district of Claiborne County in 1883 (Rodgers, 1948). A small, short-lived mine, the Hardwick was also opened at the southwestern end of Tennessee's Valley and Ridge province in 1892. The zinc mining industry's first shaft was opened during 1902 in the Knox Dolomite of Cambro-Ordovician age at Mascot in East Tennessee's Knox County.

In 1911, modern milling and mining procedures were introduced which enabled miners to go much farther underground for the much more abundant zinc sulfide resources (Secrist, 1924). This guaranteed a long and successful zinc-mining industry in Tennessee.

The first major deep mine, the Mascot, was opened by a shaft in 1911. This marked the beginning of many large and very productive deep mines for sphalerite in the Knox Dolomite of Cambro-Ordovician age in the Mascot-Jefferson City district. The initiator of this mine, the American Zinc Company, became the prominent producer in this district. Additional mines, later, greatly enlarged this district.

Recovery of zinc from the Shady Dolomite of Cambrian age began in the Bumpass Cove (Embreeville) district in 1913 and lasted until 1919 (Secrist, 1924). The small, underground Comstock mine opened in 1920 and was the first zinc operation in the Knox Dolomite of Cambro-Ordovician age within the Copper Ridge district. This district lies largely in Grainger and Hancock counties about 32 km north-northeast of the prolific Mascot-Jefferson City district, although mineralization does extend into Knox County to the southwest (S. W. Maher, pers. comm.). The recovery of zinc ore in the form of sphalerite began in the Copper Basin during 1927.

Major deep mines, Flat Gap and Idol, were active between 1955 and the late 1970s in East Tennessee's Copper Ridge district. The mine's owner and operator, The New Jersey Zinc Company, recovered zinc ore from the Knox Dolomite of Cambro-Ordovician age. The New Jersey Zinc Company and its successor, Gulf + Western Industries Company, Inc., opened the Elmwood-Gordonsville district in Middle Tennessee's Smith County in 1974. Like the other major Tennessee zinc districts, this district proved the solution-collapse-breccia type zones of mineralization within the Knox Dolomite of Cambro-Ordovician age to be very productive (W. T. Hill, pers. comm.; R. C. Gilbert, pers. comm.).

The narrow, restricted, vertical vein deposits of Middle Tennessee were known to the Indians long before the settlers mined them for their lead, barite, fluorite, and zinc minerals. The most important of the sphalerite-bearing veins, the Hoover, was discovered with a shaft in 1889 but was not economically mined until 1933. This vein, with a maximum width of 2.1 m and maximum depth of 31.7 m, was mined and milled discontinuously at its location in Readyville, Cannon County, until the late 1940s. Minor amounts of pyrite, galena, and barite were found within this Carters Limestone vein of Middle Ordovician age (Jewell, 1947). No major production ever came from the Middle Tennessee district.

Up to 1990, Tennessee had been the leading zinc producer in the United States for close to thirty years. Recent Alaskan zinc production has moved Tennessee to the second ranking (United States Bureau of Mines, 1991). The most recently published zinc-production data, 1988, indicates more than $159 million in revenue was generated by the zinc industry, ranking it third among Tennessee's mineral commodities (United States Bureau of Mines, 1989*a*, 1989*b*; Energy Information Administration, 1989). Due to the increased value of zinc in the past few years, activity has escalated. Seven mines are presently active, with another being prepared for reopening. Interest in previously explored, yet undeveloped areas, has also increased.

Crude Oil and Natural Gas--During the years from 1820 to 1866, Tennessee produced oil inadvertently from wells drilled to produce brine during salt-making ventures. This changed in 1866 when the first commercial well found oil at a depth of 38.4 m in the Fort Payne Formation of Mississippian age near Spring Creek in Overton County. This well in the Eastern Highland Rim was shut in, due to transportation problems (Nunn, 1912).

Only minor production occurred in Tennessee from 1866 to 1920. A gradual increase in average annual production occurred from 1920 to 1969 (United States Bureau of Mines, 1989*a*, 1989*b*) when the highly productive Oneida West field was discovered in East Tennessee's Cumberland Plateau.

The Cumberland Plateau, Eastern Highland Rim, and Western Valley and Ridge have been the only geomorphic provinces to provide commercial petroleum production. Ninety percent of the production comes from stratigraphic traps of Mississippian age, while stratigraphic traps of Ordovician age provide the remaining 10% (Zurawski, 1981).

Even though two-thirds of Tennessee's 95 counties have been tested by the bit, including a few deep wells in the Valley and Ridge, Cumberland Plateau, the Highland Rims, Central Basin, and Coastal Plain provinces only Morgan, Scott, Fentress, and Claiborne counties have contributed significantly to Tennessee's total-to-date production figures of greater than 13 million barrels of oil, $271 million in revenues (Independent Petroleum Association of America, 1989) and 2.18 billion m^3 (77 billion cubic feet) of natural gas (American Gas Association, 1988). Petroleum revenue ranks ninth among the mineral commodities in Tennessee.

Phosphates--Three types of phosphate (blue, brown, and white) occur in Tennessee; blue phosphate was the first to be mined in 1893 (Smith and Whitlatch, 1940). Brown phosphate, by far the most productive type, was mined originally in 1896 (Floyd, 1957). Due to its irregular occurrences, white phosphate was mined only briefly by the Tennessee Valley Authority in 1935 (Floyd, 1965).

Blue phosphate occurs in the Hardin Sandstone Member of the Chattanooga Shale Formation of Devonian age along the eastern edge of the Western Highland Rim in south-central Tennessee. Due to thick overburden and variable thicknesses, this type of phosphate became uneconomical to mine during the late 1930s (Smith and Whitlatch, 1940).

Brown phosphate has been mined primarily from the residuum of the Bigby Formation and, to a lesser extent, from the younger Leipers and older Hermitage Formation residuums (Floyd, 1957). All three of these Ordovician formations have provided phosphate rock production from the residuum of Hickman, Maury, Giles, and Williamson counties in south-central Tennessee. Columbia and Mt. Pleasant have always been the hubs of the phosphate mining and processing industry in Tennessee.

Production of phosphate has been steadily decreasing in recent years as the reserves of Tennessee rock used in the elemental phosphorous industry have continued to decline (United States Bureau of Mines, 1987). At one time, Tennessee ranked second nationwide in the production of phosphate rock; currently, Tennessee ranks fifth. Revenues derived from phosphate mining placed it seventh among the Tennessee mineral commodities with a total 1989 revenue of over $17 million (United States Bureau of Mines, 1990*a*, 1990*b*, 1990*c*). During 1991, the last producers of phosphate, Rhone-Poulenc Basic Chemicals Company, Incorporated and Occidental Chemical Corporation, terminated their mining and refining operations in Tennessee.

Silver--There has never been any silver mined as a primary metal in Tennessee, but, in 1903, out-of-state refining of the Copper Basin's copper-iron sulfide concentrates began recovering silver as a by-product. For many years afterwards, approximately 100 kg (a few thousand troy ounces) were recovered on an annual basis.

Bauxite--Bauxite was first mined in 1907 on the eastern flank of Missionary Ridge in eastern Chattanooga of Hamilton County. Eventually six mines operated in this county in southeastern Tennessee (Whitlatch, 1939), while two mines opened during and after 1912 in Carter County (King and Ferguson, 1960).

All eight operations extracted bauxite and high alumina clays from residuum found in laterally restricted sinkholes in the Knox and Shady dolomites of Cambrian age in Hamilton and Carter counties, respectively. These deposits ranged between 55 and 60% alumina and were suitable for manufacturing abrasives and salts but not metal (Whitlatch, 1939).

The Watauga and Redbird mines in Carter County produced 20,320 metric tons by the time they ceased production in 1922 (King and Ferguson, 1960), while the six mines in Hamilton County brought the final production in Tennessee up to 311,912 metric tons when they were shut down in 1928 (Whitlatch, 1939).

Dimension Sandstone--Prior to 1926, "Crab Orchard" stone quarried in the vicinity of Crossville in Cumberland County on the Cumberland Plateau was used for local building purposes. During 1926, an architect was directed to the pits in this area while trying to match the stone used in the construction of the college Southwestern at Memphis (Riley and Schroeder, 1961).

Henceforth, use of the Crossville Sandstone and Rockcastle Formation of Pennsylvania age increased as a building dimension stone and continued to grow in production until the Depression Era. Tennessee became the United State's fourth largest producer in 1941, but its production decreased dramatically during World War II.

The post-War building boom in the United States affected Tennessee's production rates by increasing them 27 times by 1955, enabling Tennessee to become the second largest dimension sandstone producer in the United States. Tennessee's production began to fall in 1958, however, and has remained fairly low ever since (United States Bureau of Mines, 1941-1987).

Granite--Two light- to medium-colored, medium- to coarse-grained, gneissoid (Born, 1936), well fractured (Floyd, 1965) granites, the Cranberry and Beech of Precambrian age, exist in the far eastern part of the Tennesseewithin Cocke, Unicoi, Carter, and Johnson counties (Hardeman, 1966). Production of dimension stone from these granites has been minimal due to the fractured nature of the rock. Crushed stone has been recovered from these granites in recent years, but production has been very small and intermittent due to the better accessibility of limestone and dolomite in the adjacent Valley and Ridge province.

Tripoli--Tripoli deposits in Tennessee are primarily found as weathered silica in residuum lying above the Warsaw and Fort Payne formations of Mississippian age in Decatur, Hardin, and Wayne counties of the Western Highland Rim province and the Knox and Copper Ridge formations of Cambro-Ordovician age in Bradley, Greene, Johnson, Rhea, and Sullivan counties of the Valley and Ridge province. These Illinoian-type tripoli deposits are whiter, more coherent, less porous, and finer-grained than the Missourian-type, and can be used as fillers in rubber, plastic, and enamel and in extenders in bricks, glass, and coatings (Whitlatch, 1939).

During the 1920s and 1930s, several mines were opened in the Western Highland Rim near Collinwood and Stout of Wayne and Hardin counties to exploit this material (Miser, 1921) found within the silica-rich (88 to 98%) residuum of weathered siliceous limestone and calcareous chert bedrock (Levings, 1923). Over 164,200 metric tons of tripoli were mined, generating revenues exceeding $264,000 between 1925 and 1939 (United States Bureau of Mines, 1989*a*, 1989*b*). More accessible mineral deposits have since replaced Tennessee tripoli. Many deposits still remain untapped in Middle and East Tennessee, while several operations are active in northern Alabama (Rheams and Richter, 1988).

Sand and Gravel--For many years, industrial and construction sand and gravel have been mined in Tennessee. Industrial sand used for glass manufacturing, foundry applications, abrasives, and hydraulic fracturing (United States Bureau of Mines, 1990*a*, 1990*b*, 1990*c*) has been open-pit mined from the Clinch Sandstone of Silurian age found on Short Mountain in Hawkins County and from Quaternary, Cretaceous, and Tertiary age formations of West Tennessee's Coastal Plain and Mississippi River Valley provinces.

Construction sand and gravel have been open-pit mined from conglomerate formations of Pennsylvanian age on the Cumberland Plateau (Born, 1936) but, to a much greater extent dredged and open-pit mined from alluvial deposits of Quaternary age in Tennessee's major river beds and floodplains. Since the 1880s, construction sand and gravel has been used as loose road and driveway aggregate, road base, and concrete and asphaltic concrete aggregate (United States Bureau of Mines, 1990*a*, 1990*b*, 1990*c*).

During 1989, over $34 million in revenue was generated by Tennessee sand and gravel operations (United States Bureau of Mines, 1990*a*, 1990*b*, 1990*c*), continuing a strong growth over the better part of the last 60 years (United States Bureau of Mines, 1989*a*, 1989*b*). Sand and gravel ranks fourth in revenues among the active mineral commodities in Tennessee.

Fullers Earth--Fullers earth, also known as bloating and bleaching clay, is a very fine-grained, montmorillonite-based, earthy material (Mason and Berry, 1968) that has been mined since the 1930s (Whitlatch, 1937) from the Porters Creek Formation of Tertiary (Paleocene) age on West Tennessee's Coastal Plain (Parks, 1971). This mineral commodity crops out in Henry, Carroll, Madison, Henderson, Chester, and Hardeman counties (Hardeman, 1966).

Mining and processing activity presently occurs in Henry and Hardeman counties where this clay is processed for use in the pet waste-absorbing industry. Other uses include lightweight oil decolorizing and clarifying, pesticide extenders (United States Bureau of Mines, 1988), and lightweight ceramic ware (Whitlatch, 1937). During 1988, over $15.5 million in revenue was generated by this mineral industry (United States Bureau of Mines, 1990*a*, 1990*b*, 1990*c*) ranking it eighth among Tennessee's leading mineral commodities.

Strontium--Celestite, a strontium sulfate mineral, can be found in a 3.7-m thick zone within the Bangor Limestone of Mississippian age along the western escarpment of the Cumberland Plateau in Fentress, Overton, and Pickett counties. During the war years of 1942 through 1944, celestite was mined in Buffalo Cove, 4.8 km southwest of Jamestown, for use in pyrotechnical compounds (Whitlatch, 1945). There has been no additional mining of this source of strontium since then due to strong competition from imports (United States Bureau of Mines, 1969). Celestite has also been found as far south as the McMinnville area (S. W. Maher, pers. comm.).

Lightweight Aggregate--Lightweight aggregate is created by the heating of carbonaceous or calcareous clay or shale to 1,223°C, fusion temperature, which forces the contained carbon dioxide gas to escape, thereby expanding and transforming the clay or shale into a vesicular material. This new form has a higher volume and lower specific gravity than either the original clay or shale.

One of the very earliest producers of this material was the Shalite Corporation which in 1949 began using Pumpkin Valley and Rome shales of Cambrian age near Knoxville to make cinder blocks from lightweight aggregate. The LaLite Corporation also used lightweight aggregate to make cinder blocks, but their source was a carbonaceous shale of Pennsylvanian age near Briceville on the Cumberland Plateau. Unsuccessful efforts were also made near Nashville during the 1960s using the New Providence Shale unit (lower Fort Payne Formation) of Mississippian age (S. W. Maher, pers. comm.).

By the early 1970s, these operations had ceased. Presently, two manufacturers of cinder blocks exist in East Tennessee, but neither acquire their lightweight aggregate from in-state mining operations.

Mica--From 1956 until mid-1964, scrap mica (muscovite) was dredged from Davy Crockett Lake near Greeneville in Greene County for use as ground mica in the paint industry (United States Bureau of Mines, 1956-1984). This mica originated in mine tailings in North Carolina and was transported by the Nolichucky River to Davy Crockett Lake where it settled.

Gem Stones--Since the late 1800s, the larger rivers in Tennessee and surrounding states have been known to host mussels which have provided pearls for the collector and shells for the thriving button industry. Due to increased fishing, river impoundment and pollution, and use of plastics for the manufacturing of buttons, the button industry ceased in the 1950s (Parmalee, 1967).

The United States Bureau of Mines considers the freshwater pearl as a gem stone and, thereby, keeps abreast of its production. Within the past 30 years, the Tennessee River mussel and pearl have become very important mineral commodities.

Since 1960, the American Shell Company has been harvesting, grinding, and shipping Tennessee River mussel shells from their West Tennessee-Camden office in Benton County to Japan to be used as an irritant in that country's highly lucrative cultured pearl industry. By 1987, the first commercially successful crop of cultured pearls was produced by American Pearl Farms, also of Camden. During 1988, gem stones, predominantly Tennessee River pearls and mussel shells, were ranked as Tennessee's fifth highest mineral commodity, generating $28 million in revenue (United States Bureau of Mines, 1989*a*, 1989*b*).

Lignite--Tennessee has a few minerals that have never been mined. Such a mineral with the greatest potential is lignite, a low-grade coal found in unconsolidated Wilcox and Claiborne sediments (Eocene age) of West Tennessee's Coastal Plain.

A lignite mine had been opened in Raleigh, a northern suburb of Memphis, during the 1800s but proved to be unsuccessful (Safford and Killebrew, 1900). It was not until the late 1970s that the resource was intensively explored with the drill bit and logging tool and found to be economically concentrated in Crockett, Dyer, Haywood, Lauderdale, and Tipton counties.

After undergoing "pre-burn" drying procedures, a pound of lignite can produce as much as 5,000 to 11,000 BTUs while being environmentally desirable due to its <1% sulfur content (Luppens, 1980). West Tennessee's lignite can be used for "mine-mouth" electric generation and chemical feedstock.

Heavy Mineral Sands--The McNairy Sand of Cretaceous age, found along the eastern perimeter of West Tennessee's Coastal Plain, has been found to contain concentrations of ilmenite and rutile, along with lesser concentrations of tourmaline, zircon, and several rare earth minerals (Wilcox, 1971). E. I. duPont deNemours and Company, among others, once held a significant lease position in this area, but, due to the industry's inability at that time to process the very fine-grained heavy minerals, they dropped their leases. Interest in these titanium oxide-bearing minerals with their great opacity and brilliant whitening abilities has increased in recent years. Processes able to recover this very fine-grained material may now exist.

Uranium and Oil Shale--Perhaps the resources with the least potential are uranium and oil shale found within the Chattanooga Shale of Devonian age of East and Middle Tennessee. The Chattanooga Shale, which crops out along the eastern escarpment of the Cumberland Plateau, eastern flank of the Sequatchie Valley, eastern slope of Clinch Mountain, western slope of Chilhowee Mountain, and escarpments of the Eastern and Western Highland Rim (Hardeman, 1966), has been researched for its uranium potential since 1944 and oil shale potential since the 1940s. The Chattanooga Shale has been used to a limited extent as a source for black paint and alum salts (S. W. Maher, pers. comm.).

Distillation tests performed on samples from both East and Middle Tennessee have presented a range of 15.1 to 159.0 with an average of 68.1 l/metric ton (4 to 42 with an average of 18 gallons/ton; Whitlatch, 1945). If oil shale ever becomes a source of fuel in the United States, it is unlikely that Tennessee's reserves could ever compete with those already delineated in the western United States.

CONCLUSION

History and mineral research have proven that at least 40 mineral commodities can be derived from the rocks and sediments of Tennessee. Every geomorphic province (Table 1) from the Unaka Mountains to the Mississippi River Valley and every geologic age (Table 2) from Precambrian granites to Quaternary river bed sands and gravels have provided at least one commodity to the Tennessee mineral industry.

Significant increases in production of the 14 presently active mineral commodities occurred during the late 1940s and early 1950s, even though commodities mined then such as manganese, limonite, pyrite, copper, sulfur, gold, and silver are no longer being recovered. The early 1970s also witnessed a dramatic increase in revenue over and above the normal growth rate (Fig. 1) for all the active mineral commodities due to mining, processing, and shipping fuel costs.

During 1989, Tennessee was nationally ranked fifteenth for industrial minerals value (revenue), thirteenth for metallic minerals value, and sixteenth for total non-fuel minerals value (United States Bureau of Mines, 1990*a*, 1990*b*, 1990*c*). Tennessee provided 2.03% of the United States' total non-fuel minerals value in 1989 while realizing a total value of $638.4 million, a $52.8 million or 9% increase above that of 1988 (United States Bureau of Mines, 1990*a*, 1990*b*, 1990*c*). Wise utilization of the mineral commodities and a broader application of mining regulations to include those commodities not presently regulated should ensure Tennessee of continuing its history of a healthy and environmentally-safe mineral industry for many decades to come.

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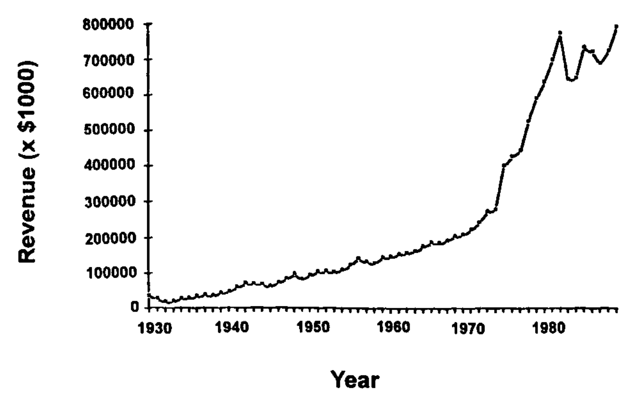

FIG. 1. Total mineral revenues for 1930 through 1988.

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