Geology of Some Copper Deposits in North Carolina Virginia, and Alabama

By GILBERT H. ESPENSHADE

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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A description of the geology of the cupriferous pyrrhotite deposits of the Fontana and Hazel Creek mines, Swain County, North Carolina, the Toncrae mine, Virginia, and the Stone Hill mine, Alabama

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GEOLOGY OF SOME COPPER DEPOSITS IN NORTH CAROLINA, VIRGINIA, AND ALABAMA

By Gilbert H. Espenshade

ABSTRACT

This report describes the geology of the Fontana and Hazel Creek copper deposits and a surrounding area of about 30 square miles in Swain County, N.C., the Toncrae copper deposit, Virginia, the Stone Hill copper deposit, Alabama, and a few smaller deposits in these areas. These cupriferous pyrrhotite bodies are similar to, but much smaller than, the well-known deposits of Ducktown, Tenn., and of the Gossan Lead, Va. They belong to the group of copper-bearing pyrrhotite and pyrite deposits that occur in the metamorphic rocks of the Blue Ridge and Piedmont provinces in several belts between northern Virginia and eastern Alabama, a distance of about 600 miles.

The Fontana and Hazel Creek deposits are on the southern slopes of the Great Smoky Mountains now within the boundaries of the Great Smoky Mountains National Park. Phyllite, fine-grain mica schist, and feldspathic sandstone of the Great Smoky Group of the Ocoee Series of Precambrian age underlie the area. These copper deposits and several smaller ones are in dominantly phyllitic rocks, apparently within a zone of shearing; small bodies of diorite, some of which are massive and some sheared, are in the same zone. Pyrrhotite, chalcopyrite, and sphalerite are the principal hypogene sulfides. The near-surface part of the ore deposits has been oxidized by weathering to limonitic gossan, which is separated from the hypogene part by a layer several feet thick of supergene sulfides, mainly chalcocite and pyrite.

The Fontana ore body has an elongate podlike shape and plunges about 45°, deviating a few degrees from the dip of the foliation but lying about parallel to linear structures (crinkles, elongated biotite flakes, quartz grains, and pebbles) within the country rocks. The deposit is about 450 feet in strike length, has an average thickness of about 10 feet and has been followed down the plunge for 2,500 feet. More than 83 million pounds of copper was produced from the Fontana mine between 1926 and 1944. The ore was shipped without beneficiation and had an average grade of about 7 percent copper and 2 percent zinc; all but a very small part of this was hypogene ore.

The Hazel Creek deposit is made up of a group of curved lenses of massive sulfides that overlap one another and seem to form a pipelike ore body; sulfide veinlets are abundant in the rock between the lenses. Individual lenses are commonly less than 100 feet in strike length and average about 3 feet in thickness; they plunge at angles of 35° to 50° and range from 50 to 200 feet in plunge length. Exploration through a vertical interval of about 250 feet has

indicated that the size of the explored part of the deposit is about 100 tons per vertical foot of massive sulfide ore (containing 3–3.5 percent copper and 3–3.5 percent zinc) and 300 tons per vertical foot of disseminated ore (containing 1–2 percent combined copper and zinc). Ore shipped during 1943 and 1944 carried a little more than 400,000 pounds of copper. More than a third of this was enriched supergene ore that averaged about 12.5 percent copper; most of the hypogene ore contained 4–5 percent copper and several percent zinc.

The Toncrae deposit is a tabular body of massive and disseminated sulfides in garnet-biotite-muscovite-quartz gneiss. It extends for about 1,100 feet along the strike, conformable to the foliation of the gneiss and has a maximum thickness of about 50 feet. Full information on drilling results is not available, and the shape and size of the deposit at depth are not certainly known. The upper weathered part of the ore body is limonitic gossan that has a maximum vertical thickness of about 60 feet. The supergene copper zone between the gossan and hypogene sulfides is about 500 feet long and has a maximum vertical thickness of about 10 feet. Supergene ore shipped from the mine contained between 6 and 14 percent copper; the best hypogene ore has between 1 and 2 percent copper. A total of several thousand tons of supergene ore was mined in 1854 and 1938–47; about 2,500 tons of hypogene ore was mined in 1905–08.

The Stone Hill deposit occurs in hornblende schist and consists of layers of massive sulfides, a few feet thick, that alternate with thicker layers of disseminated sulfides. The mineralized zone is about 1,000 feet long and about 60 feet in maximum thickness. A zone of rich supergene copper ore occurred between the gossan and the hypogene sulfides. About 1,500 tons of this ore containing 15 percent copper was shipped in 1874–75. Samples of hypogene ore from dumps and in mine workings several hundred feet deep reportedly contained 3–4 percent copper; most samples of hypogene ore taken by diamond drilling had less than 1 percent copper.

INTRODUCTION

As part of the U.S. Geological Survey's wartime investigation of domestic copper deposits, all the cupriferous pyrrhotite and pyrite deposits in the Southeastern States were examined during 1942 and 1943, with the exception of Ducktown, Tenn., the major copper-producing district in the region. The main purpose of the investigation was to gather geologic information that might be used in the exploration and development of the deposits. Detailed geologic studies were made of the mines and districts that were producing copper at that time—Fontana and Hazel Creek mines in the Swain County copper district, North Carolina, and the Toncrae mine, Floyd County, Va.—and of several other deposits that had formerly been productive. Much of the effort was spent in mapping the geology of an area of about 30 square miles in the Swain County copper district in an attempt to discover the geologic controls of the ore deposits of this district. Planetable geologic maps were made at half a dozen mines, and the Gossan Lead in Virginia was studied in some detail.

Two reports resulting from this work have been placed in open files of the Geological Survey: the Hazel Creek mine, North Carolina

(Espenshade and others, 1943), and the Gossan Lead, Va. (Wright and Raman, 1948). Geological Survey maps and other data were used in drilling exploration programs by the U.S. Bureau of Mines at several mines and are incorporated in reports on exploration at the following deposits: Toncrae and Sutherland mines, Virginia (Grosh, 1948a, b); Ore Knob mine, North Carolina (Ballard and Clayton, 1948); Tallapoosa mine, Georgia (Ballard and McIntosh, 1948); and Stone Hill mine, Alabama (Pallister and Thoenen, 1948).

The present report is mainly concerned with the results of the detailed geologic studies of the Hazel Creek and Fontana mines and surrounding area in the Swain County copper district, North Carolina. Geologic features of the Toncrae mine, Virginia, and Stone Hill mine, Alabama, are also described; geologic interpretations, largely based upon drilling results, are offered. The nature and amount of geologic data gathered were limited by the time available for these investigations in the wartime program.

These studies were carried out under the general supervision of R. S. Cannon, Jr., who directed the Geological Survey's program of investigation of domestic copper deposits during World War II. I am very grateful for the valuable contributions that Mr. Cannon has made to our study of the southeastern copper deposits during and since the field investigations. The following geologists took part in the field studies and contributed much to the work: T. W. Amsden, E. A. Brown, J. H. Eric, R. M. Hutchinson, N. D. Raman, M. H. Staatz, and R. J. Wright.

CUPRIFEROUS PYRRHOTITE AND PYRITE DEPOSITS

DISTRIBUTION

Copper-bearing iron sulfide deposits are distributed in several belts within the Southeastern States over a distance of about 600 miles between eastern Alabama and northern Virginia (fig. 1). Cupriferous pyrrhotite deposits occur in a belt within the Blue Ridge province, extending northeastward from the Ducktown district in Tennessee to the Toncrae deposit, Floyd County, Va. Farther east in Virginia, near the eastern border of the Piedmont province, a group of copper-bearing pyrite deposits extends northeastward from Louisa County to Prince William County on the edge of the Coastal Plain. Most of the deposits in the massive sulfide belt in the Piedmont province of Georiga and Alabama are of the pyritic variety also, although several pyrrhotite bodies are present. Similar deposits are also distributed through the northern Appalachian system in New England, Quebec, New Brunswick, and Newfoundland. They belong to the well-known class of massive copper-iron sulfide deposits that charac-

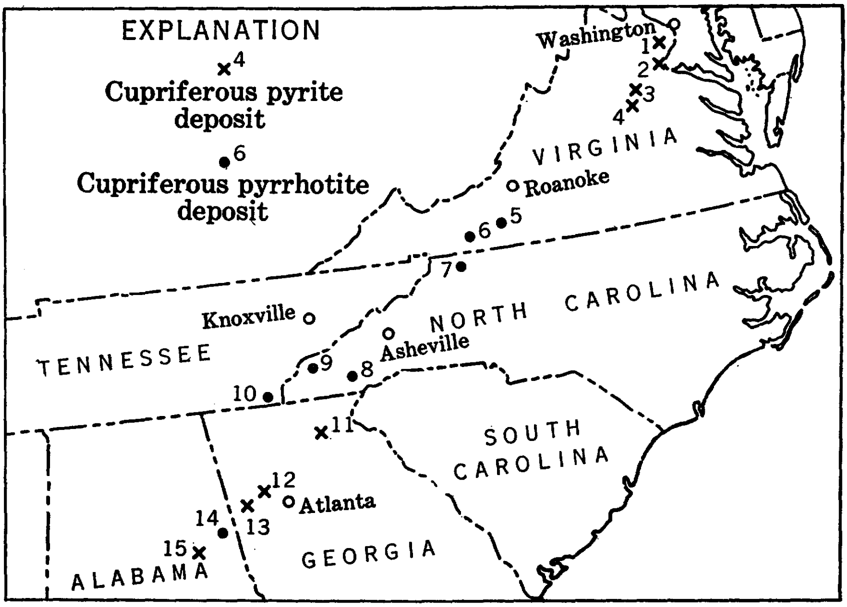

FIGURE 1.—Map showing location of principal mines and districts of cupriferous pyrite and pyrrhotite deposits in the Southeastern States. List of mines or districts: (1) Cabin Branch mine, (2) Austin Run mine, (3) Valzinco mine, (4) Louisa County district, (5) Toncrae mine, (6) Gossan Lead district, (7) Ore Knob mine, (8) Cullowhee mine, (9) Swain County district, (10) Ducktown district, (11) Chestatee mine, (12) Little Bob mine, (13) Tallapoosa mine, (14) Stone Hill mine, and (15) Pyriton district.

teristically occur in strongly folded orogenic belts in many parts of the world.

PREVIOUS STUDIES

Since the discovery of the copper deposits of Ducktown, Tenn., about 1850, many geologic reports and maps have been published on the cupriferous iron-sulfide deposits and districts of the Southeastern States. The most thorough studies of copper deposits and the ores are those by Emmons and Laney (1926) describing the Ducktown deposits and by Ross (1935) on the mineralogy and genesis of deposits of the Ducktown type. Other selected publications describing districts and deposits are as follows: Northeastern Virginia—Taber (1913), Cline, Watson, and Wright (1921), and Lonsdale (1927); southwestern Virginia—Currey (1880), Wright and Raman (1948), Grosh (1948a, b), Kline and Ballard (1949), Stose and Stose (1957), and Dietrich (1959); Ore Knob, N.C.—Olcott (1875), Ballard and Clayton (1948) and Kinkel (1962); Swain County, N.C.—Laney (1907), Espenshade, Staatz, and Brown (1943), and Kendall (1953); Ducktown, Tenn.—Ffolliott (1942), Barclay (1946), and Simmons (1950); Georgia—Shearer and Hull (1918), and Ballard and McIntosh (1948); and Alabama—Rothwell (1877), Prouty (1923), Adams (1930), and Pallister and Thoenen (1948).

During the pyrite shortage of World War I, the domestic pyrite deposits were investigated by the Geological Survey to find new sources of pyrite and pyrrhotite; results of this investigation were summarized by Smith (1918), who mentions some deposits in the Southeastern States for which little other information is available in the literature. The geology of much of the Great Smoky Mountains near the Swain County copper district, North Carolina, has recently been mapped by the Geological Survey; summaries of this work have been published by Hadley, King, Neuman, and Goldsmith (1955) and King, Hadley, Neuman, and Hamilton (1958).

MINERALOGY

HYPOGENE MINERALS

Pyrrhotite and pyrite are the dominant metallic minerals of the massive sulfide deposits of the southern Appalachians; one of these iron sulfides is commonly much more abundant that the other. Minor amounts of pyrite are present in many of the pyrrhotite bodies, but pyrrhotite is absent or scarce in most of the pyritic deposits. Chalcopyrite is found in all the pyrrhotite deposits in variable amounts, ranging from the equivalent of about one-half of 1 percent copper in parts of the Gossan Lead to more than 7 percent copper in the Fontana deposits. It likewise occurs in most of the pyrite deposits but appears to be absent or very scarce in several of them, as the Reed Mountain and Villa Rica pyrite bodies in Georgia. Sphalerite is present in minor quantities in many deposits; it is rather abundant in amounts equivalent to several percent zinc in the Fontana and Hazel Creek deposits, Swain County, N.C., in the Betty Baker segment of the Gossan Lead, in the Mary ore body at Ducktown, and in some of the Georgia pyrite deposits, such as the Little Bob mine and Swift prospect, Paulding County, and the Standard mine, Cherokee County. Galena is a relatively rare and minor mineral in these deposits. Magnetite is rather abundant in some pyrrhotite bodies, as at Ducktown and Ore Knob. Bornite, cubanite, and specularite occur in very minor amounts in the Ducktown ores; arsenopyrite is a very scarce mineral at Ducktown and in the Betty Baker segment of the Gossan Lead.

An investigation of the cobalt content of the sulfide minerals in these pyrite and pyrrhotite deposits was made by M. H. Krieger and K. J. Murata of the Geological Survey. Clean samples of pyrite, pyrrhotite, and chalcopyrite were separated by Krieger, and spectrographic determinations of cobalt were made by Murata. They reported (written communications, 1945, 1949) that pyrite from Ducktown, Tenn., had the largest cobalt content, 0.4–0.5 percent; pyrrhotite from Ducktown contained 0–0.007 percent cobalt; the one chalcopyrite sample from Ducktown that was analyzed contained a trace of cobalt. In specimens from various deposits in Alabama, Georgia, and North Carolina, the cobalt content was found to range from 0.002 to 0.05 percent in pyrite, from 0 to 0.08 percent in pyrrhotite, and from 0 to 0.02 percent in chalcopyrite. Cobalt content of ores from the Gossan Lead is evidently low; Kline and Ballard (1949, p. 9) report less than 0.01 percent cobalt and nickel for composite samples from 15 drill holes.

The suite of gangue minerals is very similar in many deposits; quartz, plagioclase—ranging in composition from albite to andesine according to Ross (1935, p. 62)—amphiboles, biotite, and chlorites are among the most abundant and widespread minerals. Carbonates, epidote, garnets, barite, and gahnite are present in smaller amounts in many deposits; pyroxenes and talc occur in some.

Sulfides and gangue minerals are associated in variable amounts. Massive sulfide ore, composed dominantly of pyrrhotite or pyrite with several percent copper and zinc sulfides and 10–30 percent gangue minerals, is typical of many deposits. The gangue minerals in such ore may be distributed rather uniformly as grains or rounded masses so as to give a granular appearance to the ore. Individual crystals of pyrite, from 1/16 inch to as much as 4 inches in size, are common in some pyrrhotite ore at Ducktown, as well as at Toncrae, Ore Knob, and in some of the Gossan Lead ore. Such pyrite has been considered by Ross (1935, p. 75, 85, 100) to be older than the other sulfides; A. R. Kinkel (oral communication, 1960) believes it possible that this type of pyrite may be a late porphyroblastic mineral. Some ores have a banded appearance, or layered arrangement of sulfides and gangue minerals, which is probably due to replacement of the country rock along the schistosity; ore from the Cranberry mine in the Gossan Lead district has the appearance of intricately folded schist that has been replaced by sulfides (Ross, 1935, p. 82). Large faces of ore at Ducktown, at the Monarat mine in the Gossan Lead district, and at the Fontana mine have the appearance of a breccia because of the presence of irregular randomly oriented fragments or blocks of schist in the ore. The gangue is more abundant than sulfide minerals in some types of ore from many deposits. At the Hazel Creek mine chalcopyrite and sphalerite occur in irregular masses and as stringers in the schist and are more abundant than pyrrhotite. In low-grade pyritic ores, in which pyrite is the principal sulfide, the pyrite is generally disseminated in quartz-sericite schist.

In his paper on the mineralogy and origin of the ores of the Ducktown type, Ross (1935) gives evidence from studies of suites of specimens from various deposits to show that these deposits were formed by hydrothermal solutions during successive stages; the minerals formed in the earlier stages were replaced in later stages by other minerals. In general, quartz and feldspar were the earliest minerals and were followed by ferromagnesian silicate minerals, such as amphiboles, pyroxenes, garnets, and biotite, which partly or wholly replaced the country rock or the earlier hydrothermal minerals. Carbonates—calcite, dolomite, ankerite, or manganiferous calcite—were generally introduced next and partly replaced the older minerals. In some deposits, silicate minerals—diopside, tremolite, and biotite—were deposited after the carbonate stage and replaced the carbonates. Metallic minerals—principally iron, copper, and zinc sulfides—were formed in the last stages of mineralization. Chloritization of biotite and some of the other silicates has taken place, but the time of this alteration has not been determined. Ross believes that the hydrothermal solutions came from differentiating magmas; igneous rocks related to the hypothetical magmas have not been identified within the region, however. He states that the successive stages of vein formation seems to have been initiated by repeated movements in the vein that permitted entrance of solutions of different composition.

The ore and gangue minerals of the deposits described in this report were not studied in enough detail by the writer to determine their spatial and age relationships and possible modes of origin. Thorough studies of the cupriferous pyrrhotite deposit of the Elizabeth mine, Vermont, which is very similar to cupriferous pyrrhotite deposits of the Southeastern States, have been made by McKinstry and Mikkola (1954) and Howard (1959). Sulfides there seem to have been deposited by replacement of schist in zones of brecciation and potential permeability associated with folds. Alteration of country rock took place in three gradational stages—before, during, and after sulfide deposition. The alteration envelope associated with sulfide deposition ranges from a few inches to 20 feet in thickness; near the ore body plagioclase and biotite were altered to sericite, and farther from the ore body hornblende and garnet were replaced by biotite; and kyanite was replaced by muscovite. In the third stage of alteration, hornblende, garnet, and biotite in the outer part of the zone were replaced by chlorite.

SUPERGENE MINERALS

The gossans of the iron sulfide deposits of the southern Appalachians are composed principally of brown to reddish-brown limonite with cellular to earthy structure; small amounts of quartz, muscovite, and other silicates residual from the original sulfide ore are commonly present. Ducktown gossans range in iron content from 40 to 50 percent, according to Emmons and Laney (1926, p. 71). Some copper also occurs in the gossans; Emmons and Laney (1926, p. 71) state that Ducktown gossan, shipped as iron ore, contained 0.3–0.9 percent copper. Several samples of gossan from the Hazel Creek and Toncrae deposits contain considerably more copper (table 1); these samples may have also carried some supergene copper sulfides. Mineralogy of the gossans has not been studied by modern methods, but it is likely that copper in the gossan occurs mainly as oxides, carbonates, silicates, and as native copper. Cuprite and native copper are reported in the Ducktown gossans by Emmons and Laney (1926, p. 72); they believe cuprite was the principal copper mineral in the gossan. Native copper was also observed in the Hazel Creek gossan. A green copper mineral, probably malachite, is abundant in some gossan at Hazel Creek, Toncrae, and Ore Knob; such gossan has a bright-red color which may be partly due to cuprite. Malachite, chrysocolla, and aurichalcite were found in supergene ores from Fontana by Short (Ross, 1935, p. 94), but he does not state whether these minerals were in the gossan or in the supergene copper sulfide ores. According to Emmons and Laney (1926, p. 50), Kemp found small flakes of sulfur in the Ducktown gossan.

The supergene sulfides typically are sooty black and have a crumbly porous texture, though some are massive and coherent; the pulverulent ores were known as smut ores and black copper ores by the early miners. Chalcocite is the most common copper mineral; it has been found to be accompanied by covellite in the few ores of this type that have been studied, such as the Ducktown ores (Gilbert, 1924; Emmons and Laney, 1926, p. 49) and the Fontana ores (Ross, 1935, p. 94). A supergene iron sulfide occurring as spheroids and veinlets was found in specimens from the supergene copper zone at Ducktown by Gilbert (1924) and at Fontana and the Betty Baker mine of the Gossan Lead district by Short (Ross, 1935, p. 94). Gilbert believes that this mineral was marcasite, but Short concludes that it was more likely to be pyrite, because it did not show anisotropism. A similar iron sulfide mineral is abundant in the Toncrae supergene ores. Pyrrhotite is replaced to a considerable extent by this supergene iron sulfide in the Ducktown ores and is completely leached from the supergene ore of the Fontana deposit. Hypogene chalcopyrite and sphalerite are replaced to a lesser extent by secondary iron sulfides and chalcocite. Magnetite, quartz, and some of the silicate minerals may be little altered.

TABLE 1.—*Partial chemical analyses of samples of gossan from some pyrrhotite and pyrite deposits in Alabama, Georgia, North Carolina, and Virginia*

[H. E. Crowe, analyst]

Deposit	Sample	Percent				
		Copper	Zinc	Lead	Cobalt	Arsenic
Pyrrhotite with >1 percent copper in hypogene sulfide ore						
Stone Hill, Cleburne County, Ala	1A	0.6	0.09	0.082	<0.001	0.015
	1B	2.0	.11	.18	.002	.004
	1C	.7	.09	.08	.004	.006
Fontana, Swain County, N.C	43E1	1.8	.13	.01	.008	<.001
Hazel Creek, Swain County, N.C	73D	3.5	.06	1.00	.008	.001
	73F	3.2	.048	.24	.004	.002
	45E3	1.6	.036	.23	.014	<.001
	45E4	1.4	.048	.01	.014	.002
Ore Knob, Ashe County, N.C	15A	1.4	.06	.006	.02	<.001
	15B	.8	.036	.006	.003	<.001
	15C	.7	.036	.015	.004	<.001
	15D	1.0	.06	.025	.003	<.001
	15E	.8	.04	.115	<.001	<.001
Toncrae, Floyd County, Va	17	.9	.06	.013	.045	.002
	43E2	.9	.10	.006	.012	.015
	43E3 [1]	18.0	.13	.006	.090	.04
Pyrite with >1 percent copper in hypogene sulfide ore						
Little Bob, Paulding County, Ga	10A	0.15	0.11	0.017	0.01	0.001
Tallapoosa, Haralson County, Ga	6A	.43	.04	.008	.007	.002
	6B	.41	.005	.002	.004	.004
Chestatee, Lumpkin County, Ga	5A	.45	.024	.01	<.001	.008
Pyrrhotite with <1 percent copper in hypogene sulfide ore						
Jenny Stone, Carroll County, Ga	16A	0.22	0.07	0.025	0.009	0.001
Swift, Paulding County, Ga	7A	.37	.08	.006	.007	.002
Pyrite, with <1 percent copper in hypogene sulfide ore						
Reeds Mountain, Carroll County, Ga	4A	0.22	0.02	0.016	0.002	0.001
	4B	.17	.016	.008	.007	<.001
	4C	.12	.004	.013	.004	<.001
Creighton, Cherokee County, Ga	12A	.15	.034	.02	.02	.003
	12B	.18	.022	.012	.01	.006
Villa Rica, Douglas County, Ga	14A	.33	.08	.032	.007	.004
Character of hypogene sulfide ore poorly known						
Berrong, Towns County, Ga	3A	0.40	0.02	0.015	0.009	<0.001
	3B	.55	.004	.005	.004	<.001
Smith-McCandless, Haralson County, Ga	9	.53	.016	.02	.016	.004
Belcher, Floyd County, Va	43E5	1.60	.068	.01	.018	.005
Sutherland, Floyd County, Va	43E4	.75	.04	<.002	.018	.001

[1] The high copper content indicates that this sample must be supergene copper ore instead of gossan.

Copper content of the enriched supergene ores varies considerably. Emmons and Laney (1926, p. 52–54) quote several observers, who state that the richer Ducktown ores generally contained 20–30 percent copper. Olcott (1875) states that 1,400 tons mined at Ore Knob in 1873 carried 25–30 percent copper. Currey (1880) says that 2,500 tons produced from the Gossan Lead in 1855 carried 14 percent copper. Shipments in 1943 of about 600 tons of secondary copper ore from Hazel Creek averaged 12.5 percent copper and 3.5 percent zinc. Supergene copper ore shipped from the Toncrae mine in 1938 carried 14.5 percent copper in 146 tons of ore; shipments of 1,926 tons in 1944 averaged 6.95 percent copper. The lower copper content of the 1944 shipments may have been caused, in part, by leaching of copper from the supergene ores by acid mine waters during the several preceding years when the mine was not worked.

STRUCTURE

The cupriferous massive sulfide deposits of the southern Appalachians have a diversity of shape, size, country rock, and other features, but all are lenticular bodies in schistose rocks and most are conformable to the schistosity of the enclosing rocks. Some deposits consist of a single lens which may have a fairly uniform strike and dip or may be moderately warped or have minor rolls. Several deposits are much elongated in one direction and have the shape of a long flattened pod. The Fontana deposit is the best example in the region of such an elongated body; its strike length is 400–500 feet, and its plunge length is more than 2,500 feet. Other deposits, such as the Hazel Creek and Stone Hill deposits, consist of groups of thin lenses of massive sulfides arranged in echelon, or in overlapping fashion; sulfides are disseminated or in stringers in the rock between the lenses. Some of the bodies at Ducktown are somewhat tabular but have large irregular finlike projections that resemble drag folds; in places the shapes are very intricate and are similar to tight sigmoid folds.

In size the deposits may be very small lenses or may range from a few hundred tons of ore per vertical foot, such as at Hazel Creek, to the very large bodies at Ducktown and the Gossan Lead that contain some thousands of tons of ore per vertical foot. Individual massive sulfide lenses at Hazel Creek average about 3 feet in thickness, have strike lengths of about 100 feet and plunge lengths of 60–200 feet; these lenses overlap one another, and the intervening ground is moderately mineralized. The Toncrae deposit is considerably larger, about 1,000 feet long and as much as 30 feet thick. The Gossan Lead is a mineralized zone about 17 miles long, that is made up of large tabular sulfide bodies, some of which are several miles long, and intervening barren or weakly mineralized stretches which range from a fraction of a mile to several miles in length. The large massive sulfide bodies at Ducktown occur in three zones or lode systems that are as much as several miles in length; some individual bodies are more than half a mile long and several hundred feet thick.

The country rock of many of the sulfide deposits consists of varieties of quartz-muscovite schist and gneiss; examples of such deposits are the Gossan Lead, Ore Knob, and Toncrae pyrrhotite deposits and some of the pyrite deposits in Virginia and Georgia. The Ducktown, Fontana, and Hazel Creek deposits are in rocks of the Ocoee Series, which is made up of feldspathic sandstone, mica schist, and phyllite. Some deposits occur in chloritic schists and hornblende schists and gneisses; examples are the Elk Knob and Cullowhee deposits, North Carolina, and the Pyriton and Stone Hill deposits, Alabama. Mafic rocks of similar composition are common in the vicinity of some of the sulfide deposits in quartz-mica schists and gneisses. Small granitic or pegmatitic bodies are associated with the sulfide deposits at the Cullowhee and Savannah mines, North Carolina.

Most deposits are conformable to the schistosity of the country rock; the Ore Knob body may be an exception, because it seems to be in a fault or shear zone that dips more steeply than the schistosity. Curved irregularities in the sulfide lenses are commonly parallel to similar schistosity trends in the wallrock, as in curving lenses of the Hazel Creek deposit. The irregularly shaped deposits of the Ducktown district are the best examples in the region of sulfide bodies that seem to be conformable to large tight folds in the metamorphic rocks (Emmons and Laney, 1926). Remnants of small drag folds, a few inches in amplitude, are found in the ores of some deposits.

Enough information is known about some deposits to show that they occur in faults or shear zones which are about parallel to the schistosity. Examples of such deposits along fault zones are many of the Ducktown deposits (Emmons and Laney, 1926, p. 54–56), the Fontana deposit, and the Monarat deposit in the Gossan Lead district (Ross, 1935, p. 79); breccia ore composed of schist fragments in a matrix of sulfide minerals occurs at these places and probably represents brecciated country rock that has been partly replaced by sulfides. At Ducktown, however, both Emmons and Laney (1926, p. 55) and Simmons (1950, p. 70) believe that the controlling factor in ore deposition was selective replacement of folded calcareous beds and that the influence of faults on ore localization was less important. Ross (1935, p. 34–38), on the other hand, gives evidence that the carbonate masses associated with ore at Ducktown have been deposited by the mineralizing solutions and are not unreplaced remnants of limestone beds. Although the original nature of the beds replaced by sulfides may be controversial, it does seem clear that the Ducktown deposits occur partly as replacements of folded beds and partly as replacements in fault zones.

The Fontana and Hazel Creek deposits are markedly elongate, and the present study has shown that these podlike bodies plunge parallel to linear structure in the country rock, such as fold axes, cleavage crinkles, cleavage intersections, and elongated and oriented minerals. This parallel relationship between plunge of ore bodies and plunge of linear structures in enclosing metamorphic rocks is a common phenomenon that occurs in many other massive sulfide deposits. Where this parallel relationship between ore body and linear structure prevails, the direction of the plunge of linear structures in the country rock, which may be observed at many places near the ore body, provides a useful guide to the plunge of the ore body. This relationship may be helpful in guiding the exploration and mining of a deposit, but the principle must be applied with caution, for in some areas several lineations plunge in different directions. Simmons (1950) points out that the fold axes in the country rock at Ducktown plunge northeast for the most part but that the folds in the ore bodies plunge either southwest or northeast.

EFFECTS OF WEATHERING

Deep weathering in the region has characteristically formed thick gossans of limonite in the near-surface parts of the cupriferous iron sulfide bodies. The base of the gossans is commonly separated from the unweathered hypogene sulfides below by a layer of enriched supergene copper ore that may be as much as 10 feet thick.

The gossans are deeper beneath hills and uplands and very shallow or absent where the ore deposits are cut by streams; depths ranging from 30 to 50 feet are common, but 100 feet is exceptional. J. D. Whitney pointed out in 1854 that the base of the gossan coincided approximately with the ground-water table (Emmons and Laney, 1926, p. 65). The contact between gossan and the enriched copper layers at Ducktown was very sharp; at the Toncrae deposit stringers of gossan extended into the supergene sulfides, and isolated masses of supergene sulfides occurred in gossan several feet above the enriched sulfide layer.

The supergene copper layer at Ducktown was as much as 10 feet thick but generally ranged in thickness from about 2 to 4 feet, according to the accounts of various observers (Emmons and Laney, 1926, p. 73). Olcott (1875) states that the black ore zone at Ore Knob was about 30 feet thick. The enriched zone at Toncrae was as much as 10 feet thick.

A clear concept of the origin of the gossan and the supergene copper ores by action of ground waters on the hypogene iron and copper sulfides was held by such early observers as Whitney, Tuomey, Safford, Currey, and T. Sterry Hunt. The downward enrichment of sulfide ores at Ducktown is well described by Emmons and Laney (1926, p. 65), who point out that copper tends to be dissolved and iron precipitated above the water table, whereas copper is precipitated and iron dissolved below the water table. When the water table subsides during normal fluctuations of level, the upper part of the chalcocite zone is exposed to oxidation, copper is leached and iron precipitated; thus the gossan gradually encroaches on the supergene copper layer, which in turn moves downward by alteration of the primary sulfides.

The chemical reactions involved are discussed at length by Emmons and Laney (1926, p. 74–78) and by Gilbert (1924, p. 18–21). In the zone of oxidation above the water table, H_2SO_4, free oxygen, and ferric sulfate are present; copper and zinc are taken into solution as sulfates. Ferric sulfate is hydrolyzed and precipitated here as ferric hydrate, which later goes to limonite; additional H_2SO_4 is also formed. In the reducing environment beneath the water table, free oxygen is absent, ferric sulfate is reduced to ferrous sulfate, and pyrrhotite reacts with H_2SO_4 to yield ferrous sulfate, H_2S, and S. The copper sulfides (chalcocite and covellite) may be precipitated here by reaction of H_2S and $CuSO_4$ or may be formed by reaction of $CuSO_4$ with pyrite and pyrrhotite. With a little H_2S present and oxygen absent, the copper sulfides are insoluble in H_2SO_4. Gilbert (1924) concludes that an essential step in the process is replacement of pyrrhotite by iron disulfide (marcasite?) which in turn is replaced by chalcocite and covellite; the FeS_2 may be formed by action of H_2S upon either ferrous or ferric sulfate.

The instability of the supergene copper and iron sulfides under oxidizing conditions was well illustrated in mine workings in the enriched copper zone of the Toncrae deposit. These workings were mined at different times between 1938 and 1945; during periods of inactivity the mine was partly filled with water, which became acid and leached copper from the secondary ores. Efflorescences of copper and iron sulfates were formed on ores exposed to air. In a poorly ventilated part of the mine, temperatures higher than 140°F were reported and were presumably due to oxidation of supergene pyrite.

DEPOSITS IN GREAT SMOKY MOUNTAINS, NORTH CAROLINA

The Swain County copper district is located along the southern slope of the Great Smoky Mountains, about 45 miles northeast of the Ducktown copper district, Tennessee (fig. 1). The district was formerly accessible by road and railroad along the north side of the Little

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Tennessee River, but these lines of access were flooded in 1944 by Fontana Reservoir of the Tennessee Valley Authority, and the area can now be reached only by boat or by foot. Fontana Village, a resort about 2 miles southwest of Fontana Dam, is the nearest settlement that can be reached by road.

Two copper mines, the Fontana and Hazel Creek, were developed in the region. Both mines were closed when transportation facilities were flooded in 1944. In 18 years of operation, from May 1926 to February 1944, the Fontana mine produced more than 83 million pounds of copper. The Hazel Creek mine was worked for a short period about 1900 and was reopened in late 1942 and operated until November 1944; during this period 415,722 pounds of copper was produced. The ores from each mine contain several percent zinc in addition to copper. Some prospects have been dug to the northeast of these mines and also to the southwest in Graham County (fig. 2).

Until the construction of Fontana Dam, the southern boundary of the Great Smoky Mountain National Park was several miles north of the Little Tennessee River; the Fontana and Hazel Creek mines and much of the land shown on plate 1 were not then in the national park. Nearly all private land north of Fontana Reservoir was subsequently acquired by the Tennessee Valley Authority and transferred to the national park.

The first geologic mapping in the region was done by Keith (1895; 1907) during the U.S. Geological Survey's early studies in the southern Appalachians. The Swain County copper deposits were first investigated at about the same time by Laney (1907). The present study was begun in May and June 1943 by detailed geologic mapping of the Hazel Creek mine and vicinity as part of the Geological Survey's wartime program of copper investigations (Espenshade and others, 1943); geology of the district (pl. 1) was mapped in November and December 1943. The geology of most of the Great Smoky Mountains was mapped between 1946 and 1955 by the Geological Survey at the request of the National Park Service. This large recently mapped area lies west, north, and east of the area shown in plate 1, but the two areas do not directly adjoin. Brief preliminary accounts of the results of these extensive studies have been published (Hadley and others 1955; King and others, 1958). Detailed studies of mineral deposits and dam sites have been made in recent years by geologists of the Tennessee Valley Authority, the Tennessee Corp., and the Ducktown Chemical and Iron Co.; Kendall (1953) has described the Fontana copper mine.

Geologists associated with the writer in the Swain County field studies were T. W. Amsden, E. A. Brown, J. H. Eric, and M. H.

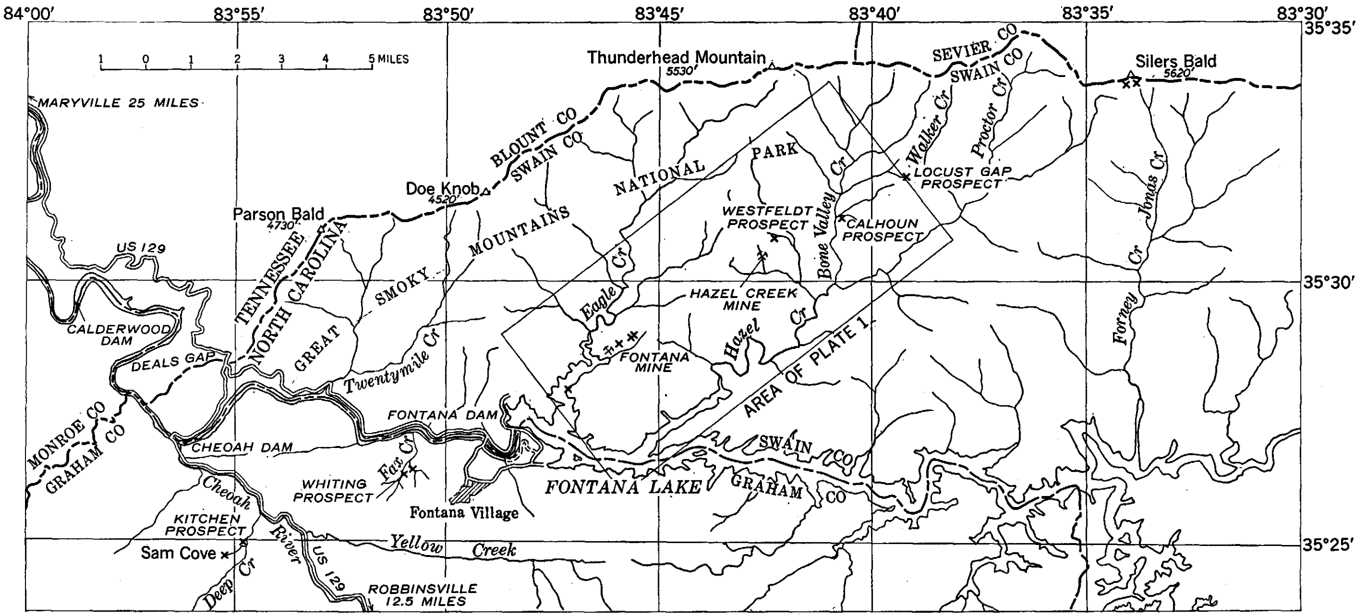

FIGURE 2.—Mines and prospects of Swain and Graham Counties, N.C.

Staatz. The investigation was aided greatly by the cordial cooperation of mine operators J. H. Gillis of the North Carolina Mining Co. (Hazel Creek mine) and James Alexander of the North Carolina Exploration Co. (Fontana mine). These companies have kindly permitted publication of production data and other records. H. F. Kendall of the Tennessee Corp. contributed geologic maps of the Fontana mine, surveyed by himself and W. H. Emmons, as well as production data and other information on the mine. Unpublished reports on the Fontana and Hazel Creek mines by geologists of the Tennessee Valley Authority were made available by that agency. G. I. Calhoun, formerly of Proctor, gave much information about the mines and prospects from his wide knowledge of the region.

GENERAL GEOLOGY

The Great Smoky Mountains, extending for nearly 60 miles along the boundary between southwestern North Carolina and southeastern Tennessee, form some of the most rugged and highest country in the southern Appalachians (U.S. Geological Survey, 1949). The mountain crest for many miles exceeds 5,000 feet in altitude, and 16 of the peaks are more than 6,000 feet above sea level; Clingmans Dome, 6,642 feet in altitude, is the highest.

Modern understanding of the geology of the Great Smoky Mountains is best summarized in the preliminary papers by Hadley, King, Neuman, and Goldsmith (1955), and King, Hadley, Neuman, and Hamilton (1958). The region is underlain by a great thickness (30,000 feet or more) of unfossiliferous terrigenous clastic sedimentary rocks that consist mainly of fine-grained argillaceous rock (slate, phyllite, and schist), siltstone, graywacke and other feldspathic sandstone, and conglomerate. Thin beds of limestone and dolomite are present locally, but there are no volcanic rocks. This sequence of rocks is called the Ocoee Series and is now regarded as late Precambrian in age. It rests unconformably upon earlier Precambrian granitic and gneissic rock on the south and east and is succeeded by the Chilhowee Group of Cambrian and Cambrian(?) age on the north and west.

The Ocoee Series is divided into broad units called the Snowbird Group, Great Smoky Group, a group of unclassified formations, and the Walden Creek Group (King and others, 1958). Contacts between groups are low-angle thrust faults at many places, and stratigraphic relations are not readily evident. In the eastern Great Smoky Mountains, however, the Snowbird Group lies unconformably upon gneisses and granitic rocks and is overlain by the Great Smoky Group. The groups are divided into formations that interfinger and grade into one another along the strike.

The Great Smoky Group is shown by King and others (1958, fig. 2) as making up the high central part of the Great Smokies and extending from the area mapped by them into the Swain County copper district. Formations of the Great Smoky Group are as follows:

Top. Unnamed higher strata	Coarse sandstone, similar to Thunderhead Sandstone.
Anakeesta Formation	Dark-gray or black silty and argillaceous rocks generally rich in carbon and sulfides; some interbedded feldspathic standstone present. Maximum thickness is about 4,500 ft.
Thunderhead Sandstone	A succession of graded layers, 5–25 feet thick, which range from light- to medium-gray fine conglomerate or coarse-grained sandstone at base, through medium- to fine-grained sandstone, to silty and argillaceous rocks at the top of each graded unit. Conglomerate and sandstone are composed mainly of quartz and potassic feldspar grains, and lesser amounts of plagioclase. Maximum thickness is about 10,000 ft.
Base. Elkmont Sandstone	Feldspathic sandstone, siltstone, and argillaceous beds in graded layers similar to the Thunderhead Sandstone, but fine grained and thinner bedded. Maximum thickness is about 9,000 ft.

P. B. King (written communication, 1960) concludes from the high content of quartz and feldspar and the prevalence of graded bedding in the Great Smoky Group that the sediments were derived from granitic terrain and were deposited in deep troughs by turbidity currents. In the Cohutta Mountain quadrangle of northern Georgia (about 65 miles southwest of the Swain County district) a sequence of graywacke, sandstone, siltstone, slate, and phyllite that has been correlated with the Great Smoky Group is also charcterized by graded bedding probably formed by turbidity currents (Mellen, 1956).

Low-angle southeastward-dipping thrust faults of large displacement toward the northwest, notably the Greenbrier fault and Great Smoky fault, are major structural features of the Great Smokies (Hadley and others, 1955; King and others, 1958). Paleozoic rocks are exposed in several windows in the Great Smoky fault, the northernmost and lowest thrust, about 10 miles north of the Swain County district. Folding and widespread foliation also resulted from the structural deformation (J. B. Hadley, and Richard Goldsmith, written communication, 1960; P. B. King, written communication, 1960). The rocks are regionally metamorphosed and became progressively higher in grade from the chlorite zone on the northwest to the kyanite zone on the southeast, a few miles north of Bryson, N.C. The

Greenbrier thrust is earlier than much of the regional metamorphism and has since been folded and faulted; the Great Smoky fault is younger than the regional metamorphism (King, written communication, 1960.) Deformation may have begun in Middle Ordovician time and may have been active as late as Mississippian time (Hadley and Goldsmith, written communication, 1960).

GEOLOGY OF SWAIN COUNTY COPPER DISTRICT

SEDIMENTARY ROCKS

The two principal types of rocks in the Swain County copper district are feldspathic sandstone and phyllite. Phyllite, with many thin beds of feldspathic sandstone (generally less than 30 feet in thickness), occurs in the central part of the district and is flanked on the northwest and southeast by massive feldspathic sandstone with some interbedded phyllite (pl. 1). The rocks have a strong foliation which commonly strikes northeast and dips southeast. In much of the area the bedding has a similar trend but has many local deviations owing to folding.

The phyllite in the central belt is principally blue gray to black in color and was probably derived mostly from graphitic shale. Silvery sericitic to green chloritic phyllite and schist, as well as some finely granular gray-green phyllite which is probably sheared siltstone, are also present in the central belt and elsewhere in the region. Garnet and small crystals of chloritoid oriented at angles to the foliation are widespread in the phyllite and seem to have grown after formation of the foliation. Pyrrhotite and other sulfides are disseminated abundantly through the graphitic phyllite and yield white efflorescences of iron sulfate and yellow stains on rock surfaces that are protected from rain.

The feldspathic sandstones are blue gray to gray where fresh and dull gray to green gray where weathered. In texture they range from fine-grained sandstone, through grit, to coarse conglomerate with pebbles several inches in diameter. Blue quartz and white feldspar grains and pebbles make up much of the sandstone and are accompanied by granite and black shale pebbles in the coarse conglomerates. Some sandstone beds are rather calcareous and weather readily owing to their carbonate and feldspar content. Ovoid limy concretions are present in the more massive beds. Pyrrhotite is disseminated in the sandstone in places, particularly near Eagle and Pinnacle Creeks. Heavy minerals in feldspathic sandstone of the Great Smoky Group in adjacent areas to the north consist mainly of zircon and ilmenite, with some tourmaline, magnetite, and apatite (Carroll, and others, 1957). Bedding in massive sandstone is generally very obscure but is commonly apparent as graded bedding in sandstone that is interbedded with phyllite. The sandstone contains small biotite flakes and garnet crystals of metamorphic origin. Grains and pebbles have been flattened along the foliation, and thin silky films of sericite have formed on the foliation planes. Some beds of coarse feldspathic sandstone in the central phyllite belt have been sheared so strongly that they approach augen gneiss in appearance.

Although these two lithologic units have not been traced into the areas mapped by King and by Hadley and Goldsmith, the feldspathic sandstone resembles the Thunderhead Sandstone, and the phyllite and schist are similar to the Anakeesta Formation. Keith (1895) originally mapped the phyllites and schists of the district as the Hazel slate, a term since abandoned; later Keith (1907) called these rocks the Nantahala Slate, which is of Precambrian(?) age, but this correlation seems dubious.

IGNEOUS ROCKS

Small bodies of diorite occur at several places along a zone trending northeast through the central part of the district (pl. 1). In addition to those shown on the map, C. E. Hunter (oral communication, 1943) a geologist formerly with the Tennessee Valley Authority, reported that a small diorite mass occurs just east of Pickens Gap and another lies near Haw Gap Branch, about a mile from its mouth.

The diorite is medium gray, coarse grained, and composed chiefly of hornblende and plagioclase with minor amounts of chlorite, zoisite, and leucoxene. Much of the diorite is massive, but parts of some of the diorite intrusions have been sheared and altered, as indicated by the complete destruction of the hornblende and by the presence of large quantities of carbonates that form a rock composed of plagioclase, chlorite, and abundant large grains of ankerite, with small amounts of zoisite and clear albite(?). Light-greenish-gray carbonate-chlorite schist, exposed for several hundred feet along the south bank of Eagle Creek about half a mile southwest of the Fontana mine, is made up of abundant ankerite grains and scattered flakes of muscovite [1] in a fine-grained groundmass of chlorite and quartz with accessory rutile. This carbonate-chlorite schist and similar carbonate-bearing schist occurring in small masses to the northeast lie along the extension of the zone of diorite bodies and may represent an extremely altered phase of the diorite in which the original hornblende and plagioclase have been completely destroyed and appreciable amounts of carbonates introduced.

Similar diorite crops out at intervals for a distance of about 35 miles northeast of the area shown in plate 1. Laney (1907) describes

[1] These two minerals were identified by C. S. Ross.

the diorite in the region and states that discontinuous dikes of diorite occur as far northeast as the copper prospect near Silers Bald (fig. 2). He points out that all the known copper deposits are within a few hundred feet south of diorite dikes and concludes that there was probably a genetic relation betwen the diorite dikes and the copper deposits. Diorite dikes and sills were found by Hadley and Goldsmith (written communication, 1960) at 10 localities along a zone trending northeast for nearly 25 miles from Clingmans Dome. The largest bodies are on the northern slope of Clingmans Dome, where three sills or lenses occur; one body can be traced for 2 miles and is as much as 350 feet thick. Hadley and Goldsmith (written communiaction, 1960) conclude that the diorite was intruded in the early orogenic stages in Paleozoic time before the peak of metamorphism occurred. The same conclusion seems to apply to the diorite intrusions in the Swain County copper district.

QUARTZ VEINS

Barren quartz veins, as much as 15 feet thick, occur here and there throughout the region; and small lenses, less than an inch thick, are abundant in deformed phyllite. Many diorite bodies have quartz veins on or near their borders. Quartz pods or lenses also are associated with the sulfide deposits. The barren quartz veins commonly are sheeted and fractured, whereas some of the quartz accompanying the sulfide deposits is glassy and unfractured. Some quartz veins carry small amounts of feldspar and carbonates. The carbonate-chlorite schist exposed on Eagle Creek has small lenses of quartz that contain well-formed rutile crystals about an inch long. Another occurrence of rutile in a small stream flowing into Bone Valley was pointed out by G. I. Calhoun (oral communication, 1943).

STRUCTURE

Throughout much of the Swain County copper district, particularly the eastern part, the bedding of sandstone and phyllite trends northeastward, as does the foliation. Many local folds exist, however, especially along Eagle Creek where the beds are considerably folded and dip to the north and west in most places (pl. 1). Overturned beds have been recognized at a few places by the relation of foliation to bedding (foliation dipping more gently than bedding), but there seems to be no large-scale overturning of beds because foliation most commonly dips more steeply than bedding. Fold axes plunge either northeastward or southwestward at angles generally less than 30°.

The rocks, especially phyllite, have well-defined foliation, which generally trends N. 50°–70° E. and dips 50°–75° SE. In a zone more than 2,000 feet wide extending from Eagle Creek northeast through

Pickens Gap (pl. 1) this foliation is undulating or much crumpled, and the phyllite carries many lenses of crushed quartz. The fact that the foliation is less deformed in the rocks lying southeast and northwest of this zone, except near the mouth of Lost Cove Creek, where both foliation and bedding strike north to northwest, suggests that considerable thrusting toward the northwest has taken place in the zone of shearing and deformed foliation.

In the phyllite along and west of the northeast-trending belt of deformed foliation, slip cleavage has commonly been imposed on the foliation. The strike of this later cleavage generally lies within 20° of the strike of the earlier foliation, but the dip is to the northwest at angles of 35°–75° in a plane nearly normal to the plane of the foliation. The cleavage planes are spaced about a quarter of an inch apart, and the foliation is dragged slightly between adjacent slip cleavage planes in a manner suggesting that thrusting toward the southeast has taken place along the later slip cleavage (shown diagrammatically in sections of pl. 1). Tiny nearly horizontal crinkles occur in the plane of foliation at the intersection with the slip cleavage. This type of slip cleavage is widespread in the phyllite of the shear zone and of the area to the west and also in the areas to the north and northeast mapped by Hadley and Goldsmith (written communication, 1960) and by King (written communication, 1960).

Tiny crinkles plunging down the plane of the foliation are common in phyllite throughout the district. Most of these linear features plunge 35°–60° and strike S. 10° E. to S. 15° W. (pl. 1). Biotite flakes and stretched quartz and shale pebbles in feldspathic sandstone are similarly oriented, as are the Fontana and Hazel Creek ore bodies. At a few places the cringles occur at the intersection of the foliation with later joint or cleavage planes that strike N. 10°–15° E. and dip 65°–75° SE. In the lower part of Eagle Creek the drag of the crinkles shows that there has been relative movement of the eastern block to the south; evidence of opposite movement is seen at a few places. A joint system which trends N. 10°–25° W. and dips 55°–80° NE. cuts the phyllite northwest of the Fontana mine. Movement along these joints has flexed the foliation planes adjacent to the joints in a way which indicates that the eastern block has moved to the north. Another joint system, which is most prominent in feldspathic sandstone, strikes N. 55°–70° W., about normal to the foliation, and dips 45°–65° NE.

The major structural features of the district are not altogether clear. A belt of phyllite with interbedded feldspathic sandstone in the central part of the district ranges in width from 10,000 feet or so southwest of Pickens Gap to about 3,000 feet northeast of Pickens Gap (pl. 1). Massive sandstone with interbedded phyllite flanks the central phyllite belt on either side. The eastern contact of the main phyllite belt is fairly regular, but owing to folding the contact with the western sandstone belt is very irregular over part of its course. The phyllite in the central belt is considerably deformed and sheared in a zone several thousand feet wide that extends from Eagle Creek at least as far northeast as the Hazel Creek mine (pl. 1). The strong folding northwest of this zone along the lower part of Eagle Creek has no counterpart southeast of the zone, and it is very likely that these two areas, differing markedly in degree of folding, are separated by a thrust fault. The ore deposits and the diorite bodies lie in the western part of the zone of deformed foliation. If this is a major zone of thrusting, its relations to the large faults mapped by King and others (1958) have not yet been determined. King (written communication, 1960) has traced a thrust fault, the Mingus fault not mentioned in the 1958 report) as far southwest as Buckeye Gap on the State-line divide, about 5 miles northeast on strike from the area of plate 1. Thunderhead Sandstone on the southeast has apparently been thrust along this fault over Anakeesta Formation on the northwest. Possibly the Mingus fault or a related fault may extend from Buckeye Gap into the zone of shearing in the copper district.

Because of the lack of fossils and marker beds, it was not possible to determine the age relations of the feldspathic sandstone on either side of the phyllite belt. Keith (1907) interprets the phyllite belt as being present in a syncline, and it is possible that the sandstone beds in the bordering belts are of equivalent age. If so, the sandstone beds are repeated by thrusting rather than recumbent folding, for no evidence was found of widespread overturning of beds, although some small-scale local overturning does exist. West of the zone of probable thrusting a syncline plunges northeast near the mouth of Lost Cove Creek; the axis of the fold may reverse its direction of plunge and emerge about three-quarters of a mile north of Pickens Gap. Such a structure would explain the pinching out of phyllite in the large amphitheaterlike valley at the head of Pinnacle Creek. The outcrops in this valley, however, are very poor and are too few to permit delineation of the structure. Pinching out of phyllite here and the decrease in width of the phyllite belt to the northeast of Pickens Gap might also be due to thrusting, to original differences in the thickness of the shaly beds (grading into feldspathic sandstone toward the northeast), or to both factors with or without folding.

Variations of outcrop width of sandstone and phyllite beds at other places in the region are also due to one or more of these factors—folding, thrusting, or original differences in thickness of the beds. The relative importance of each factor cannot be appraised, however, for the only place where the governing factor was recognized is near the mouth of Lost Cove Creek where the northeast-plunging syncline occurs.

METAMORPHISM

Sericite, chloritoid, biotite, and garnet have formed by regional metamorphism of the shale and sandstone beds. Original sedimentary characteristics of the sandstone are well preserved at many places, but shaly beds have been transformed to phyllite and very fine grained micaceous schist. Diorite has been metamorphosed to carbonate-chlorite schist at several places. The grade of metamorphism seems to be about the same throughout the region, and no mineral isograds were recognized during the course of mapping. About 10 to 15 miles east and northeast, however, Hadley and Goldsmith (written communication, 1960) have mapped the following isograds, progressing from northwest to southeast: chlorite, biotite, garnet, staurolite, and kyanite. Calcareous concretions and lenses in this area have been metamorphosed in the kyanite and staurolite zones to calcsilicate granofels, which is mostly quartz and plagioclase, with variable amounts of biotite, garnet, hornblende, and clinozoisite.

ORE DEPOSITS

MINERALOGY

The ores of the Fontana and Hazel Creek deposits contain the same minerals, but they are present in different proportions. The Fontana ores are composed of pyrrhotite, considerable chalcopyrite, and small amount of sphalerite; magnetite and galena are present, and possibly also pyrite (Short, *in* Ross, 1935, p. 92). According to Kendall (1953), the proportion of chalcopyrite and sphalerite increases and pyrrhotite decreases with depth; ore from the upper levels of the mine is characteristically massive sulfide, whereas ore from the lower levels is more schistose. Talc, chlorite, quartz, plagioclase, and ankerite are the dominant gangue minerals and are accompanied by lesser amounts of calcite, biotite, muscovite, barite, titanite, and zircon (Ross,, 1935, p. 92–94).

Chalcopyrite is the principal sulfide in the Hazel Creek ores and is accompanied by considerable dark-brown iron-bearing sphalerite and small amounts of cubanite and galena; copper and zinc are present in nearly equal proportions. Pyrrhotite is less abundant than in the Fontana ores and commonly is subordinate to chalcopyrite and sphalerite. The better-grade ore at the Hazel Creek deposit is rather massive and contains quartz, feldspar, chlorite, and carbonates with the sulfides. Stringers of chalcopyrite and sphalerite in chloritic phyllite make up the leaner ore.

Both deposits were capped at the surface by about 5 feet of heavy red to brown gossan overlying a zone of supergene copper minerals, several feet thick, in which chalcocite, native copper, cuprite, covellite, and probably supergene pyrite occurred ; malachite was present in the lower part of the gossan. The rugged topography and rapid erosion of the region have not favored the formation of thick zones of secondary copper minerals.

GRADE OF ORE

The average grade of all the ore shipped from the Fontana mine from 1931 to 1942 was 7.37 percent copper, 2.11 percent zinc, 0.0072 ounce gold per ton, and 0.385 ounce silver per ton (table 2). Massive hypogene ore at the Hazel Creek mine contains 3–3.5 percent copper, 3–3.5 percent zinc, and about 0.5 percent lead. Lower-grade ores, phyllite with sulfide stringers, contain 1–1.7 percent combined copper and zinc. Total shipments of enriched supergene ore contained 12.5 percent copper, 3.5 percent zinc, and 1.37 ounces silver per ton. Samples of gossan from the 2 mines contained 1.4–3.5 percent copper, 0.036–0.13 percent zinc, 0.01–1.0 percent lead, 0.004–0.014 percent cobalt, and less than 0.001–0.002 percent arsenic (table 1). Three samples of gossan from the Hazel Creek deposit had higher lead contents than any other southeastern gossan samples, although the average lead content of the Hazel Creek hypogene ore is only about 0.5 percent.

STRUCTURE

The structural forms of the two ore bodies are broadly similar, although the Hazel Creek deposit is considerably smaller than the Fontana, and each appears to be about conformable to the foliation of the wallrocks. Extensive mining has domonstrated that the Fontana deposit is a podlike body that is elongated along a trend deviating from the dip of the foliation of the country rock by about 15° S. (pl. 2). Development of the Hazel Creek ore body has progressed to shallow depth only, but it has shown that the deposit is made up of a series of overlapping lenses which seem to form an elongated body that also plunges in a direction deviating slightly from the dip of the foliation (pls. 3 and 4).

The Fontana and Hazel Creek deposits lie in a belt of sheared phyllite which trends about N. 55° to 60° E. (pl. 1) ; other mineralized localities have been prospected along the extensions of this belt to the northeast and southwest. Diorite and carbonate-chlorite schist also occur in this same zone, near the western border. This belt may be a thrust zone along which mineralizing solutions and diorite magma rose from depth.

Both the Fontana and the Hazel Creek ore bodies are pipes or elongated lenses whose longest dimension plunges steeply southward. The plunge of the ore bodies is virtually parallel to the plunge of tiny foliation crinkles which are widespread in the region. In places, these foliation crinkles are evidently the result of slight movement distributed along steep planes that cross the foliation planes in a northerly direction. Related or similar movement may have crumpled the foliation and bedding—and, in places, even brecciated the rock—on a much larger scale to form the steeply plunging podlike structures now occupied by the ore deposits. The ore deposits were probably formed in these podlike structures by replacement of the country rock and perhaps to a minor extent by the filling of openings.

The diorite bodies have a lenticular outline, and it is possible that they, too, are pods or elongated lenses occupying structures similar to those in which the ore deposits occur. Perhaps the mineralizing solutions and the diorite had a common origin from deep-lying magmas.

The existence of northward-trending cross structures is indicated by several types of structures near the Fontana deposit, but such structures are not readily apparent near the Hazel Creek mine. Northwest of the Fontana mine the main contact between feldspathic sandstone and phyllite along Eagle Creek trends N. 20° E. from 0.4 mile below the mouth of Lost Cove Creek to about 0.4 mile above, where a narrow tongue of the phyllite is folded northwestward into the sandstone (pl. 1). In this phyllite tongue, the strike and dip of both foliation and bedding trend north to northwest. In the area between here and the Fontana deposit, about a mile S. 20° E., joints striking N. 10°–25° W. and dipping 55°–80° NE. are common and flex the foliation in a manner indicating that the eastern block has moved to the north. Despite the presence of these north-trending structures to the northwest of the Fontana deposit, no displacement was detected in an apparently continuous sandstone bed in a ravine a quarter of a mile northwest of the mine. Although no north-trending structures are exposed at the surface in the immediate vicinity of the Fontana deposit, the foliation of the wallrock of the ore body trends northward at several places in the mine, particularly near the southwest and northeast edges of the deposit (pl. 2).

No strong structural irregularities were observed to the north or northwest of the Hazel Creek mine. Within a few hundred feet of the deposit, the only sign of structural disturbance visible on the surface is the curving of the strike of the foliation toward the northeast from the west side of the valley to the east; this feature was found by means of detailed plane-table mapping and doubtless would not have been recognized with the less-detailed methods of mapping used elsewhere in the region.

GUIDES FOR EXPLORATION

The Fontana and Hazel Creek deposits were discovered because of their exposure of gossan, but if either deposit had been completely covered by a mantle of talus or alluvium only a few feet thick, there would have been nothing to suggest the existence of an ore deposit, unless water carrying iron or copper had formed seeps. No other unexplored gossan masses are known in the region, and if any undiscovered ore deposits extend to the surface they are presumably mantled by soil or talus. Along the mineralized belt many places are covered by soil or talus—in nearly every valley—beneath which a concealed ore deposit might lie. Are there any geologic features of the country rocks which might suggest the presence of concealed ore bodies? Two features whose origin may be related to the origin of the ore deposits are certain structural anomalies and the diorite masses, which seem to have a structural form similar to that of the ore bodies. The area near the mouth of Lost Cove Creek where the small tongue of phyllite in feldspathic sandstone trends to the northwest, as do the foliation and bedding, may reflect the structure which caused the localization of the Fontana deposit a mile to the southeast. The contact between phyllite and feldspathic sandstone is folded for some distance along Eagle Creek; if such distant structures are related in some manner to the ore-body structures, the area along the mineralized belt for a mile or more northeast and southwest of the Fontana mine might contain other ore bodies (pl. 1).

The diorite bodies, the other geolic feature which may be structurally related to the ore deposits, are more widespread in the region than are the areas of anomalous structure. Diorite occurs a few hundred feet northwest of the Hazel Creek ore body; carbonate-chlorite schist, which is possibly highly altered diorite, lies several hundred yards northwest of the Fontana deposit, and a large body of diorite occurs about half a mile to the northeast. Diorite is also present a few hundred feet northwest of the Calhoun prospect. Possibly the areas lying within several hundred yards of the other diorite bodies, particularly to the southeast of them, are worthy of careful exploration, as Laney (1907) suggests. Laney also points out that the presence of numerous quartz veins and iron sulfides in the phyllite near the head of Bone Valley Creek (north of the part of the creek shown in pl. 1) may indicate copper mineralization.

Prospecting in structurally disturbed areas and near diorite bodies could probably be done best by geophysical and by geochemical methods. Two dozen samples of water from streams in the vicinity of the Hazel Creek and Fontana mines and intervening area were taken by the writer and L. C. Huff in 1945. Copper concentrations of 0.1 ppm or greater were found only in the streams draining the two mines and their dumps; concentrations of 0.02–0.04 ppm copper were found in six samples from other streams. Time did not permit a complete sampling program of all streams in the region. Since 1945 other methods of geochemical prospecting, utilizing samples of soil and stream alluvium, have been developed which might be useful in this region. Nearly all the land is now within the Great Smoky Mountains National Park where prospecting and mining are not permitted.

FONTANA MINE

HISTORY AND PRODUCTION

The outcrop of the Fontana ore deposit was reportedly discovered years ago during lumbering operations in the Eagle Creek area. The ore body was prospected near the surface by the Montvale Lumber Co. and about 2,000 tons of ore was shipped prior to May 1926. The property was acquired by the Fontana Mining Corp., affiliated with the Ducktown Chemical and Iron Co., in May 1926. This company began mining immediately and operated until February 1, 1931, when ownership passed to the North Carolina Exploration Co., subsidiary of the Tennessee Corp. The high copper content of the ores permitted continuous operation of the mine throughout the depression period of the thirties. Mining activities ceased in February 1944, and all equipment was removed. The water level of the Fontana reservoir (1,710 feet) lies about 100 feet vertically below level 1, and the mine is no longer accessible by road or railroad.

The Fontana deposit was opened near the surface by several adits and by an inclined shaft in the ore body from which 18 levels were driven at vertical intervals of 31–155 feet (pl. 2). A winze was sunk from level 18 to level 20 at an elevation of 213 feet, the deepest level in the mine. The block of ground developed and explored has a vertical depth of more than 1,700 feet and a length along the plunge of the ore body of more than 2,500 feet. Both overhand and underhand stoping were practiced down to the 14th level. The ore pillars that were left were largely removed and replaced by timber cribbing or fill. Horizontal cut-and-fill methods were used below the 14th level. During the last few years of operation, water was permitted to flood the lower levels, and after 1942 all mining was done above level 11.

The geology of the ore body was mapped by H. F. Kendall and W. H. Emmons for the Tennessee Corp. (See pl. 2.) In 1942 the mine was examined for the Tennessee Valley Authority by W. H. Emmons, assisted by R. A. Laurence and R. M. Ross, members of the geological staff of the Tennessee Valley Authority; Emmon's unpublished report contains pertinent information on the geology of the deposit. The geology in the main adit (level 1) was mapped in 1943 by G. H. Espenshade, T. W. Amsden, J. H. Eric, and M. H. Staatz of the Geological Survey.

All the ore from the Fontana mine was shipped directly to the smelters of the Ducktown district, about 75 miles distant by rail, and no attempt was made to concentrate the ore at the mine. The average grade of the ore shipped during the life of the mine was more than 7 percent copper. The production data of the mine are given in table 2. The ore shipped contained more than 83 million pounds of copper; more than half of this was produced during the first 6 years of operation.

TABLE 2.—*Production of the Fontana mine*

[Data furnished by the Tennessee Corp. Average grade of ore, 1931–42: 7.37 percent Cu, 20.9 percent S, 28.8 percent Fe, 2.11 percent Zn, 0.0072 oz gold per ton, 0.385 oz silver per ton, 2.86 percent moisture. Neither zinc nor iron was recovered from the ore]

Year	Ore	Copper	
	(Dry short tons)	(Percent)	(Pounds)
1926 [1]	2, 128		
1926 [2]	13, 372		
1927	39, 481	6. 90	5, 448, 378
1928	72, 557	7. 33	10, 636, 856
1929	71, 132	7. 21	10, 257, 234
1930	90, 259	8. 22	14, 838, 580
1931 [3]	8, 920	8. 84	1, 577, 056
1931 [4]	34, 082	8. 02	5, 466, 752
1932	19, 726	9. 13	3, 601, 968
1933	22, 050	8. 77	3, 867, 570
1934	26, 406	7. 91	4, 177, 430
1935	22, 750	7. 39	3, 362, 450
1936	19, 148	6. 80	2, 604, 128
1937	22, 015	6. 64	2, 923, 592
1938	17, 485	6. 90	2, 412, 930
1939	15, 310	6. 30	1, 928, 906
1940	20, 311	6. 56	2, 664, 804
1941	19, 402	7. 08	2, 747, 324
1942	20, 229	6. 01	2, 431, 526
1943	23, 067	4. 69	2, 163, 684
1944	3, 675	5. 52	405, 720
Total	583, 505		83, 516, 888

[1] January to May.
[2] June to December.
[3] January.
[4] February to December.

ORE BODY

The outcrop of the Fontana ore body lies near the bottom of a small gully, but most of the gossan capping of the deposit was formerly mantled by alluvium or talus. The outcrop of the Fontana ore body does not seem to have been as conspicuous as the outcrop of the Hazel Creek deposit, which was exposed on a hillside.

The Fontana deposit is a single elongated lens which strikes in general about N. 60° E. and plunges about S. 15° E. at an angle of nearly 45°. Its shape can best be described as podlike. The lens was developed for about 450 feet along the strike on several levels and was traced for more than 2,500 feet down the plunge. The deposit pinches and swells, ranging in thickness from a few feet to about 20 feet. On level 1 the lens averages about 10 feet thick. Mining revealed that the character of the ore and the shape and dimensions of the ore body are remarkably uniform at least as deep as level 17. The mine map (pl. 2) suggests that the ore body may be more irregular below level 17.

In general, the deposit follows the foliation of the wallrocks, the strike of which deviates locally from the regional trend of N. 60° E. On level 1 the ore lens and the foliation strike about east at several places, and stringers of ore with the same trend pass into the hanging wall, which here is predominantly sheared biotitic feldspathic sandstone. A bed of similar sandstone, about 10 feet thick, exposed on the surface just above the ore body, shows little shearing. On level 1 fissile sericite-chlorite phyllite with some feldspathic sandstone forms the footwall rock. Bedding was observed to be nearly parallel to foliation at a few places on level 1. Small folds in the bedding plunge southwest at low angles on this level. On the underying levels the bedding observed by Kendall and Emmons (see pl. 2) was generally parallel to the ore deposit. Striae or crinkles on foliation in phyllite plunge 30°–50° S. on level 1, as they do elsewhere in the region. The axes of small folds mapped by Kendall and Emmons also have a similar plunge, about parallel to the plunge of the ore body (pl. 2).

The deposit is cut at different places by postmineralization faults, whose trends commonly lie within 20° of east; calcite and quartz occur along some faults (Kendall, 1953). The amount of displacement of these faults is generally only a few feet. A fault trending from N. 77° E. to due east and dipping steeply southward cuts the ore body on levels 12, 13, and 14 (pl. 2). Quartz lenses, several feet thick, are associated with the ore in places.

Platy fragments of phyllite occur in abundance in parts of the ore body and impart to the ore the appearance of breccia. The fact that the ore minerals, however, are massive and little fractured may indicate that the brecciation of the country rock took place before mineralization occurred or that the ore minerals may be due to recrystallization of sulfides after brecciation of the ore occurred. Phyllite exposed on the surface near the portal of level 1 is extremely contorted for 50 feet northwest of the ore body, although a bed of feldspathic sandstone cropping out on the hillside just above the ore body shows no obvious signs of deformation. The shape of the deposit and the abundance of contained phyllite fragments suggest that the ore body is in a pipelike zone of deformation, perhaps a gigantic crumple in the foliation, similar to the many tiny crinkles in the foliation that occur throughout the region. Such a pipelike structure may have been formed by structures cutting across the foliation in a northerly direction. Northerly trend of the foliation or seams of ore have been observed near the southwest edge of the ore body on levels 1, 4, and 5 and at the northeast edge on levels 1, 18, 19, and 20 (pl. 2).

HAZEL CREEK MINE

HISTORY AND PRODUCTION

The Hazel Creek mine, also known as the Everett or Adams mine, lies in a small tributary valley of Sugar Fork, about 6 miles from the former settlement of Proctor (pl. 1). The mine was first opened about 1900, when the deposit was prospected by means of trenches, opencuts, and short adits. The property became involved in litigation after a few years, and operations ceased until 1929, when the mine was optioned to the Ducktown Chemical and Iron Co. During 1929 and 1930, the deposit was explored by means of diamond drilling under the supervision of J. A. Church, Jr. The option was subsequently relinquished. In December 1942, the North Carolina Mining Co., owner of the property at that time, reopened the mine with the aid of a loan from the Reconstruction Finance Corp. The mine was operated under the management of J. H. Gillis of Sylva, N.C., until November 1944, when the property was acquired by the Tennessee Valley Authority and the mine closed.

The ore body crops out on the east side of the valley and has been explored and developed through a vertical range of about 180 feet above stream level by adits (four of them, at levels 2, 3, 4, and 6, are in ore), various trenches and opencuts, and many shallow drill holes (pls. 3 and 4). Below level 2 (alt 2,772 ft), the deposit has been explored by a winze to an altitude of 2,734 feet and by drill holes only to an altitude of 2,700 feet. Nearly all the workings, except a few drifts and stopes, were opened about 1900 during the first period of activity at the mine. Thirty-six drill holes, totaling about 2,900 feet in depth, were drilled by the Ducktown Chemical and

Iron Co. during its exploratory program. The following work was done by the North Carolina Mining Co.: Drifting on levels 2, 3, and 4 to open up ore revealed by drilling; a short drift driven from the bottom of the winze below level 2; mining of the secondary ore above level 3; and mining of some of the primary ore between levels 2 and 4.

All the ore shipped in 1943 went directly to the smelters. A small concentrating mill with a jaw crusher, ball mill, rake classifier, and four flotation cells was erected in early 1944. The ore and concentrates were trucked to the Southern Railway at Ritter on the mouth of Hazel Creek, about 12 miles from the mine. G. H. Espenshade, M. H. Staatz, and E. A. Brown mapped the surface and underground geology of the mine and logged the cores of Church's drill holes during May and June 1943 (Espenshade and others, 1943). The Bureau of Mines sampled the mine in June 1943 and conducted milling tests on the ore.

There is no record of ore shipments from the mine prior to 1943, but if any shipments were made, they probably did not exceed 1,000 tons of ore. The copper content of the ore and concentrates shipped by the North Carolina Mining Co. in 1943 and 1944 amounted to 415,722 pounds (J. H. Gillis, written communication, 1945). The ore shipped direct to the smelters in 1943 amounted to 1,278 tons and contained 248,616 pounds of copper. Most of this ore was enriched supergene ore; although it contained several percent zinc, no payment was made for the zinc. From April to November 7, 1944, the mill treated 2,615 tons of ore to yield 406.5 tons of concentrates, which contained 167,106 pounds of copper. No recovery of zinc was made in the concentrator until shortly before the mine closed, when about 150 tons of zinc concentrate were made by floating the copper tailings from two flotation cells. Because of the scarcity of trucks, however, the zinc concentrates were not shipped; instead, they were retreated for copper, and the zinc was permitted to go into the tailings.

ORE BODY

Sericitic and chloritic phyllite with interbedded fine-grained bluish feldspathic sandstone are the prevailing rock types in the valley near the Hazel Creek mine (pl. 3). Several beds of white to gray massive sandstone with thin phyllitic beds occur near the ore body, the most persistent sandstone bed lying about 100 feet south of and 70–80 feet stratigraphically above the ore body. Outcrops of the phyllite and interbedded sandstone are scarce except in roadcuts, although float rock is rather common. The massive sandstone beds are generally well exposed in prominent ledges.

The phyllite and sandstone are schistose, and their foliation commonly dips more steeply than the bedding. Nearly all exposures show foliation, but bedding is recognizable in only a few outcrops. On the west slope of the valley the foliation strikes generally between N. 70° E. and due east; on the east slope of the valley, chiefly between N. 40° E. and N. 60° E. This slight curving of the strike of the foliation indicates a gentle anticlinal warp. The ore body appears to lie approximately along the axis of this anticline. To the south of the ore body, the dip of the foliation ranges 50°–65° SE. and is somewhat flatter than to the north.

Several hundred feet to the north of the ore deposit, diorite crops out on the east slope of the valley. The diorite seems to have an irregular lenticular shape, and its lies near the axis of the anticlinal warp. The diorite is massive and unsheared, except at a few places. Some vein quartz occurs near the border of the diorite mass.

The outcrop of the Hazel Creek copper deposit on the steep east side of the valley was marked by red soil and rather porous gossan of brick-red to dark-brown limonite. The deposit is made up of a group of curving, lenticular veins that overlap one another to form a pipe-like ore body which appears to plunge S. 5°–10° W. at angles of 25°–35° (pls. 3 and 4). The lenses trend northeastward in an irregular contorted fashion, and few of them are more than 100 feet in strike length. They rarely are more than 6 feet thick and average about 3 feet in thickness. Present development suggests that the lenses overlap one another in such a way that new lenses appear in the hanging wall down the plunge of the ore body, whereas lenses in the foot wall die out. Individual lenses seem to plunge 35°–50° S. and have plunge lengths of 60–200 feet (pl. 4). Between the lenses the phyllite in many places contains enough sulfide stringers to form low-grade ore, although not all this ground is mineralized. The phyllite is very chloritic, and it and the feldspathic sandstone commonly carry abundant biotite. Lenticular veins and irregular masses of quartz accompany the sulfide veins at many places, and small pegmatitic aggregates of pale-green feldspar, carbonate, and quartz are not uncommon with the sulfides.

The lenticular veins are generally parallel to foliation and follow the contortions of both foliation and bedding. In the upper levels phyllite forms the dominant wallrock, but on level 2 the hanging-wall lens of the deposit lies between two beds of feldspathic sandstone over part of its length. Drag folds in the bedding plunge south to southwest at angles commonly less than 30°. Small crinkles in the foliation generally plunge S. 10° W. to S. 10° E. at an angle of about 30°, almost the same as the apparent plunge of the ore body.

The northeast edge of the ore body seems to be fairly regular, and a vertical plane striking about S. 5°–10° W. could be passed near the northeast ends of the lenses on levels 2, 3, and 4. This trend is similar to the plunge of the ore body. The southwestern part of the ore body has been eroded away above level 2. The portal of level 2 is probably near the southwest edge of the deposit. No ore was found in level 1 along the strike to the southwest (pl. 3).

The levels were not connected by workings when the vertical sections shown in plate 4 were compiled in 1943, and some generalization and interpretation were necessary to show the different lenses of ore and to correlate them. Individual lenses seemingly dipped more steeply than the ore body as a whole. Considerable ground between levels 2 and 4 was opened by stopes and raises after the mine was mapped (approximate outlines of the new workings are shown in pl. 4), but it was not possible to study these new workings and revise the interpretations shown in the sections. However, J. H. Gillis, manager of the mine, has made the following observations in these new workings (written communication, 1945). Referring to the ore shoot exposed in the stope and raise between levels 2 and 3 (pl. 4, section *C–C′*) Mr. Gillis says:

> The ore shoot was very irregular and was more in the nature of lenses connected with narrow streaks of mineralized material. There was no continuation of the lenses either horizontally or along the slope, but there was a definite area in which mineralization was good although badly mixed up. The general trend of the high grade ore was correct [as shown in section *C–C′*] but much more broken up than shown.

Overlapping and splitting lenses were exposed in the new workings between levels 3 and 4, somewhat as shown in section *D–D′* (pl. 4). Gillis makes the following statement, presumably referring to conditions in general between levels 2 and 4:

> It was very hard for me to follow any continuous ore shoot as in every shot the picture seemed to be different. Certainly in one shot we would have some very rich ore and [in] the next one in the direction of the trend there would be none of it or a much narrower streak and then in the next one it would be back again.

Mr. Gillis' observations show that the actual relations of the different ore lenses are much more complex than depicted in the vertical sections shown in plate 4. Probably most of the larger individual lenses are connected with one another by a network of smaller stringers.

The thickest part of the ore body, as exposed in level 2, seems to be at the crest of an anticline (pl. 3). Here veins and mineralized phyllite occur in a zone about 100 feet wide, measured horizontally at right angles to the strike, which is equivalent to a true thickness of 40–50 feet in a plane normal to the plunge of the ore body. Along the strike to the northeast and southwest of this flexure on level 2 the lenses are thinner, and the sulfide stringers in phyllite are fewer. An anticlinal structure of the foliation and the ore body is exposed in the open cut near the portals of level 3. If this fold is the same as the one on the level below, then its axial plane is steep and would dip between the vertical and 80° E.

Many of the feldspathic sandstone beds have been sliced into lenses, and some can be traced in the mine for only a few feet. In several places, as in the winze below level 2, the structure of the rocks in the hanging wall of a lens is discordant with the structure in the footwall. These features and the crumpled nature of the foliation and bedding indicate that the ore body occupies a zone of considerable disturbance. The ore body seems to be pipe shaped and to be about along the axis of anticlinal warping of the foliation.

RESERVES

Exploration of the Hazel Creek ore deposit indicated that about 17,000 short tons of high-grade hypogene ore and 32,000 short tons of low-grade ore were present above the 2,700-foot altitude prior to active mining in 1943 (Espenshade and others, 1943). About 3,000 short tons of this high-grade ore has since been minded. Development on the lowest level in the ore body (level 2) indicated the presence of about 100 tons of high-grade ore (containing 3–3.5 percent copper and 3–3.5 percent zinc) and 300 tons of low-grade ore (containing 1–1.7 percent combined copper and zinc) for each vertical foot of depth.

OTHER DEPOSITS

About 1¼ miles southwest of the Fontana mine, a quartz vein, 6 feet wide, was opened in a shallow pit near the high-water mark of the reservoir (pl. 1). The quartz is rather glassy and is coated with red limonitic stains. Pyrrhotite stringers, as much as an inch thick, with traces of chalcopyrite and considerable pale green feldspar occur in the quartz vein. At several places along the old road near here, pyrrhotite and pyrite are disseminated in sheared feldspathic sandstone and phyllite.

About half a dozen shallow prospect pits and some trenches were sunk in or near the feldspathic sandstone bed that extends three-quarters of a mile northeast of the Fontana mine. In a gully, a quarter of a mile northeast of the mine, an adit 15 feet long has been driven in sandstone and phyllite (pl. 1). Chalcopyrite, with covellite and chalcocite coatings, is disseminated in sandstone, and a few malachite stains and a small amount of limonite are present. Sulfides occur at other prespects nearby, but no chalcopyrite was seen elsewhere.

John Proctor (oral communication, 1943), who lived at the head of Ecoah Branch valley, reports that a large rock containing copper minerals was found some years ago near the north end of the sandstone bed (about 0.9 mile northeast of the Fontana mine), but no evidence of copper minerals was seen here in 1943.

The Westfeldt prospect, lying about half a mile N. 48° E. of the Hazel Creek mine, was opened about 1900 (pl. 1) by the people then engaged in exploring the Hazel Creek deposit. Five adits and two shafts were dug at intervals in a distance of about 600 feet on the south side of a small stream flowing eastward into Haw Gap Branch. G. I. Calhoun of Proctor (oral communication, 1943) who assisted in the prospecting, reports that the main shaft extended for 110 feet down a 45° slope and at the bottom had a drift 20 feet long; this shaft is now filled with water. About 300 tons of material lie on the main dump. Alternate beds of graphitic phyllite, siltstone, and fine-grained sandstone are exposed along a hillside and in the adits. Foliation strikes N. 70° E. and dips 45° SE., about parallel to bedding. Chalcopyrite and pyrrhotite, generally disseminated very sparsely in fine-grained sandstone, are distributed in a zone parallel to foliation. The sandstone at the collar of the mine shaft bears some dark, rusty-brown stains; a few pieces of gossan were found along the small stream southwest of the shaft. Scattered pieces of ore carrying as much as 30–40 percent sulfides can be found on the dump from the main shaft, but the sulfide content generally is very low. A composite sample, taken by the writer from all parts of the dump, assayed 0.19 percent copper and 0.11 percent zinc; a sample of the richest-looking ore assayed 0.56 percent copper and 0.20 percent zinc (The Bruce William Laboratories, Joplin, Mo., analyst).

G. I. Calhoun prospected about 1½ miles up Bone Valley along the east side of the valley (pl. 1). According to Mr. Calhoun (oral communication, 1943), openings were made at a point of strong magnetic anomaly discovered by a dip-needle survey of the Ducktown Chemical and Iron Co.; no evidence of mineralization was originally visible at the surface. At one place a zone 3–4 feet wide of tough mica schist and sheared siltstone carrying disseminations and stringers of practically fresh chalcopyrite was disclosed. Irregular veinlets of quartz and ankerite, accompanied by amphibole in spray-like crystals, were exposed over a width of 15 feet. The mineralized rock does not seem to be magnetic and the cause of the magnetic anomaly is not known. The zone was opened for 20 feet along its strike, but trenching to the northeast and southwest failed to reveal any further continuation. The foliation strikes N. 35°–50° E. and dips 60°–70° SE. A channel sample 3.2 feet long, 4 inches wide, and 1½ inches deep taken by M. H. Staatz across the full width of the chalcopyrite-rich part assayed 2.66 percent copper and 0.47 percent zinc (The Bruce Williams Laboratory, Joplin, Mo., analyst).

Near Locust Gap, about 1½ miles N. 50° E. of the Calhoun prospect, G. I. Calhoun (oral communication, 1943) reports having found some chalcopyrite and native copper in a shallow pit many years ago (fig. 2). No gossan or signs of copper were found there in 1943, although sandstone with disseminated pyrite was observed.

Some prospecting was done at Silers Bald (fig. 2) on the crest of the Smokies by Mr. Calhoun and others about 1905. A shallow pit in a sandstone outcrop along the trail at the southeast end of a meadow disclosed small quartz veins, as much as 3 inches wide, and tiny stringers and disseminations of galena and chalcopyrite. On the headwaters of Jonas Creek to the northeast, about 500 feet vertically below the summit, a shallow opencut and two tunnels were dug to prospect a similar mineralized zone in sandstone. Disseminations and stringers of chalcopyrite and galena occur with narrow quartz veins in sheared feldspathic sandstone.

At the Whiting prospect, on Fax Creek one mile south of the Little Tennessee River, in Graham County, some shallow pits were sunk about 1939 by D. B. Burns of Asheville, N.C., at two sites several hundred yards apart along an abandoned lumber railroad (fig. 2). Massive sandstone, which strikes N. 30°–50° E. and dips 45° SE., carries disseminated pyrrhotite and porous fine-grained pyrite. No copper sulfides or stains were observed.

Four miles southwest of the Whiting prospect is the Kitchen prospect in Sam Cove, about 1 mile up Deep Creek from the Cheoah River (fig. 2). A short adit and a shallow shaft have been dug along the road near the mouth of Sam Cove, and another pit has been dug about 1,000 feet up the cove. Sandstone with disseminated pyrite and traces of chalcopyrite was found.

FLOYD AND FRANKLIN COUNTIES, VIRGINIA

TONCRAE MINE

HISTORY AND PRODUCTION

The Toncrae (also Toncray or Toncrey) copper deposit is in the Blue Ridge province of southwestern Virginia, about 7 miles southwest of the village of Floyd and several miles west of the eastern front of the Blue Ridge. Iron ore was mined from the gossan of the Toncrae deposit and smelted nearby at the Shelor furnace for about 60 years, probably until about 1850 (Currey, 1880). The supergene copper zone at the base of the gossan was explored by means of a tunnel, about 300 feet long, in 1854, when there was much mining activity in the supergene copper ores in the nearby Gossan Lead district and also in the Ducktown district, Tennessee. Thirty-two tons of ore was shipped at this time, and a second tunnel, 245 feet long, was driven at an elevation 70 feet below the upper tunnel. Mining stopped about 1855 and was not resumed until 1905, when the New York and Virginia Copper Co. began to develop the hypogene sulfide ores (Grosh, 1948b). A shaft was sunk to 160 feet, a Herreshoff matte furnace was built and operated for about 2 months, and about 2,500 tons of cupriferous pyrrhotite ore was mined before operations ceased in 1908.

C. H. Thompson of Hollins, Va., began exploration of the supergene copper ores here in 1935 and continued operations intermittently until 1947. This work represents the most extensive mining operation in supergene copper ores of the southeastern pyrrhotite deposits that has been undertaken during the present century. The supergene copper zone at the north end of the Toncrae deposit was thoroughly developed for about 350 feet by underground workings (pl. 5), and attempts were made to heaproast and then leach the supergeue ore and finally to precipitate copper from the leach waters by using scrap iron. In 1943 the U.S. Bureau of Mines explored for supergene copper ores by means of shallow diamond-drill holes for about 1,200 feet south of the mine workings (Grosh, 1948b). The geologic features shown on the map and drill-hole sections (pl. 5) were recorded at this time by M. H. Staatz and R. J. Wright of the Geological Survey.

Production of supergene copper ore from the Toncrae mine during the period 1938–47 is as follows:

1938—146 tons of ore, averaging 14.5 percent copper, was shipped to a custom smelter (Grosh, 1948b).

1944— 1,926 tons of ore, averaging about 7 percent copper, was shipped to a smelter, and 2,100 tons of lower grade ore was mined and stockpiled for leaching treatment (U.S. Bureau Mines, 1944, p. 337).

1945—An unspecified amount of ore, averaging 6.16 percent copper and 0.38 ounce of silver per ton, was shipped to the U.S. Metals Refining Co.; this yielded nearly all the 70 tons of copper that was produced in Virginia during the year (U.S. Bureau Mines, 1945, p. 345, 354).

1947—A small quantity of copper was produced from the leaching plant (U.S. Bureau Mines, 1947, p. 1391).

The hypogene ore zone of the Toncrae deposit has also been explored considerably in recent years, first in 1938–39 by the American Metal Co. by means of four diamond-drill holes (Grosh, 1948b). During 1954–55, Appalachian Sulphides, Inc., carried out electromagnetic surveys and soil geochemical prospecting and then drilled 11 diamond-drill holes that had a total depth of more than 5,000 feet (Dietrich, 1959, p. 129).

GEOLOGY

The dominant rock type exposed and penetrated by drilling in the vicinity of the Toncrae mine is light-gray fine-grained garnet-biotite-muscovite-quartz gneiss; fine-grained hornblende gneiss occurs locally (pl. 5). Foliation strikes N. 15°–25° E. and dips 35°–50° E. Alinement of biotite flakes in the foliation planes forms a lineation that plunges 30° NE. in one exposure (pl. 5); similar lineations are nearly horizontal in outcrops near the mapped area. It was not possible to outline the areas of biotite gneiss and hornblende gneiss or to determine local structural conditions because of the scarcity of outcrops and drilling data.

Dietrich (1959) finds in his recent geologic study of Floyd County that the dominant rocks in much of the region are gneisses, schists, phyllites, and amphibole-bearing rocks; light-gray medium- to coarse-grained muscovite-biotite-quartz schist and gneiss, containing feldspar or garnet locally, are common. Dietrich (1959, p. 69–74) groups these rocks together as the "Lynchburg" Formation of Precambrian age and points out that they seem to be lithologically equivalent to the rocks mapped by Stose and Stose (1957) as Lynchburg Gneiss, about 15 miles southwest in the Gossan Lead district, but may not be correlative with Lynchburg Gneiss of the type locality, about 50 miles northeast.

ORE BODY

MINERALOGY

Pyrrhotite is the most abundant metallic mineral in the hypogene ores. Magnetite is common and in places is nearly as abundant as pyrrhotite. Several percent of both chalcopyrite and pyrite are present; pyrite occurs as large crystals as much as an inch on the side. Minor amounts of reddish-brown sphalerite accompany the other metallic minerals.

Examination of hand specimens indicates that the principal gangue minerals are biotite, carbonates, amphiboles, feldspar, garnet, and chlorite. Biotite and chlorite are common throughout the ore; two varieties of chlorite are present, light green and dark green. Amphiboles are locally abundant in large crystals. Carbonates make up the most common gangue minerals in places. The wallrock of the deposit is much coarser grained than the typical country rock and contains considerable biotite, carbonates, and, locally, amphiboles, as well as disseminated pyrrhotite and chalcopyrite.

The ore of the supergene copper zone, called smut ore by the local miners because it stains anything that comes in contact with it, is an uncompacted sandy aggregate of dark-gray to black minerals and is soft enough to be easily dug out by pick and shovel. Although the ore has not been examined microscopically, the principal constituent seems to be pyrite, occurring as small lusterless grains of supergene origin. Large shiny crystals of pyrite, residual from the hypogene ore, are locally present with the supergene pyrite. Chalcocite and covellite presumably are the principal supergene copper minerals. Biotite, amphiboles, and other gangue minerals commonly occur as relicts from the original ore.

The overlying gossan is composed mostly of red to brown porous limonite, which ranges from cindery iron hydroxide to a schistose intergrowth of limonite and silicates. Appreciable copper is present in the gossan. Malachite is rather abundant in the lower part of the gossan, but it is likely that other unidentified copper minerals such as cuprite are also present.

The fact that the supergene pyrite oxidizes readily upon exposure to air and water has resulted in the formation of weak sulfuric acid which leaches some of the copper from the ore. Evidence of this rapid oxidation was displayed clearly in the mine workings in several ways. Encrustations of soluble copper and iron sulfates formed on the walls of the mine within a few months after the ore was opened. The mine water was acid and contained significant amounts of copper, as much as 75 ppm in one sample (L. C. Huff, oral communication, 1945). In poorly ventilated parts of the mine a bothersome gas, probably sulfur dioxide, was noticeable, and high temperatures were common. According to C. H. Thompson (oral communication, 1945), a thermometer placed in one exceedingly hot place in the mine recorded a temperature of 140°F and then broke.

GRADE OF ORE

The drill-hole samples indicate that the best hypogene sulfide ore contains 1–2 percent copper, and lower grade ore contains less than 1 percent copper (pl. 5, drill-hole sections). Copper content of both the supergene sulfide ore and the gossan is highly variable. Shipments of secondary sulfide ore ranged from 6 to 14.5 percent copper; drill-hole samples of the better grade supergene ore contain about 3–4 percent copper (pl. 5; Grosh, 1948b). Some drill-hole samples of gossan contain as much as 1–2 percent copper (pl. 5). A piece of gossan from the surface was found to contain 18 percent copper, 0.13 percent zinc, and 0.09 percent cobalt—the highest cobalt content of any of the samples from gossan of southeastern deposits (table 1); evidently this sample was incorrectly classed as gossan instead of supergene copper ore.

STRUCTURE

The Toncrae deposit is a tabular body which trends N. 10° E. for about 1,100 feet and dips about 30° E. near the surface, but perhaps as steeply as 70° at depth (pl. 5). Presumably the best surface indication of the deposit was at its north end, where the gossan and supergene copper ores were mined, but such outcrops have been destroyed or covered by mining operations. The deposit has a maximum thickness of about 50 feet here (pl. 5, section C–C′). For about 700 feet south of the old mine workings, gossan and supergene and hypogene sulfides have been found by means of drilling, but practically no signs of the deposit are now evident on the surface.

Massive sulfide ore makes up the hanging-wall part of the deposit, and the upper contact is rather well defined; however, seams of massive sulfides, several feet thick, alternate with disseminated sulfides in the footwall part of the deposit. The footwall contact is gradational and is placed somewhat arbitrarily on the maps and sections.

Results of shallow drilling along section *F–F′* (pl. 5) suggest that the ore deposit here has an anticlinal structure. About 150 feet farther north a probable fault, dipping 85° E., is exposed at one place in the south end of the drift in the footwall part of deposit (section *E–E′*). Broken vein quartz, several feet thick, and a thin layer of gouge occur along the fault. Striae on the quartz plunge downdip. This fault is possibly older than the mineralization because no brecciated ore was observed along it. Vertical movement along the fault may have flexed the rock foliation, thus influencing the shape of the later sulfide seams which replaced the country rock. Dietrich (1959, p. 129–130) states that the results of drilling by Appalachian Sulphides, Inc., suggest that the deposit has the shape of a folded lens, perhaps similar to a saddle reef. The deposit apparently pinches out between 250 and 300 feet vertically beneath the surface along section *G–G′* (pl. 5); but about 250 feet south of here, Appalachian Sulphide drill hole AS5 penetrated 31 feet of sulfide-rich zone at a depth of 204 feet, according to Dietrich (1959, fig. 5). Data on the gross structure of the deposit are indeed meager, but the body may plunge gently southward, as suggested by the presence of much gossan and supergene copper ore at the north end of the deposit and by the thick sulfide-rich zone found by means of drill hole AS5 about 200 feet beneath gossan-free surface. Data available independently to the writer and Dietrich (1959) indicate that the upper part of the body may be arch shaped.

The gossan is 30–60 feet deep and is inclined toward the east at angles more gentle than the dip of the hypogene deposit (see sections shown in pl. 5). The underlying supergene copper zone is generally less than 10 feet thick; its contacts with the gossan and the hypogene sulfides are very sharp. Both the gossan and the supergene copper zone are highly irregular in detail (pl. 5) and may have been controlled to considerable extent by the original structures of the ore deposit. In the developed part of the ore body, the supergene copper zone and the base of the gossan are undulating and about conformable to local flexures in the hypogene ore. Isolated masses or seams of supergene sulfides occur in the gossan in places, and tongues of gossan penetrate both the supergene and hypogene sulfide zones.

The gossan and supergene copper zone are thickest and widest in an interval that is 400–500 feet long at the north end of the Toncrae deposit (pl. 5). This interval may also be where the thickest part of the hypogene deposit lies in the zone of weathering. Both gossan and hypogene sulfides are present for about 700 feet south of the drill holes of section *F–F′* (pl. 5), but very little supergene copper ore occurs here.

The electromagnetic survey by Appalachian Sulphides, Inc., revealed two electromagnetic conductors, one along the trend of the Toncrae deposit and another 300–400 feet east of the north end of the deposit; this second conductor, extending northeastward for several thousand feet, was explored by means of several drill holes, and apparently some sulfides of unspecified nature were found (Dietrich, 1959, fig. 5).

OTHER DEPOSITS

Other cupriferous sulfide deposits occur within a few miles of the Toncrae deposit; the Bear Bed deposit is about 1 mile to the southeast, the Sutherland and Belcher deposits are 2–3 miles to the southwest, and the Hogan deposit is 5 miles northeast (Dietrich, 1959, p. 130–131).

The Sutherland deposit was explored in 1939 by the American Metal Co. by means of 1 diamond-drill hole in the hypogene ore and in 1943 by the Bureau of Mines by means of 14 shallow drill holes (Grosh, 1948a). This deposit seems to consist of several sulfide lenses in garnetiferous quartz-biotite schist; pyrite and magnetite are the most abundant metallic minerals and are accompanied by lesser amounts of chalcopyrite, sphalerite, and pyrrhotite (R. J. Wright and M. H. Staatz, written communication, 1943). About 23 feet of hypogene sulfide ore was cut at 100 feet below the surface by drill hole 5 of the American Metal Co.; the sample across this thickness averaged 1.78 percent zinc and 0.62 percent copper (Grosh, 1948a, fig. 3). Two of the Bureau of Mines drill holes also intersected hypogene sulfide ore containing about one-half of 1 percent copper. No supergene copper zone was discovered during the drilling. Significant amounts of gossan were found in only one drill hole (S8), which intersected about 55 feet of gossan whose copper content ranges from 0.14 to 0.94 percent; this gossan seems to be part of the sulfide lens which was cut at depth by the American Metal Co. drill hole 5 (Grosh, 1948a, fig. 3).

At the Belcher property, about half a mile southwest of the Sutherland, a little gossan with residual pyrite occurs in hornblende schist (M. H. Staatz, written communication, 1943). A sample of this gossan contained 1.6 percent copper and 0.068 percent zinc (table 1).

An old prospect, known as the Howell prospect, in western Franklin County, 18 or 20 miles northeast of the Toncrae mine and about 5 miles northwest of the village of Ferrum, was examined by R. J. Wright and N. D. Raman (written communication, 1943). Gossan is sparsely distributed for about 450 feet on the surface; country rock is quartz-biotite schist. An inclined shaft, now caved, apparently cut hypogene sulfides. Ore on the dump contains pyrrhotite, pyrite, chalcopyrite, and sphalerite; a grab sample taken by Wright contained 1.1 percent copper and 2.4 percent zinc. An adit driven 75 feet into the hill below this caved shaft apparently did not cut the hypogene sulfide ore.

CLEBURNE AND RANDOLPH COUNTIES, ALABAMA

STONE HILL MINE

HISTORY AND PRODUCTION

The Stone Hill, or Woods, copper mine is in the Piedmont province of metamorphic rocks of eastern Alabama, in sec. 35, T. 17 S., R. 11 E., Cleburne County, and sec. 2, T. 18 S., R. 11 E., Randolph County, about 12 miles south of Heflin. Copper was discovered at the Stone Hill mine in 1874 by Richard J. Woods, who started to mine the rich supergene ores (Smith, 1875, 1876). The ore was hauled by wagon to Carrollton, Ga., a distance of about 25 miles, and shipped to Baltimore, Md. About 1,500 tons of ore, averaging 15 percent copper and yielding an average return of $56.25 per ton, was shipped by October 15, 1875. About 800 tons of ore carrying 8–10 percent copper was stockpiled at the mine at this time. A small smelter was erected shortly afterward, and the ore was smelted on the property from 1876 to 1879 (Rothwell, 1877; Adams, 1930). The lower grade hypogene ores were mined after exhaustion of the supergene ores, but this operation became unprofitable because of inefficient smelting practice and poor transportation facilities, and the mine was shut down in 1879. The average grade of the ores (mostly hypogene?) mined for 1 or 2 years prior to 1877 was about 5.5 percent copper. The total production of the mine until 1879 is reported to have been $1,300,000 worth of ore, matte, and ingots. This figure, however, must be excessive considering the reported copper content of the ore, the rather small extent of the mine workings, and the fact that the 1,500 tons of rich supergene ore that was shipped had a gross value of only about $85,000.

The mine was reopened in 1896 (Adams, 1930), and during the next 3 years the shaft was deepened and several drifts run beneath the old stopes by the Lewisohn interests of New York. The work was largely exploratory, although several carloads of sorted ore were reportedly shipped. Operations ceased in 1899, and the mine has since been idle.

The geology of the Stone Hill mine area was mapped by G. H. Espenshade, E. A. Brown, N. D. Raman, and R. D. Hutchinson of the Geological Survey in February 1943 (pl. 6). Eight diamond-drill holes (pl. 7), totaling 1,355 feet in depth, were drilled by the Bureau of Mines during October and November 1943 (Pallister and Thoenen, 1948). Some geophysical exploration and drilling were done at the Stone Hill mine between 1948 and 1956, according to H. D. Pallister (written communication, 1960).

GEOLOGY

Principal rock types in the area are mica schist and hornblende schist. The Stone Hill deposit occurs near a group of narrow bodies of chlorite schist and hornblende schist that extends more than 80 miles southwest to the edge of the overlapping Coastal Plain (Alabama Geol. Survey, 1926).

The country rock of the Stone Hill copper deposit is mainly fissile fine-grained hornblende schist. Medium- to coarse-grain hornblende schist underlies the high knob to the southeast of the mine (pl. 6). The two varieties of hornblende schist are possibly derived from a gabbroic intrusion. Hornblende and epidote are the principal minerals in the hornblende schists and are generally accompanied by moderate amounts of quartz and albite; biotite and garnet are rather common in some layers; sphene, apatite, carbonates, and white mica are commonly present in minor amounts. Hornblende schist underlies most of the mapped area and crops out in a belt, half a mile or more wide, which has been traced about a mile to the northwest and half a mile to the southeast beyond the limits of the area shown in plate 6. Bluish-gray quartz-mica schist and garnet-mica schist, with bands of massive fine-grained garnet and individual garnet crystals as much as half an inch in size, are the other country rocks. The mica schist crops out in small irregular patches in the mapped area. Because of poor exposures, the structural relations of these schists to the hornblende schist are not apparent.

The contacts between the different rock types are exposed at only a very few places, but their approximate locations and trends, as determined from float rock or drilling, are indicated on plate 6. The trend of the foliation of the country rocks is variable and is generally between N. 45° W. and N. 30° E., with a dip 30°–70° E. These variations in strike suggest the presence of large folds in the foliation, whose pattern and distribution has not been determined because of the poor exposures. Small drag folds in the foliation, plunging to the northeast or southeast, are common, particularly in the fine-grained hornblende schist, and are shown at several places on plate 6.

Mafic schists and mica schists that are thought to be of both Precambrian and Paleozoic age are present within a few miles of the Stone Hill deposit (Alabama Geol. Survey, 1926; Griffin, 1951). Hence, the age of the schists in which the deposit occurs may be either Precambrian or Paleozoic.

ORE BODY

MINERALOGY

The hypogene sulfide ore consists of massive sulfides and disseminated sulfides, which differ somewhat in mineralogy. The massive sulfide ore is composed mainly of pyrrhotite and smaller amounts of pyrite, chalcopyrite, and sphalerite; gangue minerals are quartz, garnets, amphiboles, biotite, and carbonates. The disseminated sulfide ore is sericite-quartz schist with considerable disseminated pyrite and minor amounts of chalcopyrite. Quartz veins occur with the sulfides; garnet is abundant in seams several feet thick in the wall of the deposit.

The mineralogy of the supergene copper ores has not been studied carefully. Smith (1875) describes them as black copper ores (presumably mostly chalcocite and pyrite or marcasite), with some cuprite, native copper, malachite, and azurite. The gossan overlying the supergene copper zone consists of dark-red to brown cindery limonite.

GRADE OF ORE

The copper content of the richest hypogene ore apparently averages several percent, as indicated by the following assays quoted by Adams (1930, p. 73) from a private report made in 1897 by C. L. Constant to the Lewisohn Brothers:

Sample	Copper (percent)	Silver (ounces per ton)	Gold (ounces per ton)
1. Of 1,000-ton pile of ore on surface	4.07	3.10	0.02
2. 30-foot long sample across vein in cross-cut at bottom of shaft	2.93	2.49	.01

Most of the drill-hole samples taken by the Bureau of Mines contained less than 1 percent copper; composite samples contained as much as 18.3 percent sulfur, 0.13 percent lead, and 0.80 percent zinc (Pallister and Thoenen, 1948). The richest supergene copper ore averaged about 15 percent copper (Smith, 1876). Three random samples of gossan from the Stone Hill deposit contained 0.6–2.0 percent copper, 0.09–0.11 percent zinc, 0.08–0.18 percent lead, <0.001–0.004 percent cobalt, and 0.004–0.015 percent arsenic (table 1).

STRUCTURE

The hypogene part of the Stone Hill deposit is made up of layers of massive sulfides a few feet thick, alternating with thicker layers of sericite-quartz schist containing disseminated sulfides. According to Rothwell (1877, p. 86), a layer of massive sulfides, 3–3½ feet thick, formed the hanging wall of the deposit, beneath which were 15–20 feet of schist impregnated with sulfides; a massive sulfide layer, 4–5 feet thick, formed the footwall.

The trend of the ore body is marked at intervals on the surface by gossan for about 1,000 feet. In the northern half the deposit trends N. 20° E.; it curves to about S. 30° E. at the south end. The probable trend of the footwall of the deposit at the 1,100-foot elevation is shown in plate 6. No exposures exist along the strike of the ore body for about 500 feet north of the adit, because of thick soil cover and valley fill. The average dip of the ore zone is about 45° E., as indicated by old reports and the results of drilling. Individual massive sulfide lenses, however, dip 30°–50° E. Drilling in the northern part of the deposit has shown that the mineralized zone is as much as 50–60 feet thick in places. The zone was reported to be more than 30 feet thick in the lower mine workings (Adams, 1930, p. 72).

The hanging wall of the ore body is 50–100 feet below the gradational contact between fine-grained hornblende schist and coarse-grained hornblende schist, measured at right angles to the foliation. The approximate trace of this contact, assuming that its dip is 45° E., is shown on plate 6. The ore deposit possibly occupies a thrust fault or zone near the contact between the two varieties of hornblende schist.

Drag folds in foliation of the schist below the footwall of the northern part of the deposit plunge about 45° in a direction N. 70° E.; farther south, similar folds plunge 5°–15° about S. 10° E. (pl. 6). It is not known whether the ore deposit plunges in directions comparable to these fold axes in the country rock. The fact that the maximum content of copper (expressed as "feet-percent copper") was found in drill hole 5 suggests perhaps that this hole is near the most highly mineralized part of a northeast-plunging ore shoot (pl. 7). Hole

7 is not considered significant in this analysis, although it ranks next to hole 5 in copper content, because hole 7 cuts the ore zone 10–50 feet beneath the surface and its high copper content is probably due in part to supergene enrichment near the surface.

OTHER DEPOSITS

Several other sulfide deposits exist within a mile of the Stone Hill deposit. The Johnston prospect, or old Walker place, is about a mile N. 65° W. from the Stone Hill mine. An adit and five shallow shafts were dug here, probably about the time the Stone Hill mine was opened. These workings are all inaccessible now. The mineralized zone at the Johnston mine is in quartz-mica schist and seems to trend nearly west for about 500 feet. A little disseminated and massive sulfide ore occurs on the dumps, but its copper content is low. Some gossan is present.

About 1 mile north of the Stone Hill mine is the Smith prospect where three shafts and several opencuts were dug before and after the Civil War (Smith, 1875, 1876). Sericite-quartz schist carrying disseminated sulfides with very little copper is present on the dumps. The grade of ore and size of deposit at both the Smith and Johnston prospects seem to be inferior to the grade and size of the Stone Hill deposit. It has been reported that the value of the production from the Smith prospect was $1,300,000, but Adams (1930, p. 74) points out that this is an error and that the figure refers to the reported production of the Stone Hill mine. Probably very little ore, if any, was shipped from either the Smith or Johnston prospects.

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