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STEWART L. UDALL, *Secretary*

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William T. Pecora, *Director*

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By ARNOLD L. BROKAW, JOHN C. DUNLAP, *and* JOHN RODGERS

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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A brief discussion of the stratigraphy, structural geology, and related mineral deposits of two anticlinal folds

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ILLUSTRATIONS

[Plates are in pocket]

CONTRIBUTIONS TO ECONOMIC GEOLOGY

GEOLOGY AND MINERAL DEPOSITS OF THE MOSHEIM AND JOHNSON ANTICLINES, GREENE COUNTY, TENNESSEE

By Arnold L. Brokaw, John C. Dunlap, and John Rodgers

ABSTRACT

Small deposits of zinc and barite occur in limestone and dolomite of the Knox Group that are exposed in the Mosheim and Johnson anticlines in Greene County, Tenn. The deposits in the Johnson anticline are in beds that are the stratigraphic equivalents of the host rocks for the large zinc deposits of the Mascot-Jefferson City district, 35 miles to the southwest. The prospects in the Mosheim anticline are in beds that are stratigraphically lower. The anticlines are typical of larger folds in the Valley and Ridge province. These anticlines expose rocks ranging in age from Late Cambrian to Middle Ordovician, and contain internal structural features consisting of minor overturned folds, thrust faults, and tear faults. No lead or zinc ore has been shipped from any of the prospects in the two areas, but some barite has been produced from small mines in the area of the Johnson anticline.

INTRODUCTION

The Mosheim and Johnson anticlines, which expose beds containing small zinc and barite deposits, are in the southeastern part of the Valley and Ridge province, near the central part of Greene County, Tenn. (fig. 1). The Mosheim anticline and the Johnson anticline are about 7 and 2 miles northwest of Greeneville, respectively. U.S. Highway 11E and Tennessee Highway 70 pass through the areas, and the prospects can be reached by a network of secondary roads that connect these highways.

Some of the prospects in the Johnson anticline were first opened as early as 1880, but no development was done until about 1900. Zinc and lead were first discovered in the Mosheim area about 1900, but little work was done on the properties until 1943, when the East Tennessee Zinc Co. cleaned out an old shaft and dug several new trenches. No zinc or lead ore has been produced from the prospected areas, but some barite has been mined from small mines in the Johnson anticline area.

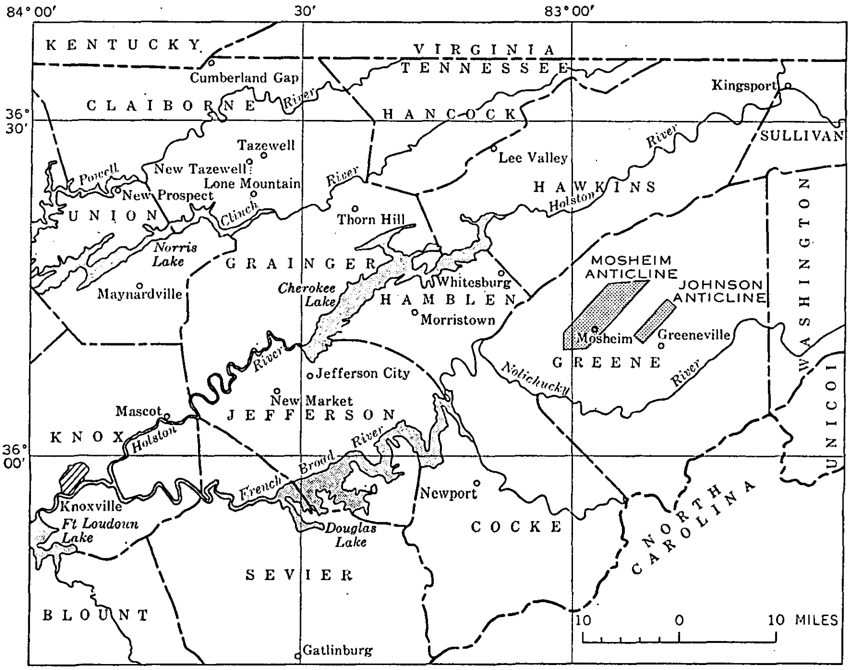

Figure 1.—Location of Mosheim and Johnson anticline areas.

The Mosheim and Johnson anticlines are of interest because zinc occurs there in rocks that are stratigraphic equivalents of the host rocks for the large zinc deposits in the Mascot-Jefferson City district, 35 miles to the southwest. In addition, some zinc is found in rocks older than those mineralized in the main zinc-producing area of eastern Tennessee.

The first significant geologic investigation pertaining to this area was done by Arthur Keith (1905). His report contains an excellent description of the rock units and the regional structural geology, but it makes no mention of the occurrence of zinc, lead, and barite in the rocks exposed in the Mosheim and Johnson anticlines.

In 1944 the U.S. Geological Survey and the U.S. Bureau of Mines conducted a small exploration program on the Brown-Tipton properties in the Mosheim area as a part of the World War II Strategic Minerals Investigations. The physical exploration consisted of trenching by bulldozer in and near the old prospect pits and sampling the mineralized bedrock. During that time the geologic maps of the Mosheim and Johnson anticlines were completed by the authors Dunlap and Rodgers.

The physical exploration program was summarized in a report by A. H. Warner (1950) of the U.S. Bureau of Mines, but the geologic maps were not published.

The present report was compiled by Brokaw, mainly from field maps and unpublished data on the stratigraphy and structure of the area by Dunlap and Rodgers. Brokaw assumes responsibility for errors that possibly developed during the preparation of the present report.

The authors acknowledge the courtesies extended the personnel of the U.S. Geological Survey by the many residents in the area. Special thanks are due Mr. Harry C. Beekner, treasurer of the East Tennessee Zinc Co., for access to the Brown-Tipton property.

GEOLOGIC SETTING

The Mosheim and Johnson anticlines are two relatively small folds that lie between the Pulaski fault on the southeast and the Bays Mountain syncline on the northwest. Rocks of Middle Ordovician age are exposed around the flanks of these folds, but of the Middle Ordovician only the Lenoir Limestone was mapped and studied in detail. Upper Cambrian rocks are exposed in the core area of the Mosheim anticline. The zinc and barite prospects occur in dolomite and limestone of Early Ordovician age.

STRATIGRAPHY

CAMBRIAN ROCKS

NOLICHUCKY SHALE

The oldest rock exposed in the area is the Maynardville Limestone Member of the Nolichucky Shale of Late Cambrian age. It occurs in the center of the Mosheim anticline, but its base is not exposed. The lowest beds seen are very silty ribboned limestone. Above these beds the formation is light-gray well-bedded dense dolomite similar to the dolomite in the lower part of the overlying Copper Ridge Dolomite but lacking the thin sandstone beds characteristic of that unit. Approximately 100 feet of the Maynardville is exposed.

On the Mosheim anticline the Maynardville occupies the lower slope and bottom of the valley below the ridge capped by the Conococheague Limestone. It does not form a distinctive topography.

COPPER RIDGE DOLOMITE

The Copper Ridge Dolomite of Late Cambrian age conformably overlies the Maynardville Member of the Nolichucky Shale. Its total thickness is about 300 feet. The lowest 100 feet of the Copper Ridge is light-gray well-bedded dense dolomite containing thin quartzitic sandstone layers in the lower part and some limestone in the upper part. The overlying 150 feet is dark-gray crystalline dolomite, having a fetid odor when freshly broken, interbedded with dark blue-gray fine-grained dolomite; the beds average a little more than 1 foot thick but are as much as 4 feet thick in the lower part of the dark-gray crystalline dolomite. The uppermost 40–50 feet of the Copper Ridge consists of dark-gray fetid crystalline dolomite similar to that in the underlying 150 feet. The formation's lower contact is placed at the base of the lowest sandstone in the light-gray part, and the upper contact is placed at the top of the dark-gray fetid dolomite.

The residual soil from the Copper Ridge Dolomite is ocher and red, and is locally mottled. The dark-gray beds yield a red sticky clay soil. The soil is similar to that derived from other formations of the Knox Group, but is slightly darker than soils from the Chepultepec Dolomite and the Conococheague Limestone. Cryptozoon chert and brown and dark-gray finely speckled chert resembling oolite are in the soil over the upper and middle part of the dark-gray dolomite. Brown oolite is present but scarce. A float of black spherical Cryptozoon chert and flat slabs of silicified Cryptozoon results from the lower part of the dark-gray dolomite.

On the Mosheim anticline the Copper Ridge occupies the scarp slope of the ridge formed by the lower part of the Conococheague, the upper limit being near the crest of the ridge.

CONOCOCHEAGUE LIMESTONE

The Conococheague Limestone is Late Cambrian in age and consists of alternating beds of cherty limestone and dolomite. The limestone is dark brownish gray, very fine grained, and contains shaly, silty, oolitic, and dolomitic bands. The dolomite is medium to dark gray, weathers light gray, and is very fine grained. The limestone and dolomite beds are commonly less than 1 foot thick, but beds of dolomite near the base are locally as much as 4 feet thick. The calculated thickness of the Conococheague is 550 feet.

The top of the Conococheague is placed at the base of the sandy member of the overlying Chepultepec Dolomite; in areas where these lowest sandstone beds are missing, or poorly developed, it is placed at the top of the beds of dark-brown oolite that is characteristic of the Conococheague. The base is placed at the top of the dark-gray fetid crystalline dolomite. A few beds of dark-gray crystalline dolomite occur above the lowest limestone beds and probably represent interfingering of the two rock types. This relationship can be seen at the Conococheague-Copper Ridge contact along U.S. Highway 11E and at the southwest end of the Mosheim anticline. The Conococheague

Limestone is typically developed on the eastern side of the Appalachian Valley in Tennessee and the Copper Ridge Dolomite on the western side of the valley. The two formations occupy equivalent stratigraphic positions and are probably of equivalent age. The Conococheague facies occurs west of the Mosheim anticline, and the small-scale interfingering of the two rock types is a local relationship that probably exists on a much larger scale in the same general area.

The residual soil from the Conococheague is orange and yellow ocher similar to the soil from the Chepultepec, although the orange predominates slightly. Three different types of chert are conspicuous and are characteristic of the soil over the Conococheague. In the soil over the upper half of the formation small flattened nodules of black dense chert and dark-brown oolite predominate; these nodules also occur sporadically throughout the formation. In soil over the lower half, dark blue-gray laminated chert and thin beds of tan to brown, silty porous chert are present.

The Conococheague is more resistant than the formations above and below it, and abundant chert causes the lower part to form a prominent ridge. The only locality where the Conococheague is exposed is on Big Ridge in the Mosheim area.

ORDOVICIAN ROCKS

CHEPULTEPEC DOLOMITE

The Chepultepec Dolomite of Early Ordovician age conformably overlies the Conococheague Limestone. It is divisible into a basal sandy member and an upper dolomite member.

The basal sandy member of the Chepultepec is a thin-bedded sandstone interlayered with dark blue-gray and brownish-gray fine-grained cherty limestone and less abundant brownish-gray fine-grained cherty dolomite. The limestone contains thin dark shaly laminae and is dark blue on weathered surfaces. The dolomite weathers light or medium gray. Near the base the sandstone beds are thin—about 2 inches thick; they are slightly thicker near the middle of the unit, and are also thin in the upper part. The thickest sandstone bed seen, however, was 1.5 feet thick and occurs at the top of the unit. This bed is exposed in a section along U.S. Highway 11E on the northwest side of the Mosheim anticline.

In most places the basal sandy member of the Chepultepec is about 250 feet thick, but at the northeast end of the Mosheim anticline it is calculated to be 300 feet thick. The lowest sandstone beds are nearly or entirely absent on the southeast flank of this anticline.

The upper dolomite member has a calculated thickness of 600 feet. Except for its uppermost 70 feet the upper member is similar to the basal sandy member though it lacks sandstone beds and contains more dolomite. The uppermost 70 feet is dark-gray laminated crystalline dolomite in beds about 4 inches thick.

The residual soil from the Chepultepec is orange and yellow and contains many manganese stains. It is generally lighter colored than the soil from the overlying Longview Dolomite. Many different types of chert are found in the soil and make an abundant but not a heavy float. The most characteristic chert is black or very dark gray; it is dense and glossy and occurs in nodular beds and as egg-shaped or ball-like nodules that are as much as 6 inches in diameter.

Wavy beds and flattened nodules of gray and brownish-gray chert 6–10 inches in diameter are abundant in the soil just above the top of the sandy member. Small white oolites occur at several places in the soil at the base, or above the lowest beds of the sandy member. A few blocks of chert containing brown oolites were seen in the soil above the lower part of the basal sandy member, but these may not be indigenous. Doubly terminated quartz crystals, averaging about 1 inch in length, and thin-walled geodes with drusy interior surfaces weather from the dolomite at the top of the Chepultepec.

The Chepultepec is less resistant to weathering and erosion than are the adjacent Conococheague and Longview Formations and commonly forms a broad shallow valley between the ridges formed by these rocks. Large sinks are characteristically formed on the outcrop of the Chepultepec and are especially numerous in the upper part of the basal sandy member.

LONGVIEW DOLOMITE

The Longview Dolomite of Early Ordovician age is predominantly dolomite that ranges in texture from very fine to coarse grained. The fine-grained beds are light gray and commonly show silty laminae on weathered surfaces. The coarse-grained beds are slightly darker, and most of them are medium gray. The beds are mostly 1–2.5 feet thick, but near the base they are more massive, and bedding planes are difficult to identify. Several very coarse grained beds in the upper third of the formation are similar in texture to dolomite that results from the hydrothermal alteration of limestone. These beds were probably limestone originally, though no limestone has been seen in the Longview in this area. Several thin beds of light-gray dense to porous doloclastic chert and nodular beds of blue-gray banded chert occur near the top of the formation; chert is scarce in the lower part of the formation. A thin bed of sandstone, which has a matrix of chert or quartz, occurs in the lower third of the formation. The calculated thickness of the Longview in a section along U.S. Highway 11E on the northwest side of the Mosheim anticline is 300 feet; it appears to be as much as 340 feet at other places on the anticline.

The residual soil from the Longview is not distinctly different from the soil of the Kingsport Limestone, although it is generally lighter colored than the soil derived from the overlying limestone of the Kingsport. The soil is red and orange at the surface, but is orange and yellow where less oxidized. In most places it contains a large amount of white or pale-gray dense fine-grained chert that has smooth or hackly surfaces. A few nodular beds of blue-gray banded chert occur in the soil at the top of the formation. The light-colored dense chert is characteristic of the Longview in the middle and western part of the Appalachian Valley in Tennessee and, together with the index fossil *Lecanospira*, is the main criterion for identifying the formation.

The lower contact of the Longview is easy to locate because the underlying Chepultepec is predominantly limestone and yields a distinctive chert. Where bedrock is exposed, the base is placed at the bottom of the light- and medium-gray fine-grained massive dolomite and at the top of the dark-gray crystalline strongly laminated dolomite that forms the upper approximately 70 feet of the Chepultepec.

The index fossil *Lecanospira* has been found in loose blocks of chert in soil from just below the base of the limestone member of the overlying Kingsport; therefore, the upper contact of the Longview is placed at the base of the limestone member. In most places this upper contact must be determined by residual chert and is difficult to place because the chalky doloclastic and nodular cherts in the upper beds of the Longview do not contrast sharply with chert from the Kingsport. The chert assemblages are further complicated by slump. Thus the location of the contact is determined in many places by the distribution of (1) the blue-gray banded chert nodules characteristic of the lower part of the Kingsport and (2) the light-gray blocks of dense Longview chert.

The large amount of resistant chert in the Longview forms a ridge that is conspicuous. Stream valleys are commonly narrower where they cross outcrops of the Longview.

KINGSPORT LIMESTONE

The Kingsport Limestone, about 230 feet thick, is Early Ordovician in age. The lower limestone member, which comprises the lower third of the Kingsport, is blue and bluish-gray very fine grained limestone. The upper two-thirds—upper dolomite member—consists of light-gray very fine grained silty dolomite. Both the limestone and the dolomite are cherty, the most common form of chert being small flattened nodules. Beds of medium-gray medium-grained dolomite occur in the upper dolomite member but are subordinate to the light-gray very fine grained dolomite. The beds are 4 inches to 4 feet thick.

The base of the Kingsport is placed at the bottom of the thick limestone in the lower third of the formation. The top of the formation is marked by the base of the lowest of the distinctive quartzitic sandstone beds that form the base of the overlying Mascot Dolomite.

The residual soil from the upper dolomite member of the Kingsport is chiefly orange; the soil from the lower limestone member is slightly darker and contains yellow and buff streaks. Flattened nodules of chert are abundant in soil derived from the limestone. Near the top are pebble- and cobble-sized blocks of light-gray dense chert that have rough surfaces. Also present are rough plates of dark blue-gray dense chert, and chert nodules containing thin disklike voids formed by the leaching of soluble material. Six-inch blocks of light-gray, rather porous chert having ropelike structures are found in a few places at the base, but these may be derived from the topmost beds of the Longview Dolomite.

The Kingsport underlies the upper slopes on the dip side of the ridge formed by the Longview and commonly forms a bench on the broader spurs projecting from the ridge. Where streams cross the strike of the beds, their valleys are locally wider over the lower limestone member of the Kingsport than over the upper dolomite member. Large and small sinks are common at this horizon.

MASCOT DOLOMITE

The dominant lithology of the Mascot Dolomite, which is of Early Ordovician age, is well-bedded light- to medium-gray fine-grained dolomite interbedded with blue-gray fine-grained limestone. The beds are generally 1–2 feet thick. Most of the dolomite beds are very light gray on weathered surfaces and contain silty laminae that stand in slight relief; the limestone beds have reticulate dolomitic and silty bands that distinguish them from the overlying Mosheim Member of the Lenoir Limestone, which has no dolomite. Some of the limestone has been altered to medium and coarsely crystalline secondary dolomite. One, and locally two, chert-matrix or quartzitic sandstone beds occur in the lower part of the formation, and the base is placed at the bottom of the lowest of these. The lower bed is about a foot thick, is partly cemented with dolomite, and yields float blocks not more than 3 inches thick. The upper bed is about 1–2 inches thick. At one locality on the Mosheim anticline where both sandstones were seen in place, the upper bed is about 70 feet above the lower. On the Johnson anticline blocks of float from a sandstone bed about 3 inches thick were found; this unit probably correlates with one of the sandstone beds in the Mascot on the Mosheim anticline. The correlation is not definite, however, because the position of the sandstone bed relative to the unexposed top of the Kingsport Limestone cannot be determined.

Several thick dolomite beds in the upper 100 feet of the formation are spotted with clusters of white calcite crystals. Nodular beds of light- to medium-gray chert about 3 inches thick occur in the dolomite together with platy rough-surfaced beds of dark blue-gray chert. A few beds of dark-gray medium-grained dolomite occur throughout the formation. Scattered sand grains and very thin sandstones that have dolomitic cement are found in the upper part.

The Mascot Dolomite is separated from the overlying Lenoir Limestone by a regional unconformity. In the road-metal quarry southeast of Albany near the northeast end of the Mosheim anticline, the unconformity appears to have as much as 10 feet of relief in a distance of 50 feet, but where observed elsewhere it is rather smooth.

On the Mosheim anticline the Mascot is about 350 feet thick, but the thickness appears to range from about 310 to 375 feet. The most reliable estimate of the thickness of the Mascot on the Johnson anticline is 275 feet. The variation in thickness is probably due to unequal amounts of pre-Lenoir erosion on the top of the Mascot.

The residual soil from the Mascot is mostly reddish brown and orange and in some places yellow and buff; residual chert is abundant at many places and consists of several different types. Blocks of light-colored chert that have rough surfaces are found throughout the residual soil over the formation. Thin lenticular beds and small nodules of light bluish-gray chert are also found, but these nodules are less numerous than other types. When freshly broken the cherts are compact in texture, but after weathering they become chalky and porous. Blue-gray ball-like nodules and rough-surfaced plates of dark blue-gray dense chert occur in the soil near the base of the formation.

The Mascot does not make distinctive topography in this area. Where rocks as low as the Longview Dolomite are exposed, the Mascot underlies most of the downdip slope of the ridge formed by the Longview. The blunt spurs that project from the Longview ridge end about at the base of the Mascot. Where the dip is low, sinkholes form in the thick limestone beds in the upper part of the formation, but elsewhere sinkholes are scarce.

KNOX GROUP UNDIFFERENTIATED

In the southeast part of the Mosheim area formations of the upper part of the Knox Group were not separately mapped. The area is known to contain all or parts of the Chepultepec Dolomite, Longview Dolomite, Kingsport Limestone, and Mascot Dolomite.

LENOIR LIMESTONE

The Lenoir Limestone of Middle Ordovician age crops out around the flanks of the Mosheim and Johnson anticlines. In the area of study it has been divided into the Mosheim Member and an upper unnamed member.

The Mosheim Member is uniformly a massive, blue to bluish-gray aphanitic limestone. At a few places wavy shaly partings occur near the top and bottom. Bedding planes are indistinct and can seldom be identified. On the Mosheim anticline the base of this member is marked by a conglomerate which consists of angular fragments of chert and dolomite. The dolomite fragments are as much as 6 inches in diameter, but the chert fragments are granule to pebble sized. On the Johnson anticline the conglomerate is composed entirely of angular fragments of dolomite. A few nodules of dark brownish-gray dense chert were observed in the Mosheim Member on the northwest side of the Johnson anticline northeast of the Cross Anchor road, but no chert has been seen at other exposures.

The thickness of the Mosheim ranges from 0 to 80 feet. Abrupt changes in thickness are typical. The Mosheim may thicken from 0 to 50 feet, or more, in a strike distance of a few hundred yards. One of the best places to observe the variation in thickness is on the northeast side of the Mosheim anticline approximately one-half mile southwest of Albany.

On weathering, the Mosheim produces a brownish-yellow sticky clay soil that is free of chert except in those places where chert from the underlying Mascot Dolomite has been washed onto it.

The Mosheim Member forms a narrow topographic depression between the Mascot Dolomite and upper member of the Lenoir Limestone. Its outcrop is locally characterized by a line of sinkholes.

UPPER UNNAMED MEMBER

The lower half of the upper member is much more silty, thinner bedded, and less nodular than the upper half, which is composed of dark-gray nodular fossiliferous limestone in beds 2–3 feet thick. Many silty reticulate partings are in the upper half. Where the member is thin, nodular and shaly limestone predominates. On the Mosheim anticline the thickness of the upper member ranges from 20 to about 90 feet. Around the flanks of the Johnson anticline the thickness ranges from about 1 foot to about 70 feet. The minimum thickness is on the southeast side of the Johnson anticline near Mount Vernon Church where the Lenoir Limestone is too thin to be shown on the map; the Lenoir Limestone may be entirely absent in the area near Mount Vernon Church. Where the Lenoir is thickest, the lower half is a massive, nodular limestone and the upper half is thinner bedded and shaly and has a zone of gray coarsely crystalline marble, 5–15 feet thick, at the top. Rarely, the topmost bed is a nodular limestone about 3 feet thick. The thinning appears to take place in the lower half. Where the Lenoir is thinnest, gray crystalline marble 1 foot thick is present. This bed may be equivalent to the marble zone that occurs elsewhere at the top of the Lenoir. Where the thin marble is exposed, it directly overlies the Mascot Dolomite and is overlain by the Athens Shale; the Mosheim Member is absent.

At many places on the Johnson anticline the Lenoir Limestone contains numerous rough lumps of black, dense chert that have an irregular ropy structure. Generally the dark color distinguishes this chert from the lighter colored cherts from the Mascot Dolomite, but in some places chert from the Lenoir weathers blue, and, if outcrops are not present and the noncherty Mosheim Member is absent, the Mascot-Lenoir contact is difficult to locate. The Lenoir yields a reddish-orange soil containing scattered shaly stringers. Black ropy chert is present locally.

The Lenoir is too thin to have a distinctive topography. It forms the upper slope and, in some places, reaches the crest of the hills formed by the overlying Athens Shale.

WHITESBURG LIMESTONE AND ATHENS SHALE

The Athens Shale of Middle Ordovician age is dark-brown to black slightly calcareous fissile shale that weathers tan or buff. In most places nodular beds of black dense limestone are interbedded with shale at the base of the formation. These basal limestone beds, which are 400 feet thick near Whitesburg, Tenn., were named the Whitesburg Limestone by Ulrich (1930). In areas where the basal beds are absent, it was not established that the lower shale beds carry the Whitesburg fauna; therefore, they were mapped with the Athens.

The thickness of the Whitesburg and Athens was not determined, but probably no more than the lower few hundred feet is in the area between the Mosheim anticline and the Pulaski fault a few miles to the southeast.

Where it is weathered, the Athens yields a thin gray silty loam that contains many small chips of shale. Commonly the shale forms the surface on the tops and slopes of hills. The residual soil is thicker and more fertile on the gentle slopes, which are often cultivated, than on the steeper slopes, which erode rapidly and which are commonly used for pastureland. In areas underlain by the Whitesburg Limestone, nodules of limestone are abundant in the surface soil.

The Athens forms distinctive rounded hills of nearly equal height that rise 100 feet or more above the stream valleys. The hills are separated by steep-sided valleys that have a dendritic pattern.

STRUCTURE

The Mosheim and Johnson anticlines are two separate structural units. The Johnson anticline is continuous to the southwest and becomes a part of the Naff (unmapped) anticline. The two folds are separated by a shallow structural saddle that contains the younger rocks. The Mosheim anticline is named for the village of Mosheim, and the Johnson anticline is named for the best-known zinc prospect on the fold.

The outcrop areas of all rocks older than Whitesburg Limestone and Athens Shale were mapped at both the Mosheim and Johnson anticlines; therefore, the mapping in these areas defines complete structural entities.

MOSHEIM ANTICLINE

The Mosheim anticline (pl. 1) is a simple fold 8 miles and as much as 1.7 miles wide. In the central part of the anticline the axis trends about N. 42° E.; at the northeast end it changes to N. 70° E.; and at the extreme southwest end it trends S. 85° W. The fold is asymmetric. In the central part the rocks on the northwest flank have an average dip of about 75°, whereas rocks on the southeast flank have an average dip of about 40°.

Minor folds are relatively scarce. A small sharp anticlinal flexure occurs on the southeast side of the anticline 2.7 miles northeast of U.S. Highway 11E, and a narrow syncline borders the southeast edge of the major fold between the villages of Mosheim and Midway.

A nearly vertical tear fault having a relative displacement of 1,000 feet was mapped on the northwest side of the anticline 2 miles northeast of U.S. Highway 11E. This fault strikes N. 87° E. to where it intersects the axis of the anticline where it turns northeast and dies out in the crest of the fold. A second tear fault having a relative displacement of 100 feet was mapped 1,500 feet to the north. It appears to be parallel to the larger fault, but its position with respect to the axis of the anticline is not definitely known. Detailed mapping near the Brown and Tipton zinc prospects indicates that it may pass through a line of sinks and then die out along bedding planes near the crest of the anticline. Along both of the faults, rocks on the north side have been displaced eastward by right-lateral movement.

A thrust fault that places Lower Ordovician rocks on the Lenoir Limestone, Whitesburg Limestone, and Athens Shale is present along the southeast edge of the anticline from 0.8 mile southwest of Mosheim to Midway. The plane of this fault is not exposed, but the relationships of the formations involved indicate that it dips at least 45° SE. Near the northeast end of the trace of this thrust, a small tear fault, having about 150 feet of displacement, enters the anticline and probably turns southwest and dies out along bedding planes. It cannot be traced because of poor exposures and intermixed residual materials.

On the opposite side of the Mosheim anticline northwest of Midway, the Mascot Dolomite is in fault contact with the Athens Shale for a short distance. This fault is interpreted as a thrust that dips southeast, but may be an underthrust whose fault plane dips northwest; alluvial cover and lack of exposures obscure the exact relationship.

JOHNSON ANTICLINE

The Johnson anticline (pl 2) is a complex of faulted folds approximately 6 miles long and as much as 4,000 feet wide. This area includes small-scale examples of most structural features that are found on a large scale in the Appalachian Valley. Open and isoclinal and normal and overturned anticlines and synclines occur with numerous thrust faults.

The major fold trends about N. 45° E., but smaller folds show many variations from this general trend. Most of the southwestern 7,000 feet of the main anticline is overturned to the northwest, and the northeastern 10,000 feet is entirely overturned. Stratigraphy is of little assistance in locating the axis position in the overturned sections because the Mascot Dolomite is the oldest rock definitely exposed and subdivisions of the Mascot have not been established. The oldest rock exposed is on the axis of the major fold about 2,000 feet northwest of Mount Vernon Church and belongs in either the lower part of the Mascot Dolomite or the uppermost part of the Kingsport Limestone. Because of the uncertainty regarding the Kingsport-Mascot contact, all the Knox Group on the Johnson anticline is mapped as the upper part of the Knox Group.

At the extreme southwest end of the Johnson anticline where the fold is not overturned, the axis is defined by good exposures and, with the strike of the rocks as a guide, can be projected into the overturned section to obtain its approximate position. In the overturned northeastern section, the axis is inferred to be near the middle of the stratigraphic section and bounded on either side by younger rocks.

The most complex parts of the Johnson anticline are the small faulted folds in the area north of U.S. Highway 11E. At Tennessee Highway 70 the Mascot Dolomite is in fault contact with the Mosheim Member of the Lenoir Limestone. The plane of the fault between the two formations is not exposed, but a reverse fault with northwest dip is inferred to explain the relationships that exist. This fault has been projected northeast to intersect a northwest-dipping fault exposed on Possum Creek; but the two faults may not be the same.

An area of very complex folding and faulting occurs about 1 mile southwest of Kidwell School where the rocks at the northwest side of the area mapped are overturned to the northwest. Beds near the top of the Mascot Dolomite here are in an overturned anticline, or possibly in overturned isoclinal folds, that plunge steeply northeast. Approximately 500 feet east of the fold or folds just described, the beds are folded into a normal anticline that terminates partly by plunging southwest and partly by being truncated by a thrust fault of small displacement; the thrust dies out at the nose of the anticline. To the northeast, a fault plane that dips 80° NW. is exposed in a road-metal quarry near the axis of the normal anticline described above. The associated drag folds indicate this is a normal fault, the northwest side having moved down with respect to the southeast side. The fault dies out in both directions along the axis of the fold. At the northeast end of the anticline the upper beds of the Mascot Dolomite are thrust over the Lenoir Limestone. An anticline that trends northwest and then northeast occurs 500 feet to the northeast; it is overturned to the west, and for a short distance along the west side the Mascot Dolomite has been thrust over the Mosheim Member of the Lenoir Limestone. This fault becomes coextensive with the normal contact between the Mosheim and the Mascot at either end. The northwest-trending overturned anticline is cut off by a thrust fault on the southeast.

Northeast of the areas described above, structural relations are more regular, but east of Hardin Chapel the overturned Mascot Dolomite is in fault contact with the overturned Mosheim Member for a short distance. This fault dies out along the normal contact in both directions. From 1,000 feet northeast of Hardin Chapel nearly to the northeastern limit of the Mascot Dolomite, as exposed on the major fold, the Mascot is in fault contact with the Lenoir Limestone. This fault dies out on the nose of the anticline to the northeast. Southwestward the fault crosses the axis of the major fold south of Hardin Chapel and terminates 1,000 feet north of U.S. Highway 11E. The fault's position is clearly indicated by three outcrop areas of Lenoir Limestone. The fault cannot be identified in the Mascot Dolomite between these areas but is inferred to be continuous as is shown on the map.

The southeast one-third of the Johnson anticline is characterized by two continuous thrust faults, several short thrust faults, and by many sharp discontinuous folds, some of which are overturned to the northwest. All the faults are of small displacement, the upper beds of the Mascot Dolomite being on the Lenoir Limestone. The southeasternmost fault dies out in the Athens Shale at the southwest end. Northeast of the Cross Anchor road it splits into two segments for a distance of 3,500 feet. Northwest of Kidwell Pond it again splits, the northwest segment dying out in the Lenoir Limestone and the southeast segment continuing to the northeast end of the anticline and dying out in the Athens Shale. The next continuous fault to the northwest terminates in the Athens Shale at the southwest end. This fault might best be considered as two separate faults because one fault terminates 1,200 feet northeast of Mount Vernon Church in an area of small plunging folds and is replaced by another fault 250 feet northwest that continues to the northeast and dies out along the crest of a small anticline.

In the southwest part of the Johnson anticline two additional thrust faults of considerable length are present but do not extend north of Possum Creek. The fault farthest southeast splits into two segments at the southwest end; at the northeast end it terminates in an area of small thrust slices northeast of Gass Creek. The fault farthest northwest terminates in the Mascot Dolomite about 1,000 feet northeast of Tennessee Highway 70; at the southwest end it gradually dies out along the contact between the Mascot Dolomite and Mosheim Member. Several shorter thrust faults were also mapped; all are of small displacement and slight extent.

One small tear fault was mapped south of the R. P. Johnson zinc prospect (pl. 2, No. 6) about 2,000 feet south of Kidwell School. Lack of rock exposures at critical points makes this interpretation questionable, but the exposures that do exist indicate a tear fault. A second small fault with northwest strike occurs northeast of the Cross Anchor road about 2,800 feet northeast of Hardin Chapel at the northwest side of the area mapped. The fault plane dips 65° SW. and the southwest side appears to be upthrown with respect to the northeast side.

MINERAL DEPOSITS

MOSHEIM ANTICLINE

Lead-zinc ore was first found on what was known as the Eb Foshie property more than 40 years ago. Later, a shaft 30 feet deep dug on this prospect intersected oxidized ores of lead and zinc, some sulfides (sphalerite, galena, pyrite), and much limonite. Mr. Foshie tried to induce various zinc companies to explore the property for zinc, but there was no interest and prospecting ceased. Later, the property was sold to Mr. Lloyd Brown of Greenville, Tenn., and in 1943 mineral rights were leased to the East Tennessee Zinc Co. The old shaft was cleaned out and a trench dug from the shaft to a point 50 feet to the southeast. At the same time another trench 60 feet long and a maximum of 18 feet deep was dug on the Tipton property (pl. 1) to the west. This trench showed much limonite, some smithsonite, and a little sphalerite.

The ore-bearing formation of the Mosheim anticline is the Chepultepec Dolomite. It consists of alternating beds of limestone and dolomite and has been divided into an upper dolomite member and a basal sandy member. The upper member consists mainly of medium- to dark-gray fine-grained limestone containing bands of dark-gray crystalline dolomite. These beds commonly contain nodules and beds of black chert, some of which is oolitic. This unit contains the best zinc prospects in the area. The basal member has the same types of limestone and dolomite as the upper, but also has numerous thin quartzitic sandstone beds. Many of the limestones and dolomites in this member have sand grains and chert fragments scattered through them. In addition, many of the chert beds have Cryptozoon structures. These lithologic features are useful in establishing stratigraphic control for structural interpretations. Because of poor outcrops, most key beds cannot be followed continuously throughout the area.

The known zinc deposits occur on the northwest side of the Mosheim anticline. Two tear faults (pl. 1) pass through the area. The northernmost fault has a displacement of 10–60 feet; its trace strikes N. 60° W. and passes through a line of five sinkholes. The plane of the fault is not exposed but must be nearly vertical, the north side being displaced to the southeast. The bedding on the south side of the fault is dragged in the direction opposite to that expected on such faults. This same relationship is found on several other tear faults in this area (not shown on pl. 1) and in other parts of the East Tennessee district. This fault probably passes into bedding planes at its southeastern end. In addition there are many minor tear faults with displacements of a few inches to 40 feet. The strike of these faults ranges from N. 45° W. to N. 20° W. and may be controlled somewhat by changes in the regional strike of the beds around the nose of the Mosheim anticline. The displacement is not consistently in the same direction. Several minor flexures were mapped in the area. One occurs to the south of the main prospect pits.

The sharp flexures and the faults have produced large areas of brecciation. Two such brecciated areas are just west of the prospect pits. The breccias are 130 feet below the top of the Chepultepec and involve about 60 feet of limestone beds that have been dolomitized and brecciated. The dolomitization is apparently related to the tear fault that cuts the anticline south of the prospect area; the limestones have been dolomitized along the strike for 2,000 feet or more northeast and southwest of the fault. Similarly, the beds along the smaller faults are dolomitized, but the alteration extends only a few feet in either direction along strike. The dolomitization in some places has resulted in a fine-grained dolomite but more commonly has produced coarsely crystalline dolomite and some white crystalline dolomite.

PROSPECTS

The Brown prospect consists of one trench 50 feet long and 30 feet deep at the back of the prospect. The mineralized rock contains limonite, smithsonite, cerussite, pyrite, sphalerite, and galena. The oxidized minerals are concentrated in weathered brecciated dolomite along open cavities. The sphalerite is dark brown to black and occurs as masses and veinlets together with some pyrite and galena in the breccia along a fault trending N. 45° W. The breccia zone exposed in the trench is about 20 feet long and 10 feet wide. It is reported that from this trench the U.S. Bureau of Mines cut several channel samples which averaged 4 percent zinc.

The Tipton prospect, a trench 60 feet long and 15 feet deep, is caved. Limonite and a little smithsonite occur in vugs along open cavities. The prospect is in the same stratigraphic zone as the Brown prospect. No faults pass through this prospect, but a nearby flexure probably brecciated the rocks just west of the pit. The breccia is cemented with white dolomite that contains sparsely scattered crystals of dark-brown sphalerite.

The Colvard prospects, 2,300 feet southeast of the Tipton prospect, consist of two prospects about 500 feet apart. Here masses of light-brown sphalerite and white crystalline dolomite occur in massive brecciated dolomite beds in the basal sandy member of the Chepultepec Dolomite. Sphalerite is more abundant at the eastern prospect.

JOHNSON ANTICLINE

The known mineral deposits in the area, shown on the geologic map of the Johnson anticline, consist of 2 zinc prospects and 24 barite occurrences. The two occurrences of sphalerite have been explored by shallow test pits. Barite has been mined at four places, and a few other occurrences have been slightly explored. Most of the barite is white and crystalline, and is free from impurities, but dark-gray crystalline barite, also present, emits a fetid odor when freshly broken. The locations of the sphalerite and barite occurrences are shown on the geologic map (pl. 2).

The zinc and barite on the Johnson anticline occur principally in the Mascot Dolomite, but two barite prospects are known in the overlying Mosheim Member of the Lenoir Limestone, and the Roberta

Johnson zinc prospect is probably in the upper part of the Kingsport Limestone.

Because of the many thrust faults on the Johnson anticline, all occurrences of sphalerite and barite are within a few hundred feet of a thrust fault. Seven barite prospects and the Roberta Johnson zinc prospect are on or very near thrust faults. The R. P. Johnson zinc prospect is between a thrust fault and a small tear fault but is not definitely known to be related to either. Several of the barite occurrences consist of a cluster of barite crystals in unfractured limestone or dolomite.

The rocks in the Johnson anticline have been more closely folded and contain many more faults than do the rocks in the Mosheim anticline. Thus, it seems reasonable that the barite and zinc occurrences are principally localized in areas where favorable limestone beds have been cut and brecciated by thrust faults.

PROSPECTS AND MINES

Tine Britton barite prospect

The workings at the Tine Britton prospect consist of two small caved pits 30 feet apart along the strike of the beds. Abundant lumps of white and gray crystalline barite are scattered around the pits. Coarse-grained dolomitized limestone containing much white dolomite is exposed in the southeast side of the southwest pit, but no barite was seen in the rock. The pits are stratigraphically about 45 feet below the top of the Mascot Dolomite. A thrust fault occurs about 50 feet northwest of the pits. The beds southeast of the pits strike N. 10° E. and dip 35° SE.

J. J. King barite prospect

The pits at the J. J. King prospect were opened by J. H. Bass of Greeneville, Tenn., about 1925, on land owned by J. J. King, also of Greeneville. Two prospect pits are in an area 50 by 25 feet. One pit is now filled with water, and no bedrock is exposed. The walls of the other pit show secondary coarse-grained dolomite that is in part replaced by white and dark-gray barite. The barite occurs as crystalline aggregates, and some appears to fill fissures. No sulfide minerals were seen. This prospect is in the upper part of the Mascot Dolomite. Southeast of the prospects the beds strike N. 18° E. and dip 30° SE. The incomplete exposures are suggestive of a cross anticline just northeast of the prospect.

Matt Cox barite prospect

The Matt Cox prospect consists of three small pits about 120 feet below the top of the Mascot Dolomite. A thrust fault is exposed 15 feet to the northwest. Two of the pits contain white barite and fetid dark-gray barite in beds composed of very finely crystalline limestone and large blocks of coarsely crystalline dolomite.

Roberta Johnson zinc prospect

The Roberta Johnson prospect consists of a small pit with a loose block of coarsely crystalline dolomitized limestone that contains a small amount of yellow sphalerite. The zinc occurs with white dolomite and a little white barite. Fifty feet southwest along the strike, the bed that is mineralized at the pit is aphanitic limestone; 50 feet to the northeast the same bed is altered to coarse-grained dolomite but no zinc or barite was found.

The beds strike N. 40° E. and dip 55° SE. The pit is in the upper part of the Mascot Dolomite about 70 feet southeast of a thrust fault.

R. P. Johnson barite mine

The R. P. Johnson mine was developed as an open pit 60 by 25 feet and about 5 feet deep. The long axis trends northeast, parallel to the strike of the beds. The mineralized material occurs in the clay residuum and consists of pieces of white crystalline barite and black fetid barite.

Bedrock, exposed in the northeast wall of the pit, is the Mascot Dolomite. The rock is light- and medium-gray mottled fine-grained dolomite in beds 4 inches to 1 foot thick. The beds strike N. 25° E. and dip 40° SE. The pit is 250 feet southeast of a thrust fault.

Scattered pieces of barite occur on the surface between this mine and the R. P. Johnson zinc prospect. These pieces may have been hand-carried from the mine or they may be weathered material from the same ore zone present at the mine.

R. P. Johnson zinc prospect

The mineralized material in the R. P. Johnson prospect is exposed in one caved pit about 10 feet in diameter and 2 feet deep. The host rock consists of loose blocks of medium- and dark-gray, coarsely crystalline Mascot Dolomite that contains much white crystalline dolomite, a small amount of yellow sphalerite, and nodules of black dense chert.

Some folding of strata near the pit is indicated by changes in strike, which ranges between N. 25° E. and N. 48° E. The beds dip 45° SE. The pit is about 125 feet southeast of a thrust fault and about the same distance northwest of a small tear fault.

A few pieces of dark fetid barite and white crystalline barite occur in light-gray fine-grained dolomite about 100 feet northwest of the prospect pit. About 200 feet southwest of the pit, along the strike, a bed of coarse-grained crystalline dolomite is exposed. It is probably the same bed that is exposed in the pit. No barite or sphalerite was seen in this outcrop.

Maxwell Emmet Harmon barite mine

According to T. R. Harmon of Greeneville, Tenn., the Maxwell Emmet Harmon mine was opened about 1880, but the operators and the amount of barite mined are not known.

The workings consist of a badly slumped cut 100 feet long and 10–15 feet deep. T. R. Harmon stated that the cut was originally more than 30 feet deep. No bedrock is exposed in the vicinity of the pit.

The mine is in the Mascot Dolomite. In the road-metal quarry about 1,100 feet southwest of the mine coarse-grained crystalline dolomite about 3 feet thick is exposed. This bed may be the same as the mineralized unit at the pit. The mine is along the projected strike of a fault exposed in the quarry, but exposures near the mine are too poor to determine with certainty that the fault passes through the mine.

Nell Harmon barite prospect

The workings of the Harmon prospect consist of one caved pit 30 feet long, 15 feet wide, and 4 feet deep. Granule- to cobble-sized pieces of black fetid barite occur in material removed from the pit.

No bedrock is exposed in the prospect area. The mineralized area is between two minor thrust faults in rocks near the top of the Mascot Dolomite.

W. H. Matthews barite prospect

Abundant float of white crystalline barite in pebble- and cobble-sized pieces occurs at the W. H. Matthews prospect in an area 50 feet wide and 75 feet long. The float is from the upper part of the Mascot Dolomite. The area has not been prospected.

James Berkey barite prospect

A few pieces of light-gray slightly fetid barite and much hydrous iron oxide was found at the James Berkey prospect. The iron oxide is scattered over an area of 100 square feet, but barite was seen at only one place. This prospect is on a thrust fault; the barite probably comes from the Athens Shale just under the fault plane.

N. C. Hartman barite mine 1

The original pits from which barite was mined at the N. C. Hartman mine are now caved and filled. Pebble-sized pieces of white and dark-gray barite were found in a ditch near the old pits. The occurrence of barite falls on the projected position of a thrust fault. Near the pits coarse-grained dolomitized limestone, belonging to the upper part of the Mascot Dolomite, occurs in scattered exposures. No barite was seen in outcrops.

N. C. Hartman barite mine 2

The Hartman 2 mine consists of a single pit 20 by 15 feet and 4 feet deep. The pit was opened about 1935 and some ore was shipped, but the amount is not known. Many small pieces of white and dark-gray fetid barite were seen around the edge of the pit.

The pit is near the top of the Mascot Dolomite near the axis of an overturned anticline. The small thrust fault mapped to the northeast may extend as far as the pit.

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