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VIRGINIA DIVISION OF GEOLOGY

WILLIAM M. McGILL, *State Geologist*

Bulletin 70

Sulfide Mineralization in the Shenandoah Valley of Virginia

By

PAUL HERBERT, JR., and ROBERT S. YOUNG

CHARLOTTESVILLE, VIRGINIA

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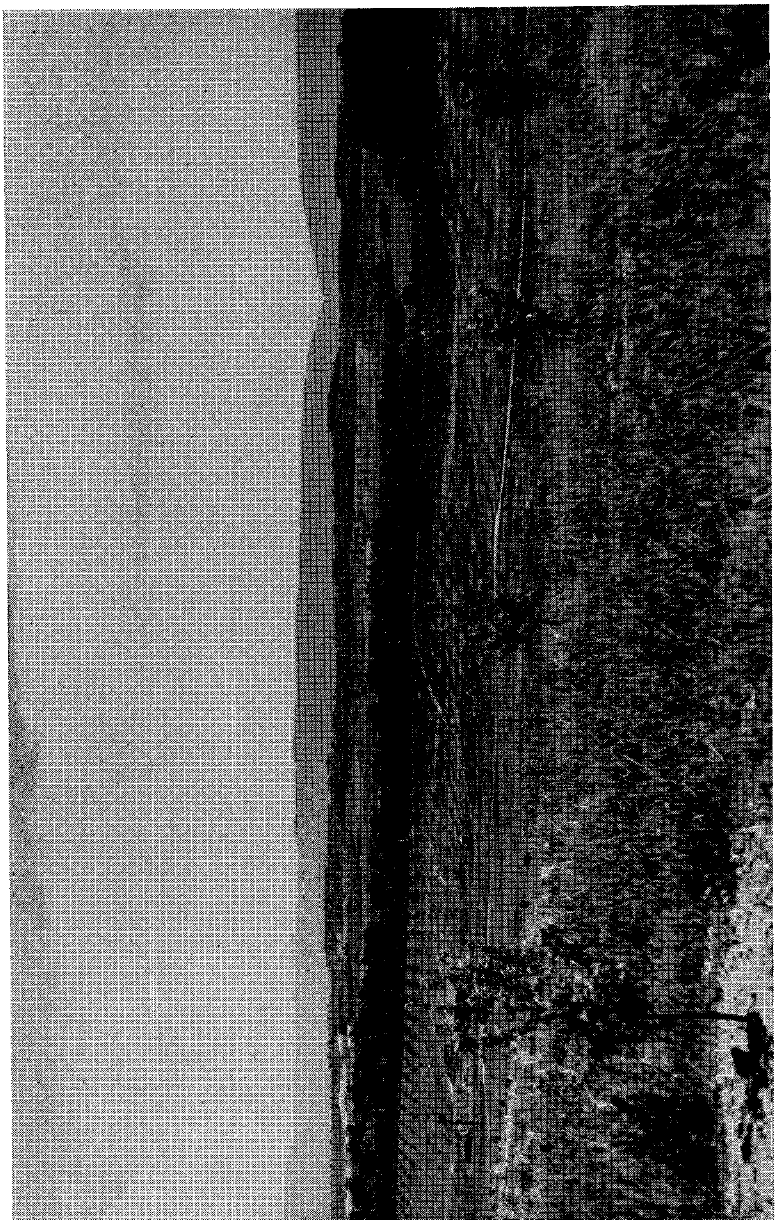
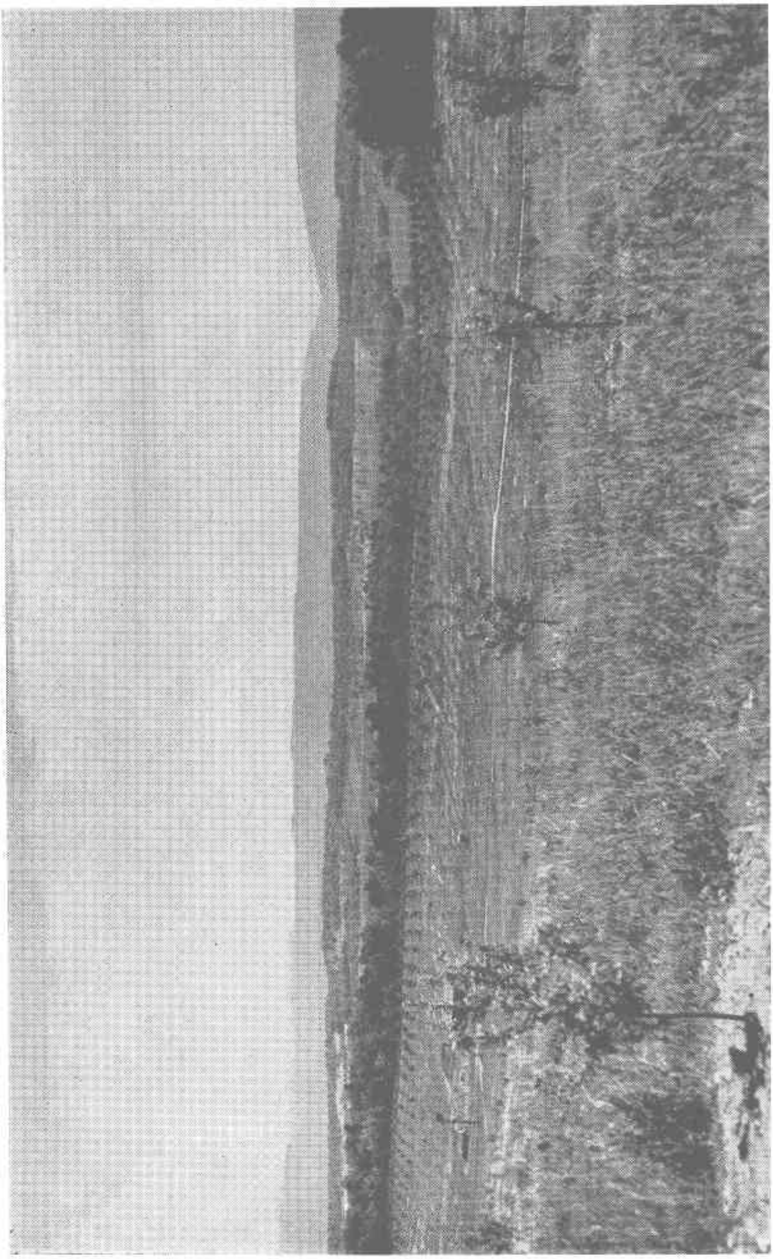


The Cambro-Ordovician lowland of Shenandoah Valley as seen from Baer Ridge, Broadway quadrangle. The distant ridge is Massanutten Mountain, prominently broken by New Market Gap (right center). The middle ridge, Timber Ridge, is the site of the Timberville mine, which is located about midway along the length of the ridge.



The Cambro-Ordovician lowland of Shenandoah Valley as seen from Baer Ridge, Broadway quadrangle. The distant ridge is Massanutten Mountain, prominently broken by New Market Gap (right center). The middle ridge, Timber Ridge, is the site of the Timberville mine, which is located about midway along the length of the ridge.

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LETTER OF TRANSMITTAL

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND DEVELOPMENT
DIVISION OF GEOLOGY

CHARLOTTESVILLE, VA., May 21, 1956.

To the Department of Conservation and Development:

GENTLEMEN:

I have the honor to transmit for publication as Bulletin 70 of the Virginia Division of Geology, the text, geologic maps, and other illustrations of a report on *Sulfide Mineralization in the Shenandoah Valley of Virginia,* by Dr. Paul Herbert, Jr., of Tri-State Zinc, Inc., and Dr. Robert S. Young, of the Virginia Division of Geology.

This report was prepared as a cooperative project of Tri-State Zinc, Inc., and the Virginia Division of Geology. Through the courtesy of Tri-State Zinc, Inc., information was made available on the results of core drilling and other exploratory work done in Virginia by that corporation and permission granted to include the same in this report.

The report contains detailed information on the geology and occurrence of sulfide minerals in parts of Rockingham and Shenandoah counties in the Shenandoah Valley of Virginia. This information will be of much value to those interested in the occurrence of sulfide ores, particularly lead and zinc, in the district covered by the report.

Grateful appreciation is expressed to Dr. Paul Herbert, Jr., and the management of Tri-State Zine, Inc., for their wholehearted cooperation in this project.

Respectfully submitted,

WILLIAM M. MCGILL,
State Geologist.

Approved for publication:

Department of Conservation and Development,
Richmond, Virginia, May 21, 1956.
RAYMOND V. LONG, *Director*

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ILLUSTRATIONS

Sulfide Mineralization in the Shenandoah Valley of Virginia[1]

By

PAUL HERBERT, JR., AND ROBERT S. YOUNG[2]

ABSTRACT

Sphalerite and associated sulfides occur in scattered outcrops of upper Beekmantown dolomite (Ordovician) over an area 50 miles long and 25 miles wide, centered near Timberville, Rockingham County, Virginia. Drilling in the central-western part of the area has proved one orebody and several geologically similar, though sparsely mineralized, zones.

The principal sphalerite occurrences are: (1) disseminated through beds of coarse "recrystalline" dolomite; (2) with white dolomite in veins; and (3) with white dolomite in breccias. Although both sedimentary and tectonic breccias are present, only the latter are important as hosts. Tectonic breccias are classified as: (1) bedded, (2) chatter, and (3) fault. Chatter breccias are the potential ore producers.

The primary metallic mineralization is sphalerite-pyrite, locally with minor amounts of galena and chalcopyrite. Secondary products are smithsonite and greenockite. The order of primary sulfide deposition was: (1) pyrite, (2) galena, and (3) sphalerite with chalcopyrite. These minerals selectively replace white-dolomite-cemented breccias and post-date a period of thrust faulting.

The location, type of occurrence, and local geology of the most important properties are described. The properties are: (1) Timberville, (2) Zirkle, (3) Gordon, (4) Bowers-Campbell, (5) Vetter, (6) Bowman, (7) Armentrout, (8) Showalter, (9) Minnick, (10) Tusing, (11) "Wiseland," and (12) Grove Hill.

The ore-bearing breccia body (Bowers-Campbell property) is a southward pitching, irregular lens, 700 feet long, as much as 100 feet wide, and extending to a depth of more than 700 feet. The breccia lens parallels the strike of the rocks (N. 34° E.) and cuts vertically across the dip (30° E.). Breccia fragments have a rather uniform size distribution, a definite though subtle lineation, and within the breccia mass stratigraphic units have moved down. The enclosing beds, though tilted and faulted, show no local folding.

Three breccia bodies are irregularly spaced along the strike of the western Beekmantown belt. Subsurface data indicate that these near-vertical breccias may tend to repeat, one nearly above the other. These indications and the observation that tension was the apparent stress lead

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[1]This report is based in large part on a paper presented by the authors before the Southeastern Section, Geological Society of America, Durham, North Carolina, April 1955.
[2]Tri-State Zinc, Inc., and Virginia Division of Geology.

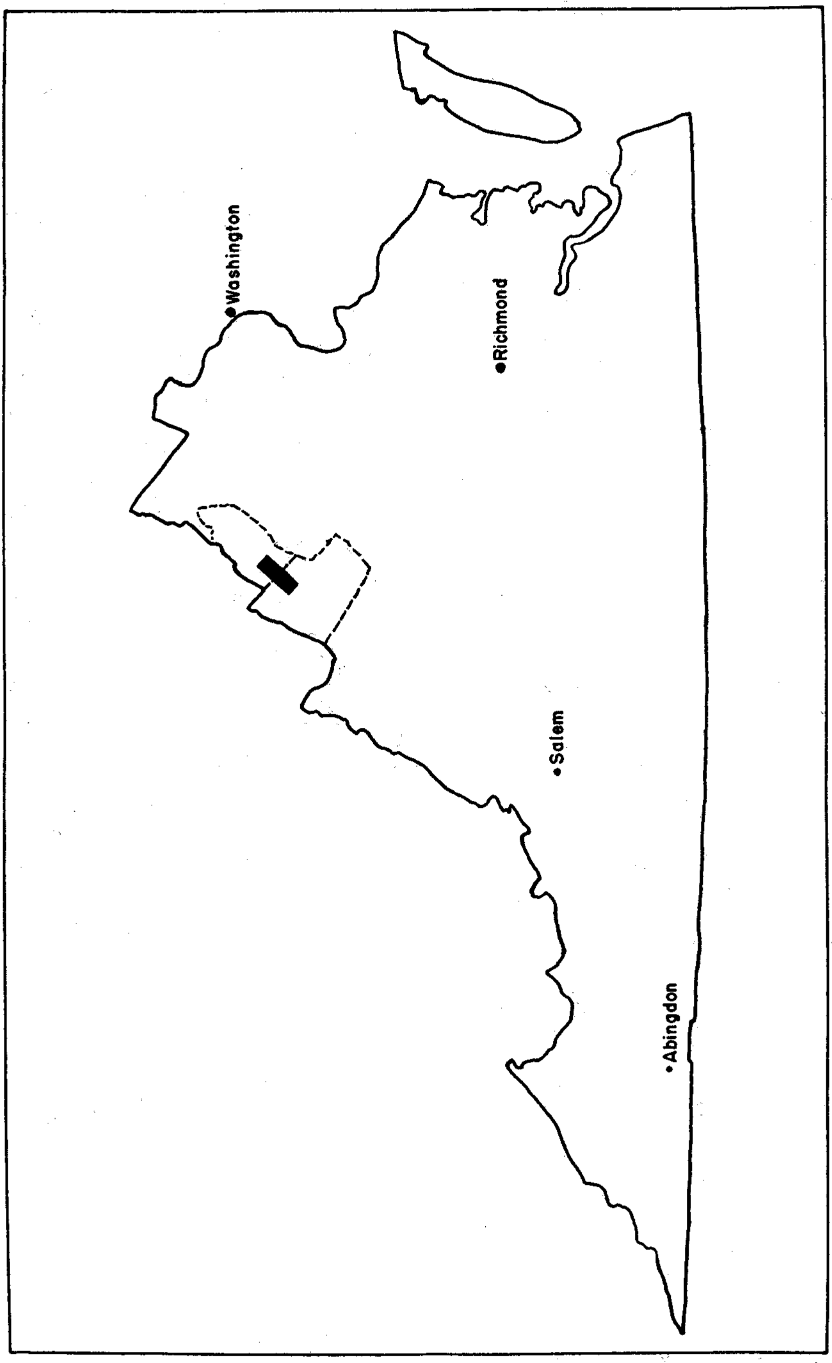


Figure 1.—Index map of Virginia showing Rockingham and Shenandoah counties and the map area of Plate 3.

the authors to postulate that the breccias are large-scale chatter lenses related to a major anticlinal cross-warp and the North Mountain fault.

The nature of the sulfide minerals, their distribution areally and within individual deposits, and the proximity of igneous rocks form the basis for classifying the mineralization as low-temperature hydrothermal.

INTRODUCTION

Recent zinc prospecting in the northern Shenandoah Valley of Virginia has indicated the possibility that a part of this area may become a new mining district. The most intensely mineralized part of the district centers near the town of Timberville, a few miles west of New Market, in Shenandoah County, Virginia (Pl. 3; Fig. 1). This central part is surrounded by minor shows of zinc sulfide dispersed over an area approximately 50 miles long and 25 miles wide. The underlying rocks are Cambro-Ordovician limestones and dolomites. Sphalerite, widespread and predominant among the sulfides, occurs most frequently in upper beds of the Beekmantown dolomite (Ordovician).

This report is designed to provide detailed information on the various prospects, as well as broader aspects of regional hydrothermal mineralization, in an effort to aid future prospecting.

HISTORY

The date of first sulfide production from this district is not known; however, unverified reports indicate that galena was extracted from the Wine (now Gordon) property during the Civil War period. The first recorded mining agreements are those for the Wine property, dated February 8, 1893, and the Shacklett (now Bowers) property, dated May 30, 1894. The nature and extent of work performed under these agreements are unknown, but an old headframe is reported to have been standing on the Bowers property about 1900. In the early 1900's, Thomas M. Wise, New Market, Va., did surface prospecting in the general area and is known to have dug pits on the Weatherholtz property (Timberville mine) and on his own property south of New Market. About 1913, The New Jersey Zinc Company churn drilled several holes on the Wise (now Minnick) property. In late 1929 and early 1930, the old workings on the Wine property were reopened by the Harford Talc and Quartz Company of Bel Air, Md., in cooperation with the Levering Brothers of Baltimore. The work consisted of cleaning out two existing shafts and a short drift, east from the north shaft.

The first organized attempt to exploit zinc deposits in the district was in 1948-50, when local interests organized the Timberville Mining Company and developed what has been known as the "Timberville mine," on the Weatherholtz property. A small amount of ore was shipped to Mascot, Tenn., before the mine closed in 1950.

In 1949, Carl Stehle of New York became interested in the Bowers and Zigler properties. The latter is located 1½ miles northeast of the Bowers property. In the fall of 1949, a resistivity survey was run on these properties by F. W. Lee, and comprehensive geological reports were written by Robert C. Stephenson (1949; 1950). In January and February of 1950, a diamond-drill program was carried out. One hole, drilled on the Bowers property, intersected 60 feet of zinc sulfide ore.

During the period 1950-54, The American Zinc Company of Tennessee, The New Jersey Zinc Company, and Tri-State Zinc, Inc., initiated and maintained programs of intensive exploration within the district. However, the only orebody found is on the adjacent Bowers and Campbell properties; to the present time this deposit has not been developed.

PREVIOUS WORK

A comprehensive report has not been published on zinc mineralization in Shenandoah Valley. Nason (1917, p. 838) refers to three sets of "fissures" associated with zinc deposits near New Market. Currier (1935a, p. 94), in a report devoted primarily to the lead and zinc ores of southwestern Virginia, mentions two localities in Shenandoah County. One is the Gordon prospect and the other is apparently the Timberville mine. In reference to the latter locality Currier mentions that, according to a personal communication from Charles Butts, the prospect is probably in the Mosheim limestone. However, the Timberville mine, as most other prospects, is in upper Beekmantown. Oder and Hook (1950, p. 85) briefly describe the area and types of deposits. Green (1951, p. 347) published partial results of a spectrographic study of minor elements in the sphalerite, indicating that the ores were of low-temperature origin. Herbert and Young (1955, p. 1689) defined the limits of the district and pointed out the apparent importance of certain breccia bodies.

It should be noted that the unpublished reports by Robert C. Stephenson (1949; 1950) represent the most comprehensive work on the area known to the authors. They include investigations of the principal mineralized localities in the Broadway syncline and geologic mapping for about 2 square miles around the Bowers property. The importance of brecciation was recognized, and breccias possibly accompanied by thrust faulting were considered the controlling factors in localizing ore solutions. However, the breccias were thought to be parallel to the bedding. In the supplemental geologic report, subsequent to drilling, Stephenson (1950) concluded that the breccias may have developed in brittle beds along flexure zones. He also pointed out that zinc deposits in the area occur on a broad anticlinal cross-warp which extends northwesterly from the Blue Ridge to the Appalachian Plateau.

ACKNOWLEDGMENTS

We are grateful for the cooperation of Tri-State Zinc, Inc., and William M. McGill, State Geologist, for the support of the field and laboratory work upon which this bulletin is based. We are particularly indebted to Michael H. Loveman, Robert F. Playter, and Victor C. Allen of Tri-State Zinc, Inc., and to Raymond V. Long, Director of the Department of Conservation and Development, for authorization to publish this manuscript as a Division Bulletin. For reading and offering criticisms of the manuscript, we wish to express our gratitude to Raymond S. Edmundson, University of Virginia; Herman W. Ferguson and Pruitt R. Crumpton, Tennessee Coal & Iron Corp.; J Harlen Bretz, University of Chicago; and Kathleen McQueen, United States Geological Survey.

Special acknowledgment is made to the following: Charles R. L. Oder and The American Zinc Company of Tennessee for the release of information on the Gordon and Timberville properties; Wilton T. Millar, United States Bureau of Mines, for information on the Timberville mine; Roy A. Bailey, United States Geological Survey, for mineral identifications; Robert W. Johnson, United States Geological Survey, for discussions of geophysical data; Harold Weaver, assistant to Paul Herbert, Jr., in field work; Allen V. Heyl, United States Geological Survey, for stimulating discussions on the structural and economic geology of the area as well as criticising the manuscript; and to Clarice P. Bryant and Linwood H. Warwick, Virginia Division of Geology, for editorial assistance.

To the citizens of the district we offer special thanks for the cooperation and many courtesies extended during the period of field work.

STRATIGRAPHY

With few exceptions, the sulfide minerals are restricted to the upper part of the Beekmantown formation, especially the upper 1000 feet. The following description of the Lower Ordovician and lower Middle Ordovician stratigraphy of Shenandoah Valley identifies this part of the column with other areas.

LOWER ORDOVICIAN

Chepultepec limestone.— The basal Ordovician Chepultepec consists of approximately 500 feet of dark-gray, fine-grained limestone with scattered tan dolomites. These beds are gradational both with subjacent Conococheague limestones and dolomites (Cambrian) and with succeeding Beekmantown dolomites (Ordovician). Faunal content indicates correlation with the Gasconade of Missouri and the Stonehenge of Pennsylvania and Maryland (Fisher and Young, 1955; Unklesbay and Young, 1956).

Beekmantown formation.—The Beekmantown, in this part of the Valley, is about 2500 feet thick and is predominantly dolomite (Pl. 2A), but with as much as 50 percent interbedded limestone in the upper 100-200 feet. Several chert horizons are present near the middle of the unit. Although the Beekmantown has not been divided into members in this area, Butts (1940, pp. 116-117) recognizes two faunal zones, an upper *Ceratopea* zone and a lower *Lecanospira* zone, which correlate respectively with the Bellefonte and Nittany members of the Beekmantown of Pennsylvania. Other probable equivalents are the upper part of the Knox group of Tennessee, the Arbuckle limestone of Oklahoma, and the Ellenburger limestone of Texas.

The top of the Beekmantown is marked, throughout the Valley of Virginia, by an unconformity with varying degrees of relief.

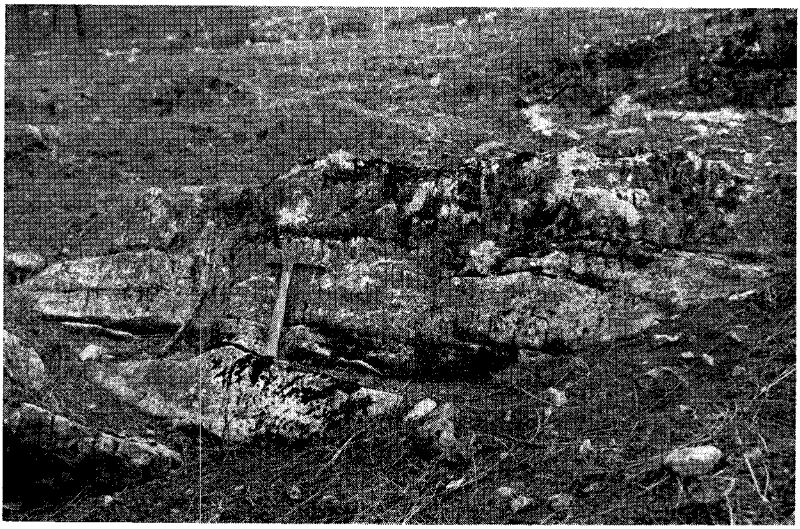
As most of the known mineralization is in the upper part of the Beekmantown, core drilling has made possible the recognition of a detailed stratigraphic section for the upper 1000 feet of the unit. This section is based on the presence of 10 marker beds. The most important markers are dark carbonaceous layers, several oolite beds, and persistent thin cherts. Exact correlation is possible for at least 25 miles along the strike of the westernmost Beekmantown belt (Pl. 3).

Plate 4 is a detailed stratigraphic section for the uppermost Beekmantown, showing relief of the unconformity, key beds, and stratigraphic position of zinc deposits. This subsurface section has greatly aided surface prospecting.

MIDDLE ORDOVICIAN

New Market limestone ("Mosheim").—The New Market limestone consists, in most part, of a series of thick-bedded, dove-gray calcilutites

Virginia Division of Geology Bulletin 70 Plate 2



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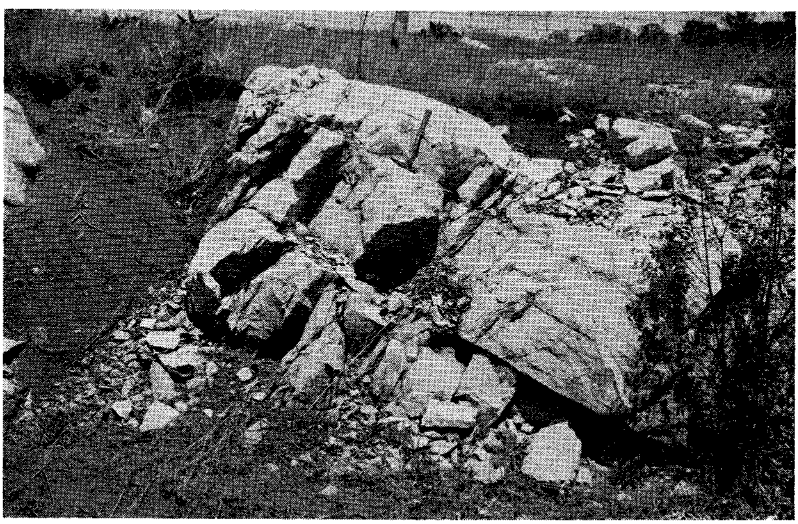
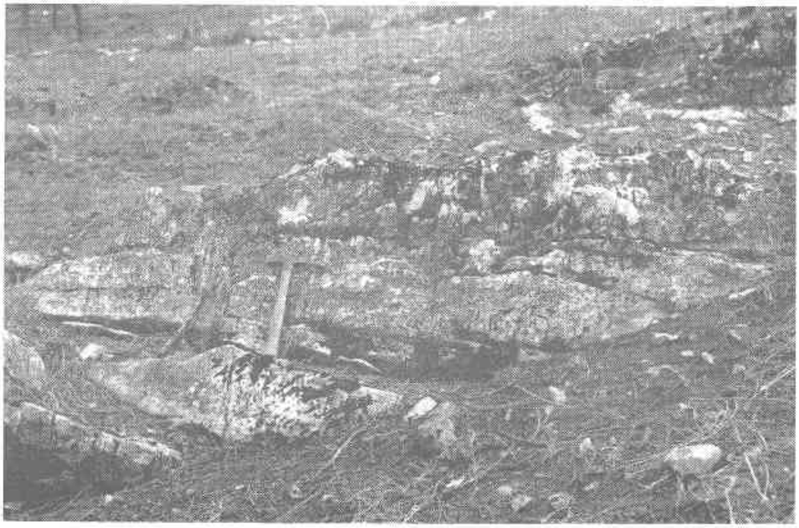


B.

A, Medium-bedded, fine-grained gray dolomites of the upper Beekmantown. These beds are exposed, above the sphalerite horizon, on the Minnick property.

B, Thick-bedded calcilutites of the mid-New Market, exposed along State Road 881 west of Timberville.



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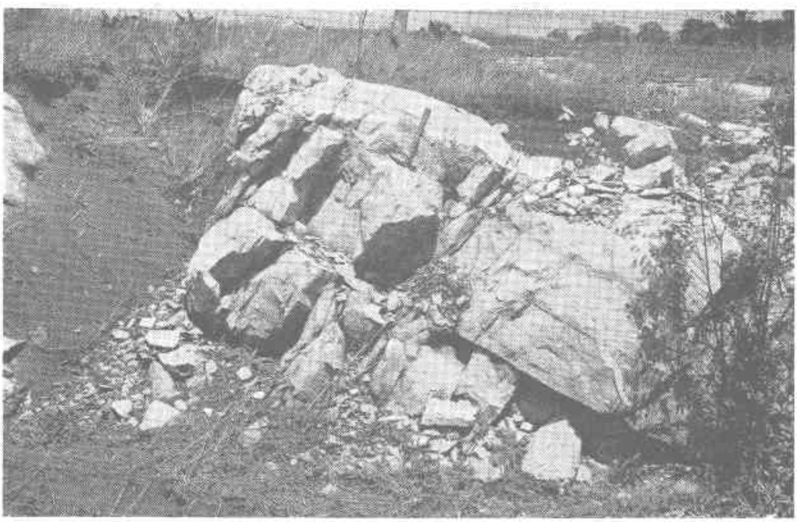


B.

A, Medium-bedded, fine-grained gray dolomites of the upper Beekmantown. These beds are exposed, above the sphalerite horizon, on the Minnick property.

B, Thick-bedded calcilutites of the mid-New Market, exposed along State Road 881 west of Timberville.

(Pl. 2B). The lower part of the formation is commonly thin-bedded and somewhat impure. Thickness of the New Market varies considerably because of disconformable relations with the underlying Beekmantown. In Shenandoah Valley the thickness usually is 60 to 200 feet. Widespread correlations of the New Market are uncertain.

MINERAL DEPOSITS

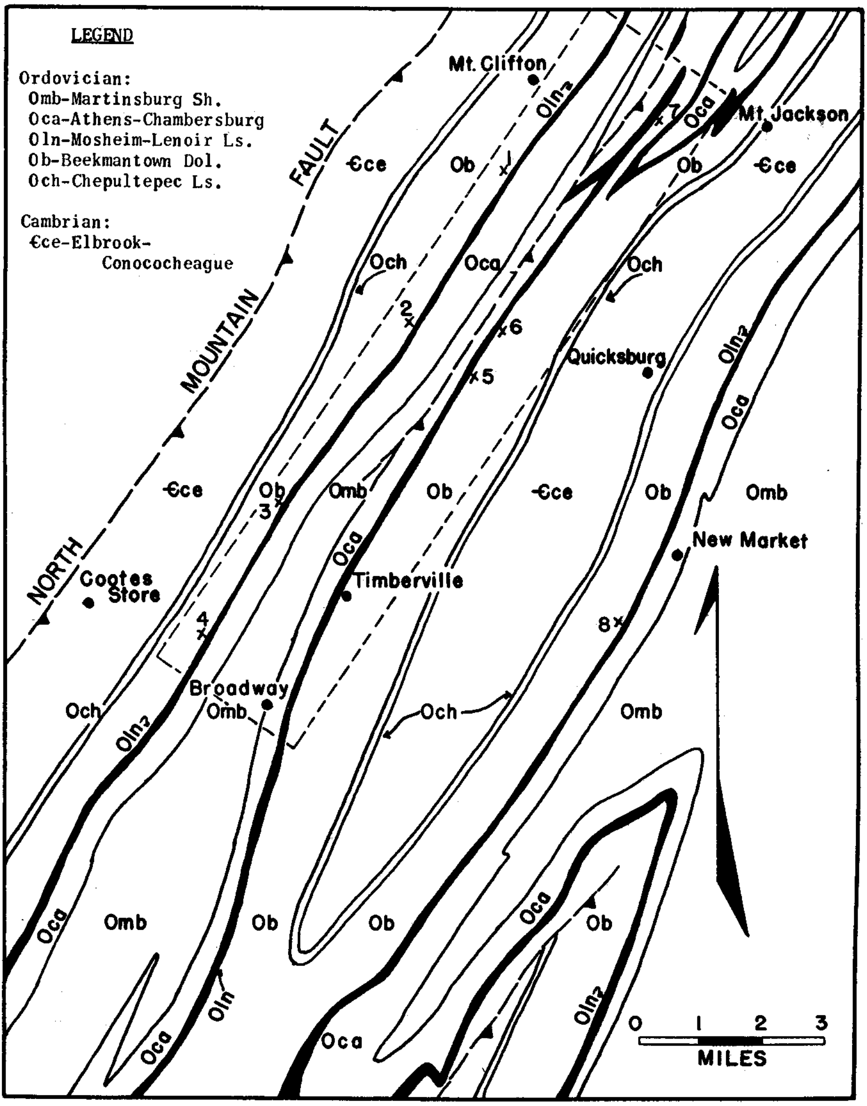
Most of the zinc deposits occur within the 40 square miles outlined in Plate 3. Specific areas of discussion are indicated. Some of the minor sphalerite localities which outline the district are not shown on Plate 3, but are described in the text of this report.

MINERALOGY

The mineralogy of the sulfide deposits is simple; sphalerite, galena, pyrite, chalcopyrite, and greenockite are known. Within the district, sphalerite predominates over all other sulfides, with local concentrations of galena known. Pyrite and greenockite are widespread, most often in minor amounts. Chalcopyrite is known only in one locality, but its presence is suspected in several other areas. Fluorite is known to occur with zinc at several localities. One unknown mineral has been reported from the Timberville mine (Stow, 1950, pp. 384-385).

All mineralized outcrops show some degree of oxidation, generally expressed as concentrations of zinc carbonate. The depth of complete oxidation is very shallow, generally less than a few feet, and in many outcrops sphalerite occurs to the surface. Because of the sparsity of pyrite, no mineralized outcrops have a well-developed gossan. However, at the Bowers-Campbell and Minnick properties gossan fragments are present in dump material.

Sphalerite is by far the most important base-metal sulfide of the Timberville district, both in concentration and geographic distribution. A striking feature of the sphalerite is the color variation from place to place within the district. Brown, honey-yellow, red, and various shades of green-brown sphalerite are known. Within limits, the colors are characteristic of specific localities, and apparently represent definite variations in iron content of the sphalerite. Galena is much less widely distributed than sphalerite; only three concentrations are known, none of which have proved economically significant. Pyrite has been identified in every known prospect; it is usually present as disseminated grains, although thin stringers or veinlets are not uncommon. Chalcopyrite has been recognized only at the Minnick prospect, occurring there as microscopic grains in sphalerite. A poorly defined linear arrangement of the chalcopyrite grains within the sphalerite indicates that they may be oriented along cleavage planes. Detection of copper in trace element analyses of sphalerite from other prospects points to the possibility that chalcopyrite may be more common than revealed by microscopic examination. Smithsonite and greenockite (and hemimorphite?) are known only in zones of oxidation. Smithsonite occurs as rounded incrustations and honeycomb-like masses on sphalerite-bearing outcrops throughout the district (Pl. 5). Greenockite is found as thin films on fracture sur-



Geologic map of the Timberville area. The area of most intense mineralization is shown in dashed outline. The principal prospects are: (1) Tusing, (2) Gordon, (3) Bowers-Campbell, (4) Vetter, (5) Timberville, (6) Zirkle, (7) Bowman, and (8) Minnick. Geology adapted from Edmundson (1945).

faces and with secondary zinc on mineralized exposures.[3] Fluorite, commonly a purple variety, has been noted at several zinc localities. It is not known to occur in quantities of commercial significance.

PARAGENESIS

At those few places within the district where pyrite, sphalerite, and galena occur together, the order of deposition appears constant. Minor evidences of reversals of paragenetic sequence indicate that there must have been considerable periods of time overlap. Furthermore, it is probable that compositional changes within the mineralizing solutions took place on both broad and local scales.

Sulfide and gangue mineralization seems to have followed the general sequence illustrated in Figure 2.

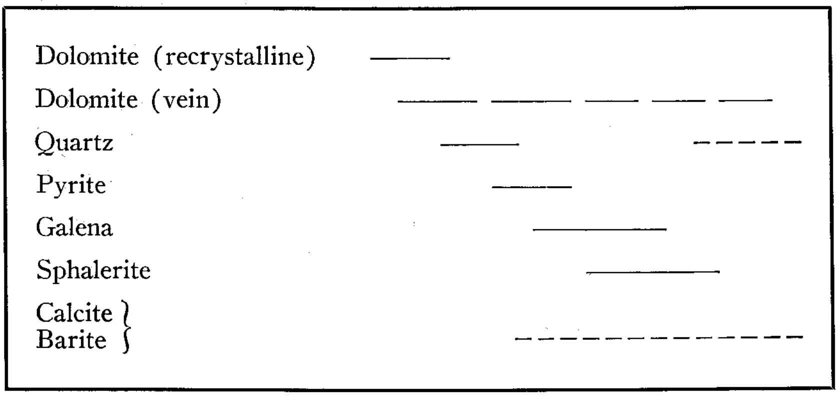
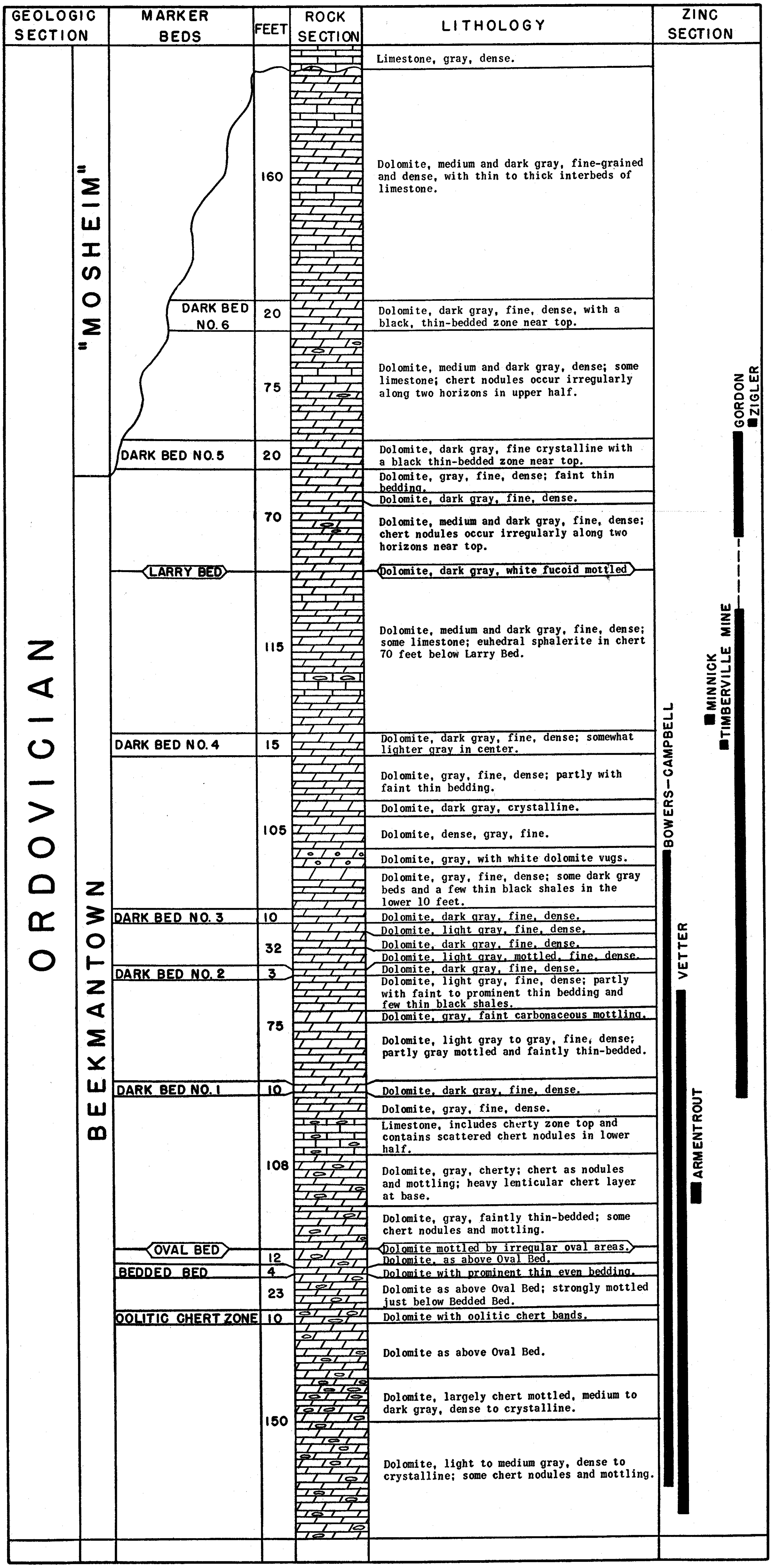


Figure 2.—Paragenetic sequence of primary sulfides and gangue in the Timberville district.

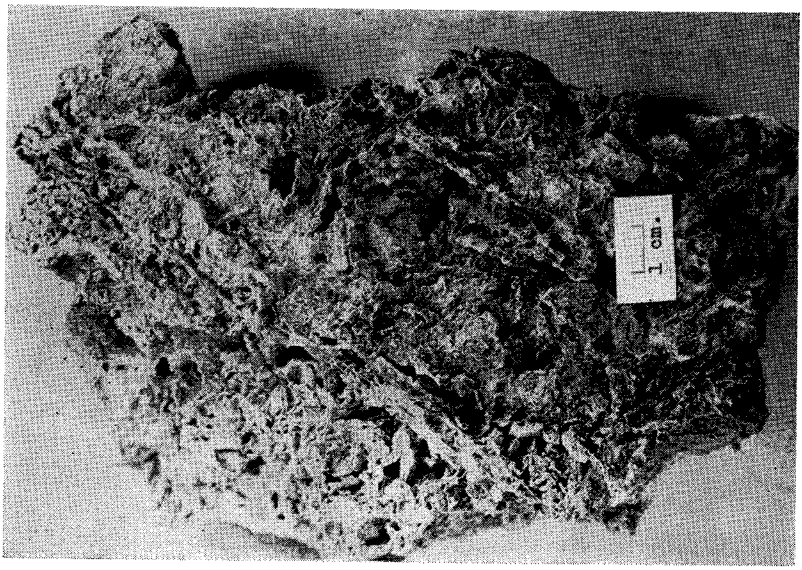
As previously noted, sphalerite color changes are evident throughout the district and even within individual deposits. The Bowers-Campbell breccia deposit is an example of the latter condition. In this deposit, there were either two closely spaced stages of sphalerite deposition or a change in conditions during deposition, for the central part of larger crystals is red-brown sphalerite while smaller crystals and the outside of larger crystals are honey-yellow sphalerite. The gradational character of color change suggests a continuous compositional variation of mineralizing solutions.

If a generalization can be made with respect to sphalerite throughout the district, it is that the lighter shades of sphalerite are found in those deposits nearer the district limits. There is little doubt that color variations directly reflect variations in sphalerite iron content. If the rough zonation suggested above is valid, the iron content of the sphalerite de-

3. Greenockite was identified by R. A. Bailey, U. S. Geological Survey, through chemical tests and x-ray pattern.



Detailed stratigraphic section of the uppermost Beekmantown in the Timberville area. Note the vertical distribution of zinc mineralization.



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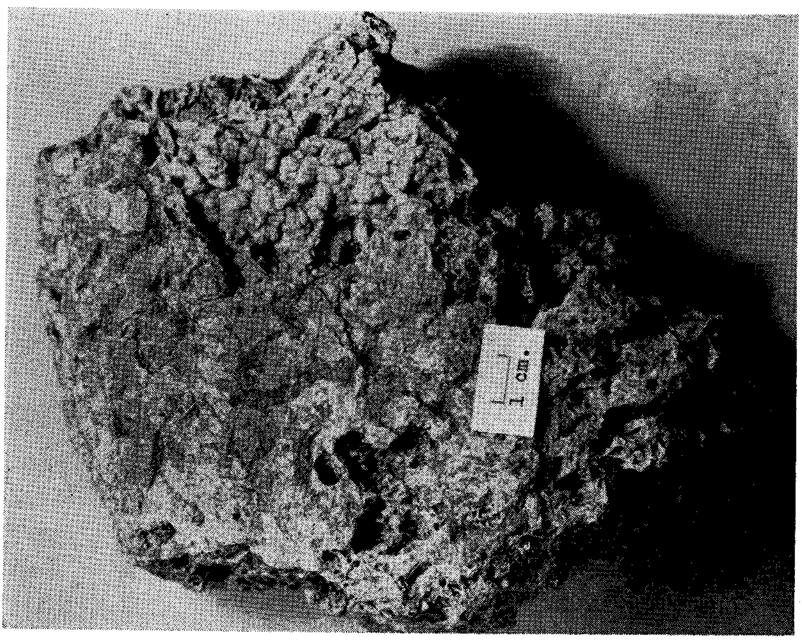
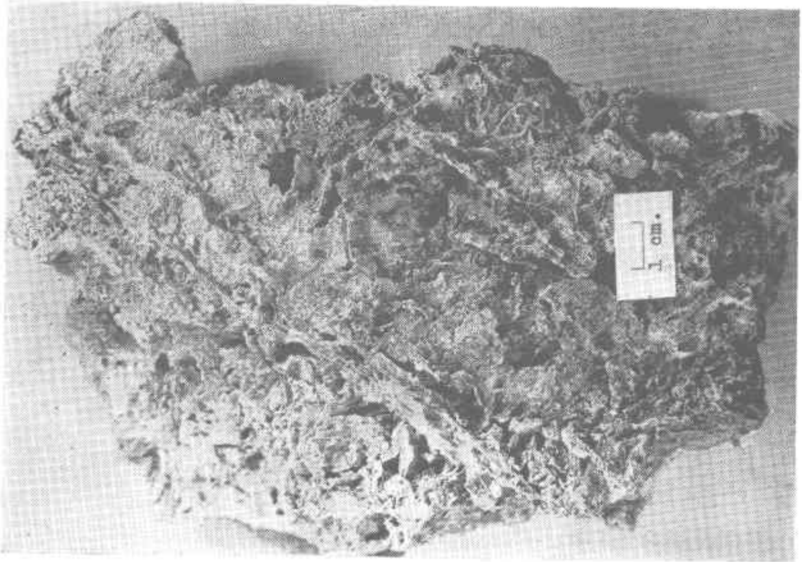


B.

Physical varieties of smithsonite, Timberville mine; A, honey-comb; B, rounded incrustations.



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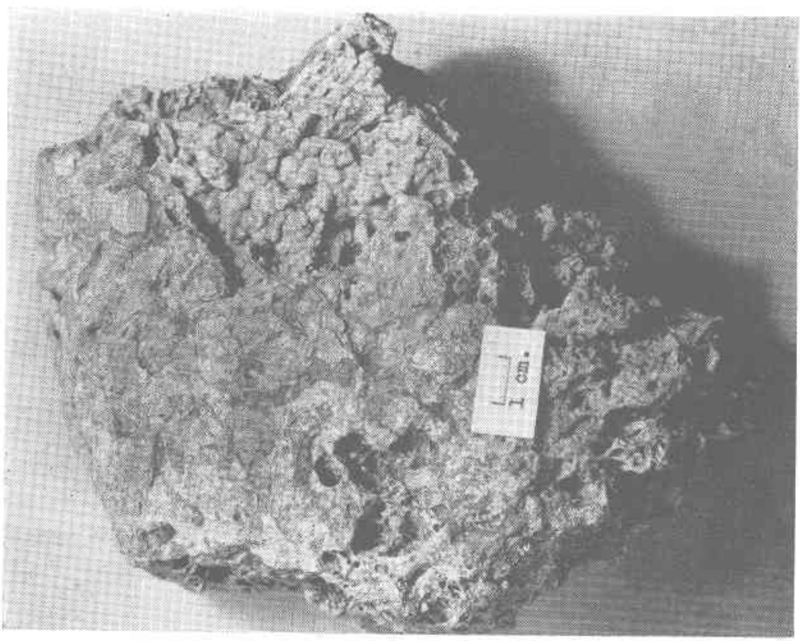


B.

Physical varieties of smithsonite, Timberville mine; A, honey-comb; B, rounded incrustations.

creases away from the most intensely mineralized part of the district.

TRACE ELEMENTS

Green (1951) briefly reported the presence and significance of trace elements in "pure" sphalerite samples from both limbs of the Mt. Jackson ("Timberville") anticline. Trace elements tested for and those detected are given in Table 1.

Table 1.—*Trace element analysis of sphalerite samples, east and west limbs of the Mt. Jackson ("Timberville") anticline.*

S—strong, +0.5%; W—weak, <0.10%>0.01%; Tr—trace, <0.01%; nd—not detected.

	Cd	Ga	Ge	In	Sn	Tl	As	Mn	V	Au	Cu	Co	Fe	Pb	Ni	Cr
West limb	S	W	Tr	nd	nd	nd	nd	nd	?	nd	Tr	nd	S	Tr	nd	Tr
East limb	S	W	Tr	Tr	nd	nd	nd	nd	?	nd	Tr	nd	S	Tr	nd	nd

Two composite samples from the Bowers-Campbell orebody yielded the partial analyses of Table 2.

The question immediately arises as to the validity of using trace elements as indicators of relative temperature of deposition and in correlation of types of deposits. This in turn leads to the problem of which of the trace elements are chemically combined with the sphalerite and which are mechanically included. Warren and Thompson (1945, p. 313) state that, "On the basis of our own polished section studies and of the conclusions arrived at by other workers, we consider that the following elements are chemically combined with the sphalerite: cadmium, gallium, germanium, indium, manganese, and iron. On the other hand, the presence of arsenic, antimony, tin, copper, bismuth, tellurium, gold, silver, and lead are probably the result of one or more minerals containing these elements being mechanically included in the sphalerite." On the basis of limited study, the authors agree with these conclusions and have therefore indicated, in the comparative chart that follows (Table 3), the more doubtful elements.

In an attempt to form a comparison with other similar areas and types of mineralization, a comparative chart of trace elements in sphalerite has been prepared and is presented as Table 3. Comparisons are based largely on published data. The trace elements listed for Timberville are those cited by Green (1951), because that spectrographic study utilized individual samples rather than the composites shown in Table 2.

Table 2.—*Partial analyses of composite samples of Bowers-Campbell ore.*

Asterisks indicate spectrographic determination.

	ASSAY #607110	ASSAY #607111
Iron	3.81	1.80
Lead	0.03	0.02
Cadmium	0.0010	0.0015
*Gallium	tr.	tr.
*Germanium	tr.	tr.
*Arsenic	0.01	tr.
*Copper	tr.	tr.
*Antimony	tr.	tr.
*Nickel	tr.	tr.
*Cobalt	tr.	tr.
Gold	none	none
Silver	none	none

Disregarding relative percentages present, trace element content more closely allies the Timberville deposits with the low-temperature barite veins of central Kentucky than with any other type. This apparent correlation is based on the mutual absence of Mn, Sn, Tl, Co, Ni, As and the presence of Cd, Ge, Ga, In.

There is not complete agreement on the significance of the various trace element suites, differences centering about the importance of cadmium as an indicator. This difference of opinion is based on absolute cadmium content, and Stoiber (1940, p. 513) states, "High concentrations of cadmium (greater than 0.6%) would seem most likely to occur in sphalerite from deposits of other than low temperature type." It is interesting to note that cadmium assays on samples from Timberville district range between 0.001 and 0.6% Cd (Green, 1951). Warren and Thompson (1945, pp. 327-329) draw the following conclusions regarding temperature: (1) Cd, Cu, and Fe occurred in all samples examined; (2) high iron-bearing sphalerite is most apt to be found in high-temperature de-

Table 3.—*Trace element content of sphalerite from selected localities in the eastern United States.*

All data except Timberville from Stoiber (1940, p. 504).

	Cd	Mn	Ge	Ga	In	Sn*	Tl	Co	Ni	Bi*	Mo	As*
Timberville, Va.	X	nd	X	X	X	nd	nd	nd	nd	?	?	nd
Tazewell, Tenn.	X	X	X	X	nd	nd	nd	nd	X	nd	nd	nd
Austinville, Va.	X	X	X	nd	nd	nd	nd	nd	X	nd	nd	nd
Mascot, Tenn.	X	nd	X	X	nd	nd	nd	nd	nd	nd	nd	nd
Friedensville, Pa.	X	X	X	X	nd	X	nd	nd	nd	nd	nd	nd
Central Kentucky	X	nd	X	X	X	nd	nd	nd	nd	nd	nd	nd

*—of doubtful value; X—present; nd—not detected.

posits; (3) high concentrations of Cd are most likely to occur in moderate- to low-temperature types; (4) Mn favors high temperatures; (5) Ga, In, and Sn are most prominent in medium temperatures; and (6) Ge and V are more likely to occur in low-temperature types of deposits.

Conclusions based only on trace element content reveal that the zinc sulfide deposits of the Timberville district may be classified as moderate- to low-temperature types. However, it is well to note a point emphasized by Stoiber (1940, p. 519): ". . . contrasts in minor element content in sphalerite from deposits of similar temperature type may be ascribed not only to variable temperature of sphalerite formation within the range considered, but also, and in large part, to the contrasting chemical character of the depositing solutions in the different metallogenetic regions."

TYPES OF OCCURRENCE

Base-metal sulfides are found in the Timberville district in three major occurrences: (1) associated with recrystallized rock dolomite ("recrystalline"), (2) with white vein dolomite as simple fracture fillings, and (3) with white vein dolomite cementing breccias. All types are widespread, but at present it seems that the breccias are the potential ore producers. Problems relating to the origin of these host-rock conditions are not discussed in the following brief physical descriptions.

"Recrystalline".—The recrystalline is a common rock type in the upper Beekmantown and is identical with recrystallines described from the East Tennessee zinc district (Oder and Miller, 1945, pp. 3-4).

There appear to be two general recrystalline types in the Timberville district: (a) light-gray, coarse-grained dolomite with somewhat darker interstitial material, and (b) medium-gray, coarse- to medium-grained dolomite with up to 10 percent or more of carbonaceous interstitial material. In places there are gradations between types, which may be due to differences in the amount of solution attending recrystallization.

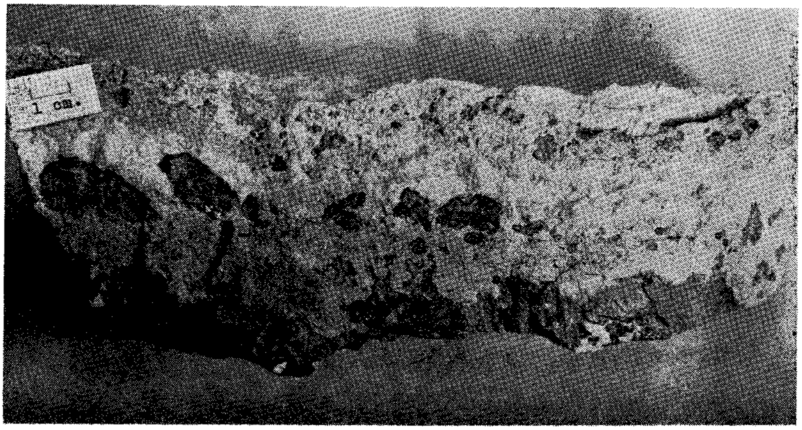
Almost any traverse or drill hole crossing as much as several hundred feet of section will encounter one or more intervals of recrystalline. The type parallels bedding, and in most outcrops gives the appearance of a stratigraphic unit. Individual recrystalline beds may range from less than 1 foot to more than 10 feet thick. Some exposures show recrystalline in lenticular or pod shapes and, where such areas can be examined in detail, they are found to end by lateral intergradation with beds of limestone. Thus, some recrystallines are an alteration of Beekmantown limestone. However, it seems probable that some recrystallines were formed at the expense of pre-existing dolomites.

Commonly associated with both recrystalline types is an extremely coarse-grained white dolomite, referred to in this report as "vein" dolomite. This type of dolomite occurs as irregular bedding-oriented veins and lenses (Pl. 6A). The character of vein dolomite, in many occurrences, suggests replacement of the recrystalline.

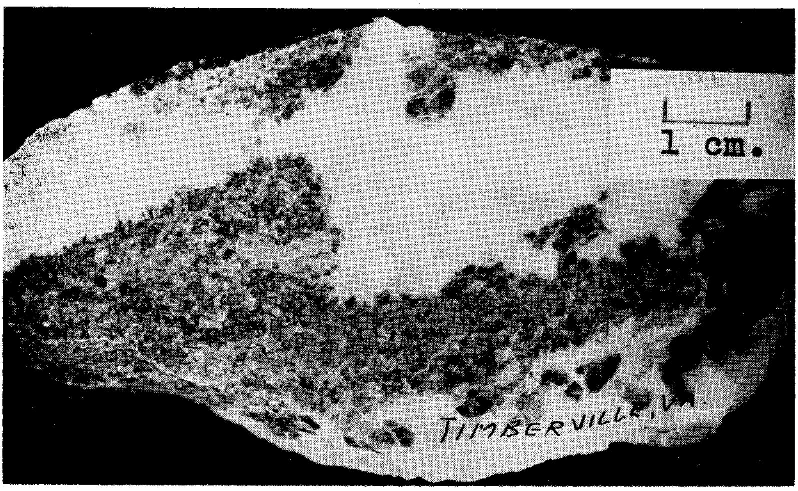
Where mineralized with sulfides, the recrystallines always contain sphalerite and pyrite; chalcopyrite and galena are known only from one locality each. Sphalerite is the dominant sulfide in the recrystalline and is a replacement occurrence. The usual appearance is as disseminated crystals, generally smaller than ⅛ inch (Pl. 6B). Where larger crystals occur, they are in associated vein dolomite. By far the most spectacular "show" of sphalerite in the district is the zinc-bearing recrystalline exposed at the Minnick prospect (Pl. 6A). Here, zinc sulfide crystals 2 inches in diameter are not uncommon, but this is unique for the district.

Veins.—Simple veins are widespread in Beekmantown dolomites, but drilling has shown that from place to place they may be very common or essentially absent. These veins range from tight cemented cracks to 1 or 2 inch vein-dolomite-filled breaks. Calcite or vein dolomite or both may occur as the cementing material. Quartz is a usual minor associate of vein dolomite where the latter cements fractures in cherty zones. Vein dolomite in fractures larger than a few inches, and ranging up to 2 or more feet, has been intersected by drill holes near the lower part of the Bowers-Campbell breccia body.

Considering the abundance of these simple dolomite-filled veins, occurrences of associated sulfides are rare. However, sphalerite, galena and pyrite are known to occur either as complete vein fillings or with vein dolomite. Sphalerite is the predominant sulfide, found usually as a few isolated crystals in a simple fracture or series of veins. Occasionally, small fractures may be entirely healed by sphalerite or, less commonly,

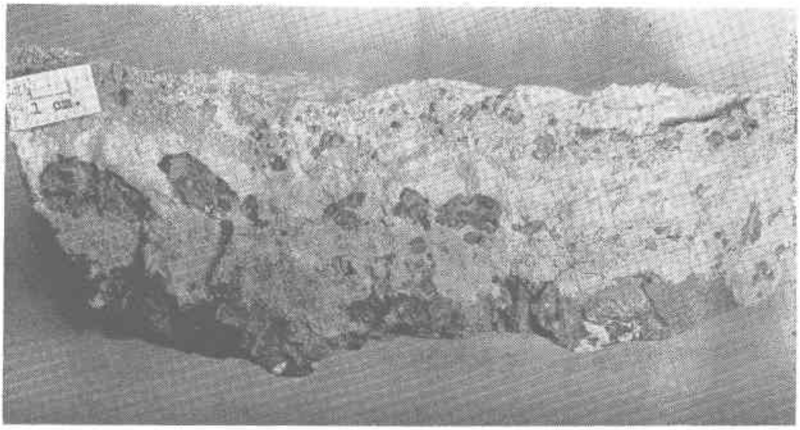


A.

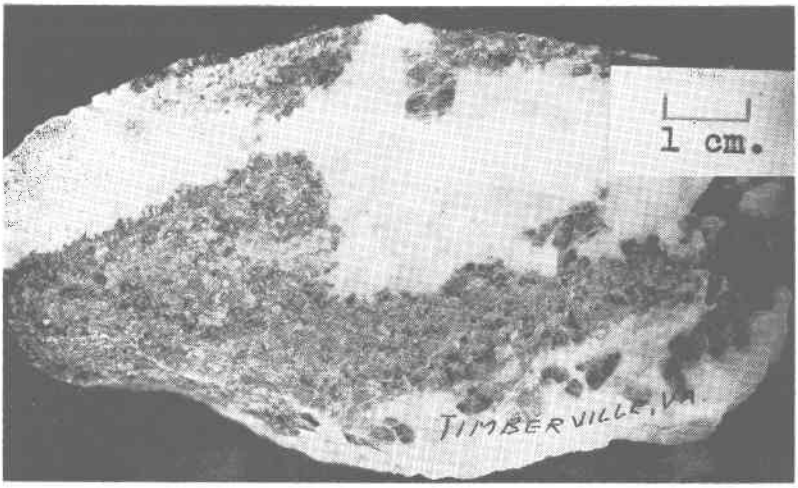


B.

A, Sphalerite (black) in recrystalline and vein dolomite, Minnick property. The coarse-grained vein dolomite in the center of the specimen parallels the bedding of enclosing recrystallines. B, White vein dolomite and gray recrystalline dolomite, Timberville mine. Green-brown sphalerite is disseminated throughout the recrystalline and occurs as large crystals in the vein dolomite.



A.



B.

A, Sphalerite (black) in recrystalline and vein dolomite, Minnick property. The coarse-grained vein dolomite in the center of the specimen parallels the bedding of enclosing recrystallines. B, White vein dolomite and gray recrystalline dolomite, Timberville mine. Green-brown sphalerite is disseminated throughout the recrystalline and occurs as large crystals in the vein dolomite.

galena or pyrite. As mineralized veins are widespread, their relationship to more concentrated mineralization is unknown.

Breccias.—In view of apparent economic importance, as well as relative abundance, Beekmantown breccias have been fundamentally classified as (1) *sedimentary* or (2) *tectonic*. Each breccia type is described below; however, problems of genesis of the tectonic breccias are discussed later in this report.

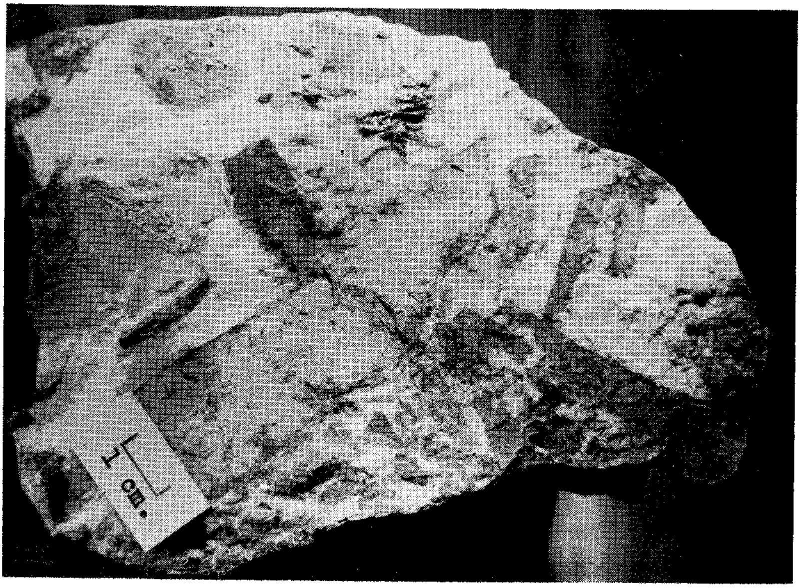
Sedimentary breccias ordinarily consist of angular fragments of a uniform lithology (often tan fine-grained dolomite) cemented by dark-gray carbonaceous dolomite. One such intraformational breccia is well exposed 0.7 mile N. 20° W. of Mt. Clifton in the Edinburg, Va.-W. Va., quadrangle, and marks the base of the Beekmantown. This particular breccia is made up of sharply angular blocks of faintly laminated buff dolomite in a matrix of dark-gray crystalline dolomite.

These relatively thin intraformational breccias have been noted within the lower Beekmantown, and some may have stratigraphic regularity. Because of relative thinness and lack of associated structures, either tectonic or slump, these breccias are thought to represent early desiccation and random shifting of resulting fragments. To date, sedimentary breccias in this area have never been found to contain sulfide minerals.

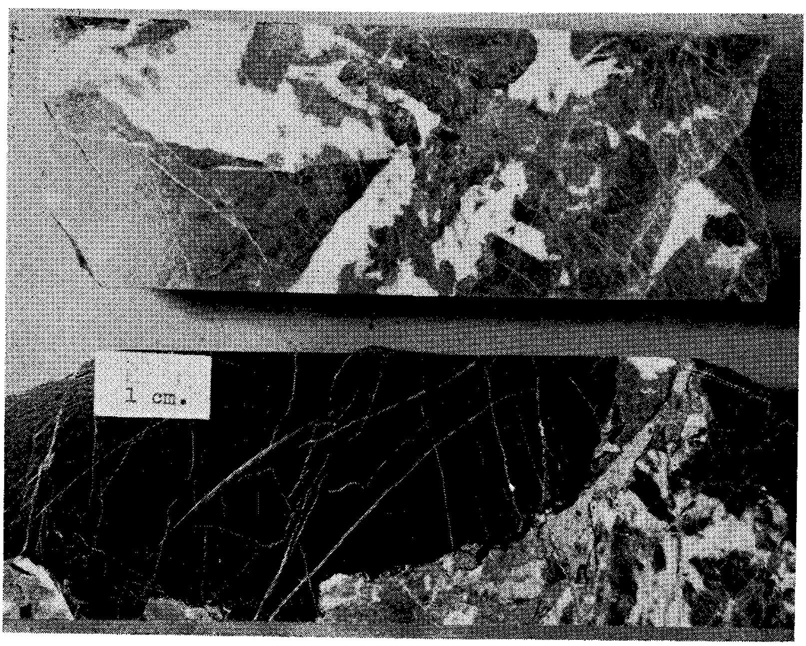
Tectonic breccia types are (1) bedded, (2) chatter, and (3) fault. The term "bedded" as here applied refers to tectonic breccias which are: (1) elongate parallel to bedding, (2) confined to a definite bed or series of beds, and (3) may be gradational laterally with nonbrecciated beds. The breccia fragments are of the same lithology as enclosing rocks. Each fragment is sharply angular and partly or completely separated from adjacent blocks. Very often the original, pre-fracture position of adjacent fragments is clearly indicated. Typical vein dolomite, occasionally with scattered sphalerite crystals, is the cementing material. Such areas of brecciation are known which have a length up to several hundred feet along the strike and which are up to 10 feet thick. In outcrop the bedded breccias closely resemble the "shatter" or "crackle" breccias of the East Tennessee and southwest Virginia zinc districts (Norton, 1917; Currier, 1935a, 1935b).

Although there are physical similarities between sedimentary and bedded breccias the main points of distinction are: (1) gross character of the cementing material and (2) relation of the fragments in reference to their pre-brecciation position.

Considering only the breccia mass, chatter breccias have at first appearance a marked similarity to the bedded breccias. Fragments may be similar in size, sharp outline, and degree of separation. The breccias differ in that (1) various lithologies are involved and (2) individual fragments, though showing no rounding, have been rotated to all degrees of orientation (Pl. 7). Rarely do fragments display any pre-

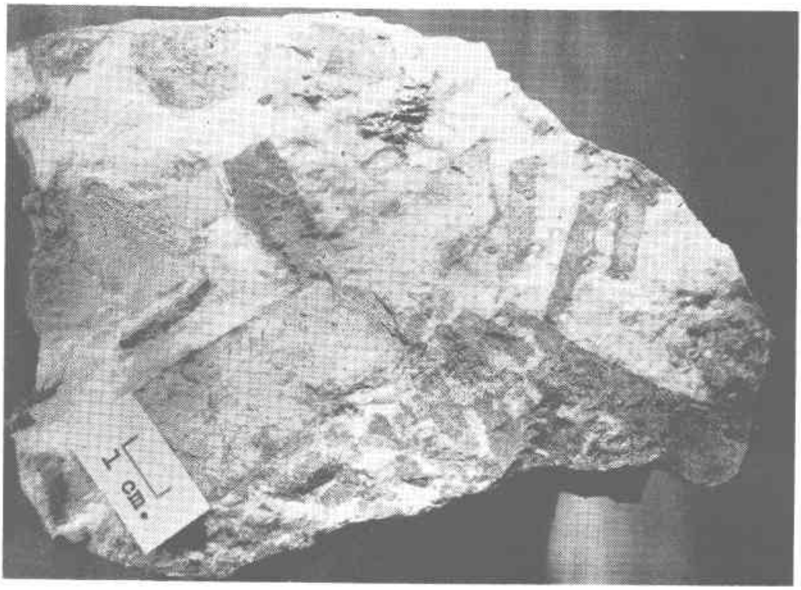


A.

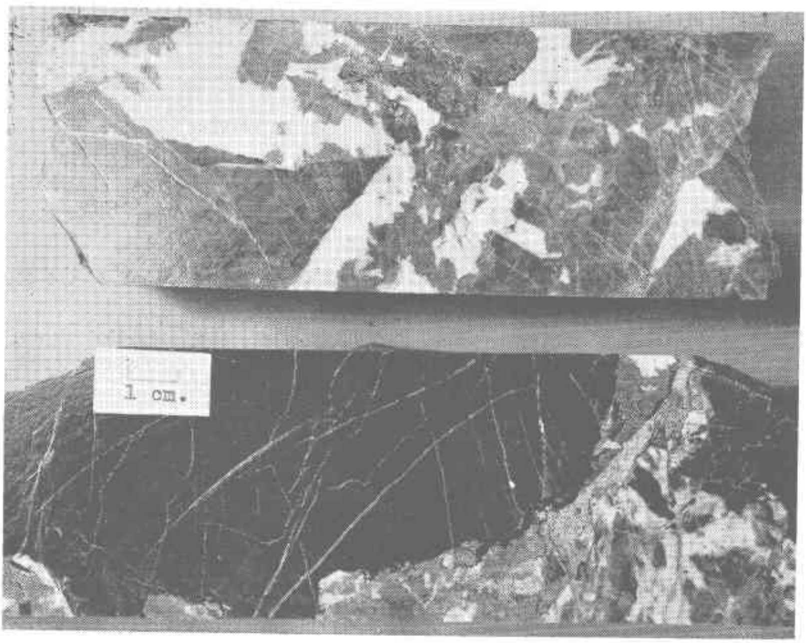


B.

Chatter-type breccia specimens: A, Gordon property; note galena crystal in vein dolomite; B, Bowers-Campbell property; note stylolite contacts.



A.



B.

Chatter-type breccia specimens: A, Gordon property; note galena crystal in vein dolomite; B, Bowers-Campbell property; note stylolite contacts.

fracture relation. Stylolite surfaces may represent contacts between adjacent fragments (Pl. 7B). Vein dolomite, sulfides, and black carbonaceous material make up the breccia cement. Locally, any one cement may be found to the complete exclusion of all others. Sphalerite and galena occur both as scattered developments in vein dolomite and as fracture cements. As far as known, the chatter breccias occur in a long, narrow, pod-like shape and lie along the strike of the enclosing strata, cutting across the dip of the bedding at a high angle.

Brecciation accompanying shearing manifests widely varying characteristics. Fault breccias usually appear as thin zones with considerable lateral persistence. Brecciation was more prevalent in wall rock adjacent to the fault zone than in the fault itself. Some such breccias display mixing of lithologies, and nearly all show rounding of constituent fragments. Compared with other tectonic types, fault breccias are made up of rounded, more closely packed, smaller fragments. Sulfides are present as more or less scattered crystals in vein dolomite that cements the breccias. If the breccia fragments have been recrystallized, sphalerite occurs as disseminated crystals in the recrystalline and as large irregular masses in accompanying vein dolomite.

Miscellaneous.—Outside the immediate area of consideration, but within the Valley region, sphalerite has been noted (1) forming the nuclei of concretions in Devonian Millboro black shale, (2) filling fractures in Devonian Chemung sandstone, and (3) filling the interiors of fossils in the Devonian Hamilton formation.

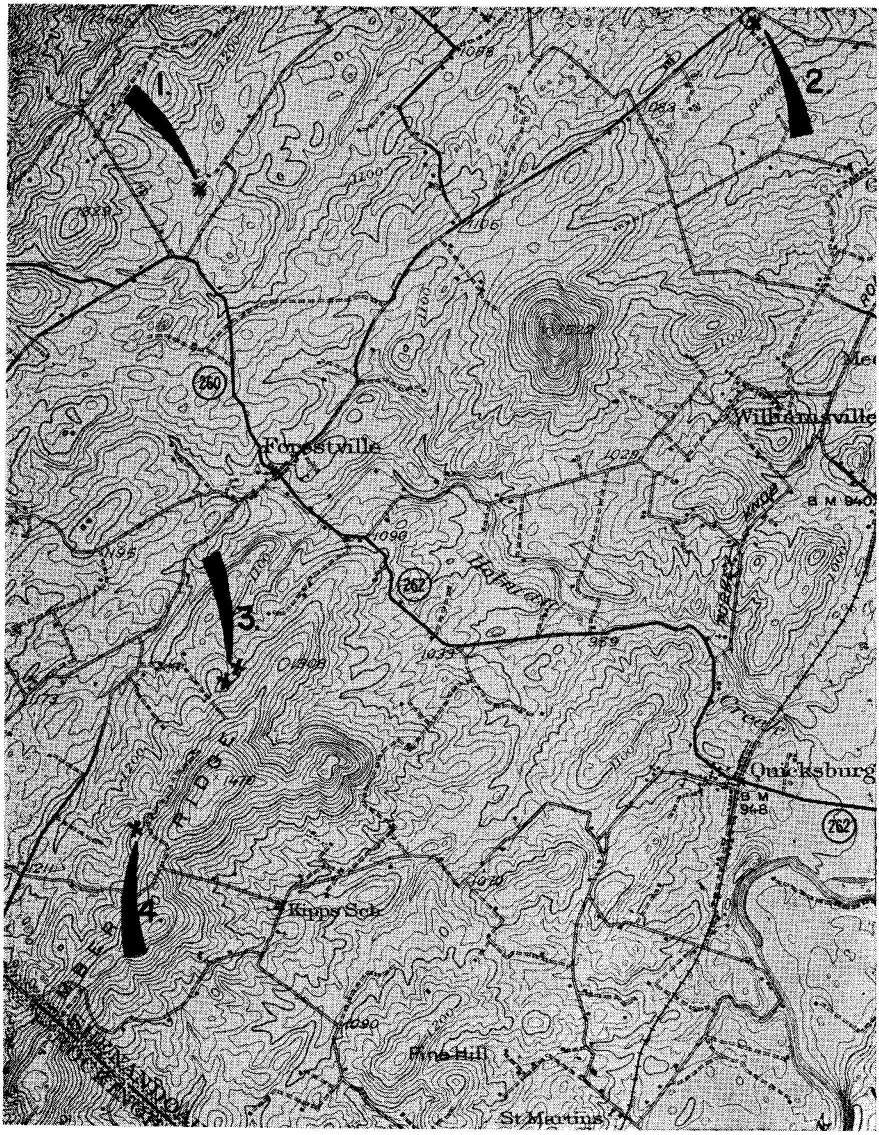


Figure 3.—Location map of (1) Tusing property, (2) Bowman property, (3) Zirkle property, and (4) Timberville mine. Northwest one-ninth, Mt. Jackson quadrangle, scale 1:62,500.

LOCALITY DESCRIPTIONS

In the following specific locality descriptions, it is readily noted that more detail is given for two deposits, the Timberville mine and the Bowers-Campbell property (Pl. 3). Not only is more information available for these deposits, but they also occur in breccias, the type of host most likely to prove economically significant. Much more is known of many of the other properties than is cited here; however, considerable subsurface data from the district are not available for publication at this time.

TIMBERVILLE AREA

Timberville mine (Weatherholtz property).[4] The Timberville mine is located in the Mt. Jackson quadrangle, on the west side of Timber Ridge 2 miles S. 22° W. of Forestville (Fig. 3). The headframe and ore hopper are still standing and are clearly visible on the east side of State Highway 42.

The sulfide minerals are sphalerite and pyrite; these occur in a shear zone in upper Beekmantown dolomite. The horizon can be traced through scattered outcrops for approximately 1.5 miles northeast of the shaft. This extension includes the prospect on the Zirkle property. The mineral suite appears constant throughout the total length, and in the mine it is known to continue in depth to at least 80 feet. Oxidation has been noted to a depth of 6 feet. Sphalerite, pyrite, greenockite, smithsonite, and barite are found in addition to the usual dolomite. Stow (1950, pp. 384-385) reported the presence of small prismatic crystals of a lemon-yellow mineral of anomalous optical and x-ray properties. This mineral remains unidentified. Sphalerite, the predominant sulfide at Timberville, is a definite and characteristic green-brown, existing as small crystals (1/8-1/4 inch) in recrystalline dolomite and as large crystalline masses (1/2-2 inches) in associated vein dolomite. The vein-like deposit lies parallel to the bedding (N. 40° E.; 70°-80° NW.), and has a thickness of up to several feet. In outcrop the vein appears to consist of recrystalline dolomite with vein dolomite in the central few inches to 1 foot. However, much of the dump rock from the mine is a breccia of recrystalline in vein dolomite and in the mine a zone of breccia is reported to be 3 to 4 feet thick.

Workings, when operations ceased, consisted of three shafts and less than 100 feet of drifts (Pls. 8, 9A). The main shaft is an 80-foot 75° W. incline with a 33-foot north drift, 18-foot south drift, and an 18-foot crosscut from the south drift. A small 30-foot prospect shaft is located about 565 feet northeast of the main shaft (Pl. 8). In 1949 the U. S. Bureau of Mines put down three shallow exploratory drill holes.

[4]The following was drawn largely from data supplied by the U. S. Bureau of Mines in Open File Report 91.1618 and by C. R. L. Oder, The American Zinc Company of Tennessee.

Drill hole M4-1: A 60° hole located 255 feet northeast of the main shaft and designed to sample the vein at 65 feet down-dip. Only heavy clay and dolomite "ribs" were encountered in this hole. The drill was pulled at 65 feet, and a cavern assumed.

Drill hole M4-2: A 60° hole located 230 feet northeast of the main shaft. The vein was intercepted in the interval 16.8 to 20.2 feet. Drilling stopped at 22 feet.

Drill hole M4-3: A 45° hole located 410 feet northeast of the main shaft. Total depth attained was 26 feet, and the vein was sampled between 20.0 and 24.1 feet.

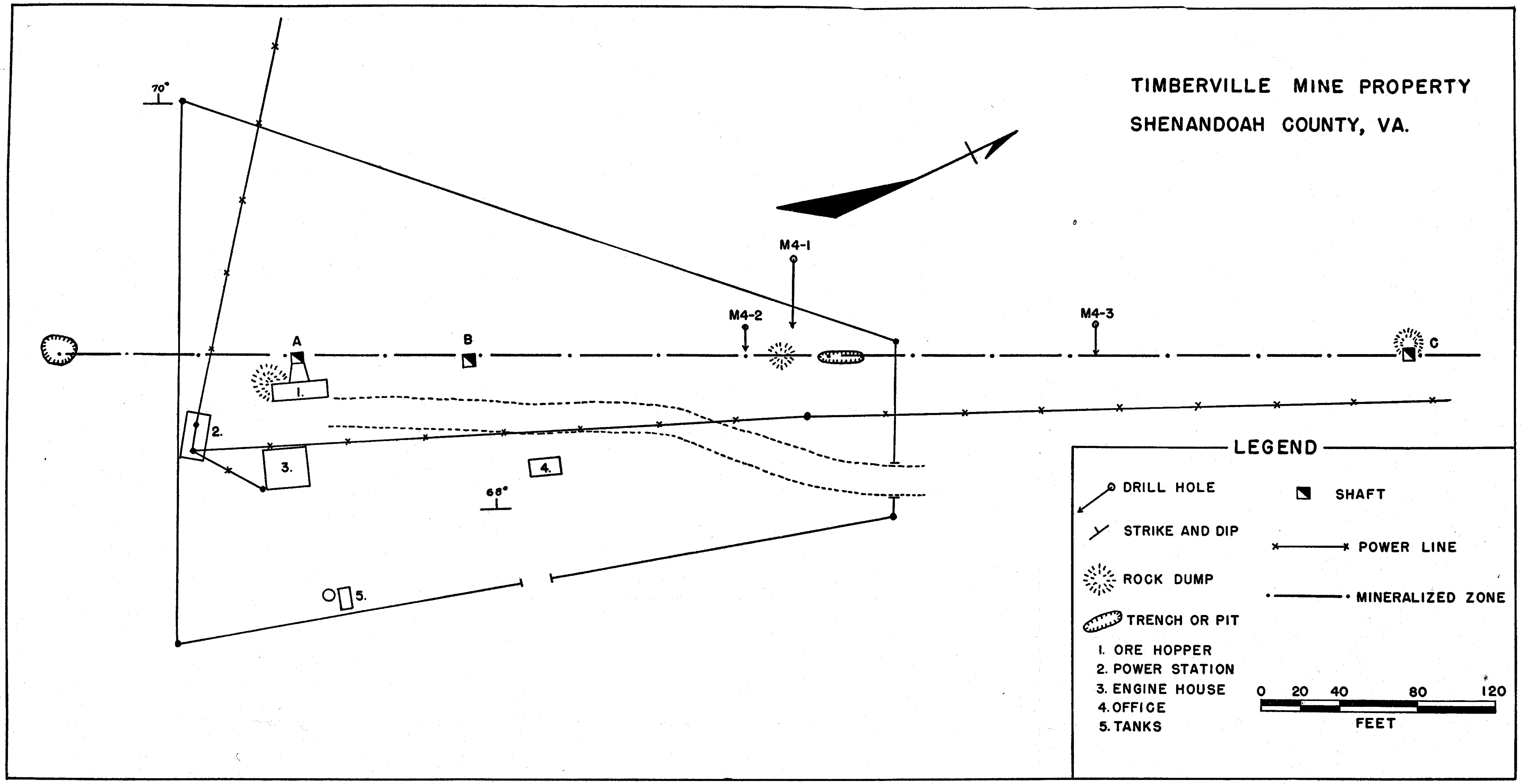
The following assays are cited by the U. S. Bureau of Mines (Open File Report 91.1618):

Location	*Sample Thickness*	*Zn%*
1. In trench 240 feet northeast of main shaft.	1.2 feet	28.50
2. At depth of 42 feet in main shaft.	1.0 foot	11.24
3. Bottom of main shaft (80 feet).	2.2 feet	12.90
4. DH M4-2, 20 feet down-dip.	1.2 feet	8.90
5. DH M4-3, interval 20.0-24.1 feet.	4.1 feet	17.80

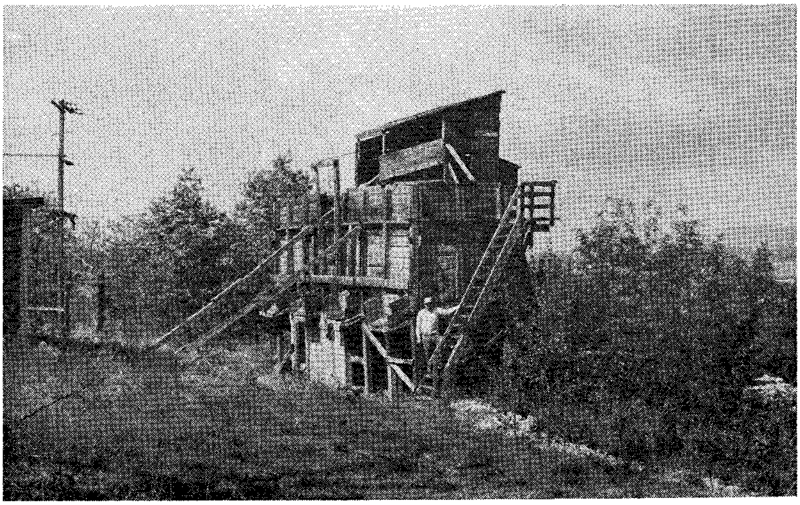
The small amount of ore produced from the Timberville mine was processed at Mascot, Tenn., by The American Zinc Company of Tennessee. In 1949, 101 tons of 4.89% Zn ore were shipped which produced 6.74 tons of 60.59% Zn concentrates. The 48 tons of 7.28% Zn ore shipped in March 1950, produced 5.56 tons of 60.10% Zn concentrates.

Zirkle prospect.—This prospect is in the Mt. Jackson quadrangle, and lies on the west side of Timber Ridge at a point 1.2 miles S. 13° W. of Forestville (Fig. 3).

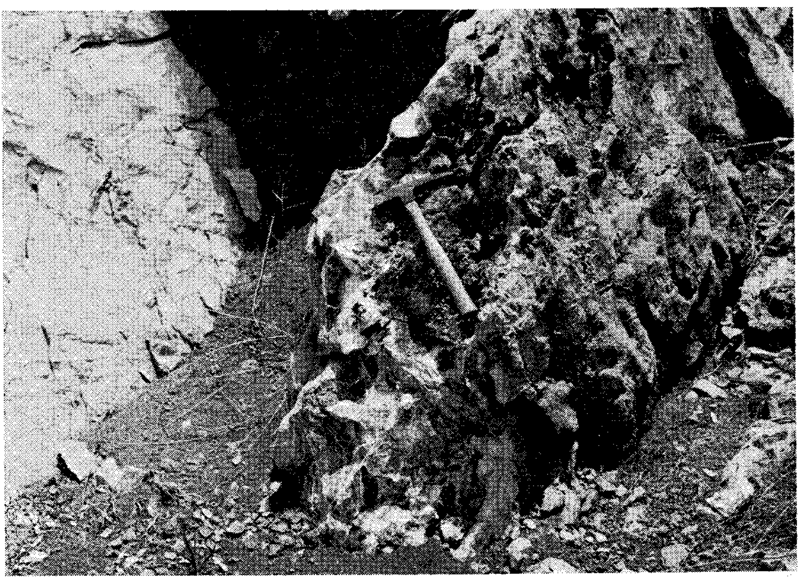
This deposit is the northern extension of that at the Timberville mine, and is nearly identical to it in mineralogy and type. The recrystalline and recrystalline-breccia horizon is exposed from place to place for several hundred yards across the Zirkle property, with one slight structural offset. This offset is of some interest. The mineralized recrystalline bed is well exposed over a northeast-southwest distance of about 400 feet, dipping rather uniformly at 60°-65° NW. (Pl. 9B). The uniformity of strike and dip is interrupted at one point by a small flexure, located 210 feet northeast along the strike from the old farm road leading southeast from the Charles Zirkle farm. At this point the recrystalline trends into



Property map of the Timberville mine area, showing the details of culture and the mineralized zone.

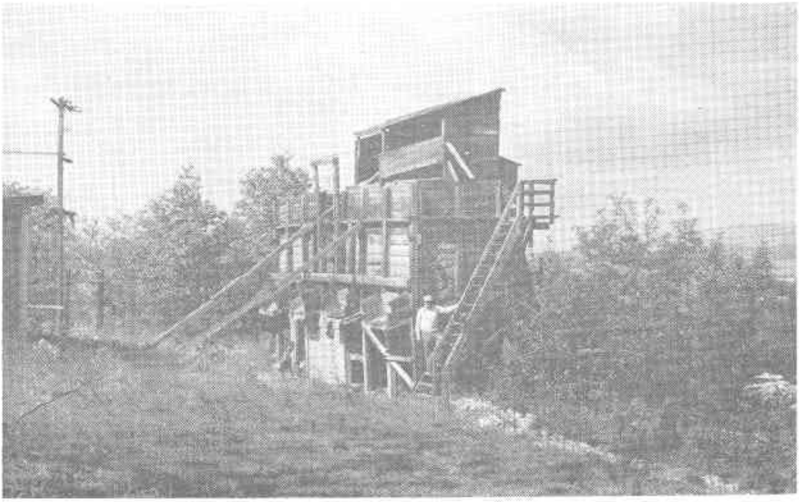


A.

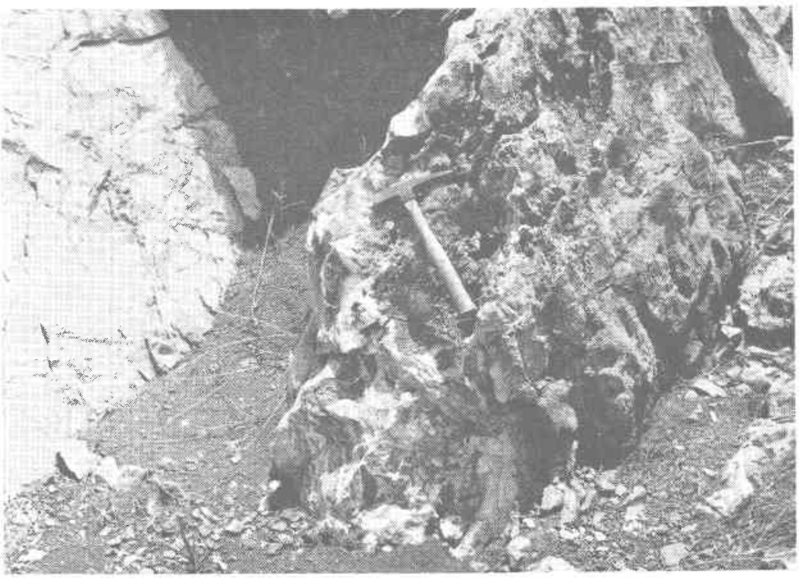


B.

A, Orehopper and headframe for Shaft "A," Timberville mine. B, Mineralized recrystalline exposed in a prospect pit, Zirkle property. Zinc carbonate occurs on the weathered surface; sphalerite is found on the fresh surface below hammer.



A.



B.

A, Orehopper and headframe for Shaft "A," Timberville mine. B, Mineralized recrystalline exposed in a prospect pit, Zirkle property. Zinc carbonate occurs on the weathered surface; sphalerite is found on the fresh surface below hammer.

an outcrop of fractured or shattered, fine-grained dolomite (*not* recrystalline). Sphalerite is present as thin fracture fillings in the shattered dolomite. There is no indication, in either up-dip or down-dip outcrops, of extension of the flexure. The vertical continuity of the fold is unknown. If this very minor fold represents a deeper offset in tear position, the intersection of this cross-fracture and the known breccia zone is a favorable structural locus for ore deposition. Regardless of size, this fold is one of the few evidences of cross-fracture patterns in the district. In one of the prospect blast holes 900 to 1000 feet northeast of this flexure, specimens of well-developed breccia were collected. This breccia could be a similar shattered zone.

The Zirkle property has been prospected over about 500 yards by several blast holes. Similar mineralized recrystalline shows in two other blast-hole pits on the trend, one 900 feet and the other 1800 feet north of the Zirkle property.

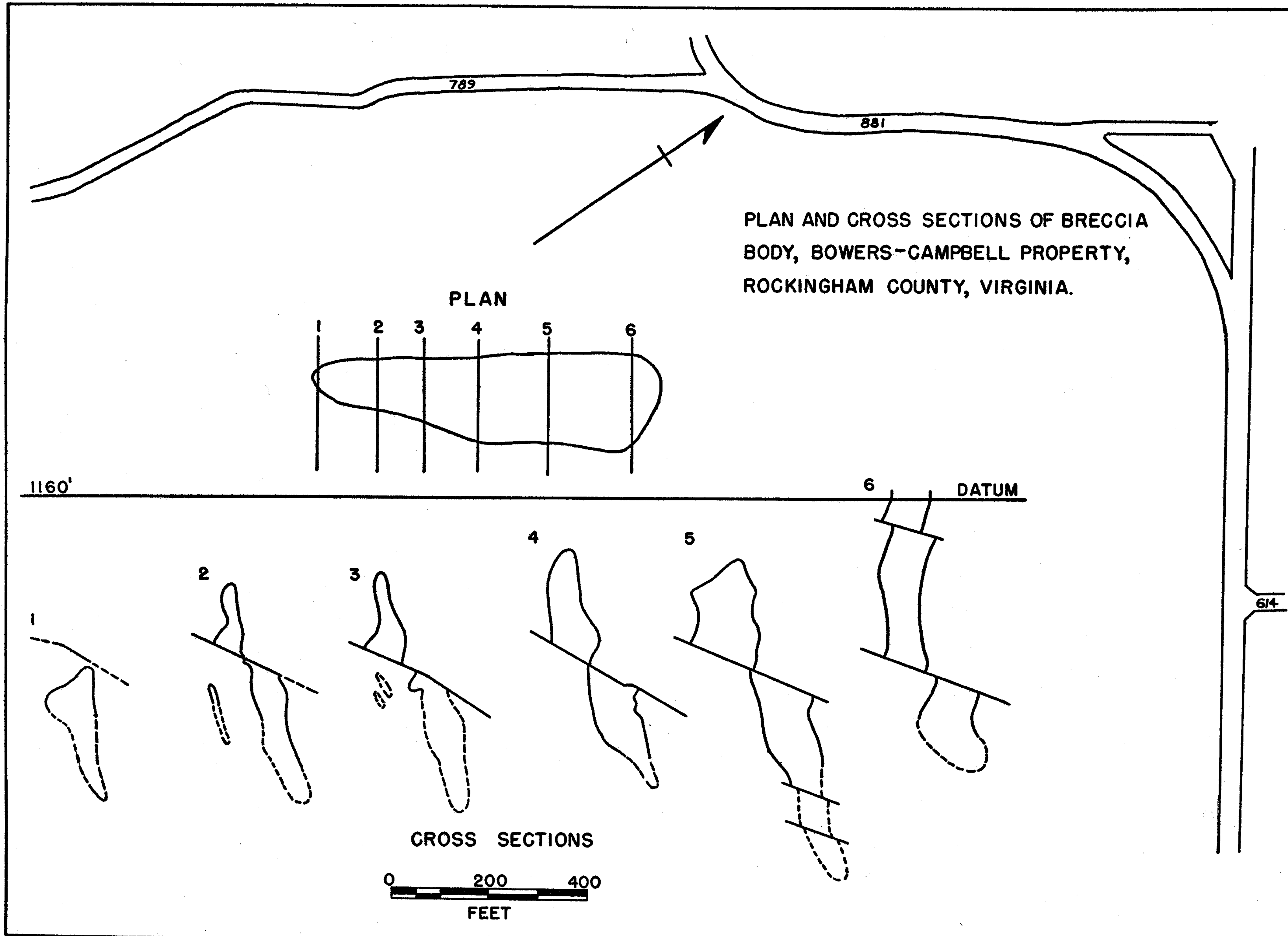
Gordon property.—This property is in the Broadway quadrangle, 4.6 miles N. 13° E. of the center of Timberville and 0.7 mile S. 7° E. of Moores Store (Fig. 4).

Galena is the chief ore mineral, with minor sphalerite and pyrite, in this upper Beekmantown breccia. The breccia is typical of the chatter breccias, composed of sharply angular fragments of gray, fine-grained dolomite cemented by white vein dolomite. This breccia is characterized by unusually large amounts of black carbonaceous films and stringers surrounding the blocks and in vein dolomite. Galena occurs as irregular masses in vein dolomite and as thin fracture fillings in breccia blocks (Pl. 7A). Sphalerite is found both in the dolomite cement and replacing the outer surfaces of selected dolomite blocks.

The actual extent of the breccia, described by Oder (1955) as "a small pitching pipe," has been further delimited in drilling by The New Jersey Zinc Company. The small amount of underground development, two shallow shafts with short drifts and crosscuts, showed thorough brecciation throughout and minor sulfides. The American Zinc Company put down six closely spaced diamond drill holes, ranging from 100 to 255 feet in depth, 25 to 75 feet east of this prospect. Breccia was cut in three of the holes nearest the prospect but was not found below 36 feet. Minor zinc and lead sulfides in breccia, recrystalline and rock dolomite were cut in one or more horizons in each hole.

A recrystalline dolomite partly brecciated and containing disseminated sphalerite crops out several hundred feet north of the old shaft. Because of sparse outcrops, the precise relation of the recrystalline to the breccia is unknown; however, it is possible that a genetic relationship exists. Five vertical holes drilled 75 feet east of the line of this outcrop by The American Zinc Company encountered only minor traces of sulfides.

Bowers-Campbell property.—This property is 1.9 miles N. 39° W. of the center of Timberville and 3.55 miles N. 62° E. of Cootes Store; it



Plan and cross-sections of the Bowers-Campbell breccia body. The plan view represents the vertical projection of *both* segments of the faulted breccia body. Cross-section datum is elevation 1160 feet.

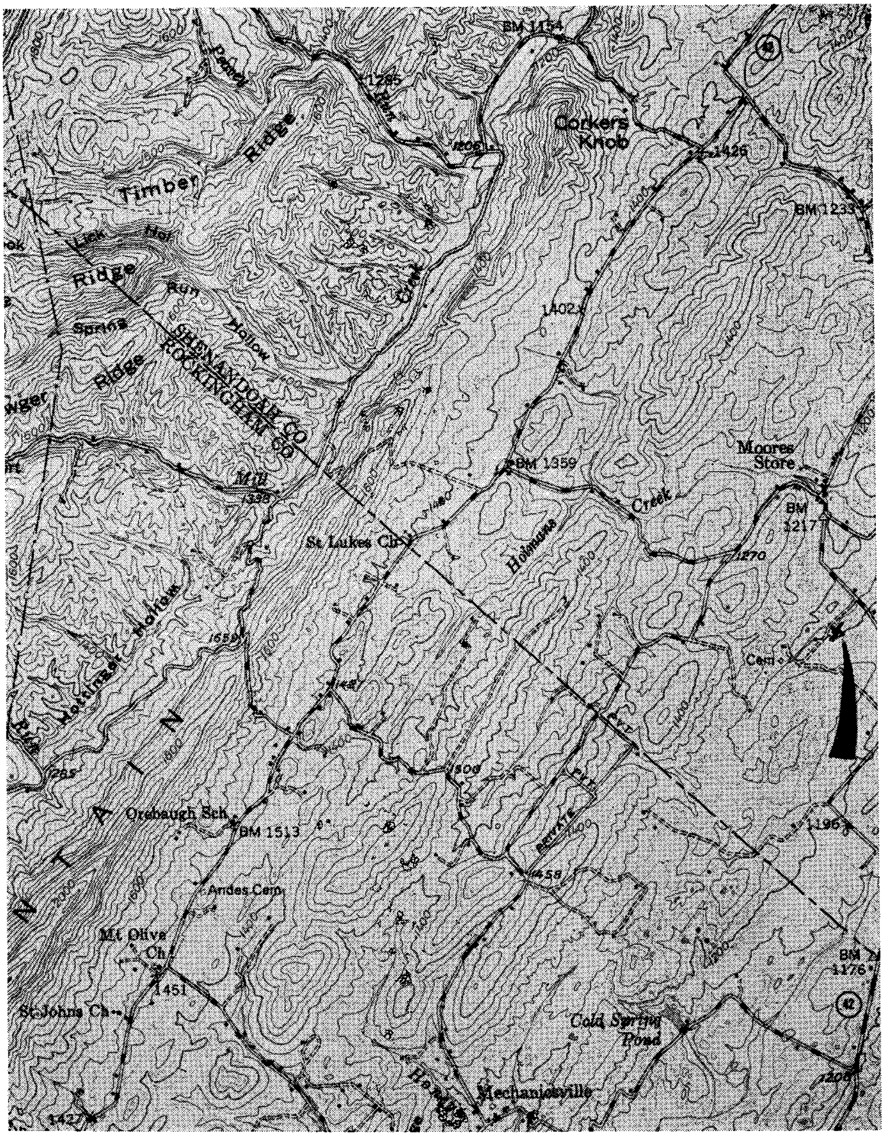


Figure 4.—Location map of Gordon property. Northeast one-ninth, Broadway quadrangle, scale 1:62,500.

is in the Broadway quadrangle (Fig. 5). The Bowers-Campbell property was subject to an intensive, detailed program of surface mapping, geochemical soil testing, and diamond drilling by Tri-State Zinc, Inc. Consequently, far more information is available, to the authors, about this property than any other in the district. Further, the Bowers-Campbell breccia is the only known orebody in the Timberville district, and it is believed that the data presented here will aid in future prospecting.

This orebody occurs in a breccia of the chatter variety, and is enclosed in dolomites of the upper Beekmantown. It is one of the several mineralized breccias exposed in outcrop along the western Beekmantown belt (Pl. 3). At this locality the original outcrop exposed many square yards of breccia, showing dolomite blocks which vary in large dimension from a few inches to several feet (Pl. 11). Where bedding can be determined, these blocks have all variations of strike and dip; however, in a general way there is a subtle though definite lineation. A vertical diamond drill hole in the center of this outcrop began in mineralized breccia and continued in it to a depth of 355 feet.

Plate 10 is a map outline of the breccia, with nearly equally spaced cross-sections. The breccia body has a strike of N. 34° E. which parallels the strike of the enclosing strata. The dolomite beds dip southeastward about 30°, with the breccia cutting vertically across them.

The breccia body is 700 feet long, up to 100 feet wide, and extends in depth to over 700 feet. The six vertical cross-sections of Plate 10 show the change in irregular lens shape from north to south, and the definite southward pitch of the top. A bedding-plane thrust fault offsets the upper half of the breccia body to the west, and other minor bedding thrusts dislocate the breccia in similar manner.

The central cross-section (Pl. 12) has been chosen to illustrate: (1) types of data upon which all the cross-sections are based, (2) distribution of ore within the breccia, and (3) relation to stratigraphic markers. The straight lines with numerical designation represent drill holes. The irregular outline of the breccia is established by vertical drilling. Drill cores in the upper breccia begin to show some oxidation near 340 feet, then pass into fault gouge (cataclasite), and from there into highly fractured, bedded dolomite. Vertical holes immediately east of the upper breccia penetrate dense, unmineralized, bedded dolomite to depths of nearly 400 feet, where oxidized dolomites and fault gouge are encountered. Below this main fault, these holes penetrate breccia, the upper 50 feet of which is almost obscured by intense, highly siliceous sulfide mineralization. The ore is confined to the upper breccia and to the upper 50 feet of the lower breccia. Obviously, the fault is post-breccia, and because of distinct mineralization differences above and below the fault, faulting is considered to be pre-mineralization.

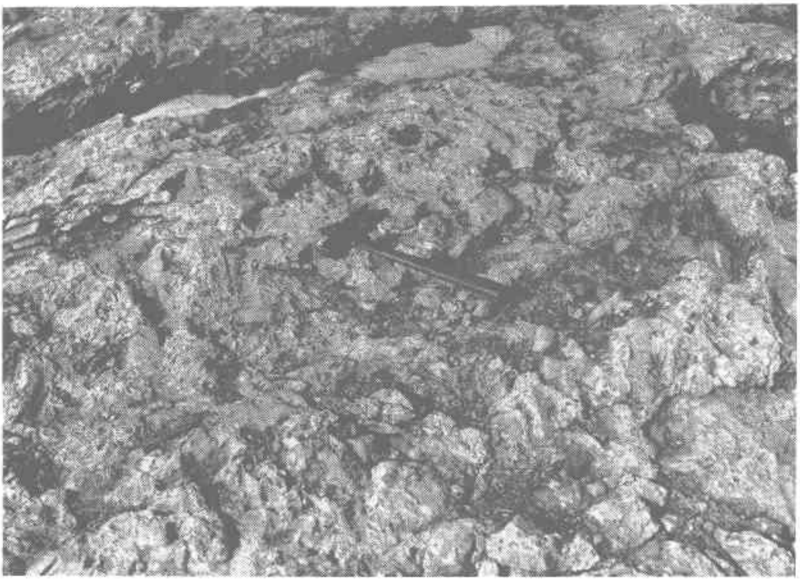
Outside the breccia body, thin, persistent marker beds show no indication of structural disturbance departing from the uniform eastward dip.

Figure 5.—Location map of (1) Bowers-Campbell property, and (2) Vetter property. East one-ninth, Broadway quadrangle, scale 1:62,500.

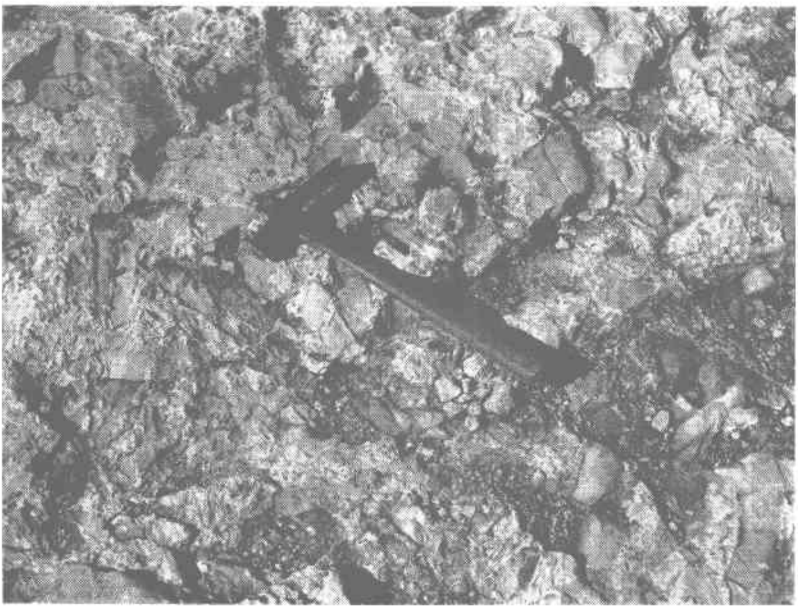
A.

B.

A, Part of the outcrop area, Bowers-Campbell orebody. B, Detail of the central area of A.

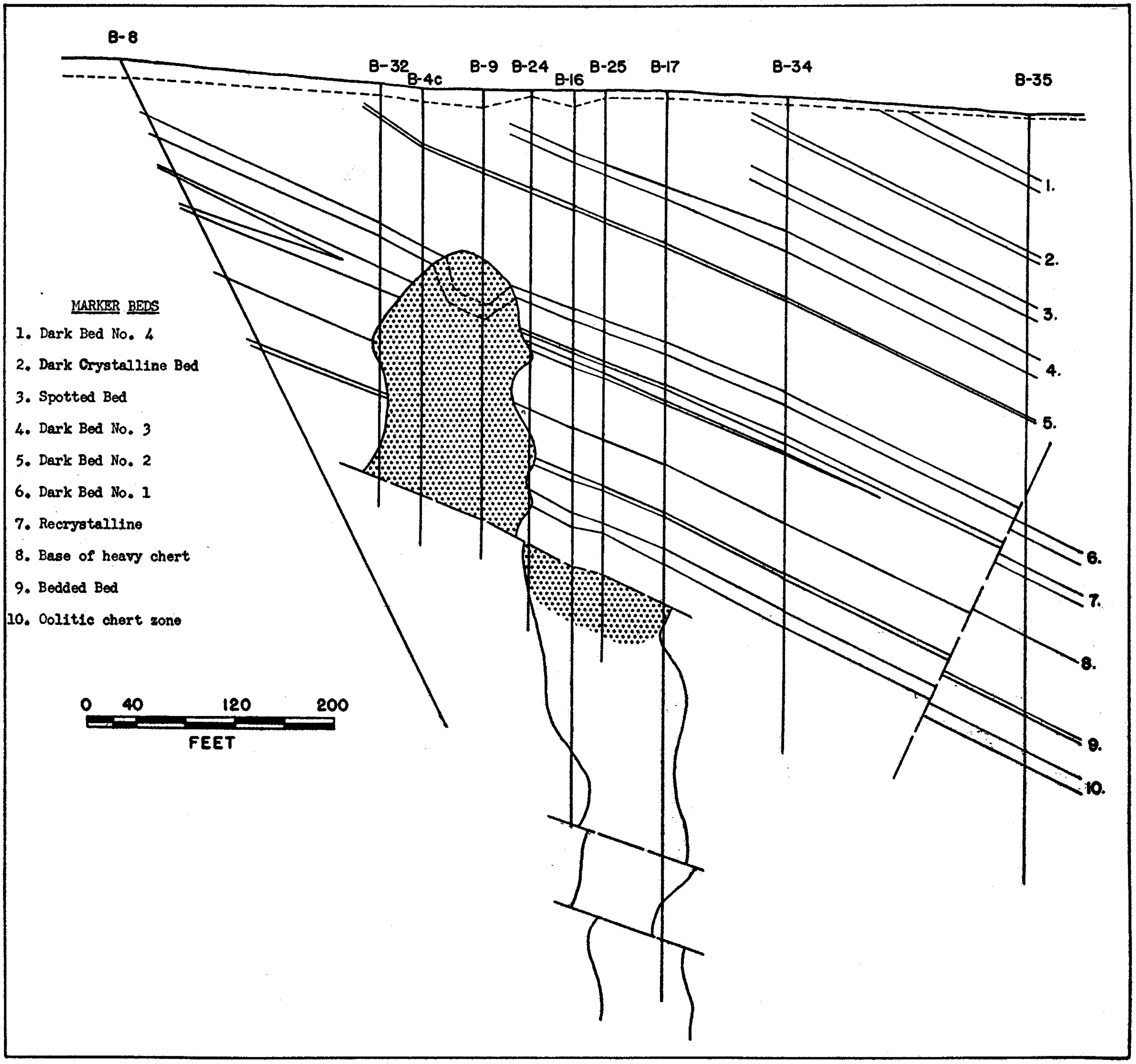


A.



B.

A, Part of the outcrop area, Bowers-Campbell orebody. B, Detail of the central area of A.



Central cross-section of the Bowers-Campbell orebody. Stipled area indicates ore-grade mineralization. Heavy lines with numerical designation represent drill holes. Figures on right refer to stratigraphic column.

However, within the breccia body, concentrations of fragments of the more prominent stratigraphic markers, especially Dark Bed No. 1, have been determined. Such concentrations always occur considerably below their normal level outside the breccia. In the northern part of the orebody, where the breccia crops out, adjacent drill holes in the breccia show that the amount of down-drop is approximately the same in each hole location. Thus, where the most information is available, the down-drop of any given unit appears as a graben cross-section (Pl. 12). Where stratigraphic units other than Dark Bed No. 1 have been recognized in breccia cores, they show a similar structural relation, but marker beds above the breccia show not the slightest deviation from the normal dip. Plate 13 is a structure contour map on Dark Bed No. 1, in the area of the Bowers-Campbell orebody. In Plate 13, the outline of the breccia, depicted by the heavy part of the angle holes, extends well beyond the disturbance of contours on the structure marker. The disturbance is confined to that area where the southward pitching breccia lies above the marker. Where the breccia extends southward and below Dark Bed No. 1, there is no deviation of the marker. Drill holes over the southern part of the breccia intersected the key bed precisely where predicted. Perhaps most important of all, structure contours reveal that *there is no local folding related to the breccia.*

The ore minerals in the breccia body are sphalerite and galena. Although galena is found rather commonly in dump rock near the old Bowers shaft, it is rarely recognized in core and then only as a small crystal or two outside the orebody. Galena, therefore, is considered as an unimportant ore mineral with spotty distribution, concentrated in the uppermost part of the breccia. Sphalerite, the common ore mineral, occurs as crystals from pin-head size up to an inch or more. Ore is conspicuously made up of the larger crystals dispersed in white dolomite breccia cement.

The gangue minerals are the predominant white vein dolomite and minor amounts of quartz, calcite and pyrite. Most of the pyrite occurs as tiny disseminated crystals which tend to partly replace dolomite breccia fragments and outline crystals of vein dolomite. Heavy concentrations of disseminated iron sulfide were noted both in dump rock (producing scattered gossan) and in a zone adjacent to the main fault. Tangible mineralization as a halo beyond the orebody is present only in minor degree. In ore holes, "shines" usually occur only within 10 feet of ore, if they are present at all.

Zinc carbonate is present on mineralized outcrops, and greenockite is rather widespread in the breccia, as a film on fracture surfaces.

Beds of recrystalline have been encountered in drilling above, beyond the ends and sides, and as fragments within the orebody. These recrystallines occur in a definite place in the stratigraphic column, below Dark Bed No. 1 (Pl. 12). Although these are known to persist to outcrops 300 feet west of the breccia and in drill holes 400 feet east of the breccia, they give way to limestones within 100 feet north and south beyond the ends. This indicates a relationship to the mineralization. These recrystalline beds are only partly mineralized. Mineralization was apparently limited to small areas, one centered over the top of the south end of the breccia and another extending a few feet beyond the west side. This relationship suggests that the loci of most intense mineralization in recrystalline beds elsewhere in the district would logically be places where deep drill holes might encounter mineralized breccias.

Vetter property.—The Vetter property lies in the western Beekmantown belt in the Broadway quadrangle. It is 1.6 miles N. 38° W. of the center of Broadway and 2.4 miles S. 78° W. of Timberville (Fig. 5).

Sphalerite and pyrite occur in a chatter-type breccia, the third such breccia known in the district. The only surface indications of this breccia are a few hat-sized outcrops 10 to 50 feet south of the property line. These show fracturing and minor brecciation, with vein dolomite carrying yellow sphalerite. A drill hole cross-section consisting of one angle hole and two vertical holes located just north of these outcrops encountered typical chatter breccia. The length is unknown, but probably less than 400 feet. The drill holes showed that the shape in cross-section is similar to the upper half of the Bowers-Campbell breccia as illustrated in Section 4, Plate 10. The breccia width is 125 feet and it extends in depth from 99 to 468 feet, where it terminates against a bedding plane fault.

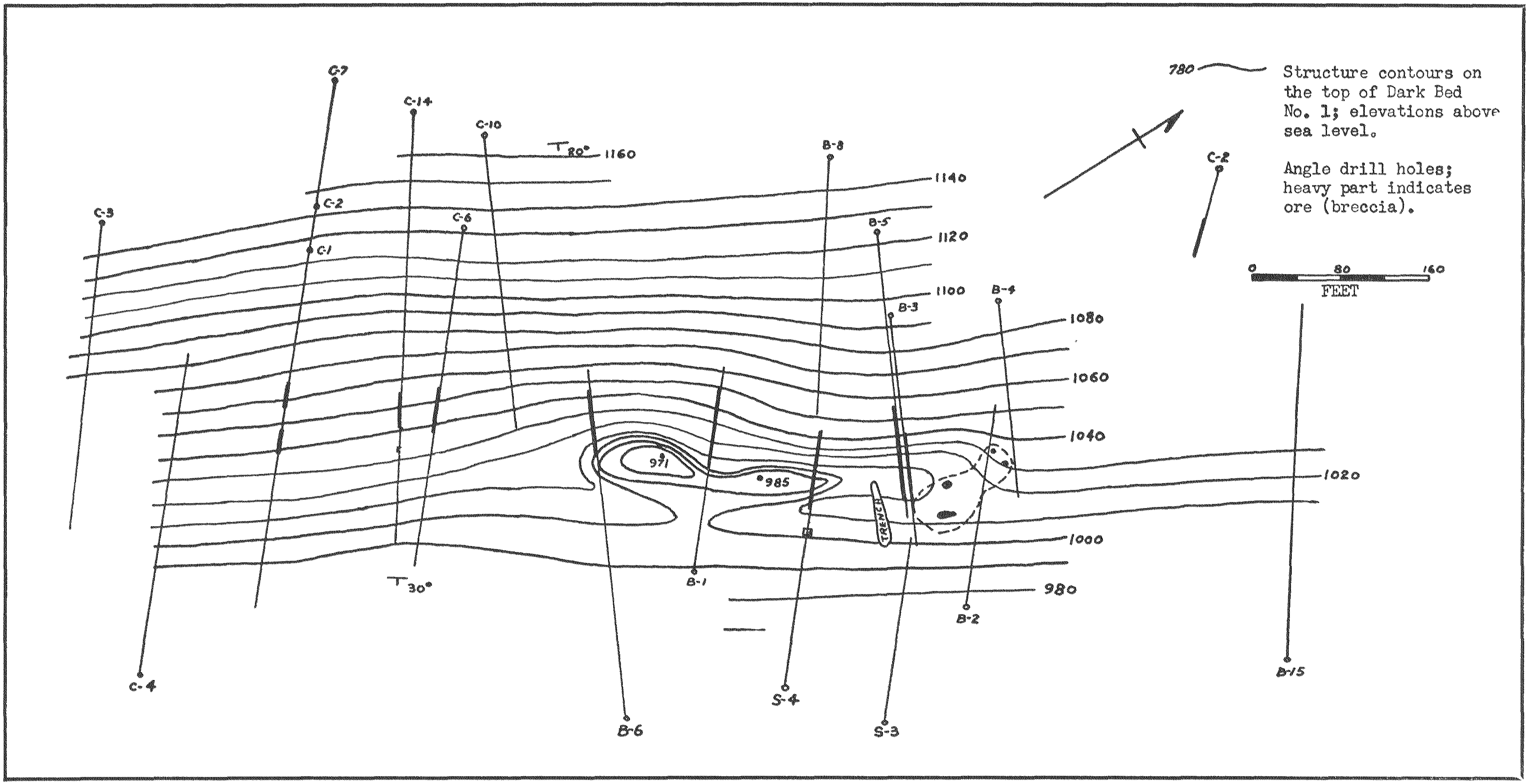
The metallic minerals thus far encountered in the Vetter breccia consist of minor amounts of honey-yellow sphalerite and some pyrite. The breccia was not encountered in drilling 200 feet north and south, and because of the low zinc content the exact extent of the breccia was not determined. Also, the possibility of an orebody in the lower part of the breccia, offset by bedding-plane faulting, was not investigated.

RINKERTON AREA

Bowman property.—A prospect on the Bowman property, in the Mt. Jackson quadrangle, is 1.95 miles N. 85° W. of the center of Mt. Jackson and 3.4 miles N. 47° E. of Forestville (Fig. 3).

The surface exposure, consisting of loose blocks around a small pit, shows the sulfides to be pale-yellow sphalerite crystals (up to ½ inch) and minor disseminated pyrite in two types of breccia.

One type closely resembles the chatter breccias, while the other, though similar, is composed of rounded fragments which are smaller and more tightly packed. The physical characteristics of this latter breccia present the possibility that this entire breccia may be due to faulting. This is further indicated by the proximity of minor flexures in enclosing upper Beekmantown beds. However, until proof by drill data is available, the



Structure contour map on the top of Dark Bed No. 1 in the vicinity of the Bowers-Campbell orebody. Dashed outline indicates breccia outcrop area, with solid areas indicating prominent outcrops. Breccia is also exposed in the trench.

possibility that the Bowman breccia may represent a faulted chatter breccia lens should not be discounted.

This and adjacent properties were drilled by The New Jersey Zinc Company.

EDOM AREA

Armentrout property.—Mineralized rock on the Armentrout property crops out over 0.25 mile near Joes Creek; best exposures are 1.85 miles S. 89° E. of Singers Glen and 2.2 miles N. 29° W. of Edom, in the Broadway quadrangle (Fig. 6).

Sphalerite occurs here as translucent, yellow to red crystals (up to 1 inch) in white vein dolomite cementing a breccia. Exposures are in three outcrop areas widely spaced along an 1100-foot strike length. The northeasternmost outcrop is slightly off strike and about 60 feet stratigraphically lower. A mineralized width of 20 to 40 feet is indicated. Diamond drilling by Tri-State Zinc, Inc., revealed that the central and southwestern outcrops are the surface exposures of a bedded breccia 700 feet long, about 100 feet wide, and 8 to 10 feet thick. This breccia is apparently weakly and erratically mineralized. The mineralized exposure to the northeast is evidently unrelated, and does not extend southward below the central and southern outcrops. Sphalerite in minor fractures is found in several beds stratigraphically higher than the bedded breccia.

Because of tabular form and restriction of a given breccia to essentially the same stratigraphic horizon, the Armentrout breccia is designated a *bedded* breccia. In physical expression, this breccia most closely resembles the "shatter" breccias of the East Tennessee zinc district.

Showalter property.—The Snapp Creek lead "mine" is a prospect on the Max Showalter property, in the Broadway quadrangle, 2.5 miles S. 25° W. of Singers Glen and 3.95 miles S. 85° W. of Edom (Fig. 7).

Exposures of bedrock are very scarce in the vicinity of this prospect, and precise stratigraphic identification is impossible. However, by strike projection it is obvious that this particular deposit is not in the usual upper Beekmantown position. Recrystallization and brecciation have obscured original bedrock characteristics, but as closely as can be determined the prospect is in either lowermost Beekmantown or uppermost Chepultepec.

Galena is the only known base-metal sulfide and occurs in veins, up to several inches thick, of white dolomite and quartz. The relationship of this sulfide mineralization to barren breccia, exposed only as dump material, is not known.

NEW MARKET AREA

Minnick property.—Mineralized rock on this property is exposed in a series of prospect pits, which center 1.75 miles S. 47° W. of the inter-

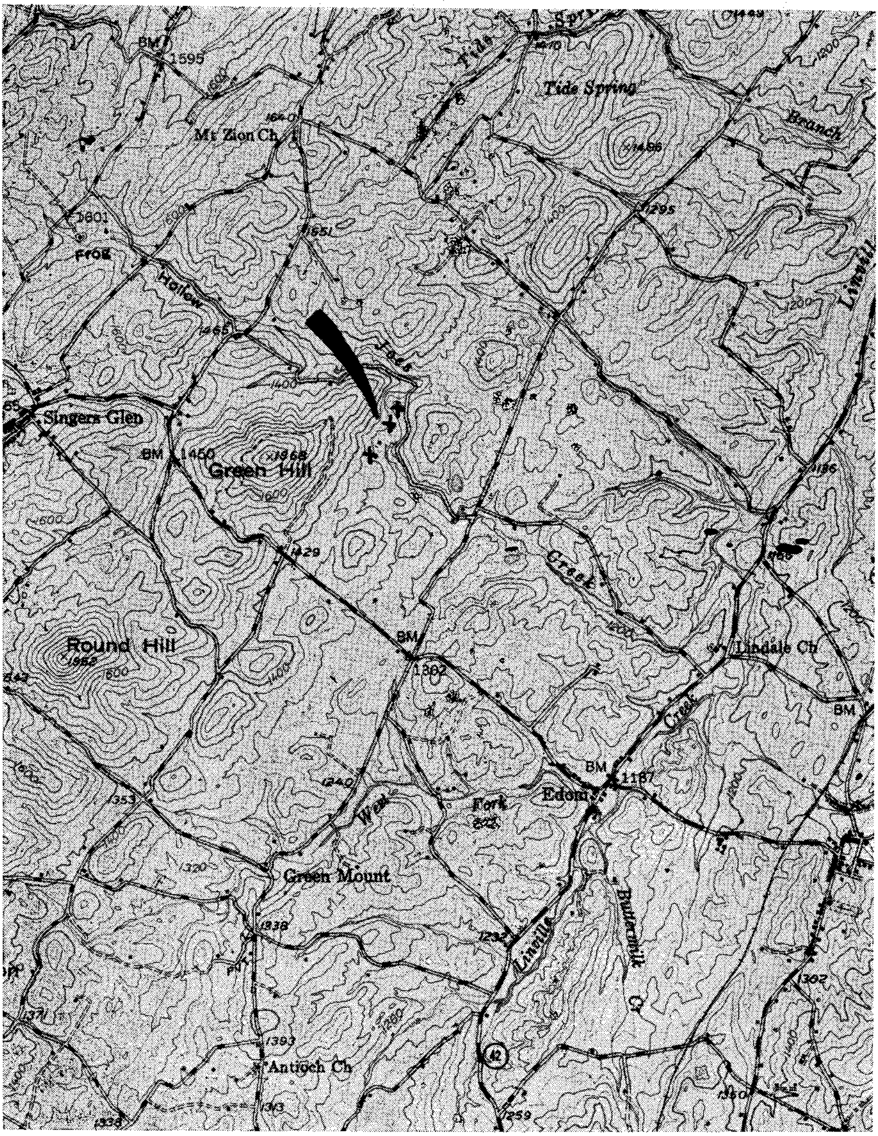


Figure 6.—Location map of Armentrout property. South one-ninth, Broadway quadrangle, scale 1:62,500.

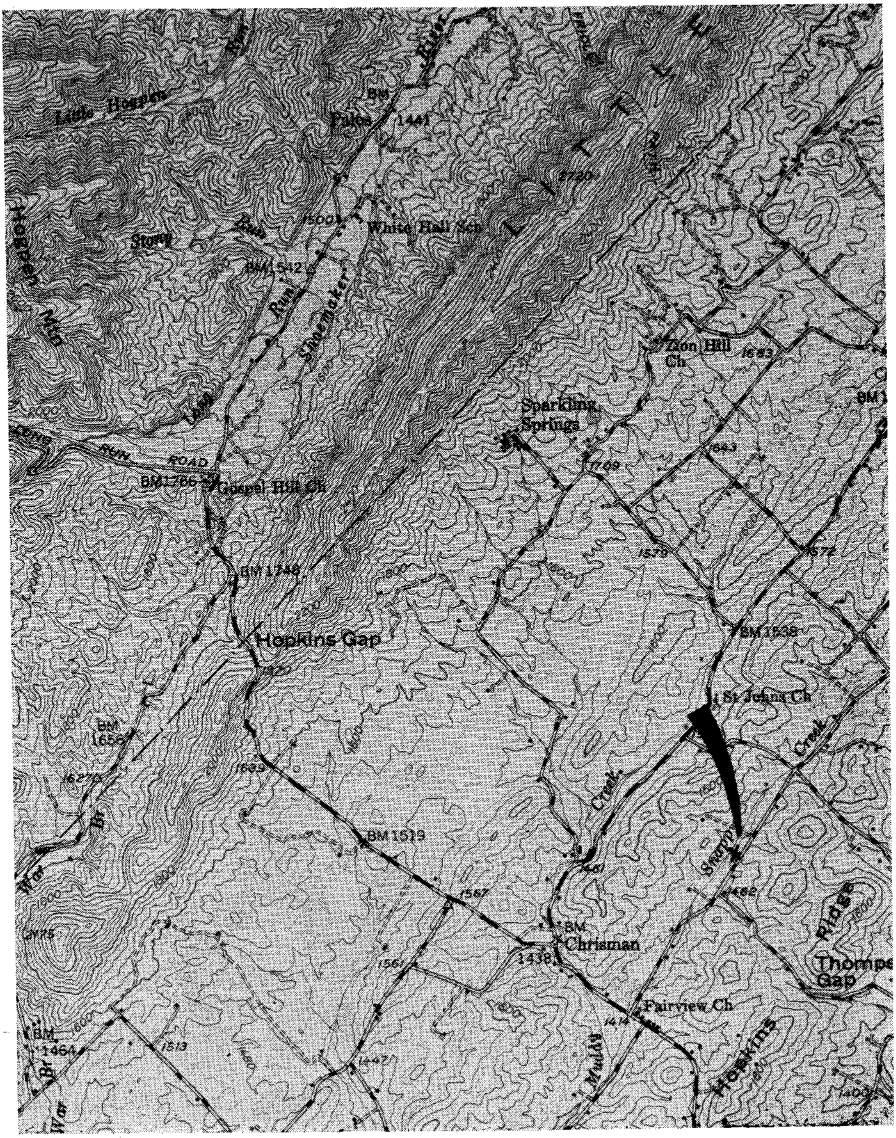


Figure 7.—Location map of the Showalter property ("Snapp Creek mine"), Southwest one-ninth, Broadway quadrangle, scale 1:62,500.

section of U. S. Routes 11 and 211 in New Market (Mt. Jackson quadrangle). The pits follow the west side of a low ridge, and are about 0.5 mile northwest of U. S. Route 11 (Fig. 8).

Sulfide minerals consist of sphalerite, with pyrite and chalcopyrite rare. Brown sphalerite occurs as massive tabular crystals lying in the bedding of a recrystalline dolomite (Pl. 6A), which is exposed in four prospect holes over a strike distance of 800 feet. The northern prospect is barren of sulfides, the only minerals being large masses of milky calcite and dolomite. The three southern prospects have impressively rich stockpiles. Very little sphalerite or pyrite is exposed in the prospects, but where visible they are in a recrystalline bed, which appears to be not more than 1 to 2 feet thick (Pl. 14A). The intensely mineralized areas were apparently localized for each prospect, as adjacent well-exposed outcrops of the same recrystalline bed show only small and widely disseminated sphalerite crystals. At each prospect there appears to be a slight cross flexure and joint which may have played a part in localizing the unusual quantities of sphalerite. Outcrops for a distance of 0.5 mile northeast and 0.75 mile southwest along the strike expose recrystalline areas which apparently represent the same limestone bed. Almost all of the recrystalline developments in this bed display disseminated sphalerite crystals which indicate a 1.5 mile trend of mineralized rock. In addition to prospect pits, it is reported that, about 1913, The New Jersey Zinc Company drilled three churn drill holes just east, down-dip, of each of the prospect pits. Results apparently were negative.

MT. CLIFTON AREA

Tusing property.—This property is in the Mt. Jackson quadrangle, 1.5 miles N. 16° W. of Forestville and 4.9 miles S. 82° W. of the center of Mt. Jackson (Fig. 3).

As well as can be determined from generally poor outcrops, sphalerite at this prospect occurs as disseminations in a bed of recrystalline dolomite. In places, purple fluorite is associated as one-half to one inch lenses and crystals. Mineralized float and small outcrops are found in cultivated fields along strike for at least half a mile. A sphalerite-bearing recrystalline, probably representing the same horizon, crops out 0.65 mile northeast of the Tusing farm.

HARRISONBURG AREA

"Wiseland".—Small sphalerite crystals occur in upper Beekmantown recrystalline, which crops out on the south side of a small stream valley traversing a farm known as "Wiseland." This property is 3.25 miles S. 63° E. of Melrose and 5.0 miles N. 33° E. of the bench mark at Keezletown, in the Harrisonburg quadrangle (Fig. 9). No prospecting has been done at this locality, and the extent of the recrystalline is unknown.

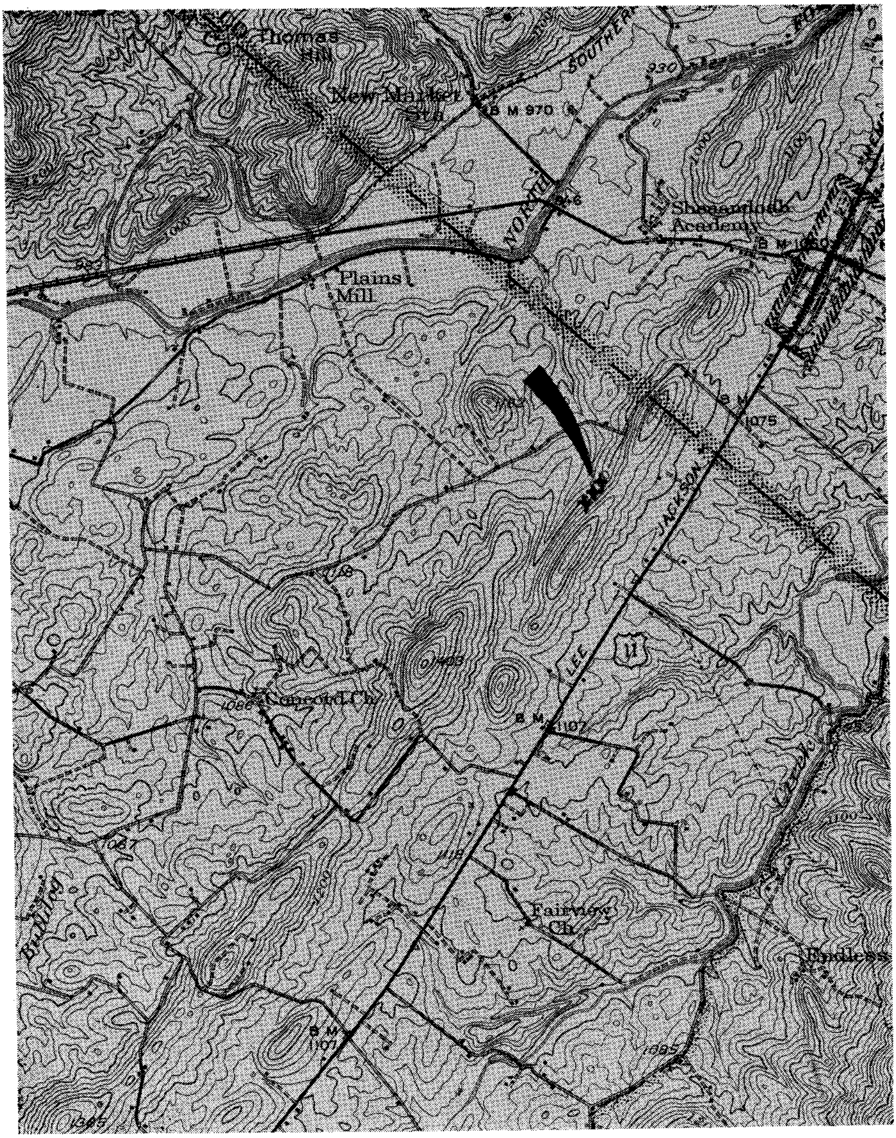
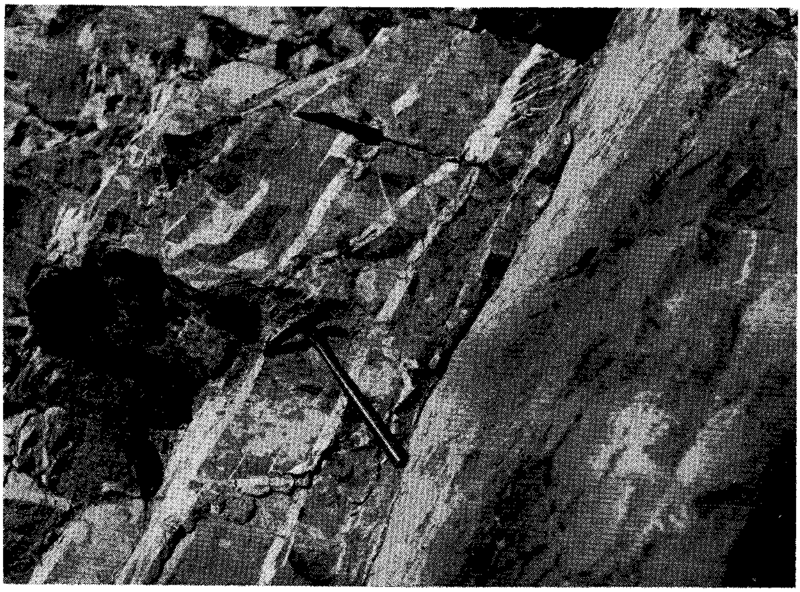


Figure 8.—Location map of the Minnick property. West one-ninth, Mt. Jackson quadrangle, scale 1:62,500.

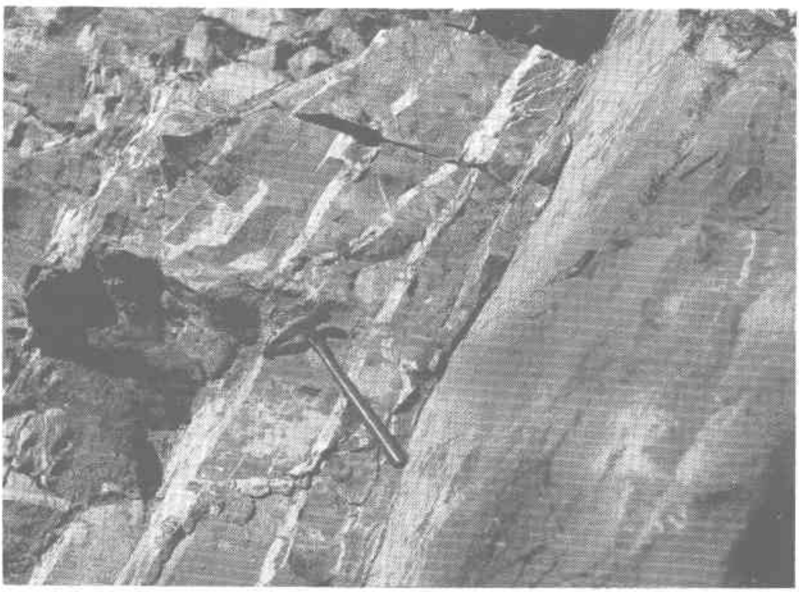
A.



B.

A, Recrystalline horizon exposed in a prospect pit, Minnick property. B, Mineralized outcrop on State Highway 340, Grove Hill. Sphalerite is found in vein dolomite and disseminated through the basal gouge (base of hammer).

A.



B.

A, Recrystalline horizon exposed in a prospect pit, Minnick property. B, Mineralized outcrop on State Highway 340, Grove Hill. Sphalerite is found in vein dolomite and disseminated through the basal gouge (base of hammer).

SHENANDOAH AREA

Grove Hill.— Zinc mineralization is known east of the axis of the Massanutten synclinorium, and occurs in a road cut on State Highway 340 (old Route 12), 200 yards north of the South Fork of the Shenandoah at Grove Hill (Fig. 10). Grove Hill is in the southeastern part of the Mt. Jackson quadrangle. In addition to exposing zinc mineralization, this new road cut affords an excellent opportunity to examine upper Beekmantown recrystalline dolomites.

At Grove Hill, sphalerite is associated with a minor bedding-plane fault, with disseminated crystals replacing thin gouge and larger crystals in vein dolomite cementing fractured beds (Pl. 14B). The extent of mineralized rock, either down-dip or on strike, is not known.

Figure 9.—Location map of the "Wiseland" sphalerite locality. Northeast one-ninth, Harrisonburg quadrangle, scale 1:62,500.

ORIGIN OF ORE OCCURRENCES

The foregoing descriptions make it obvious that certain conditions—recrystalline, fracturing, or brecciation—are necessary host conditions for sulfide mineralization. As such they were pre-ore, and served as favorable loci for deposition from sulfide-bearing solutions. Thus, in order to present a complete picture, it becomes necessary to attempt explanations for both tectonic breccias and recrystalline dolomites.

BRECCIAS

In this discussion, problems pertaining to the origin of sedimentary breccias are not pursued. Such problems are more adequately taken up in several textbooks and articles than is possible here. This is not to imply that tectonic breccias in general have not been as fully investigated as the other types; however, because of economic importance and the perhaps unique character of the chatter breccias, some further discussion of tectonic breccias is deemed necessary here.

Bedded breccia.—In brief review, this breccia type has the following characteristics: (1) restriction to a bed or a series of beds, (2) intergradation with nonbrecciated beds through a zone of fracturing, (3) sharply angular fragments which may be completely or only partly separated, (4) little rotation, thus the pre-fracture position of adjacent fragments is often clear, and (5) cementation of fragments by white vein dolomite. In no place have evidences of large-scale solution, sufficient to have produced a collapse breccia, been noted. It is believed that the bedded breccias of the Timberville district are expressions of local shearing stresses, transmitted by competent beds. Precisely why such stresses should manifest themselves in such different forms as minor faults, local folds, or breccia is not known. However, it seems logical to assume that in a thick-bedded dolomite sequence not all sections would react similarly to local differential stresses. In some cases, bedding plane faults would result, whereas in others, where bedding slippage was inhibited, brecciation of least competent (more brittle?) beds would represent easiest relief. In general, thick-bedded Beekmantown dolomites did not lend themselves to local folding as did thin-bedded limestones of adjacent formations.

Fault breccia.—Fault breccias are sufficiently familiar to most geologists to require little explanation. Their recognition depends largely on the following characteristics: (1) small breccia fragments, usually with evidence of granulation, (2) breccia associated with known stratigraphic offset, (3) a shattered bed bottomed by gouge zone, and (4) a thin brecciated zone with considerable lateral extent showing granulated fragments, and perhaps mixing of underlying and overlying lithologies. Fault breccias may be concordant or discordant with bedding, though most in

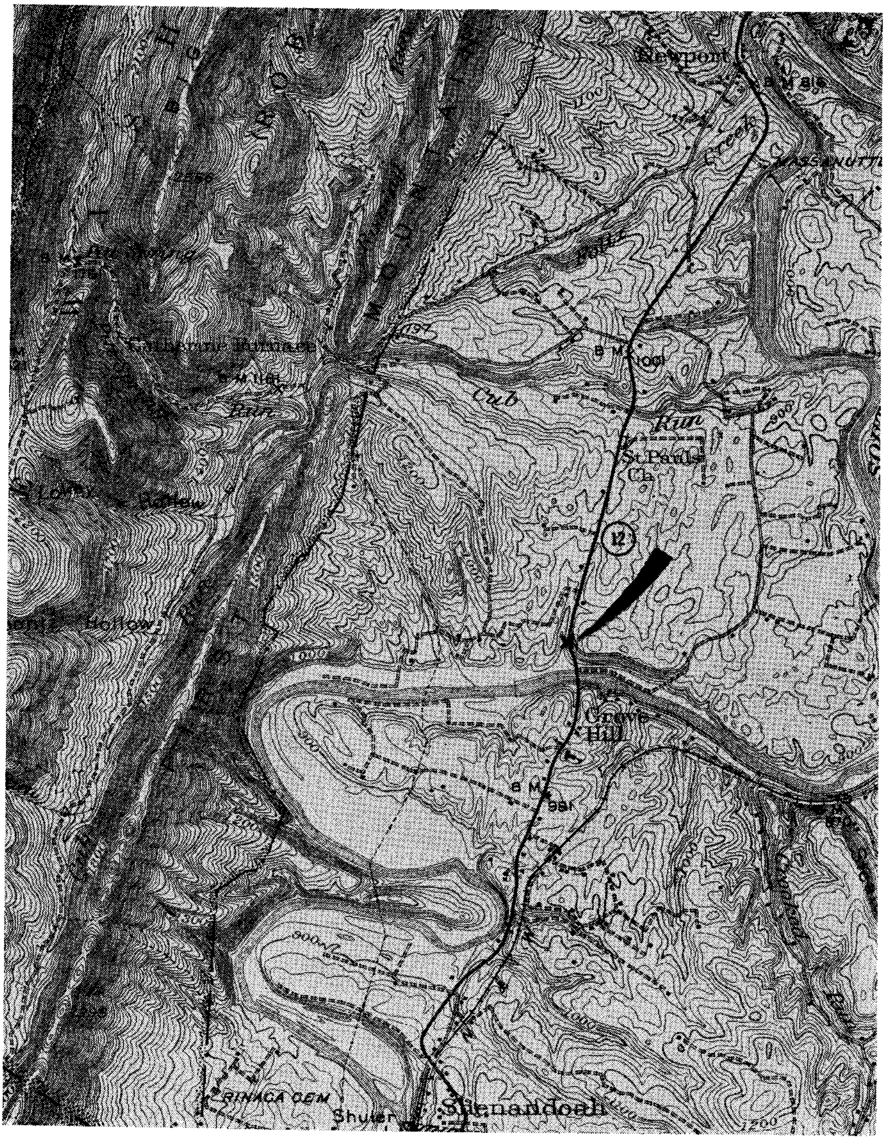


Figure 10.—Location map of the Grove Hill sphalerite locality. South one-ninth, Mt. Jackson quadrangle, scale 1:62,500.

the Timberville district appears to be associated with bedding-plane thrusts.

Chatter breccia.—The chatter breccias of the Timberville district are apparently unique geologic features for the Appalachian Valley region. Throughout this bulletin the authors have referred to these breccias as "tectonic." Obviously these references represent the authors' belief. However, because several geologists have suggested the possibility of an origin by cavern collapse, this discussion will point out the evidences for a particular and unusual tectonic origin, and the evidences against a solutional origin.

Defining the Bowers-Campbell breccia as the "type" chatter breccia, the physical characteristics may be summarized thus:

I. Size and form of the body:
   A. The breccia mass is 700 feet long, up to 100 feet wide, and over 700 feet deep.
   B. The body is in the form of an irregular pitching pod, with the plane of major and intermediate axes lying parallel to the strike.
   C. The breccia has well-defined walls cutting nearly vertically across the dip of enclosing beds.
   D. Several bedding plane thrusts displace the breccia.

II. Characteristics of the breccia:
   A. Breccia blocks are sharply angular and vary greatly in size.
   B. Insofar as known, brecciation involved only the Beekmantown formation.
   C. There is a definite though subtle lineation of the blocks.
   D. Some key bed lithologies can be recognized as fragments within the breccia. Though each of these lithologies is distributed among other fragments, a rough grouping is maintained, which shows nearly uniform down-drop with reference to the position of source key bed outside the breccia body.
   E. The breccia is cemented by white vein dolomite and sulfides; stylolite contacts between fragments or fragments and cement are not uncommon.

III. Breccia mineralization:
   A. The entire breccia body is mineralized, to some degree, by sulfides.
   B. Sulfide mineralization is essentially restricted to the vein-dolomite cement; replacement of breccia blocks is negligible.
   C. The more massive sulfides are localized immediately adjacent to the larger thrust cutting the orebody.

D. Pyrite is relatively concentrated below the major dislocating thrust, sphalerite below the thrust and throughout the upper orebody, and galena in the upper reaches of the breccia.

Analysis of the foregoing features indicates that (a) the breccia, insofar as known, is confined to the Beekmantown; (b) it is prethrusting; (c) thrusting is premineralization; and (d) breccia fragments are locally derived and not well mixed.

In order to introduce a tectonic origin for these breccias, several premises based on structural setting and stratigraphic relations must be considered.

The three known chatter breccias all lie in the westernmost Beekmantown belt, approximately 2 miles east of the North Mountain thrust fault (Pl. 3). The North Mountain fault is the major fault of the Shenandoah Valley, with a mapped lateral extent of about 170 miles. The stratigraphic sequence is normal in the overthrust block, ranging from Elbrook (Cambrian) along the leading edge to Martinsburg (Ordovician) in the Broadway syncline. Although several of the units in the section have thicknesses comparable to that of the Beekmantown, the Beekmantown is the only carbonate rock formation with a high degree of homogeneity in lithology and bedding thickness. Further, the Beekmantown is predominantly dolomite.

In an analysis of an Appalachian low-angle thrust fault, it is rather difficult to conceive that movement of the overriding block was either smooth or constant. Rather, the reverse seems a probability. It is also probable that along the fault front forward movement of the hanging wall block varied from place to place. Thus, some segments would relatively lag, within elastic limits, until stresses could be built up sufficient to overcome local friction, when the lag segments would "rebound" to a normal position. At this time, sharply irregular forward movement, or "chattering," of the thrust block would be expected. Depending on intensity and frequency of the chattering and the physical characteristics of the rocks involved (lithology and bedding), folding, faulting, flowage, or brecciation would result.

The foregoing circumstances apply to the Timberville area. The Cambro-Ordovician section east of the North Mountain fault represents a former, hanging wall, lag block. Chattering, owing to lag and elastic rebound, induced stresses which resulted in folds and flowage in the relatively plastic shales and limestones and in brecciation and possibly faulting in the brittle dolomites. Further, application of the strain ellipsoid shows that a zone of relative tension developed parallel to the strike and cut vertically across the dip of the beds. The authors believe that in this zone of tension the lens-shaped breccias were formed as chatter breccias. The Beekmantown formation is the only one sufficiently homogeneous, brittle, massive, and thick-bedded to contain breccias of appreciable size. Minor, off-setting, sympathetic thrusts probably closely followed brecciation.

The possibility that the Beekmantown chatter breccias are the result of solution collapse has been a recurring suggestion. Currier (1935a) in his consideration of the zinc-lead region of southwestern Virginia was also faced with tectonic *vs.* collapse origin for mineralized breccias. Although the breccias of these two Virginia districts are dissimilar in overall form, Currier's (1935a, p. 84) conclusions on collapse through solution are nonetheless applicable: "If the breccias that carry the sulphides were formed by the collapse of solution caves one would expect to find vugs or other open cavities, great variation in size of fragments, depositional structures common to caves, 'cave earth,' and associated joint planes in the roof that were once widened by solution."

In addition, the breccias in the Timberville area have an irregular pod-shape completely lacking any indication of the anastomosing pattern so common to caves.

If it could be conceived that isolated, slightly irregular, pod-shaped solution openings could have been developed, they could be filled with breccia blocks only when in the vadose zone. Under phreatic conditions, solution would tend to remove any loose blocks that might form. Further, if either phreatic- or vadose-developed openings were filled with blocks and fragments, these would certainly represent a conglomerate mixture derived from overlying horizons, rather than a filling preserving any indication of the stratigraphy in the surrounding walls.

It has been suggested that such a breccia could form by upward stoping of fractures formed in sympathy to stratigraphic solution and thinning of some bed not yet penetrated by drilling. It is difficult to conceive of such a stoping process extending over the high vertical range and narrow width of the chatter breccias. However, if such a breccia could form by stratigraphic solution, the fact that brecciation preceded faulting indicates that the proposed solution breccia developed prior to the Appalachian revolution; and the facts that the breccia apparently does not involve post-Beekmantown limestone and post-Beekmantown limestone shows no stratigraphic thinning, indicate that the breccia probably formed prior to the deposition of the overlying limestones. At this time the strata were horizontal. A breccia initiated by stratigraphic thinning in some lower bed would have had to stope upward, not vertically, but at 60° to the bedding.

The only place for solution in the formation of these breccias is in the possibility of hydrothermal solutions enlarging a pre-existing chatter breccia pattern.

In summary, a regional structural and stratigraphic setting exists into which tectonic breccias may be fitted. The structural details are unknown.

On the other hand, the details of known breccias prevent consideration of the breccias as being due to collapse by "structural" or "stratigraphic" solution.

RECRYSTALLINE DOLOMITES

The problem of origin of recrystalline dolomites is perhaps even more perplexing than that of the chatter breccias. The recrystallines were, during one phase of exploration, considered as a possible guide to sulfide mineralization. After thorough field study and evaluation of the mineralization-recrystalline relation, the following conclusions may be stated: (1) sulfide mineralization is not found without some degree of recrystallization of enclosing limestones; (2) bedded sulfides (not bedded breccia) always occur in recrystallines; (3) recrystallines without sulfides are indistinguishable in color and texture from those with sulfides; (4) recrystalline fragments occur in chatter breccias; (5) fault breccias are recrystallized; (6) recrystallization affected limestones and probably pre-existing dolomites; and (7) the vast majority of Beekmantown recrystallines are not mineralized by sulfides.

The usual and close association of sulfides with vein dolomite and recrystalline beds suggests a strong genetic relationship. Although all coarsely recrystalline beds may be related to the period of hydrothermal sulfide mineralization, the presence of recrystalline blocks in chatter breccias and the widespread occurrence of unmineralized recrystallines suggest a possibility of two ages and two modes of origin of recrystallization.

Barren recrystallines show no characteristics sufficiently defined to allow postulation of a precise formative process. It is probable that they could have been formed by either meteoric or juvenile waters, moderately rich in calcium and magnesium. For reasons to follow, the authors prefer a hydrothermal origin.

The mineralized recrystallines, through associated sulfides, offer some clue to origin. The superabundance of white, coarsely crystalline vein dolomite in which sulfides commonly occur implies that the basic mineralizing solutions were charged with Ca-Mg as well as less common metallic ions. Detailed studies in better known areas of sulfide-mineralized carbonate rock show that certain beds in a carbonate sequence are favored as hosts above others. Precise reasons for such selectivity are unknown, but inherent porosity-permeability factors are logical probabilities. The major problem is to allow contact of mineralizing solutions with favorable carbonate sections. This initial entry problem does not appear to be as complex in Shenandoah Valley as in other areas. In most local mineralized areas, faulted or shattered zones provided major ore solution channelways, and bedding and joints provided dispersing channelways.

The ascending nature of mineralizing solutions is most strongly indicated by the distribution of pyrite, sphalerite, and galena within individual orebodies and by the presence of a suite of certain trace elements. In the Bowers-Campbell orebody, the major thrust fault is mineralized; pyrite is concentrated in the breccia below this fault; galena is found only in the upper reaches above it; and sphalerite predominates in the intervening area. This zonal arrangement not only follows that suggested by solubility laws but also that of decreasing temperature. Thus, the spatial relations of vein dolomite, pyrite, sphalerite, and galena imply that all were deposited from rising aqueous solutions of somewhat elevated temperature. The mineralized solutions probably rose along a fault and into the breccia from a deeper source, solution temperature decreasing most rapidly upon entrance into the breccia area, with probable damming at the major offsetting fault.

If the foregoing hypothesis is valid, the basic mineralizing solution is responsible for the recrystallization in or near sulfide shows. Textural relations reveal that recrystallization and dolomitization in large part preceded sulfide deposition, though some overlap is present (see paragenetic chart, Fig. 2). This supports Hewett's (1928, p. 852) statement, " . . . the conclusion is reached that broadly the process of dolomitization of limestone seems to distinctly precede deposition of sulphides, even though here and there some dolomite is deposited later." Currier (1935b, p. 272), in a report on East Tennessee zinc deposits, also places the "recrystallization" stage within the period of mineralization.

REGIONAL STRUCTURE AND ORIGIN OF ORE

The Timberville district is adjacent to an area which has provoked much structural discussion in past years. Massanutten Mountain, lying east of the Timberville district, is the dominant structural and topographic feature of Shenandoah Valley. This mountain, a complex syncline, nearly bisects the Valley longitudinally and is about 45 miles long. The Massanutten Mountain synclinal trend has an extent of slightly more than 100 miles in Virginia. The mountain is conspicuously "broken," both structurally and topographically, about midway in its length, forming New Market Gap. Southeast of New Market Gap, the geologic map of Butts (1933) shows a structural embayment extending to the Blue Ridge front. Northwestward, several major folds plunge out or otherwise change form in this latitude (Pl. 15). These structural and topographic phenomena have led many geologists to postulate a real—as opposed to relative—cross-fold of major proportions. However, until recently there was little in the way of positive evidence to support this postulate.

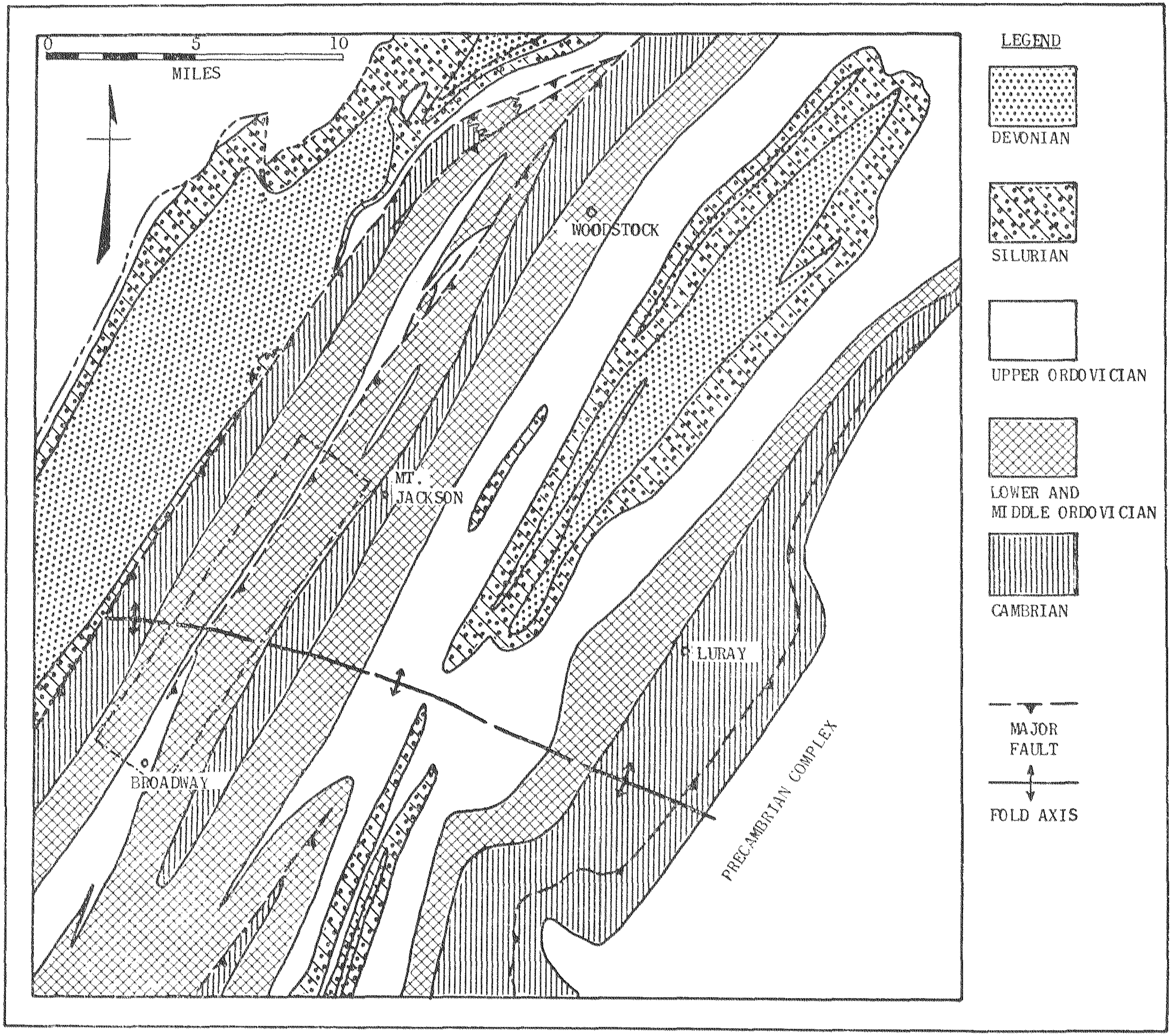
Early in 1955, an aeromagnetic longitudinal profile was made along the west side of Massanutten Mountain. The following information on this profile was made available through the cooperation of the U. S. Geological Survey.

> "A recently flown aeromagnetic profile paralleling the regional strike from Winchester to Lexington showed considerable apparent basement relief. One positive magnetic feature, extending approximately from Woodstock to Bridgewater, has a peak between Timberville and Broadway. Depth estimates are impossible without further information in the transverse direction. There is magnetic indication of a few scattered occurrences of igneous rock at or near the surface."[5]

There is no indication, from this aeromagnetic profile, of whether the basement high was *topographic* or *structural*. However, spatial relations of folds in the region strongly suggest the latter. This further implies a certain structural instability of the area.

Perhaps the point most pertinent to the problem at hand, and one worthy of repetition, is that *"there is magnetic indication of a few scattered occurrences of igneous rock at or near the surface."* The problem of origin of the Appalachian lead-zinc ores has remained enigmatic for decades. Nason (1917, p. 832) states: "in the zinc fields of . . . eastern Tennessee, Virginia and Pennsylvania, the ore deposits are characterized by heavy faulting and are also remarkable for the entire absence of eruptives of any kind . . . . fluorite is the only hint of the possible presence of eruptives in the vicinity of the zinc mines." Basic eruptives do outcrop in the Timberville district, in general, northwest and southwest of the

[5]Personal communication: R. W. Johnson, U. S. Geological Survey, Washington, D. C., July 13, 1955.



Geologic map of the central part of Shenandoah Valley illustrating the trend of an apparent cross-warp and its relation to the area of most intense sulfide mineralization. Geology adapted from Butts (1933).

Timberville-Broadway "peak" mentioned by Johnson. None of these dikes is known to be mineralized. The authors can see no direct correlation between exposed igneous rocks and sulfide mineralization. However, as sponsors of a hydrothermal origin for the ore solutions, the authors cannot dismiss igneous rocks in this mineralized district as merely coincidental. Admittedly, it is doubtful that the known igneous rocks were capable of supplying sufficient MgO to account for the widespread dolomitization. Along this line Hewett (1928, p. 853) states, ". . . . no igneous rocks are known . . . in Tennessee or Virginia that can be considered as competent to promote the circulation of, much less supply, the waters that deposited the zinc, lead and copper deposits of the region. . ." The possible relation of the parent, or differentiating, igneous body to mineralization has not been speculated upon, to date.

Green (1951, p. 347) stated that "the deposits (Timberville) are believed to have originated in a dolomitic environment by the interaction of meteoric water and hydrothermal emanations." The details of sulfide mineralization in the Timberville district yet remain to be uncovered. The generalizations discussed in preceding paragraphs are based on areal geology, geographic distribution of mineralization, and detailed drilling of one orebody. Any attempt to pursue the origin and occurrence of the zinc and lead sulfides beyond generalization is uncertain and unwarranted.

Little can be said about the exact age of sulfide mineralization in the Timberville district. The sulfides occupy, in part, structures formed during Appalachian orogeny. The sulfides are not known to have undergone significant deformation. This implies that the mineralization is no older than very late Paleozoic. The Valley igneous bodies, primarily dikes and plugs, have been assigned Late Triassic age (Butts, 1940, p. 435). If a valid mineralization-igneous activity relation is established, the age of mineralization will be fairly well defined. One additional point in favor of a Triassic age is the recent discovery of a minor zinc-lead occurrence in beds of that age near Culpeper, Virginia.

FUTURE OF THE DISTRICT

Despite widespread sulfide mineralization in Shenandoah Valley only one large orebody is known, the Bowers-Campbell breccia body. In the past, minor amounts of ore have been produced from both fault breccias and chatter breccias, and recrystalline beds have been prospected. However, recent exploration indicates that only the chatter breccias are of sufficient size to be potential major ore producers. Sulfides in recrystalline dolomite, while spectacular, serve only as guides to regional mineralization.

Several mineralized chatter breccias crop out along the western Beekmantown belt, one of which contains an orebody. The fact that these breccias outcrop is pure geological fortuity, and there is no reason to assume that *all* of the breccias present are exposed. More breccia lenses undoubtedly exist, but future prospecting techniques will greatly benefit if the relations of two or more closely spaced breccias can be worked out. Whether or not other breccias will be sufficiently mineralized to warrant such prospecting is the unanswered question.

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