VIRGINIA DIVISION OF MINERAL RESOURCES PUBLICATION 27

CONTRIBUTIONS TO VIRGINIA GEOLOGY—IV

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES
Robert C. Milici, Commissioner of Mineral Resources and State Geologist

CHARLOTTESVILLE, VIRGINIA
1980

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FRONT COVER: Isoclinal folds (F_2) in kyanite quartzite of the Arvonia Formation at Woods Mountain, Buckingham County, Virginia. (Pocket knife just below center of photo serves as scale.)

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DEPARTMENT OF PURCHASES AND SUPPLY
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CONTENTS

EVIDENCE FOR THE CORRELATION OF THE KYANITE QUARTZITES OF WILLIS AND WOODS MOUNTAINS WITH THE ARVONIA FORMATION[1]

By

James F. Conley and John D. Marr, Jr.

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ABSTRACT

Rocks of the study area are, from oldest to youngest, the Candler, the Chopawamsic and the Arvonia formations. The Chopawamsic conformably overlies the Candler and is unconformably overlain by the Arvonia. In the western part of the area, the Arvonia Formation is composed of a basal, discontinuous, locally kyanitic quartz-mica schist, a thin sequence of locally kyanitic banded quartzites and a sequence of graphitic metapelites; the metapelites are at the top of the section. At its type section the formation does not contain kyanite. The Arvonia is shown to include kyanite quartzite at Willis and Woods mountains in the eastern part of the area.

[1] Portions of this publication may be quoted if credit is given to the Division of Mineral Resources. It is recommended that reference to this report be made in the following form: Conley, J. F. and Marr, J. D., Jr., 1980, Evidence for the correlation of the kyanite quartzites of Willis and Woods mountains with the Arvonia Formation, *in* Contributions to Virginia Geology—IV: Virginia Division of Mineral Resources Publication 27, p. 1-11.

The quartzite at Willis and Woods mountains was thought by previous workers to be interlayered with a gneiss unit. Present work shows that this gneiss, which is an amphibolite facies of the Chopawamsic Formation, is unconformably overlain by a kyanite-quartz-mica schist which is overlain by the kyanite quartzite. At Willis Mountain the kyanite quartzite is overlain by graphitic metapelite. From the similarity of the stratigraphic sequences at Willis and Woods mountains to those of typical sections of the Arvonia, the kyanite quartzite is interpreted to correlate with the Arvonia Formation.

INTRODUCTION

Willis Mountain and Woods Mountain are located in the Willis Mountain and Andersonville 7.5-minute quadrangles, Buckingham County, in the south-central Virginia Piedmont (Figures 1, 2, 3). The mountains are prominent monadnocks that stand from 100 to 500 feet (30-152 m) above the typical rolling Piedmont terrain. Kyanite quartzite is exposed at each of the mountains and occurs at several other places in an area approximately 30 miles (48 km) long in parts of Buckingham, Prince Edward, and Charlotte counties. Although these kyanite quartzites do not form a pronounced strike belt, they were named the kyanite belt of central Virginia by Jonas (1932). The area containing the kyanite quartzite was named the Farmville district by Espenshade and Potter (1960).

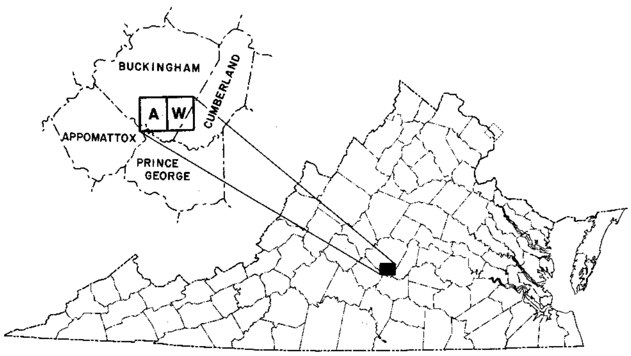

Figure 1. Index map.

During a field check of the geologic mapping of the Willis Mountain and Andersonville 7.5-minute quadrangles,[2] relict cross-bedding was found in the kyanite quartzite on the eastern flank of Woods Mountain. Further examination showed that the quartzite on the east ridge of Willis Mountain also contains preserved cross-beds. Previous authors (Taber, 1913, Jonas, 1932, Espenshade and Potter, 1960; Bennett, 1961 and Brown, 1969) are in agreement that the kyanite quartzite of the region is a product of the metamorphism of aluminous sandstones, but relict cross-beds have not previously been reported in the unit. The presence of these and other primary structures makes possible a definitive statement about the environment of deposition of the sediments from which the kyanite deposits were formed. Data obtained during the present study necessitates a revision of the stratigraphic section of the area. The section proposed differs markedly from those previously suggested (Table 1).

PREVIOUS INVESTIGATIONS

Taber (1913) mapped a sequence of mica gneisses and schists, amphibole gneisses and schists, and ferruginous quartzites that together are now considered to be, in part, the Chopawamsic Formation (Pavlides and others, 1974); the rocks are in the area of the gold belt (later named the gold-pyrite belt by Lonsdale, 1927). Taber showed these rocks to be unconformably overlain by the Arvonia slates, rocks from which Walcott (*fide* Darton, 1892) identified Ordovician fossils. Taber recognized thin conglomerates and quartzites at the base of the Arvonia slates. The age of the Arvonia is Middle to middle Late Ordovician (Higgins, 1973). Stose and Stose (1948) considered the Arvonia to occupy a double syncline; Conley (1978) suggested that this structure is a syncline refolded around the nose of a later-formed anticline.

Espenshade and Potter (1960) mapped the Willis Mountain area and recognized two units, a biotite gneiss, and an overlying hornblende gneiss. They thought that the kyanite quartzite of Willis Mountain was interbedded with the top of the biotite gneiss unit. Brown (1969), during mapping of the Dillwyn 15-minute quadrangle, which is immediately north of the Willis Mountain quadrangle, recognized a sequence of metavolcanic and metasedimentary rocks that he tentatively correlated with rocks of the Evington Group; these rocks are now considered to be Chopawamsic (Conley and Johnson, 1975). Brown (1969) mapped on-strike equivalents of the Willis Mountain kyanite quartzite as "rocks of uncertain age" and showed the Arvonia Formation to unconformably overlie this sequence of rocks (Table 1). The kyanite quartzite was earlier con-

[2] These investigations are part of a cooperative project between the Piedmont Planning District Commission and the Virginia Division of Mineral Resources.

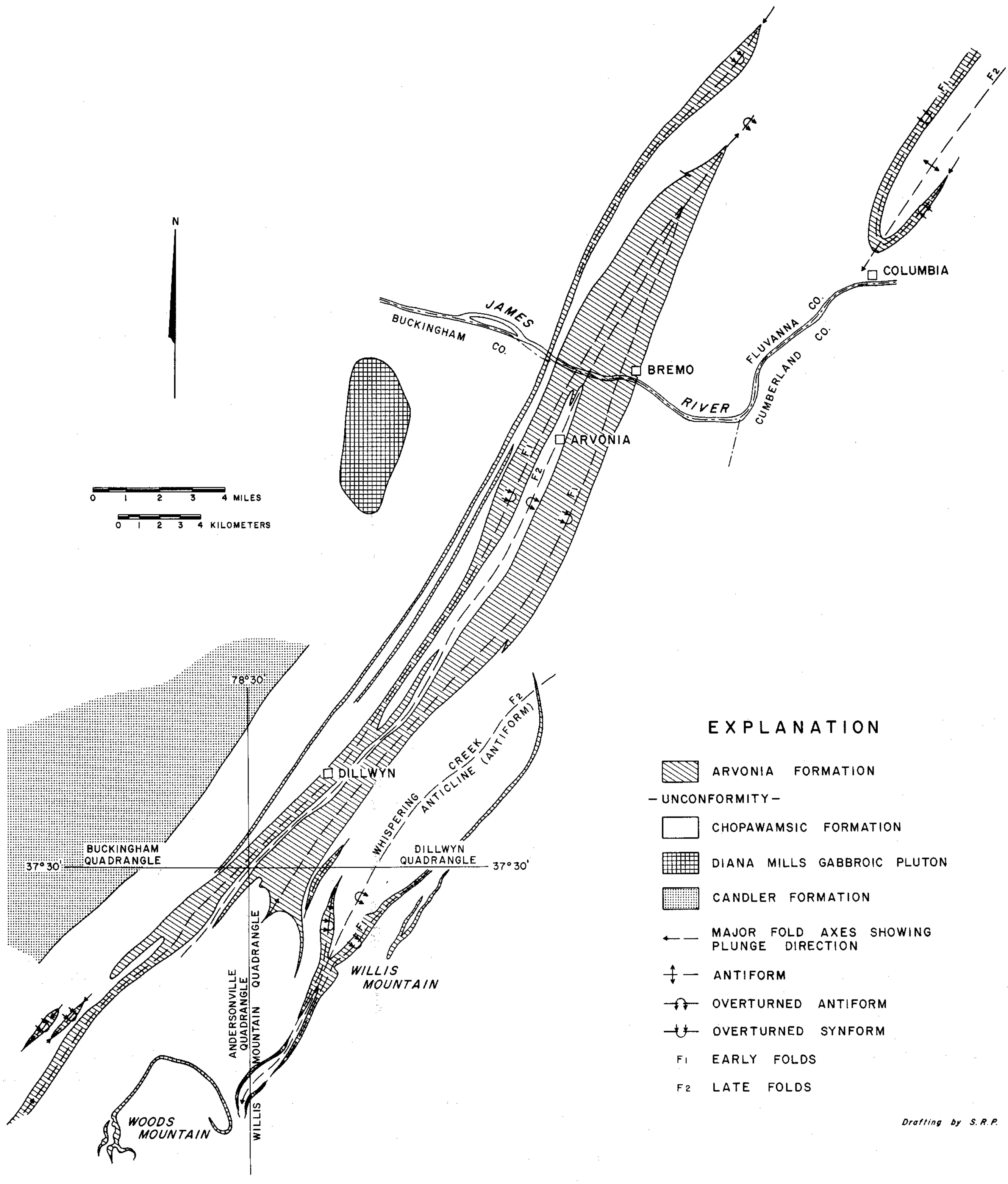

Figure 2. Interpretative regional geologic sketch map.

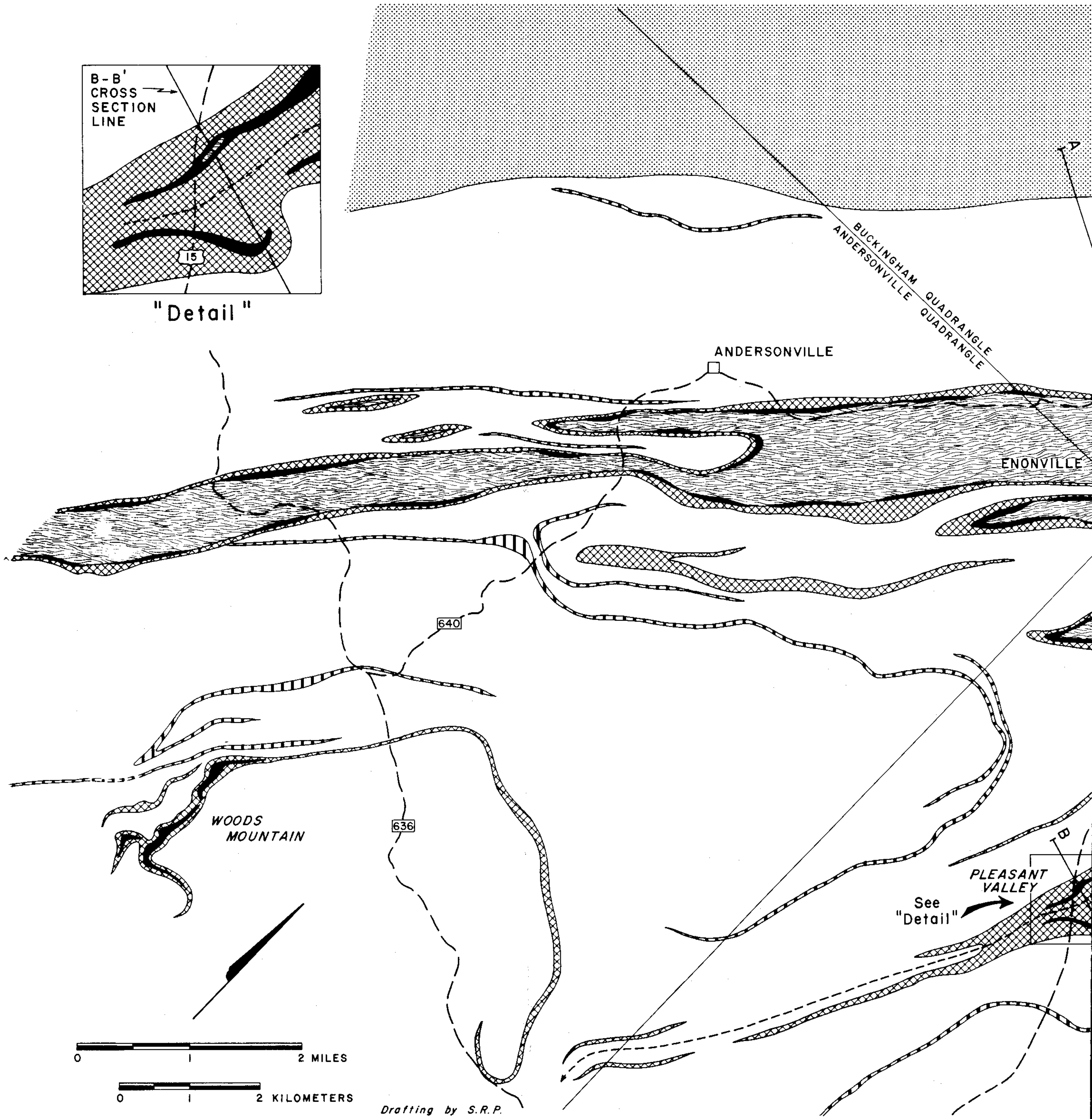

Figure 3. Generalized geologic map and cross-sections of parts of Willis Mountain and Andersonville quadrangles and adjacent areas.

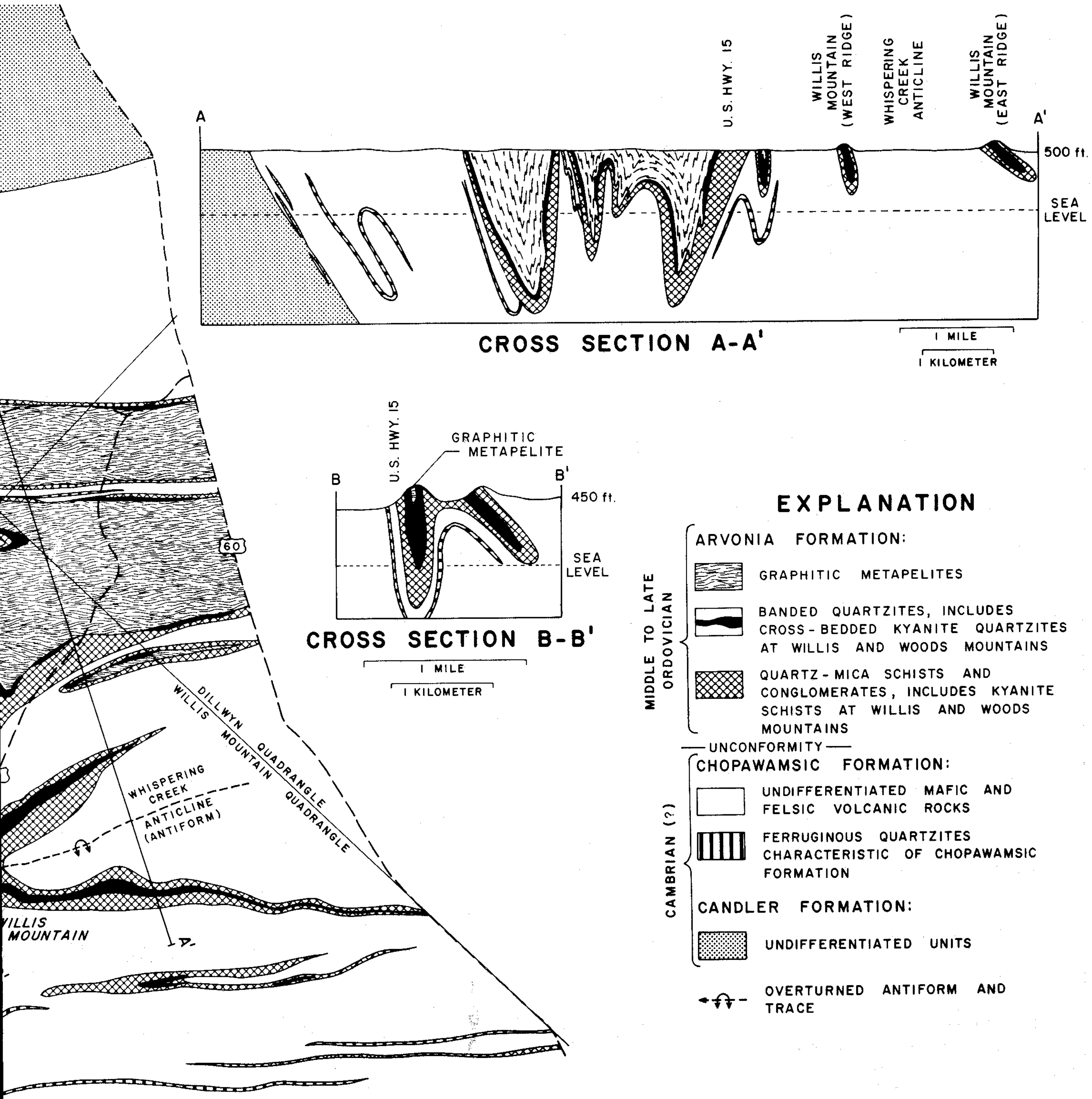
A
A'
U.S. HWY. 15
WILLIS MOUNTAIN (WEST RIDGE)
WHISPERING CREEK ANTICLINE
WILLIS MOUNTAIN (EAST RIDGE)
500 ft.
SEA LEVEL
CROSS SECTION A-A'
1 MILE
1 KILOMETER
B
B'
U.S. HWY. 15
GRAPHITIC METAPELITE
450 ft.
SEA LEVEL
CROSS SECTION B-B'
1 MILE
1 KILOMETER
60
DILLWYN QUADRANGLE
WILLIS MOUNTAIN QUADRANGLE
WHISPERING CREEK ANTICLINE (ANTIFORM)
WILLIS MOUNTAIN
EXPLANATION
MIDDLE TO LATE ORDOVICIAN
ARVONIA FORMATION:
GRAPHITIC METAPELITES
BANDED QUARTZITES, INCLUDES CROSS-BEDDED KYANITE QUARTZITES AT WILLIS AND WOODS MOUNTAINS
QUARTZ-MICA SCHISTS AND CONGLOMERATES, INCLUDES KYANITE SCHISTS AT WILLIS AND WOODS MOUNTAINS
UNCONFORMITY
CAMBRIAN (?)
CHOPAWAMSIC FORMATION:
UNDIFFERENTIATED MAFIC AND FELSIC VOLCANIC ROCKS
FERRUGINOUS QUARTZITES CHARACTERISTIC OF CHOPAWAMSIC FORMATION
CANDLER FORMATION:
UNDIFFERENTIATED UNITS
OVERTURNED ANTIFORM AND TRACE

Table 1. Stratigraphic relations of rock units in study area*.

<table>
<tr><th>Espenshade and Potter 1960</th><th colspan="2">Brown, 1969</th><th colspan="3">This Paper</th></tr>
<tr><td>Top of Section</td><td colspan="2">Top of Section</td><td colspan="3">Top of Section</td></tr>
<tr><td rowspan="3">Arvonia Formation</td><td rowspan="3">Arvonia Formation</td><td>Slate</td><td rowspan="3">Arvonia Formation</td><td colspan="2">Graphitic metapelite</td></tr>
<tr><td>Biotite-garnet slate and schist</td><td>Quartzite</td><td>Kyanite quartzite of Espenshade & Potter, 1960; Brown, 1969</td></tr>
<tr><td>Conglomeratic quartz-sericite schist</td><td>Quartz-mica schist</td><td>Kyanite-mica schist</td></tr>
<tr><td>Unconformity</td><td colspan="2">Unconformity</td><td></td><td colspan="2">Unconformity</td></tr>
<tr><td>Amphibolite</td><td colspan="2">Evington Group?</td><td rowspan="4">Chopawamsic Formation</td><td colspan="2">Upper Member</td></tr>
<tr><td>Biotite gneiss</td><td colspan="2">Rocks of uncertain age</td><td colspan="2" rowspan="3">Lower Member</td></tr>
<tr><td>Kyanite quartzite</td><td colspan="2">Kyanite quartzite</td></tr>
<tr><td>Biotite gneiss</td><td colspan="2">Rocks of uncertain age</td></tr>
<tr><td></td><td colspan="2"></td><td colspan="3">Candler Formation</td></tr>
</table>

*Vertical section diagramatic and not to scale sidered to be correlative with the Wissahickon Formation of Pennsylvania (Jonas, 1932).

STRATIGRAPHY

Candler Formation

The Candler Formation, the oldest unit in the area, is exposed in the northwestern part of the Andersonville quadrangle (Figures 2 and 3). The Candler is a dark-greenish-gray, chlorite-sericite-quartz phyllite that locally contains magnetite, garnet and chloritoid porphyroblasts. Thin interlayers of dark-grayish-green, quartz-feldspar-chlorite-sericite metagraywackes and impure micaceous quartzites occur sparingly in the unit. The phyllite has a well-developed penetrative foliation. Bedding consists of fine laminae (1-5 mm), where it can be observed, and the unit locally contains thin (about 1 mm) quartzite layers. The Candler grades upward into the Chopawamsic Formation.

Chopawamsic Formation

A major change in the depositional environment of the area occurred at the end of Candler time, for the monotonous sequence of phyllites of the Candler is conformably overlain by metamorphosed coarse volcaniclastic and volcanic rocks of the Chopawamsic Formation. The Chopawamsic is composed of metamorphosed tuffaceous graywackes, pillow basalts, (tuffaceous?) shales, felsic and mafic pyroclastic rocks and associated volcanogenic gold deposits, massive sulfide deposits, and ferruginous quartzites (Pavlides, 1976; Conley, 1978). Conley and Johnson (1975) divided the formation into a lower unit and an upper unit. The lower unit is composed of metagraywackes, tuffaceous metagraywackes, Candler-like metapelites, and interlayered felsic and mafic metavolcanic rocks. The lower unit grades upward into predominantly interlayered felsic and mafic metavolcanic rocks of the upper unit. The interlayered predominantly felsic and mafic rocks of the upper part of the Chopawamsic are represented by biotite gneiss, biotite-hornblende gneiss and hornblende gneiss and schist in the southeastern part of the area, an area where metamorphic grade is relatively high. Ferruginous quartzites, which are found only in the Chopawamsic Formation in this area, are thought to represent the distal deposits of volcanic exhalants associated with volcanogenic massive sulfides and gold deposits occurring in the formation (Espenshade and Potter, 1960; Hodder and others, 1977; Good and others, 1977; Conley and Marr, 1979).

The age of the Chopawamsic is late Precambrian or Cambrian. Glover and others (1971) report that the gneisses in the strike belt to the south (west of Virgilina) range in age from 620 to 740 m.y. Glover (1974) reports an age of 530 to 570 m.y. for the Chopawamsic.

Arvonia Formation

The Arvonia Formation overlies the Chopawamsic with angular unconformity. The basal part of the Arvonia Formation is a locally discontinuous quartz-mica schist that contains lenticular layers of micaceous quartzite and micaceous conglomerate. The conglomerate contains blue quartz pebbles (Figure 4). These pebbles were not derived from the Chopawamsic or the Candler, for these units do not contain masses of blue quartz. Gold disseminated in

Figure 4. Quartz-mica schist containing stretched quartz pebbles at the Chestnut Grove Church, Andersonville quadrangle.

the basal, clastic rocks of the Arvonia represents a fossil placer deposit—the gold was likely derived from gold-bearing sulfides in the Chopawamsic Formation. The quartz-mica schist, which contains fuchsite and minor amounts of biotite, grades upward into a persistent, micaceous, banded quartzite. Graphite and pyrite are disseminated through both the quartz-mica schist and the banded quartzite.

Higher in the sequence, the Arvonia consists primarily of a thick section of dark-gray, graphitic metapelite that ranges from slate to schist, depending on metamorphic grade. The metapelite consists of thin, interbedded metasiltstones and metaclaystones and rare quartzite interlayers. Pyrite is a common accessory mineral in these beds.

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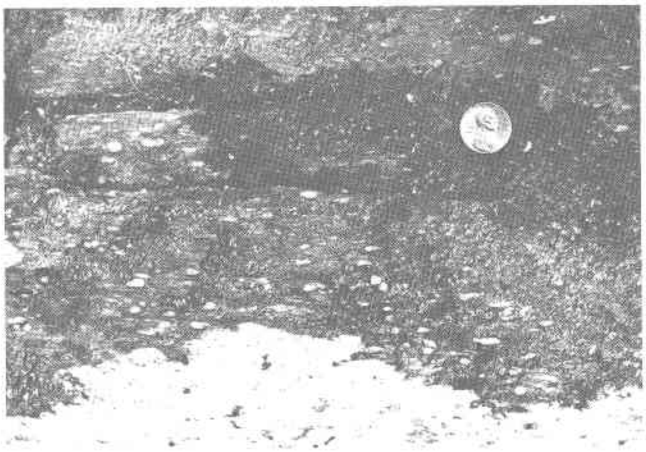

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In the southwestern part of the Andersonville quadrangle, the Arvonia Formation is at relatively high metamorphic grade. Here, the basal quartz-mica schist contains kyanite, garnet and staurolite and the metapelites of the upper part of the Arvonia are garnet-kyanite schists.

Rocks of the Arvonia Formation contain fossils identified as being either Middle or Late Ordovician in age; forms include brachiopods, trilobites, crinoids, pelecypods and bryozoans (Darton, 1892; Dale, 1906; Watson and Powell, 1911; Smith, Milici and Greenburg, 1964; Brown, 1969; Tillman, 1970 and Higgins, 1973).

Harper and others (1973) have dated the slates of the Arvonia Formation at 300 m.y. using the whole rock K-Ar method. This date, which is too young for the Acadian orogeny (345 m.y.;van Eysinga, 1978), and too old for the Alleghanian orogeny, probably represents a time following a metamorphic event during which the rocks cooled to a low enough temperature to allow a closed K-Ar system to form (Hadley, 1964).

ROCKS AT WILLIS AND WOODS MOUNTAINS

Description of Units

The rocks that underlie Willis and Woods mountains are here divided into a lower kyanite-quartz-mica schist, and an upper kyanite quartzite. A graphite metapelite, which overlies the kyanite quartzite, occurs in the saddle on the northwestern ridge of Willis Mountain near Pleasant Valley. The schist is composed primarily of quartz and muscovite with lesser amounts of biotite, staurolite, garnet and kyanite. The kyanite quartzite is composed of quartz and kyanite with varying amounts of muscovite. Accessory minerals include fuchsite, pyrite, and rutile. Graphite occurs as flakes (about 0.3 mm maximum dimension) interspersed throughout the sequence.

The kyanite quartzite contains preserved primary structures which consist of wedge-shaped sedimentary packages composed of quartzite and quartzose kyanite couplets. The basal beds of many of these packages consist of "jelly bean" gravels that grade upward into fine quartzite and terminate at the top as a layer of almost pure kyanite. These primary sedimentary packages are interpreted as representing fining-upward sequences as originally deposited (Figure 5). Each sequence was originally composed of a basal quartz gravel or coarse quartz sand that fined upward into silt and clay. Each package is truncated by the next overlying package. There are small-scale cross-beds (Figure 6) in some packages. Structures which are almost certainly channels

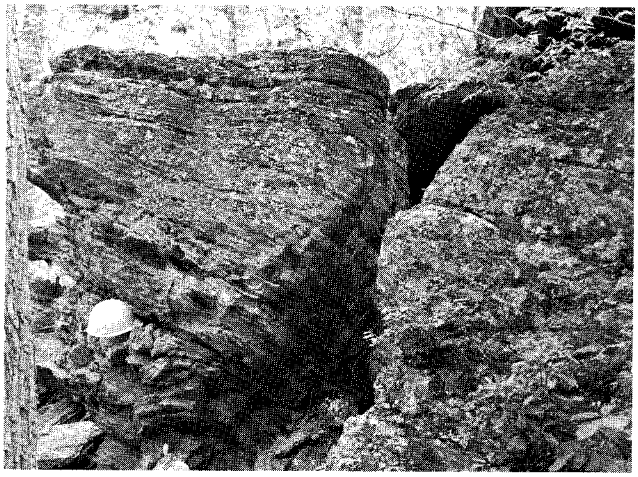

Figure 5. Fining-upward sequence in kyanite quartzite, Arvonia Formation, east ridge of Willis Mountain.

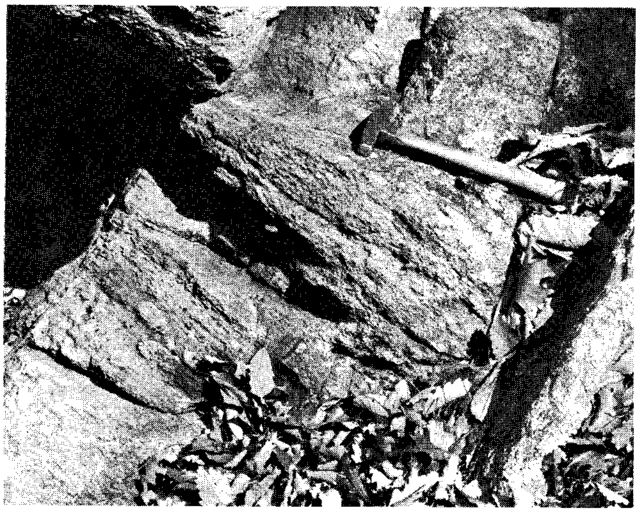

Figure 6. Small-scale cross-beds in fining-upward sequence in kyanite quartzite, Arvonia Formation, east ridge of Willis Mountain.

truncate some of the cross-beds (Figure 7). Primary structures which may have existed in the clay layers at the top of the sedimentary packages have been obliterated by the growth of disseminated kyanite crystals.

Correlation

Espenshade and Potter (1960) and Brown (1969) considered the kyanite quartzite at Willis Mountain to be interlayered with a sequence of gneisses. These gneisses were traced into the Chopawamsic Formation during mapping (Conley and Marr, 1979) and the stratigraphic correlation of these gneisses with the Chopawamsic is confirmed by the fact that they contain ferruginous quartzites that are found in the Chopawamsic Formation and in no other formation in Central Virginia. The kyanite quartzite does not belong to the Chopawamsic, for although the Chopawamsic contains ferruginous quartzites quadrangle, the Arvonia Formation is at relatively high metamorphic grade. Here, the basal quartz-mica schist contains kyanite, garnet and staurolite and the metapelites of the upper part of the Arvonia are garnet-kyanite schists.

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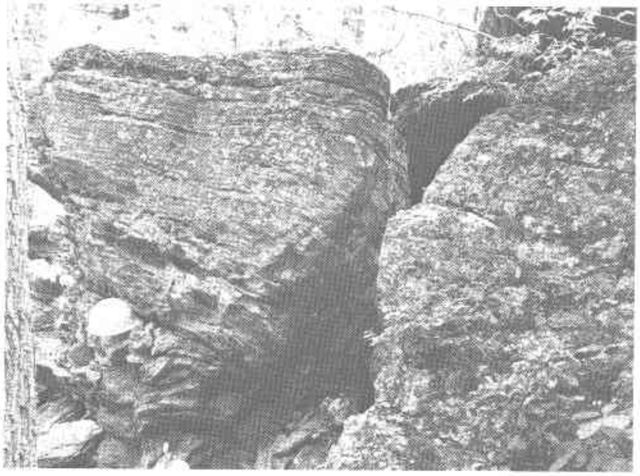
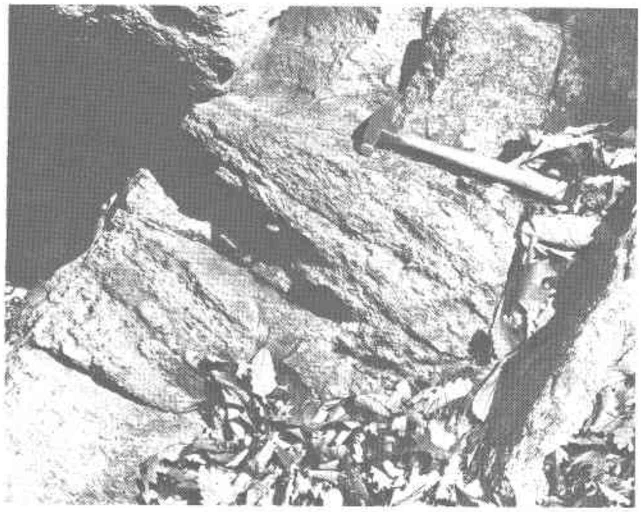


Figure 5. Fining-upward sequence in kyanite quartzite, Arvonia Formation, east ridge of Willis Mountain.



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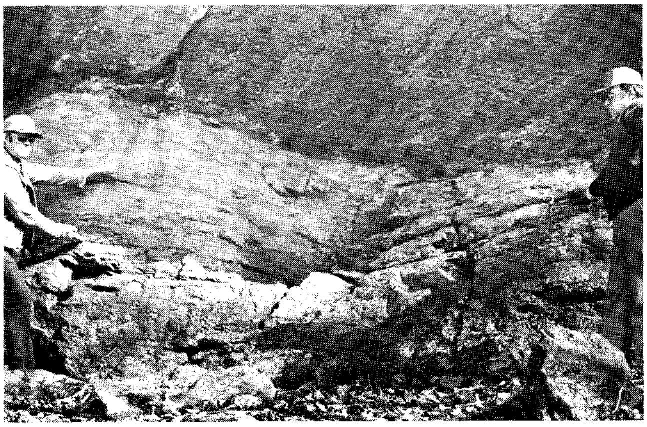


Figure 7. Channel deposit in kyanite quartzite, Woods Mountain.

(probably volcanic cherts or siliceous sinter deposits), it contains little or no terrigenous clastic rocks. Therefore, it is not likely that the cross-bedded quartzites at Willis and Woods mountains belong to the Chopawamsic—a typical "quartz starved" volcanic sequence. Rather, the kyanite quartzite must be correlative with the banded quartzite widely present in the Arvonia. The reasons for this conclusion are several. (1) Both the banded quartzite typical of the lower Arvonia and the kyanite quartzite present at Willis and Woods mountains are underlain by a locally conglomeratic, discontinuous quartz-mica schist which is the basal unit of the Arvonia Formation (Figure 8). The

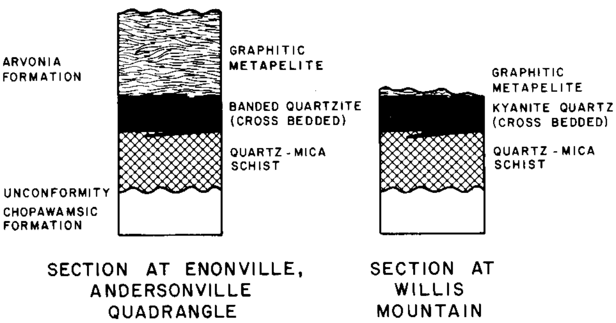


Figure 8. Correlation of units within the Arvonia Formation at Enonville, Andersonville quadrangle with the rocks exposed at Willis Mountain, Willis Mountain quadrangle.

quartz-mica schist is generally covered at Willis and Woods mountains, but the unit, which locally contains kyanite, was observed in a few exposures in these mountains and in a continuous cut across the southern end of Willis Mountain. (The cut was made by the Colonial Gas Company). In the cut, the strike of the quartz-mica schist was seen to be discordant with the underlying gneiss of the Chopawamsic Formation. Therefore, the kyanite quartzite which overlies the quartz-mica schist is not an interlayer in the gneiss. (2) A most convincing evidence for the correlation of the Willis and Woods mountain sequences with the Arvonia Formation is the discovery of graphitic metapelite in the saddle on the west ridge of Willis Mountain and it is inferred that erosion has removed the unit farther east at Woods Mountain. The graphitic metapelites at Willis Mountain is indistinguishable from this rock unit as it occurs in the Arvonia Formation throughout the Andersonville 7.5-minute quadrange (Figure 3). It has not been determined whether the unit on Willis Mountain is interbedded with the upper part of the kyanite quartzite or overlies it. (3) Graphite occurs as disseminated particles in thin sections of both the banded quartzites of the typical Arvonia and in the kyanite quartzite at Willis and Woods mountains; graphite is not present in the Chopawamsic Formation. (4) In addition, fuchsite occurs in both the basal part of the typical Arvonia and in the kyanite quartzite at Willis Mountain.

Structure

Two major systems of folds are recognized in the Arvonia Formation. The older set of folds is characterized by extremely elongate isoclines whose axial surface dip to the southeast at angles generally exceeding 45°; the younger set of folds in the Arvonia is made up of tight warps whose axial surfaces are generally steeply dipping.

The two kyanite quartzite ridges that make up Willis Mountain were interpreted by Espenshade and Potter (1960) as the limbs of an upward-closing structure, which they named the Whispering Creek anticline. They also described a tight, parasitic synclinal fold in the west limb of the anticline. The eastern limb was described as having a homoclinal dip to the southeast.

During present mapping it was shown that the Whispering Creek anticline is a broad, open, slightly asymmetrical fold cored by biotite gneiss and amphibole gneiss of the Chopawamsic Formation (Figure 3, cross sections A-A' and B-B'). The anticline is flanked on either side by two tight isoclinal synclines. Both synclines are cored by kyanite quartzite. Penetrative cleavage parallel to the axial surfaces of the two synclines diverges across the Whispering Creek anticline. The divergence is evidence that this cleavage has been warped during a stage of deformation following development of the isoclinal synclines and of the cleavage. Presumably the later stage of folding was the event during which the Whispering Creek anticline formed.

Woods Mountain is shown by Espenshade and Potter (1960) as an anticlinal structure containing two bands of kyanite quartzite on each of its limbs.

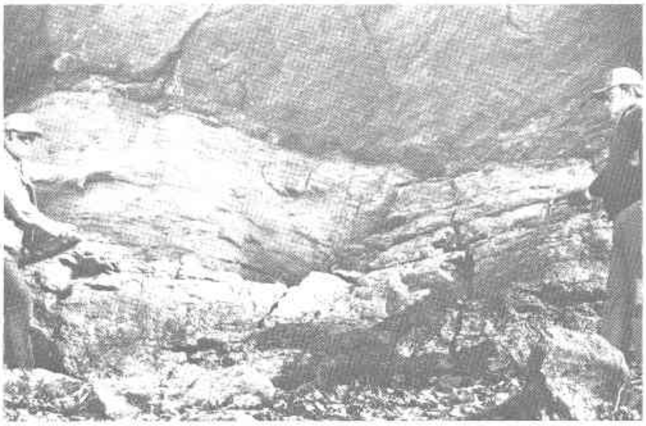
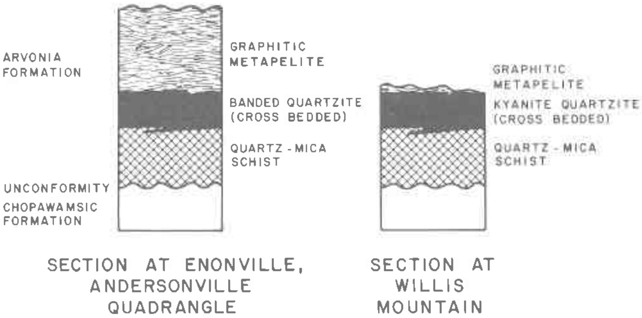


Figure 7. Channel deposit in kyanite quartzite, Woods Mountain.

(probably volcanic cherts or siliceous sinter deposits), it contains little or no terrigenous clastic rocks. Therefore, it is not likely that the cross-bedded quartzites at Willis and Woods mountains belong to the Chopawamsic—a typical "quartz starved" volcanic sequence. Rather, the kyanite quartzite must be correlative with the banded quartzite widely present in the Arvonia. The reasons for this conclusion are several. (1) Both the banded quartzite typical of the lower Arvonia and the kyanite quartzite present at Willis and Woods mountains are underlain by a locally conglomeratic, discontinuous quartz-mica schist which is the basal unit of the Arvonia Formation (Figure 8). The



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These two bands of kyanite quartzite, and several minor ones as well, were recognized during recent mapping. Each of the major bands is interpreted here as a tight syncline. The evidence for this interpretation is the symmetry of minor isoclinal folds in the most westerly band of kyanite quartzite. The tightly folded synclines predate the anticline.

CONCLUSIONS

The unconformity developed on the Chopawamsic Formation was probably a post-epeirogenic event. This development of an erosional surface on the Chopawamsic was followed by deposition of the sediments of the Arvonia Formation. The early depositional environment of the Arvonia Formation in the Andersonville and Willis Mountain quadrangles was fluvial to estuarine as shown by cross-beds, cut-and-fill structures, and repeated rythmic bedding; at a later time the environment became marine, judging from similar strata near Arvonia which contain diverse marine fossils. The Arvonia Formation was folded during the Taconic orogeny, an event producing widespread metamorphism in the central Virginia Piedmont. The event produced greenschist facies in the Arvonia Formation in the area around Arvonia and amphibolite facies in the formation in the areas of the Andersonville and Willis Mountain quadrangles to the southeast. The Whispering Creek anticline formed during the Acadian orogeny; metamorphism during this orogeny was not as intense as during Taconic tectonism. Retrograde metamorphism of kyanite to kaolinite and hydrothermal alteration of rocks in the general area (Bennett, 1961) may have occurred during the Acadian orogeny.

ACKNOWLEDGMENTS

The writers thank Mr. Eugene K. Rader, Chief Geologist, Eastern Mapping Section, Virginia Division of Mineral Resources and Dr. Robert C. Milici, State Geologist of Virginia, for pointing out fining-upward sedimentary packages, cross-beds, and channel-fill deposits in kyanite quartzites on Willis and Woods mountains and for confirming the writers' observations that these quartzites contain cross-beds.

Dr. Michael W. Higgins, U.S. Geological Survey, read the manuscript and pointed out regional stratigraphic relationships. Dr. John R. Carpenter, Professor of Geology, University of South Carolina, also read the manuscript and made several comments which were used in revising the text. Shirley Pearson did the drafting. Permission from the Kyanite Mining Corporation (Dillwyn, Virginia) to study the geology of the kyanite deposits of Willis and Woods mountains is here acknowledged.

The writers take sole responsibility for the correctness of the data and for the interpretations presented.

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CONODONTS FROM STRUCTURAL WINDOWS THROUGH THE BANE DOME, GILES COUNTY, VIRGINIA[1]

By
John E. Repetski[2]
and
William J. Perry, Jr.[3]

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ILLUSTRATIONS

TABLES

ABSTRACT

Early Ordovician conodonts were found in dolostones in two outcrop areas interpreted here as windows through a thrust fault under the Bane dome in southern Giles County in southwestern Virginia. These conodonts again confirm the existence of the Knox Group beneath the dome, and they add more detailed information on the age of these dolostones.

INTRODUCTION

The Bane dome in southern Giles County, southwestern Virginia is structurally the highest culmination between the Saltville and Saint Clair faults. The highest part of this culmination is defined by the outcrop of Rome Formation (Cambrian), an area 2.5 miles (4.0 km) long by about 0.5 mile (0.8 km) wide in the southwestern part of the Pearisburg, Virginia, 7.5-minute quadrangle (Figure 1). The Rome at the exposure consists of red and greenish-gray shale interstratified with moderate-to dark-gray argillaceous dolostone beds which are similar to, but generally more shaly than, those of the overlying Honaker Dolomite of Middle Cambrian age. The Rome is severely deformed; it contains boudins and tectonic slices of imbricated dolostone as much as 5 feet (1.5 m) thick and 40 feet (12.2 m) long enveloped

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[1] Portions of this contribution may be quoted if credit is given to the Virginia Division of Mineral Resources. It is recommended that reference be made in the following form: Repetski, J. E. and Perry, W. J., Jr. 1980, Conodonts from structural windows through the Bane dome, Giles County, Virginia, *in* Contributions to Virginia Geology—IV: Virginia Division of Mineral Resources Publication 27, p. 12-22.

[2] U.S. Geological Survey, E-501 U.S. National Museum, Washington, D.C. 20560.

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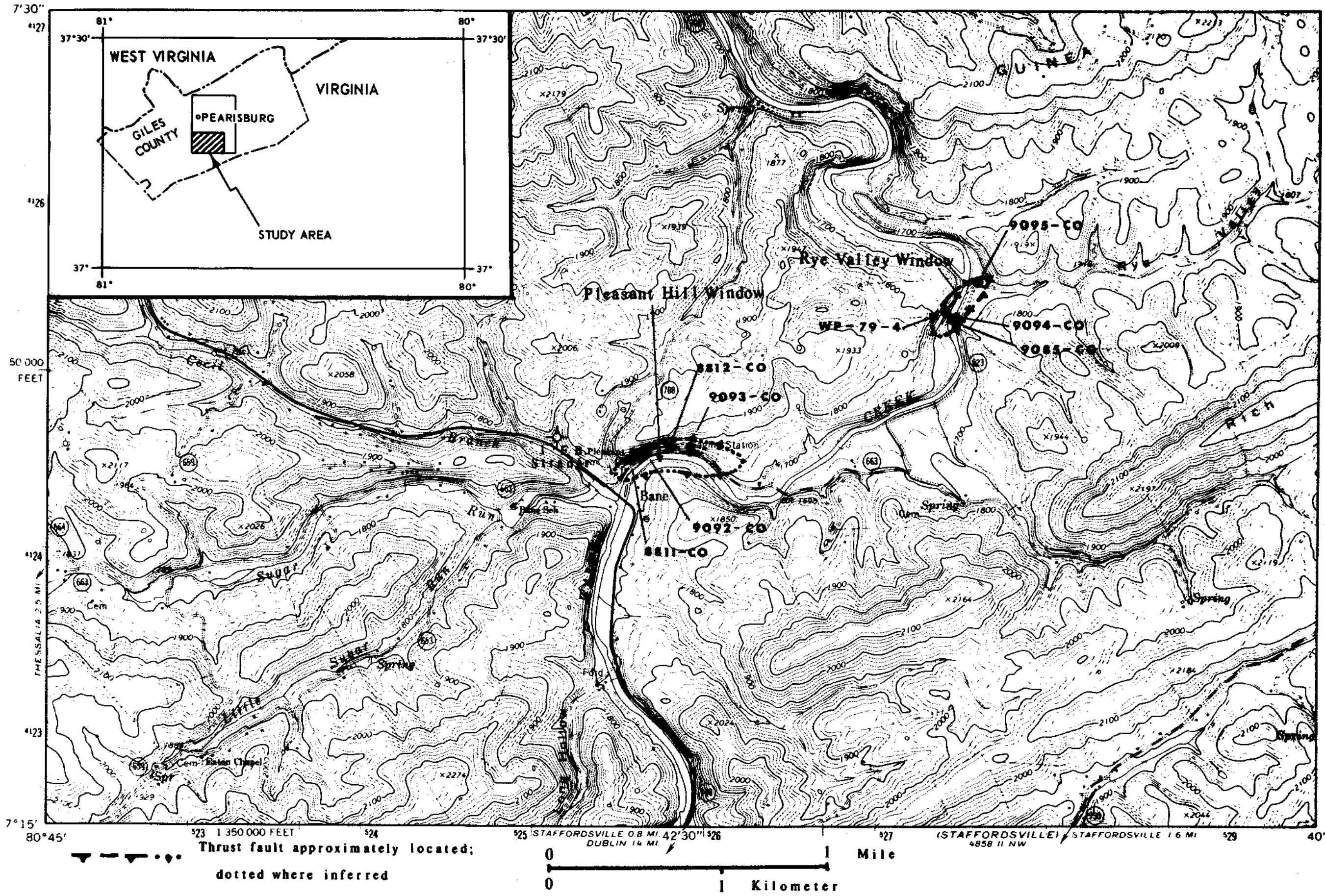

Figure 1. Index map.

in a matrix of red and gray shale. The F. P. Strader no. 1 well (Figure 1) was drilled through this deformed Rome and penetrated Ordovician dolostone of the Knox at a depth of only 18 feet (5.5 m) (Perry and others, 1979). The subdivisions of the Knox Group recognized in Lee County, Virginia, and adjacent northeastern Tennessee (Harris, 1969) are recognized in the F. P. Strader no. 1 well; from a depth of 18 to 228 feet (5.5 to 69.5 m) in the well, the dolostone is identical with that of the Mascot Dolomite, and the section from 228 to 450 feet (69.5 to 137 m) is identical with the Kingsport Dolomite of northeastern Tennessee (Perry and others, 1979). Similar rocks that crop out along Walker Creek east and northeast of the Strader well are the subject of the present report. These outcrops are windows of the Knox Group surrounded by outcrops of the Rome Formation and are herein named the Pleasant Hill (western) and Rye Valley (eastern) windows.

The occurrence of these Ordovician dolostones beneath the Rome Formation of the Bane dome requires the presence of a major décollement within the upper part of the Rome Formation. The Rome was arched concentrically with the enveloping beds by a deformational event that was later and deeper seated than the one forming the décollement. This décollement is most probably the eastern extension of the Saint Clair thrust, the root zone or sole thrust from which both the Narrows and Saint Clair thrusts ramp upward to the surface farther northwest (Perry and others, 1979).

Eight samples of dolostone from the two small structural windows near Bane were processed for conodonts. Standard processing techniques were used except that formic acid, rather than acetic, was used; the use of formic acid necessitated sample sieving every 24 to 48 hours to avoid etching and dissolution of the conodonts. Two other precautions were needed. A 200-mesh sieve was used because of the extremely small size of many of these conodont elements. Second, because of the abundance of disaggregated dolomite rhombs in the sieved residue, tetrabromoethane was needed for heavy-liquid separation of the residue. The 8 samples totalled 88 pounds (40.1 kg) of rock processed. Six of the samples yielded 171 specimens identifiable as conodonts (Table 1); average yield for all samples was 9.5 conodont elements per pound (4.3 conodont elements per kilogram). Most of the conodonts are preserved well enough to be identified to genus level. The elements commonly are fractured, their surfaces are etched somewhat, and many show a whitish "silky" patina. This last effect is probably the result of the formic acid treatment, or, less likely, is due to slight surface etching by apatite-corrosive diagenetic fluids. Most of the elements have epitaxial overgrowths of dolomite. Surface effects notwithstanding, a color alteration index (CAI; see Epstein and others, 1977) of 4 to 4½ was determined; this CAI indicates that the host rock reached temperatures of at least 190° to 230° C.

FAUNAS AND AGE RELATIONSHIPS

The faunules found in the Knox Group dolostones of the Bane windows are diagnostic of North American Midcontinent Province Early Ordovician conodont Fauna C. This fauna is the middle of five Early Ordovician conodont assemblages for North American cratonic and miogeoclinal successions established by Ethington and Clark (1971). Since 1971 the concept of these faunas has been confirmed and they have been applied in other areas by other workers (e.g. see Barnes and others, 1976; Repetski, 1977; Repetski, in press). Of the 10 form species whose ranges are limited, or substantially limited, to Fauna C, seven (and questionably an eighth) occur in the Bane structural windows. Conversely, of all the conodont taxa found in the Bane windows, only 3 are thought to range from subjacent Fauna B, and only one, *Ulrichodina*, has been reported from

	Pleasant Hill window				Rye Valley window				All samples
Sample mass before/after processing (g)	4900/135	7300/100	2000/5	6700/5	6600/175	7800/70	1900/30	2900/130	40.1kg/0.65kg
U S G S Fossil Locality Number	8811-CO	9092-CO	8812-CO	9093-CO	9094 CO	9095-CO	9085 CO	no USGS no.	
Acanthodus lineatus (Furnish)	–	–	–	1	–	–	–	–	1
cf. *Acanthodus lineatus* (Furnish)	–	–	–	–	1	–	–	–	1
Acodus oneotensis Furnish s.f.	–	–	1	–	–	–	–	–	1
cf. *A. oneotensis* Furnish s.f.	–	–	–	–	–	1	–	–	1
Acontiodus iowensis Furnish s.f.	–	2	1	–	1	2	–	–	6
Chosonodina herfurthi Müller	–	–	–	–	3	–	–	–	3
Clavohamulus densus Furnish	2	5	–	–	11	2	–	–	20
Clavohamulus ? sp. of Ethington & Clark (1971)	–	3	–	–	–	–	–	–	3
Clavohamulus sp.	–	–	–	1	–	2	–	–	3
Drepanodus parallelus Branson & Mehl s.f.	2	–	1	–	2	–	–	–	5
cf. *D. parallelus* Branson & Mehl s.f.	–	–	–	1	–	2	–	–	3
Juanognathus ? n. sp.	–	–	–	2	6	–	–	–	8
Loxodus bransoni Furnish	3	–	–	–	1	–	–	–	4
cf. *L. bransoni* Furnish	–	–	–	–	–	1	–	–	1
cf. *Oistodus mehli* Furnish s.f.	–	–	–	–	1	–	–	–	1
Paltodus bassleri Furnish	4	4	6	3	5	13	–	–	35
Scolopodus sulcatus Furnish s.f.	–	2	–	2	–	–	–	–	4
S. cf. *S. sulcatus* Furnish s.f.	–	–	–	–	1	–	–	–	1
Ulrichodina sp. s.f.	–	–	–	–	–	1	–	–	1
New Genus A, n. sp. A (Repetski, IN PRESS)	–	7	4	3	12	3	–	–	29
? New Genus A, n. sp. A (Repetski, IN PRESS)	2	–	–	–	–	–	–	–	2
drepanodontiform elements, gen. & sp. indet.	–	4	–	–	4	–	–	–	8
oistodontiform elements, gen. & sp. indet.	–	–	–	1	–	–	–	–	1
paltodontiform elements, gen. & sp. indet.	–	–	–	–	–	1	–	–	1
scandodontiform elements, gen. & sp. indet.	–	–	–	2	–	1	–	–	3
indeterminate cone elements	1	4	2	–	8	10	1 ?	–	26
TOTALS	14	31	15	16	56	39	1 ?	barren	172

Table 1. Occurrence of conodonts in Bane dome samples.

significantly higher strata. [It should be noted here that *Ulrichodina* species elements occur sporadically, and rarely in large numbers, throughout the range of the genus. Additionally, *Ulrichodina* is now known to occur both as low as strata containing Fauna C elements (Repetski, in press) and upward into Middle Ordovician strata.] The assemblage of conodonts found in the structural windows near Bane is therefore firmly established as belonging to Fauna C.

Some observations on the geographic ranges of taxa identified from the windows follow. *Acontiodus iowensis* s.f. (Plate 1, Figures 5, 7) and *Scolopodus sulcatus* s.f. (Plate 2, Figure 16) occur in the North American midcontinent and also in Australia, where they are in miogeoclinal rocks (Druce and Jones, 1971). Two species have not previously been reported from eastern North America. *Chosonodina herfurthi* (Plate 1, Figures 2, 10, 11) was known from Oklahoma (Mound, 1968), Arkansas (Repetski and Ethington, 1977), and Colorado (Ethington and Clark, 1971). Additional occurrences from eastern Pennsylvania are in rocks correlative with part of the Knox Group (J. E. Repetski, unpublished data). *Clavohamulus?* sp. (Plate 2, Figure 4) was known previously only from Oklahoma (Mound, 1968) and Colorado (Ethington and Clark, 1971).

New taxa from the Bane dome include *Juanognathus?* n. sp. (Plate 1, Figure 15; Plate 2, Figure 13) which occurs also in Pennsylvania, New York and Alaska (J. E. Repetski, unpublished data). Its stratigraphic range may be limited to the upper part of Fauna C and possibly low into the zone of Fauna D. *Acontiodus* sp. A (Hass in Sando, 1958) from the Stonehenge Formation near Chamberburg, Pennsylvania is probably *Juanognathus?* n. sp. Another new taxon, New Genus A, n. sp. A (Repetski, in press), is a distinctive multi-element species that is widespread in early Canadian cratonic and miogeoclinal rocks of North America. It is known also from Asia (Muller, 1973) and Australia (Druce and Jones, 1971; Jones, 1971). The form is illustrated in Plate 1, Figures 4, 6 and in Plate 2, Figures 11, 12, 15.

Acanthodus lineatus (Plate 2, Figure 14), *Acodus oneotensis*, *Clavohamulus densus* (Plate 1, Figures 12, 16; Plate 2, Figures 7, 10), *Loxodus bransoni* (Plate 1, Figure 8), and *Paltodus bassleri* (Plate 1, Figure 9; Plate 2, Figures 3, 17) are other important Fauna C constituents that are present in the Bane windows.

STRATIGRAPHIC RELATIONSHIPS

The light-gray, fine-grained dolostones of the Pleasant Hill and Rye Valley windows are assigned to the Mascot Dolomite. Rocks in the windows are lithologically and faunally similar to the Mascot as seen in the interval from 18 to 228 feet (5.5 to 69.5 m) in the Strader no. 1 well (Perry and others, 1979). The following observations are indirect evidence that the sampled outcrops in the windows are in the lower part of the Mascot Dolomite. *Acodus oneotensis* s.f., the only conodont from the well whose range is restricted to Fauna C, was recovered from Pleasant Hill window and from the well interval logged as Kingsport Dolomite (Perry and others 1979), which is below the Mascot in the interval from 228 to 450 feet (69.5 to 137 m). *Scolopodus filosus* s.f., which occurs in Fauna D and younger strata, is in the well section between 110 and 127 feet (33.5 to 38.7 m), an interval which is no lower than 101 feet (30 m) above the base of the Mascot Dolomite. The species was not found in the windows. In addition, a conodont sample, USGS loc. 9096-CO, which was collected at a horizon within the Mascot Dolomite from the allochthonous plate of the Bane dome, contained a Fauna D conodont assemblage. Species include *Scolopodus gracilis* Ethington and Clark, *S. quadraplicatus* Branson and Mehl s.f., *S. triplicatus* Ethington and Clark s.f., *S. filosus* Ethington and Clark s.f., and *Ulrichodina deflexa* Furnish s.f. The remainder of the assemblage consisted entirely of "simple cones" assignable chiefly to various species and form species (s.f.) of *Drepanoistodus, Paltodus, Protopanderodus,* and *Scandodus*. There are very few elements in common between this faunule and those from the windows; the faunule from the allochthon definitely is younger.

REGIONAL FAUNAL COMPARISONS

Although very little data on Early Ordovician conodonts from the eastern United States have been published thus far, some faunas of this age have been studied or are now undergoing study. Conodonts from Beekmantown age rocks at several localities in and near Virginia are compared in Table 2. Strata at each locality bear a Fauna C assemblage; those assemblages which include species of *Cordylodus* are judged to lie in the lower half of the range of Fauna C. This genus is not present in the samples from Rockingham County, Virginia nor in samples from the Bane dome. This may indicate that the sampled strata at these areas are in the upper part of the range of Fauna C, or only that the samples represent environments adverse to species of that genus. The conodonts from the Beekmantown Group of western Maryland and from northern and central-western Virginia show conclusively that the dolostones exposed in the Bane windows occupy a stratigraphic position low in the thick Lower Ordovician carbonate sequence of the region, but somewhat above its base.

SUMMARY AND CONCLUSIONS

Conodonts recovered from dolostones in the Pleasant Hill and Rye Valley structural windows are of early, but not earliest, Early Ordovician age. They are assignable to Early Ordovician conodont Fauna C of the North American Midcontinent Province, and probably belong high in the range of that fauna, i.e., above the range of *Cordylodus*. The occurrence of Fauna C conodonts in the Mascot Dolomite of the Pleasant Hill and Rye Valley windows and Fauna D conodonts from within the Mascot of the allochthonous plate is consistent with the downhole sequence of lithologies and conodonts in the F. P. Strader no. 1 well. Finally, this study and that of Perry and others (1979) show the utility of conodonts in solving structural and stratigraphic problems in the thick sequence of Cambrian to Mid-

Table 2. Comparison of Early Ordovician (Fauna C) conodont faunules from the eastern United States.

Locality*	Lithologic Unit	Species Present ( )
Washington County, Maryland[1]	Upper member (higher of two members) of Stonehenge Limestone (sample from base of member)	(1) *Acontiodus iowensis* Furnish s.f. (2) *Acodus oneotensis* Furnish s.f. (3) *Cordylodus angulatus* Pander s.f. (4) *C. prion* Lindstrom (5) *C. rotundatus* Pander s.f. (6) *Paltodus bassleri* Furnish (7) New Genus A, new species A
South-central Pennsylvania[2]	Upper member of Stonehenge Limestone	*Paltodus bassleri* (= *Distacodus* sp. B), (6) and (8) *Acanthodus lineatus* (Furnish) (= A. sp. A) (9) *Loxodus bransoni* Furnish
Pennsylvania and Maryland[3]	Upper member of Stonehenge Limestone	(6), (8), (9)
Frederick County, Virginia-Sample A[4]	Stoufferstown Member of Stonehenge Limestone (97 feet, 29.6 m, above base of member)	(1) through (4), (6), (7) (10) *Acodus? triangularis* (= *Oistodus? triangularis* Furnish of Ethington and Clark, 1971). (11) *Cordylodus intermedius* Furnish s.f. (12) *Juanognathus?* n. sp.
Frederick County Virginia-Sample B[5]	Upper member of Stonehenge Limestone (28.1 feet, 8.6 m, above base of member)	(1) through (7), and (12)
Rockingham County, Virginia[6]	Lower Limestone Unit, Beekmantown Group (upper part of unit sampled)	(2), (6), (7) and *Clavohamulus densus* Furnish

[1] USGS loc. 4742-CO; collected by W. J. Sando, geologic section no. 12 (Sando, 1957).
[2] Near Chambersburg, Pennsylvania; reported in Sando, 1958.
[3] Reported in Tipnis and Goodwin, 1972.
[4] USGS loc. 4714-CO; collected by W. J. Sando.
[5] USGS loc. 4715-CO; collected by W. J. Sando.
[6] On north bank of North River about one mile (1.6 km) upstream from the confluence with the South River, Grottoes, Virginia 7.5-minute quadrangle; at section measured by T. M. Gathright, II, W. S. Henika, and J. L. Sullivan, III, written communication, 1978.

* Repetski prepared conodont information for all samples except those from localities marked by footnotes 2 and 3.

dle Ordovician carbonate rocks in the southern Appalachians, strata which generally lack usable macrofossils.

ACKNOWLEDGMENTS

We thank all the colleagues with whom we discussed this problem, especially Anita G. Harris, Leonard D. Harris, and Robert B. Neuman, who critically reviewed, and improved, this manuscript. M. E. Hunt and E. F. MacDonald provided excellent technical support. Elinor Stromberg, H. E. Mochizuki, and R. H. McKinney assisted with the illustrations. S. G. Braden (SEM Laboratory, U.S. National Museum of Natural History) photographed the fossils. Special thanks go to D. Kohler Repetski for typing the final draft of this manuscript.

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EXPLANATION OF PLATE 1

Conodonts from Rye Valley window. Figures 1, 3, 6, 7, 9, 12, and 13 are from USGS loc. 9095-CO; others are from USGS loc. 9094-CO. All figures are stereopair (8-degree separation) SEM photomicrographs. Illustrated specimens are in the collections of the U.S. National Museum (USNM), Washington, D.C.

Figures

1. cf. *Loxodus bransoni* Furnish. Inner lateral view, x90. USNM 304387.

2,10,11. *Chosonodina herfurthi* Muller. Posterior view of three specimens. Figure 2 USNM 304388, x100. Figure 10 USNM 304389, x125. Figure 11 USNM 304390, x100.

3. *Ulrichodina* sp. Anterolateral view, x125. USNM 304391.

4,6. New Genus A, n. sp. A of Repetski (in press) Anterolateral and posterolateral views, respectively, of coniform elements USNM 304392, x100, and USNM 304393, x150.

5,7. *Acontiodus iowensis* Furnish s.f. Posterior views of USNM 304394, x100, and USNM 304395, x125, respectively.

8. *Loxodus bransoni* Furnish. Inner lateral view, x100. USNM 304396.

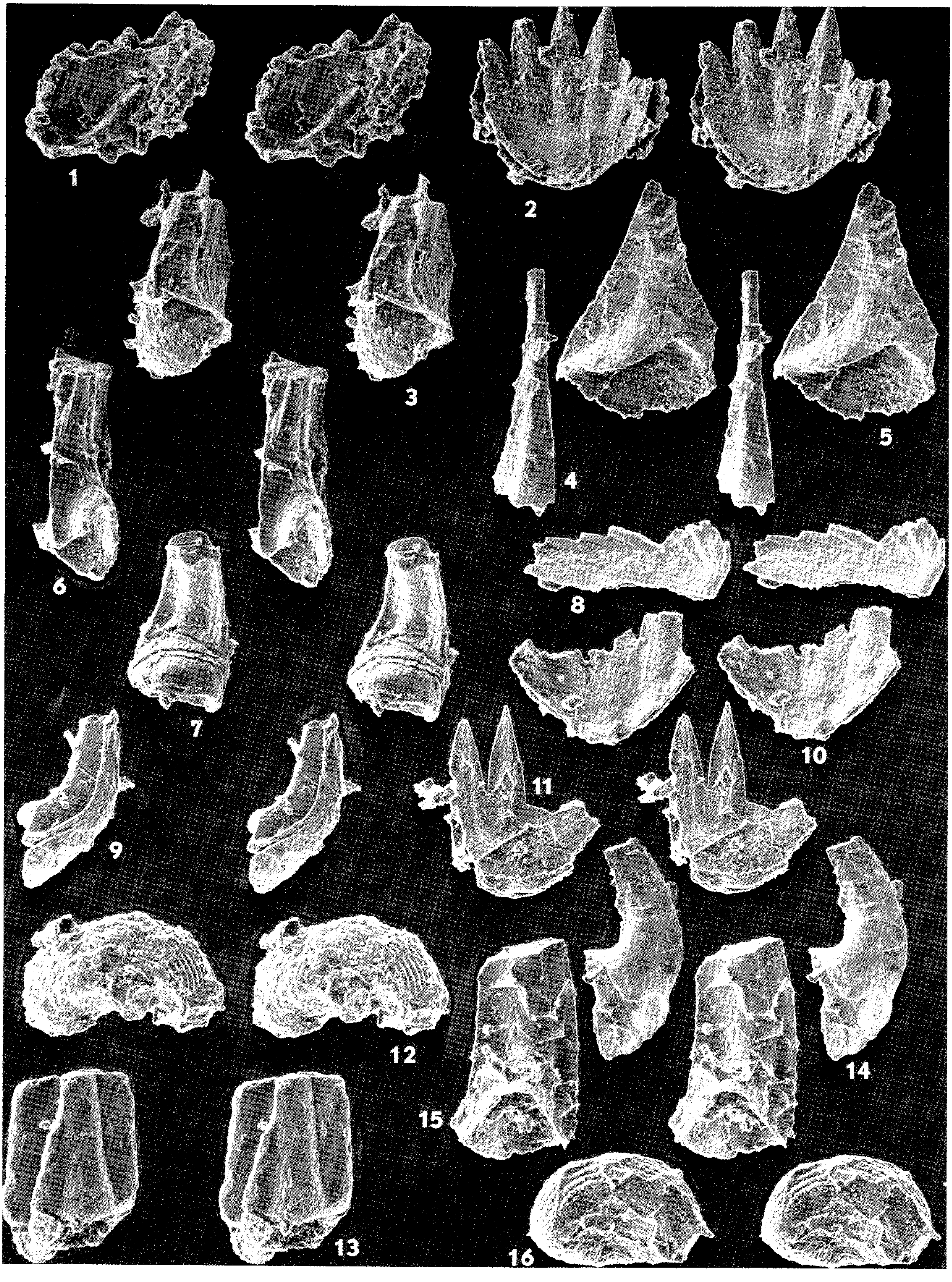
9. *Paltodus bassleri* Furnish. Inner lateral view, x130. USNM 304397.

12,16. *Clavohamulus densus* Furnish. Posterior views of USNM 304398, x125, and USNM 304399, x125, respectively.

13. cf. *Acodus oneotensis* Furnish s.f. Posterior view, x150. USNM 304400.

14. *Drepanodus* n. sp. s.f. Inner lateral view, x50. USNM 304401.

15. *Juanognathus?* n. sp. Posterior view, x100. USNM 304402.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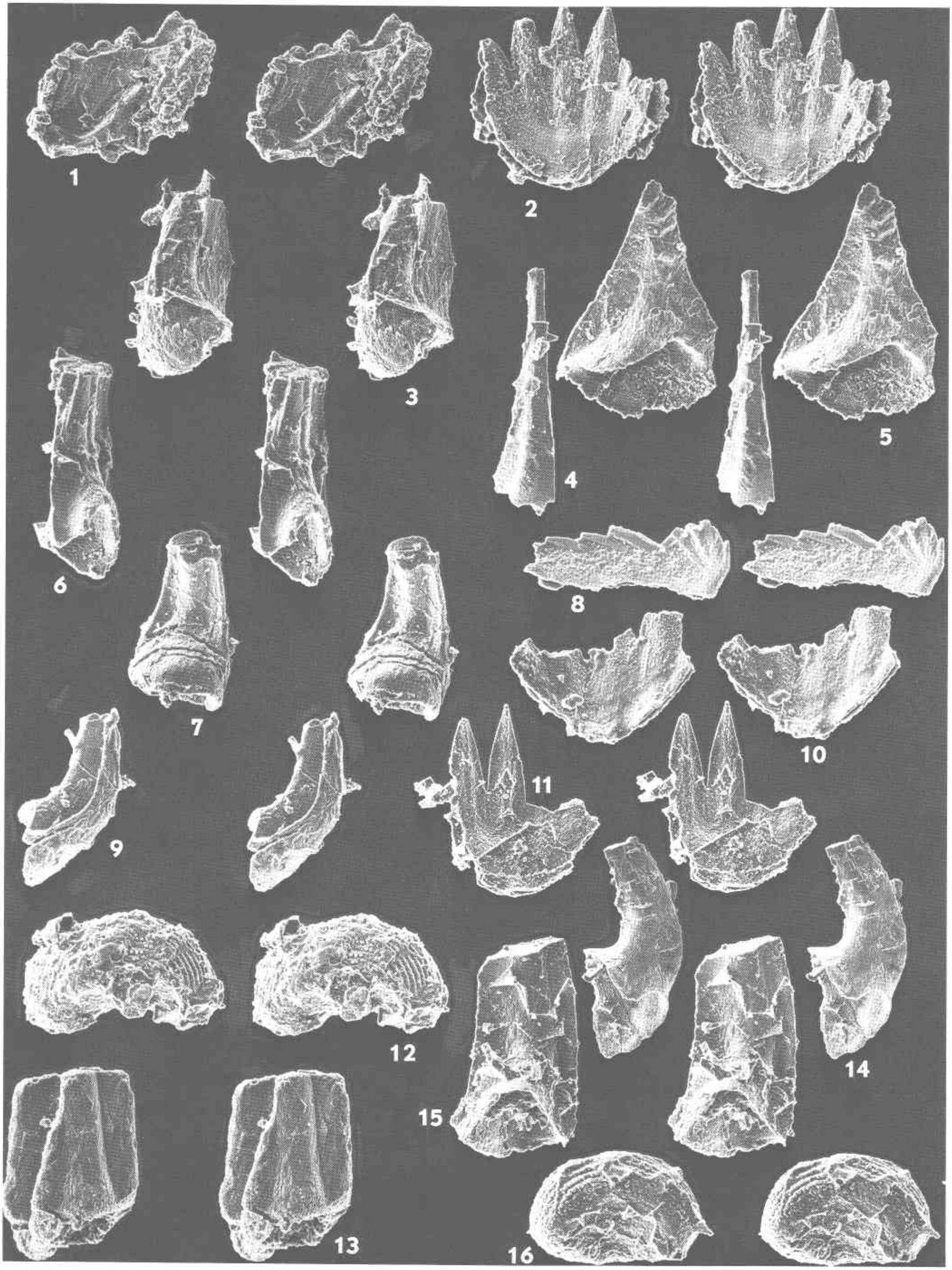
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EXPLANATION OF PLATE 2

Conodonts from Pleasant Hill window and from Mascot Dolomite outcrop approximately 2½ miles (4.0 km) northwest of Pleasant Hill window. Figures 1,2,5,6,8, and 9 are from USGS loc. 9096-CO; figures 3,4,7, 10-12, and 16 are from USGS loc. 9092-CO; figures 13-15 and 17 are from USGS loc. 9093-CO.

Figures

1,2. *Scolopodus gracilis* Ethington and Clark. Lateral views of graciliform elements USNM 304403, X75, and USNM 304404, X60, respectively.

3,17. *Paltodus bassleri* Furnish. Inner lateral views of USNM 304405, X150, and USNM 304406, X80, respectively.

4. *Clavohamulus?* sp. (*sensu* Ethington and Clark, 1971). Posterolateral view, x100, USNM 304407.

5. *Ulrichodina* sp. s.f. Posterolateral view, x60. USNM 304408.

6. *Ulrichodina deflexa* Furnish s.f. Posterolateral view, x70. USNM 304409.

7,10. *Clavohamulus densus* Furnish. Posterior and basal views of USNM 304410 and USNM 304411, X150.

8. *Scolopodus quadraplicatus* Branson and Mehl s.f. Posterolateral view of USNM 304412, x60.

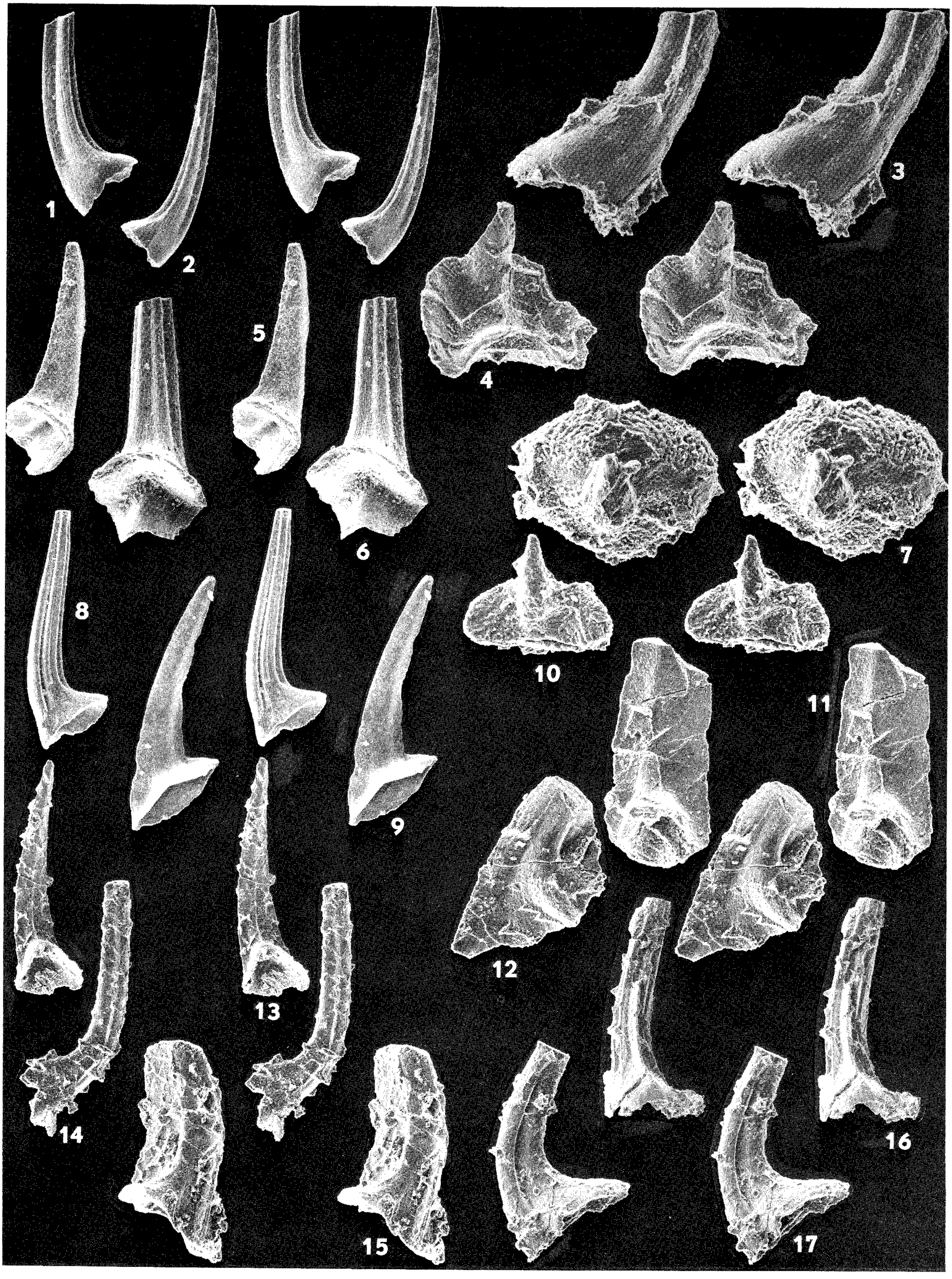
9. *Paroistodus?* sp. Inner lateral view of oistodontiform element, USNM 304413, X50.

11,12,15. New Genus A, n. sp. A of Repetski (in press) Figures 11 and 15, posterior and posterolateral views of coniform elements USNM 304414, X88, and USNM 304415, X80, respectively. Figure 12, inner lateral view of oistodontiform element USNM 304416, X100.

13. *Juanognathus?* n. sp. Posterolateral view of USNM 304417, X40.

14. *Acanthodus lineatus* (Furnish). Lateral view of USNM 304418, X75.

16. *Scolopodus sulcatus* Furnish s.f. Lateral view of USNM 304419, X40.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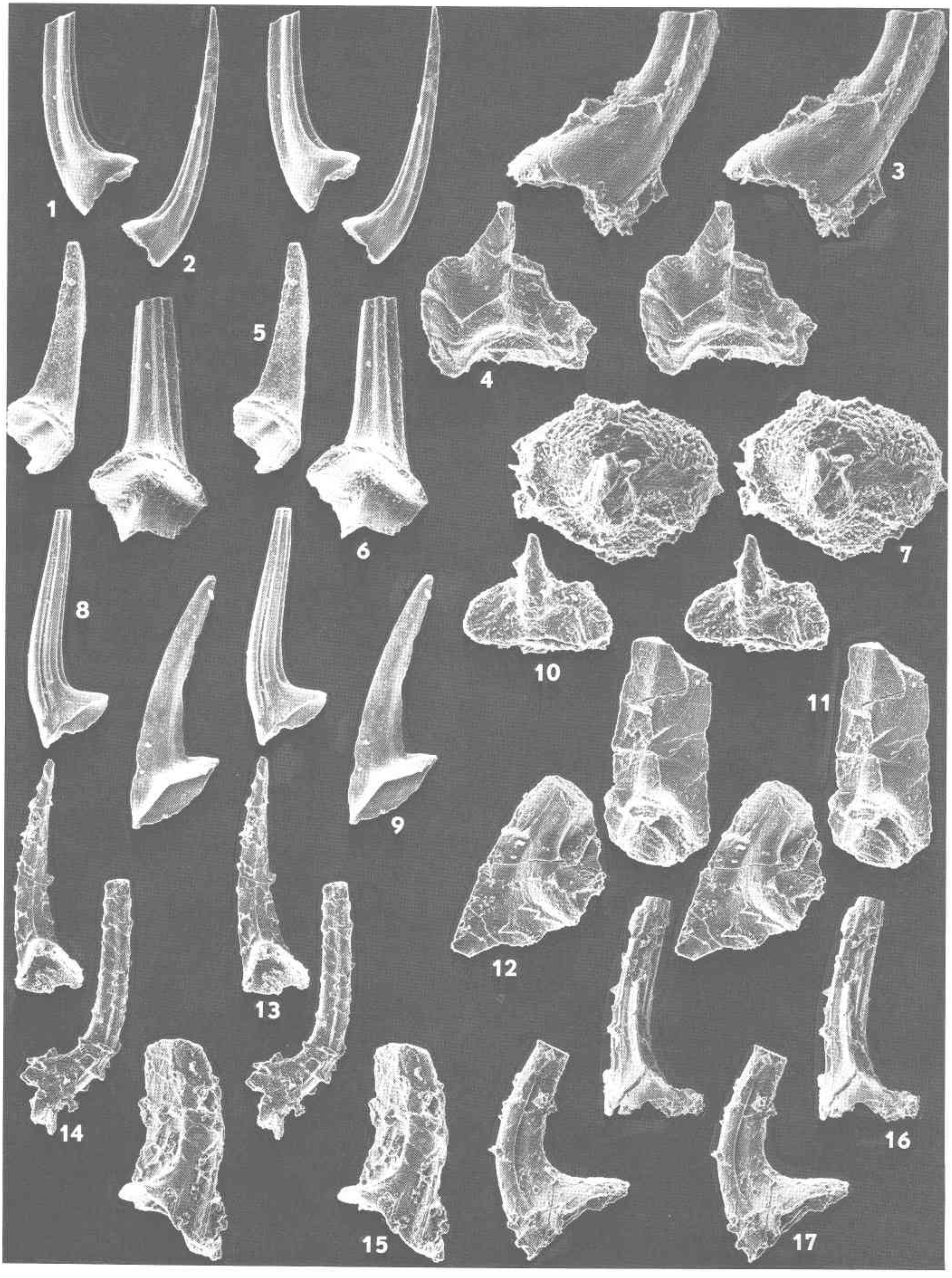
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APPENDIX

DESCRIPTION OF CONODONT COLLECTION LOCALITIES

Pleasant Hill window localities:

(1) USGS loc. 8811-CO. Pale-olive-gray (5Y 7/2) to light-olive gray (5Y 6/1), fine- to medium-grained dolomite with very closely spaced hairline fractures. Along north side of State Road 663, 400 to 500 ft. (122 to 152 m) northeast of Pleasant Hill Church, north side of Walker Creek.

(2) USGS loc. 9092-CO. Dolostone; from north side of Walker Creek. Sample from approximately 8 ft. (2.4 m) below chert stringers, and about 950 ft. (290 m) east of junction of State Road 663 with State Highway 100. Near USGS loc. 8811-CO.

(3) USGS loc. 8812-CO. Pale-gray (5Y 7/2) to medium-light-gray (N-6), fine-grained dolomite. Along north side of State Road 663, approximately 1250 ft. (381 m) northeast of Pleasant Hill Church; north side of Walker Creek.

(4) USGS loc. 9093-CO. Dolostone; from outcrop on north side of State Road 663, immediately north of gaging station on Walker Creek. Approximately 850 ft. (259 m) east of USGS loc. 9092-CO. and about 175 ft. (53 m) east of USGS loc. 8812-CO.

Rye Valley window localities:

(1) USGS loc. 9094-CO. Dolostone; on east bank of Walker Creek and below (west of) State Road 623. Massive pale-gray dolostone topographically below Rome-Honaker contact that is above road level. About 50 ft. (15 m) north of USGS loc. 9085-CO. Approximately 750 ft. (229 m) south-southwest of sharp bend in State Road 623 at west end of Rye Valley.

(2) USGS loc. 9095-CO. Dolostone; from small tributary to Walker Creek at mouth of Rye Valley. Just downstream (about 25 to 40 ft., 8 to 12 m) from State Road 623 bridge over this tributary. Approximately 775 ft. (235 m) north-northeast of USGS loc. 9094-CO. Near house (just outside fence). Dolostone has some burrow-mottling and small amounts of quartz sand.

(3) USGS loc. 9085. Dolomite, light-gray, fine-grained. Outcrop on east side of Walker Creek and below (west) of State Road 623 about 790 ft (240 m) south-southwest of sharp bend in State Road 623 just west of Rye Valley. About 1.4 miles (2.2 km) east-northeast of intersection of State Highway 100 and State Road 663 at village of Bane.

(4) Sample WP-79-4 (no USGS loc. no. assigned). Dolostone; light-gray, fine-grained. Outcrop on west bank of Walker Creek at elevation of about 1700 ft. (518 m). About 720 ft. (220 m) southwest of bend in State Road 623 just west of Rye Valley and about 7220 ft. (2200 m) east-northeast of road intersection at village of Bane.

Allochthon locality 2.5 miles (4.0 km) northwest of Pleasant Hill window:

(1) USGS loc. 9096-CO. Intraclastic, bioclastic lime wackestone. On west side of northbound lane of State Highway 100, about 720 to 790 ft. (220 to 240 m) south of intersection with State Road 622; approximately 1.33 miles (2.15 km) north of Prospectdale. Lowest limestone in roadcut of mostly coarse dolostone. Reconnaissance sample from the Mascot Dolomite.

GEOLOGY OF THE TAYLORSVILLE BASIN, HANOVER COUNTY, VIRGINIA[1]

By
Robert E. Weems[2]

CONTENTS

ILLUSTRATIONS

TABLES

ABSTRACT

The Taylorsville basin, exposed in a 50 square mile area in Hanover and Caroline counties, Virginia, contains conglomerate, sandstone and siltstone and some shale, coal and limestone of late Triassic age; the age assignment is based on palynomorphs. The sediments comprise the three members of the Doswell Formation. The names of the basin, the members, and the formation are formally proposed in this work.

INTRODUCTION

The rocks in the vicinity of Taylorsville, Virginia (Figure 1) were recognized as being Triassic in age as early as 1840 (Rogers, 1884). These beds were considered to represent a small outlying satellite of the Richmond basin (Roberts, 1928 and Krynine, 1950). The basin as a structural feature is herein named the Taylorsville basin and the sedimentary strata within the basin are named the Doswell Formation. Exposed Triassic rocks of the Taylorsville basin

[1] Portions of this contribution may be quoted if credit is given to the Virginia Division of Mineral Resources. It is recommended that reference be made in the following form: Weems, R. E., 1980, Geology of the Taylorsville basin, Hanover County, Virginia, *in* Contributions to Virginia Geology—IV: Virginia Division of Mineral Resources Publication 27, p. 23-38.
[2] U.S. Geological Survey, Stop 928, Reston, Virginia 22092.

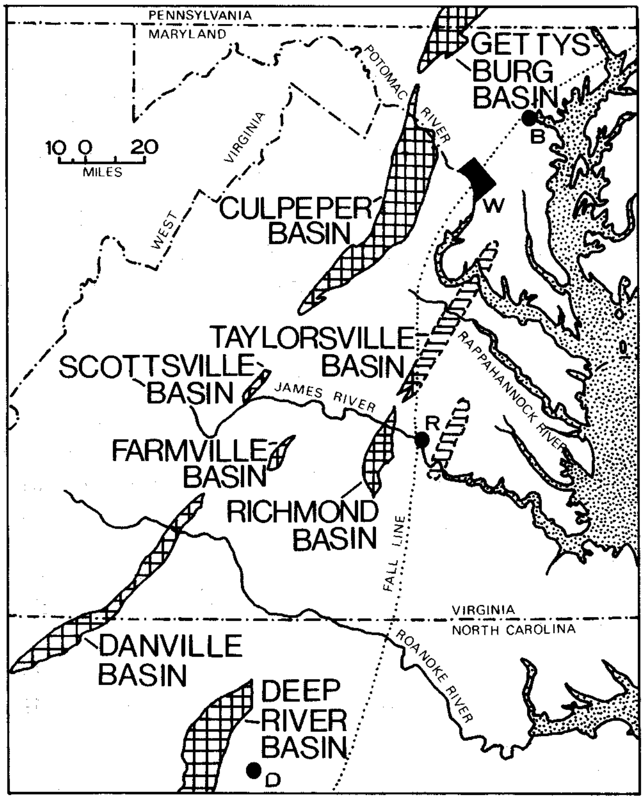

Figure 1. Map of eastern Virginia and vicinity showing the major surface (solid lines) and subsurface (dashed lines) basins containing Newark (Upper Triassic-Lower Jurassic) sediments (Dunay and Fisher, 1974). The buried basin east of Richmond is unnamed. B—Baltimore, D-Durham, R—Richmond, W—Washington.

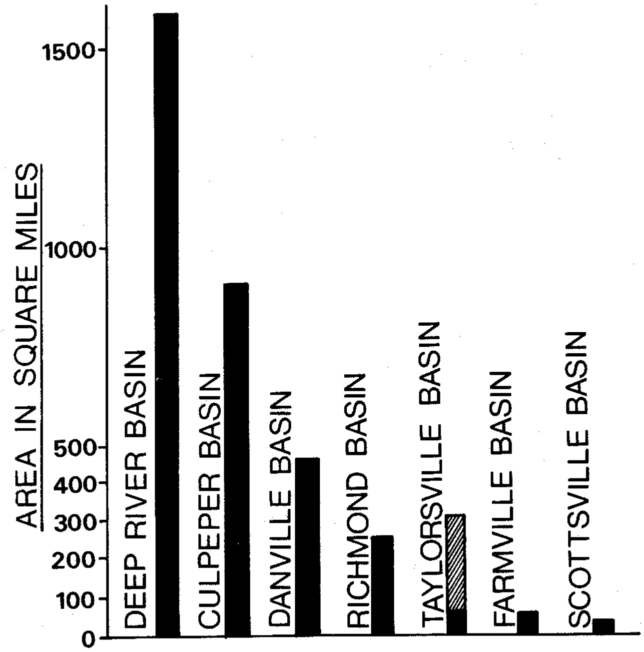

Figure 2. Bar graphs showing the relative areal extent of the exposed basins plotted in Figure 1. Two sizes are indicated for the Taylorsville basin; the smaller is the exposed area of the basin and the larger is the maximum possible area of the buried portion of the basin. Part of the buried region could represent basins separated from the Taylorsville basin.

underlie approximately 50 square miles (140 sq. km) of Hanover and Caroline counties, Virginia. Although many of the stream divides are covered by Coastal Plain deposits, which are nowhere more than 100 feet (30 m) thick, exposures are adequate to demonstrate that the deposits occupy a single basin. The exposed portion of the basin is comparable in size to the Farmville basin (Figure 2), but in subsurface it is probably much larger, for it likely extends to the northeast into Maryland. This contention is supported by well data from areas along regional strike near Bowling Green (Caroline County) and King George (King George County) in Virginia and near La Plata (Charles County) in Maryland where Triassic rocks were encountered. If these areas are part of the Taylorsville basin, the basin could be as large as 300 square miles (483 sq. km), the approximate size of the Richmond basin (Figure 2).

TRIASSIC STRATIGRAPHY

The Taylorsville basin contains sandstone, conglomerate and siltstone and some coal, shale and limestone (Table 1). Most of the estimated 5000 feet (1524 m) of strata are of repetitive sequences of cross-bedded or massive sandstone and siltstone and conglomerate. The rocks are generally black to gray in subsurface but weather to a very dark red at the surface. Only rare natural exposures are fresh enough to show colors observed in rocks from the subsurface.

Doswell Formation

The Doswell Formation, here named for the village of Doswell in Hanover County, is confined to the Taylorsville basin and is bounded downdip (to the northwest) by a major fault. The formation lies nonconformably upon the early Carboniferous Petersburg granite (Wright and others, 1975). It is overlain by nearly flat-lying, unconsolidated strata of Miocene to Recent age. The formation is composed of about 5000 feet (1524 m) of sandstone, conglomerate and siltstone. Minor quantities of shale, coal and limestone are confined to an interval between 800 to 2000 feet (244 and 610 m) above the base of the formation. This interval is distinctive and is used as the basis for dividing the Doswell Formation into three members. These members, herein named, are from oldest to youngest, the Stagg Creek, Falling Creek and Newfound members.

Stagg Creek Member: The Stagg Creek Member

Table 1. Triassic stratigraphy in the Taylorsville basin.

Age		Name			Character	Thickness in feet (meters)
TRIASSIC	Late Carnian	Doswell Formation	Newfound Member	siltstone/ sandstone facies	Siltstones, massive, and sandstones, massive, poorly consolidated, rare conglomerates except in top several hundred feet. Rare casts of stem fragments	1500 ± -2500 ± (485 ± - 805 ±)
TRIASSIC	Late Carnian	Doswell Formation	Newfound Member	sandstone/ conglomerate facies	Sandstones and conglomerates, massively cross-bedded, well consolidated, rare siltstone lenses. Common stem casts of *Auracarioxylon*.	500 ± -1500 ± (165 ± - 485 ±)
TRIASSIC	Middle Carnian	Doswell Formation	Falling Creek Member		Sandstones, well bedded and flaggy, and shales, gray to black, fissile, some siltstones and rare coals. Sandstones and shales commoly calcareous. Fish (*Dictyopyge*) and reptile bones in lenses.	1200 ± (385 ±)
TRIASSIC	Middle Carnian	Doswell Formation	Stagg Creek Member		Sandstones, massive to massively crossbedded, and conglomerates, massive, rare siltstone lenses. No known macrofossils.	800 ± (244 ±)

is named for the section exposed along Stagg Creek south of State Highway 54 (Figure 3); stratigraphic section 1 (see Appendix) is at the type section. The member is composed of about 800 feet (244 m) of massive sandstone and conglomerate with a few siltstone layers which contain many large feldspar crystals and much sand-size quartz. Other exposures of the Stagg Creek Member occur on the North and South Anna rivers along the southeast margin of the basin (Figure 3). The approximate size composition of this and other members is shown in Figure 4. The member nonconformably overlies the Petersburg granite and is overlain conformably by the Falling Creek Member of the Doswell Formation. Palynomorphs occur in a single six-inch- (15-cm-) thick lense of carbonaceous siltstone near the base of this member (stratigraphic section 1, interval 10) and are indicative of a middle Carnian age (Cornet, 1977).

Falling Creek Member: The Falling Creek Member is named for exposures along a tributary to Falling Creek, 2.1 miles (3.4 km) northwest of the junction of U.S. Highway 1 and State Highway 54 in Ashland. Sandstone, generally laminated and flaggy, is the dominant lithology. Green siltstone and green and gray to black shale are common and coal, limestone and calcareous sandstone are somewhat common. It is inferred that there are conglomeratic beds at the basin margins. Total thickness is about 1200 feet (366 m). Black shale and sandstone are dominant in the lower one-half of the member in which two species of fish, *Dictyopyge macrura* (Redfield, 1841) and *D. meekeri* Schaeffer and McDonald, 1978, and crustaceans (branchiopods) are common. The upper one-half of the member is characterized by sandstone and green bioturbated siltstones; unionid bivalves are common. There are thin beds of coal at the top of the member near the center of the basin and about 500 feet (152 m) above the base of the member near the western edge of the basin (stratigraphic section 1, interval 59; Rogers, 1884).

The base of this member is placed below, but generally not immediately below, the first limestone, coal or black shale above the base of the Doswell Formation. Because one or more of these key lithologies typically appears within a sequence dominated by paludal to lacustrine clays or siltstones (for example, stratigraphic section 3, intervals 9-14), the base of the Falling Creek Member is placed at the top of the first massive sandstone beneath the lowest limestone, coal or black shale in the sequence. The top of the member is placed at the top of the youngest clay, siltstone or well-laminated sandstone beneath the lowest, massively cross-bedded sandstone or conglomerate of the Newfound

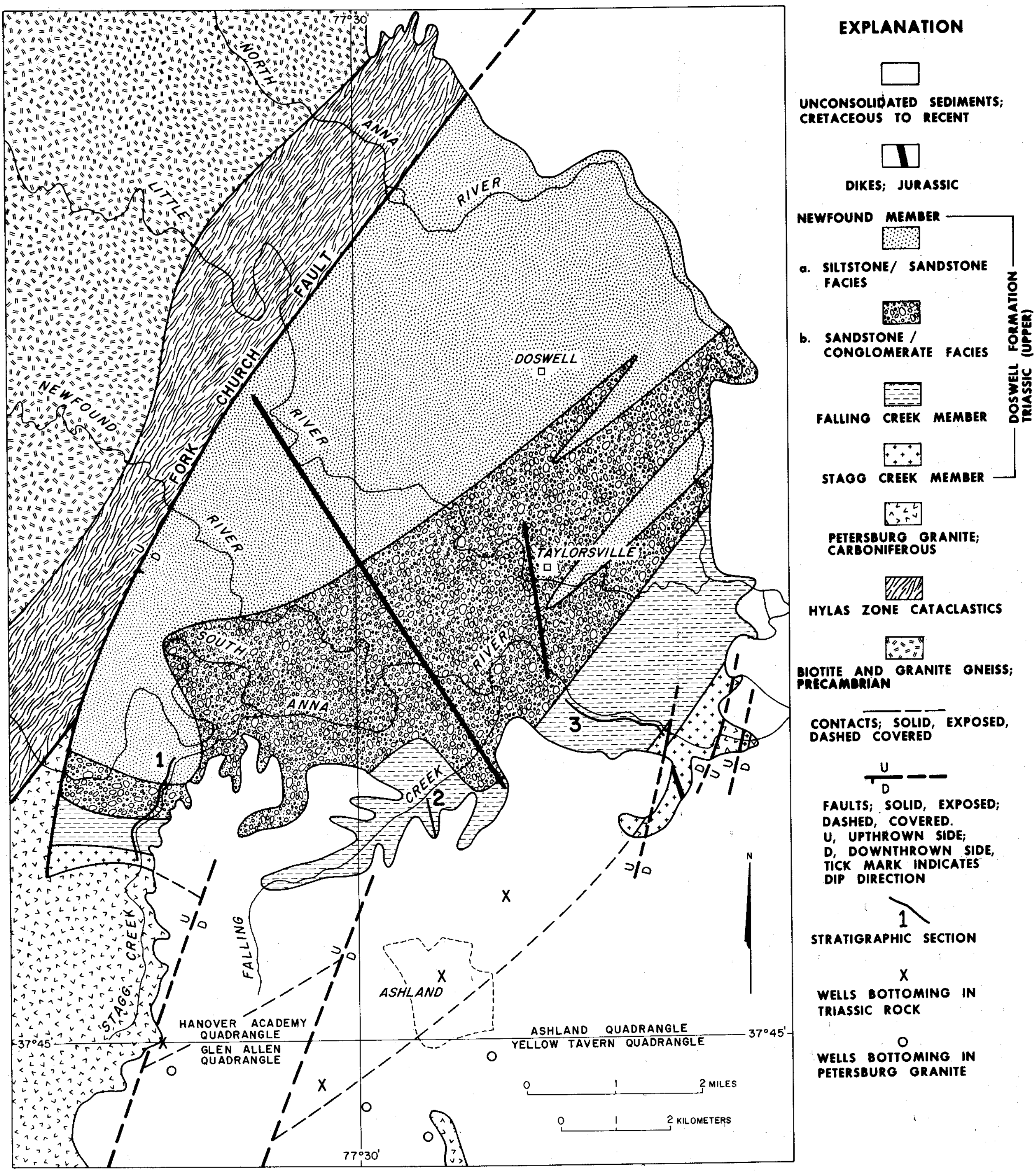

Figure 3. Map of the geology of the Taylorsville basin and surrounding area, including such subsurface control as exists.

Member (stratigraphic section 1, interval 95); the sequence is conformable. Palynomorphs from the upper part of the member are suggestive of a middle Carnian age (Cornet, 1977).

Newfound Member: The Newfound Member is named for strata exposed along the lower part of the Newfound River, a tributary of the South Anna River. It consists of two broadly intertonguing

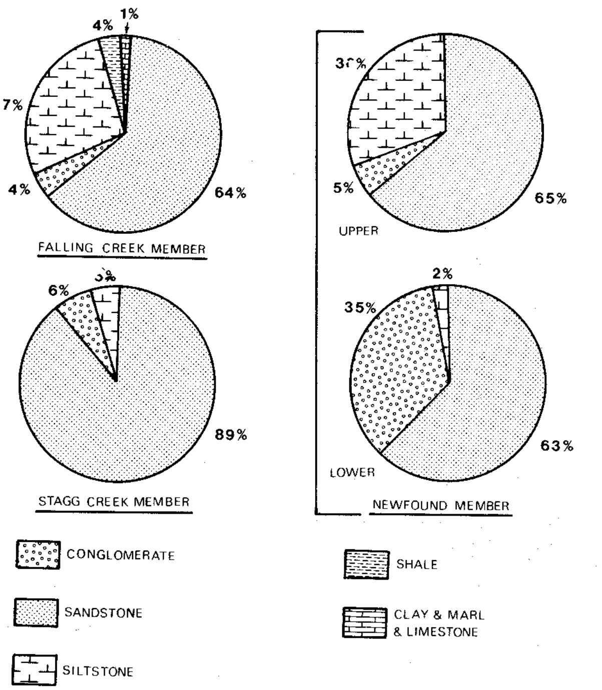

Figure 4. Circular diagrams showing relative proportions of different lithologies in the members and facies within the Doswell Formation.

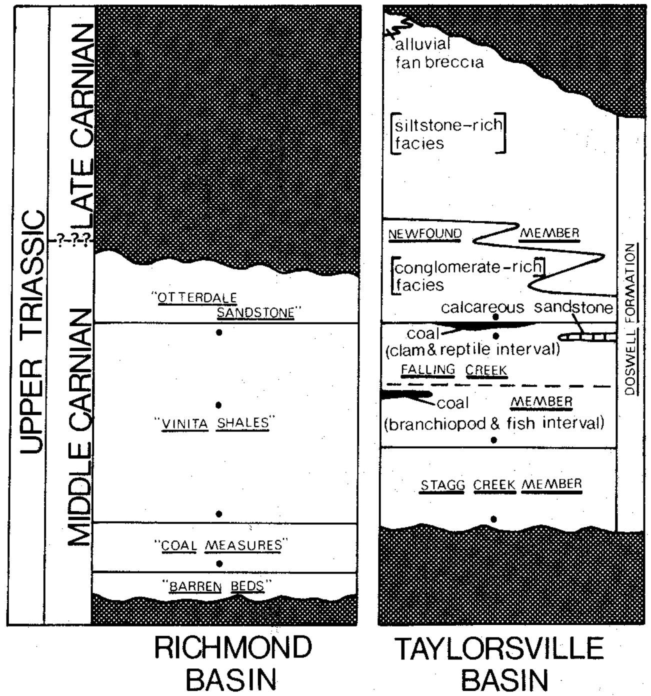

Figure 5. Comparative columnar sections of the units within the Richmond basin and the Taylorsville basin, showing relative ages of the strata in these two basins and approximate locations (black circles) of palynomorphs on which correlations were made. Pollen data from Cornet (1977).

facies, one composed of gravel- and sand-size clastics, the other of finer particles; member thickness is about 3000 feet (915 m). The sandstone/conglomerate facies, consisting of massive and also cross-bedded sandstone and some conglomerate, is well exposed north, east and south of the confluence of the Newfound and South Anna rivers (Figure 3). Beds described in stratigraphic section 1, intervals 96 through 144, are typical. The sandstone/conglomerate facies is thickest along the northwest border of the basin and thins markedly to the southeast where it intertongues with a sandstone/siltstone facies; maximum thickness is about 1000 feet (305 m). The sandstone/siltstone facies crops out in the bed of Stagg Creek and also near Cherrydale, an old estate located north of the Newfound River four miles (6.4 km) west of Gum Tree. This facies contains approximately equal quantities of massive, red (on weathering) siltstone and massive, light-brown sandstone. Deposits described in stratigraphic section 1, intervals 145 through 179, are typical of this facies. Locally, near the northwestern edge of the basin along the Newfound, Little and North Anna rivers there are semi-consolidated angular breccias at the top of sequences belonging to this facies. The facies is thickest (about 2500 feet, 762 m, thick) near the center of the basin; it thins to the southeast because of erosion or nondeposition, or both, and it is replaced to the northwest by the sandstone/conglomerate facies (Figure 5).

The deposits of the Newfound Member are interpreted as representing alluvial fan (especially conglomerate phases), fluvial and perhaps floodplain deposits. A few thin silty sequences a few hundred feet above the base may represent oxbow lakes. Otherwise, lacustrine deposits are absent. There are a few petrified trunks and casts of trunks of *Araucarioxylon* in the Newfound Member. A specimen of this genus described by Knowlton (1899) is most likely from this member. Palynomorphs from the oldest Newfound beds are middle Carnian; palynozones identified from deposits of similar age in other basins are suggestive of an age near the middle-upper Carnian boundary (Cornet, 1977). Perhaps most of the Newfound Member is late Carnian in age.

Dikes

There are two north-trending and one northwest-trending diabase dikes in the Taylorsville basin. The dikes thin toward basin margins and do not extend beyond them, yet similar dikes do occur in nearby areas outside the basin. One dike cuts youngest Newfound beds and it and the other two dikes in the basin are presumed to be of Jurassic age in accordance with those in other Newark basins (Cornet and others, 1973). No flows nor sills were found in the basin; evidently the igneous activity postdates sedimentation.

STRUCTURE

The most prominent fault in the area lies on the northwest side of the Taylorsville basin. The fault is herein named the Fork Church fault for a church by that name which lies on the fault. Smaller faults in the basin have produced offsets or folds in associated strata. The largest of these secondary faults parallels Stagg Creek for a short distance and can be traced some tens of miles to the southwest of the basin (Bruce Goodwin, personal communication, 1973). It apparently produced drape folding in the Falling Creek Member, and it presumably cuts the Stagg Creek beds. The critical area is covered by Coastal Plain gravels and the fault cannot be seen there (Figure 3), but well data are consistent with the inferred position of the fault. Other small faults cut Stagg Creek and lowest Falling Creek strata along the basin's southeastern margin. A syncline developed in Newfound beds in the southwestern corner of the basin (Figure 3) may also be the result of a northwest-trending basement fault or faults not directly expressed at the surface. Monoclines may represent small drapes over buried faults. *En echelon* faulting such as that documented in the Richmond basin (Shaler and Woodworth, 1899; Goodwin, 1970) probably occurs throughout the Taylorsville basin. Also, observations in other basins (Cloos and Pettijohn, 1973) support the idea that southern and eastern margins of the basin may be fault contacts. These contacts were earlier interpreted as being nonconformable on basement rocks.

GEOLOGIC HISTORY

Sources of Triassic Sediment

The Petersburg granite is the only source rock to the south and east. To the east, granite is known to occur as far as the Studley basin (Figure 1), which is totally buried beneath the Coastal Plain (Daniels and Onuschak, 1974); and to the south, granite occurs continuously as far as the Richmond basin (Goodwin, 1970). Northwest of the Taylorsville basin, however, the rocks are dominantly biotite-gneiss (Kingston and Weems, 1976). The cobble content of conglomerates in the basin records the changes in sediment supply from these source areas. Some of the cobbles from the metamorphic terrane, however, reflect a lower metamorphic grade than any of the rocks now exposed to the northwest. This observation is a reasonable one in view of the great amount of erosion which this area must have undergone.

Developmental History Of The Basin

Sediments of the Taylorsville basin nonconformably lie upon the Lower Carboniferous (330 m.y. ± 8 m.y.) Petersburg granite (Wright and others, 1975). On the northwest edge of the basin is the Hylas zone (Figure 3), a region of cataclastic rocks (Bobyarchick and others, 1976) that also forms the northwest border of the Richmond basin (Goodwin, 1970). The Hylas zone is probably a zone of late Paleozoic faulting and most major faults in the Richmond and Taylorsville basins parallel it. Triassic faulting may represent re-activation of pre-existing faults.

Subsidence along these faults began in middle Carnian time, and was accompanied by deposition of poorly sorted feldspathic sands and polymictic gravels and cobbles which entered the basin from several directions (Figure 6A). On the southern and eastern borders, cobbles are of Petersburg granite, and on the northwest, they are of mylonites and gneisses. Fine sediments of this age are generally absent; either they were transported to the northeast (where they now are buried) or else they escaped the basin by sedimentary bypassing. There were probably no lakes in the basin during deposition of the Stagg Creek Member.

Following 800 feet (244 m) of subsidence and infilling, sediments of the Falling Creek Member began to be deposited as the basin was closed and partially filled with water (Figure 6B). Fossils and bedding features are evidence of lake development as are the fine sediments, which now remained in the basin. Locally, around the margins of the basin, there are conglomerates which seem to represent small deltas built into the ancient lake. Clast composition and a generally uniform thickness for this interval reflect sediment influx from diverse directions. Clast size and angularity are suggestive of nearby sources and are evidence that the basin was not appreciably wider than at present. About 1200 feet (366 m) of sediment accumulated continuously in the lake, and, near the end of its existence, paludal environments developed near the center of the basin where coal formed.

Lacustrine conditions ceased toward the end of middle Carnian time and in latest middle Carnian, and probably well into late Carnian, subaerial environments are again represented (the Newfound Member). At this time, however, dominant sediment transport is from the northwest, as is indicated by the relationships of the sandstone/conglomerate facies and the siltstone/sandstone facies (Figure 6C). But some clasts of Petersburg granite occur within the basal few hundred feet of this sequence along the eastern margin of the basin. Higher, there is no evidence for any eastern sediment source. It thus appears that only during the latest stage of the basin filling was the basin tilted to the northwest; earlier subsidence may well have been trough-like and nearly symmetrical.

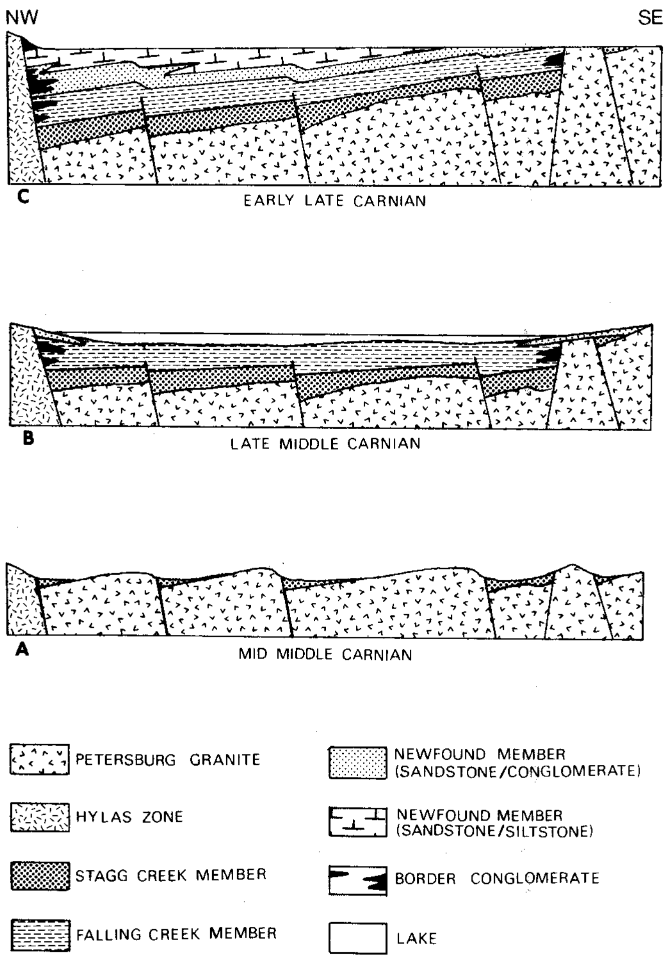

Figure 6. Diagramatic cross-section of the Taylorsville basin showing the major stages in the formation and filling of the basin as inferred from cobble lithology studies and the relative thicknesses of the units mapped in this basin. Vertical exaggeration is X2.

The influx of sand-size and coarser sediments that spread across the basin, primarily from the northwest, ceased after deposits attained a maximum thickness of about 1000 feet (305 m). Fine-grained sediments, which had been largely confined to the eastern margin of the basin during conglomerate formation, were now deposited throughout the basin. Thicknesses of 2000 feet (601 m) resulted. At the very end of the basin's depositional history, another pulse of rapid deposition spread breccias of angular, unsorted and uncemented rock fragments along the northwestern basin margin. The angularity of the clasts is evidence that a fault scarp developed along the trace of the Fork Church Fault. No earlier cobbles of comparable size, including those at the basin's margins, are so angluar. Clasts elsewhere, like at the margin, may range up to a foot (30 cm) in diameter, but all earlier conglomerates consist of moderate- to well-rounded clasts. Thus, an exposed fault scarp appears to have developed only in the latest phase of the basin's history; earlier motions on faults apparently produced only low hills along the basin's borders. From erosion and transportation of materials from these areas, somewhat rounded clasts were shaped and deposited in the basin.

Because deposition of the Newfound Member was rapid, there is no reason to suppose that it includes beds younger than late Carnian. Basal beds of the member are middle Carnian based on palynomorphs; palynological data from higher zones are lacking. A Rhaetian age for these strata was suggested on the basis of a single footprint ascribed to a prosauropod (Weems, 1972); Donald Baird (personal communication, 1972) disputed this identification. The age assignment was certainly wrong because excellent palynological samples from the same beds as the footprint are Carnian.

Correlations of strata in the Taylorsville and Richmond basins, based on Cornet's (1977) work, are indicative of similar histories for the two basins (Figure 5). It is possible that the basins were connected by rivers or low lands of the intervening Petersburg granite. Fish faunas from the two basins are similar to each other and to those of the Scottsville basin (Halifax County), but are different from those of other Newark basins (Schaeffer and McDonald, 1978). Any sediments in the intervening area must have been thin. Because granite cobbles derived from the south make up portions of the Stagg Creek and lower Falling Creek members, the possible time during which interbasin sediments could have accumulated is constrained to the last half of the basin's depositional history.

The proximity of the Taylorsville basin to the Coastal Plain makes it unlikely that it has undergone significant erosion since the Early Cretaceous. Most of the sediment deposited in the basin probably has remained there as reflected by the nearly unconsolidated state of the highest beds of the Newfound Member.

ECONOMIC GEOLOGY

Coal is the only resource which has been mined in the Taylorsville basin. As early as 1840, thin coal seams were reported along "Stag Creek" and "Beach Creek" (now Stagg Creek and Beech Creek), but these were not thought to have economic significance (Rogers, 1884, p. 445). Nevertheless at least two attempts were made to exploit this resource, for there are traces of mines and pits beside Stagg Creek 0.3 mile (0.48 km) west-southwest of Patrick Henry High School in the Hanover Academy quadrangle and along an unnamed tributary of the South Anna River 1.1 mile (1.8 km) west-southwest of Ashland Mill in the Ashland quadrangle. No records for either mine were located; probably each supplied only a very local market.

Because most of the Doswell Formation is well consolidated and cemented, water flow in it generally is restricted to joint and fracture systems. Only the siltstone/sandstone facies of the Newfound Member is soft enough to be easily drilled and permeable enough to be regularly used as a source of near surface water.

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APPENDIX

STRATIGRAPHIC SECTIONS

Section 1: Stagg Creek

Type section of the Doswell Formation, including all of the Stagg Creek Member, the Falling Creek Member and about one-half of the Newfound Member, as found along Stagg Creek in the Hanover Academy 7.5-minute quadrangle beginning at Hanover Country Club (0.2 mile north of Virginia Highway 54) and continuing south to contact wiht the Petersburg granite. Total measured thickness is 2607 feet (1099 m).

Interval	*Lithology*	*Thickness of bed (feet)*	*Thickness (cumulative) (feet)*
Doswell Formation			
Newfound Member (1684 feet, 513.3 meters, Section incomplete)			
Sandstone/siltstone facies			
179	Sandstone, coarse-grained, light brown, massive, well cemented	20	1684
178	Covered	5	1664
177	Siltstone, dusky-blue, laminated	7	1659
176	Covered	9	1652
175	Sandstone, fine-grained, light-gray, massive, slightly micaceous	13	1643
174	Sandstone, coarse-grained, moderate-red, massive	1	1630
173	Covered	12	1629
172	Sandstone, coarse-grained, poorly sorted, grayish-orange, massive, pebbly, slightly micaceous	8	1617
171	Sandstone, fine-grained, light-brown, massive, slightly micaceous	28	1609
170	Covered	5	1581
169	Sandstone, fine-grained, light-gray, massive	4	1576
168	Covered	20	1572
167	Sandstone, fine-grained, light-gray, massive	3	1552
166	Covered	19	1549
165	Sandstone, fine-grained, grayish-orange layers interbedded with dusky-blue layers, slightly silty	11	1530
164	Sandstone, fine-grained, grayish-orange, slightly silty, massive	11	1519
163	Covered	7	1508
162	Sandstone, fine-grained, grayish-orange, cross-bedded, slightly micaceous	16	1501
161	Covered	12	1485
160	Siltstone, dark-gray, slightly sandy, laminated	10	1473
159	Sandstone, medium-grained, grayish-orange, massive	2	1463
158	Covered	46	1461
157	Sandstone, fine-grained, medium-gray, very silty interbeds, soft	14	1415
156	Covered	12	1401
155	Sandstone, very coarse-grained, moderate-red, contains a few cobbles of mylonite and vein quartz, massive	4	1389
154	Sandstone, fine-grained, medium-gray, slightly silty, micaceous, massive	5	1385
153	Covered	16	1380
152	Sandstone, medium- to coarse-grained, medium-gray, massive	19	1364
151	Covered	15	1345
150	Sandstone, fine- to medium-grained, grayish-orange, massive	15	1330
149	Covered	15	1315
148	Sandstone, medium-grained, grayish-orange, slightly micaceous, massive	15	1300
147	Covered	91	1285
146	Sandstone, very coarse-grained, moderate-red, massive	17	1194
145	Covered, laterally equivalent to thick-siltstone bed, moderate-blue, exposed in gulley to east	74	1177

Sandstone/Conglomerate facies

144	Sandstone, fine-grained, medium-gray, massive	11	1103
143	Sandstone, very coarse-grained, grayish-orange, massive, contains a few mylonite and vein quartz cobbles	17	1092
142	Covered	14	1075
141	Sandstone, coarse-grained, grayish-orange, massive	20	1061
140	Covered	26	1041
139	Sandstone, coarse-grained, grayish-orange, massive	1	1015
138	Covered	8	1014
137	Sandstone, very coarse-grained, grayish-orange, massive	1	1006
136	Covered	13	1005
135	Sandstone, very coarse-grained, grayish-orange, massive	12	992
134	Sandstone, medium-grained, grayish-orange, massive, soft	24	980
133	Covered	24	956
132	Sandstone, very coarse-grained, grayish-orange, massive	1	932
131	Sandstone, medium-grained, grayish-orange, massive	14	931
130	Sandstone, very coarse-grained, grayish-orange, crossbedded	60	917
129	Covered	32	857
128	Siltstone, medium-gray, slightly silty, laminated	1	825
127	Sandstone, very coarse-grained, fine-grained sandstone interbeds, grayish-orange.	63	824
126	Sandstone, fine- to medium-grained, grayish-orange, massive	23	761
125	Sandstone, very coarse-grained, grayish-orange, massive, slightly micaceous	13	738
124	Covered	36	725
123	Sandstone, very coarse-grained, grayish-orange, massive	13	689
122	Covered	34	676
121	Sandstone, very coarse-grained, moderate-brown, massive, slightly micaceous	12	642
120	Sandstone, medium-grained, moderate-brown, massive, soft	7	630
119	Covered	10	623
118	Sandstone, very coarse-grained, grayish-orange, some fine-grained sandstone lenses, numerous pebbles of vein quartz and mylonite less than one inch in diameter	53	613
117	Covered	60	560
116	Sandstone, very coarse-grained, grayish-orange, cross-bedded, numerous pebbles and cobbles of vein quartz and mylonite	98	500
115	Siltstone, light-gray, slightly sandy, massive	13	402
114	Covered	25	389
113	Sandstone, very coarse-grained, grayish-orange, some fine-grained sandstone lenses, cross-bedded, numerous pebbles and cobbles of vein quartz and mylonite	50	364
112	Sandstone, medium-grained, grayish-orange, slightly silty, massive, soft	25	314
111	Covered	37	289
110	Conglomerate, grayish-orange, rounded cobbles of mylonite	2	252
109	Sandstone, fine-grained, grayish-orange, massive	10	250
108	Covered	37	240
107	Sandstone, very coarse-grained, grayish-orange, massive	1	203
106	Covered	10	202
105	Sandstone, very coarse-grained, grayish-orange, massive	3	192
104	Covered	36	189
103	Sandstone, very coarse-grained, grayish-orange, cross-bedded	36	153
102	Sandstone, fine-grained, grayish-orange, massive	5	117
101	Covered	24	112
100	Sandstone, fine-grained, grayish-orange, massive	39	88
99	Siltstone, medium-gray, massive	6	49
98	Conglomerate in matrix of much coarse-grained sandstone, grayish-orange, cobbles of mylonite	10	43
97	Covered	23	33
96	Conglomerate, little sandstone matrix, grayish-orange, cobbles of mylonite	10	10

Falling Creek Member (1160 feet, 353.8 m)

95	Clay, light-gray, massive	9	1160
94	Covered	31	1151
93	Clay, medium-gray, laminated	3	1120
92	Covered	6	1117
91	Sandstone, coarse-grained, moderate-blue, massive, slightly micaceous	3	1111
90	Covered	145	1108
89	Sandstone, fine-grained, grayish-orange, poorly laminated	14	963
88	Covered	42	949
87	Conglomerate, grayish-orange, massive, vein-quartz and mylonite cobbles up to 4 inches in diameter	4	907
86	Covered	21	903
85	Siltstone, light-gray, massive	4	882
84	Covered	11	878
83	Clay, light-gray, massive	14	867
82	Covered	13	853
81	Sandstone, fine-grained, grayish-orange, massive	2	840
80	Clay, light-gray, massive	14	838
79	Sandstone, fine-grained, grayish-orange, poorly laminated	29	824
78	Sandstone, fine-grained, grayish-orange, well laminated	2	795
77	Covered	21	793
76	Clay, light-gray, massive	15	772
75	Sandstone, fine-grained, grayish-orange, well laminated	18	757
74	Covered	2	739
73	Sandstone, fine-grained, grayish-orange, well laminated	20	737
72	Siltstone, medium-gray, with interbedded medium-gray clay layers	18	717
71	Sandstone, fine-grained, grayish-orange, well laminated	19	699
70	Siltstone, medium-gray, massive	7	680
69	Sandstone, fine-grained, light-gray, well-laminated	9	673
68	Sandstone, very coarse-grained, grayish-orange, massive	3	664
67	Sandstone, fine-grained, grayish-orange, well laminated	34	661
66	Clay, light gray, massive	4	627
65	Siltstone, medium-gray, mostly massive	8	623
64	Sandstone, fine-grained, grayish-orange, well laminated	3	615
63	Siltstone, medium-gray, laminated	9	612
62	Sandstone, fine-grained, grayish-orange, massive	18	603
61	Siltstone, medium-gray, massive	4	585
60	Sandstone, fine-grained, grayish-orange, well laminated	8	581
59	Covered, laterally equivalent to east with interval containing coal mines	226	573
58	Sandstone, fine-grained, pale-red, well-laminated	9	347
57	Covered	9	338
56	Sandstone, fine-grained, grayish-orange, well-laminated	9	329
55	Covered	6	320
54	Sandstone, fine-grained, grayish-orange, poorly laminated	17	314
53	Covered	8	297
52	Sandstone, fine-grained, grayish-orange, well-laminated	12	289
51	Covered	12	277
50	Sandstone, fine-grained, grayish-orange, massive	5	265
49	Siltstone, mostly dusky-red but with many black interbeds	11	260
48	Sandstone, fine-grained, grayish-orange, massive	2	249
47	Siltstone, medium-gray, massive	2	247
46	Sandstone, fine-grained, grayish-orange, well-laminated	5	245
45	Siltstone, moderate-red and medium-gray interbedded	3	240
44	Covered	27	237
43	Sandstone, fine-grained, grayish-orange, well-laminated	4	210
42	Siltstone, medium-gray, massive	2	206
41	Covered	33	204
40	Sandstone, fine- to medium-grained, grayish-orange, massive, slightly micaceous	42	171
39	Shale, black, fissile, with a few thin sandstone interbeds	6	129
38	Sandstone, fine-grained, grayish-orange, massive	2	123
37	Covered	65	121
36	Sandstone, fine-grained, grayish-orange, well-laminated	7	56
35	Siltstone, medium-gray, well-laminated	3	49
34	Sandstone, fine-grained, grayish-orange, well-laminated	10	46
33	Covered	36	36

Stagg Creek Member (763 feet, 232.6 m)

32	Sandstone, coarse-grained, grayish-orange, massive	3	763
31	Covered	74	760
30	Sandstone, coarse-grained in lower part grading continuously upward through medium-grained to fine-grained, massive	74	686
29	Sandstone, coarse-grained, grayish-orange, massive	4	612
28	Covered	18	608
27	Sandstone, coarse-grained, grayish-orange, massive, scattered cobbles of mylonite	1	590
26	Covered	14	589
25	Sandstone, coarse-grained, grayish-orange, massive, with scattered mylonite cobbles	35	575
24	Covered	64	540
23	Clay, pale-pink, massive	10	476
22	Sandstone, coarse- to medium-grained, grayish-orange, massive, with pebbles of quartz smaller than one inch in diameter	117	466
21	Sandstone, coarse-grained, grayish-orange, poorly bedded, interbedded cobble conglomerates with cobbles up to 3 inches in diameter	129	349
20	Sandstone, fine-grained, grayish-orange, well-laminated	2	220
19	Sandstone, coarse-grained, grayish-orange, massive	20	218
18	Sandstone, coarse-grained, grayish-orange, interbedded cobble conglomerates	20	198
17	Covered	5	178
16	Sandstone, coarse-grained with small quartz pebbles, grayish-orange, massive	24	173
15	Covered	3	149
14	Conglomerate, grayish-orange, massive, cobbles of mylonite	8	146
13	Covered	9	138
12	Conglomerate, grayish-orange, massive, cobbles of mylonite up to 3 inches in diameter	21	129
11	Sandstone, medium-grained, medium-gray with dusky-red blotches, interbedded with dark-gray siltstones	3	108
10	Sandstone, medium-grained, moderate-red, massive, with cobbles of Petersburg granite and more rarely cobbles of vein quartz, micaceous gneiss and mylonite, well-rounded to subangular and up to 5 inches in diameter, 6-inch-thick, lens of carbonaceous siltstone with palynomorphs occurs near base	6	105
9	Siltstone, dusky-red with medium-gray blotches, massive	8	99
8	Sandstone, medium-grained, moderate-red, massive	3	91
7	Sandstone, medium-grained, moderate-red, massive, scattered small quartz pebbles	3	88
6	Siltstone, dusky-red, massive	10	85
5	Covered	23	75
4	Siltstone, dusky-blue, massive	7	52
3	Covered	16	45
2	Clay, dusky-red, massive	1	29
1	Covered	28	28

(Section rests either nonconformably on or in fault contact with the Petersburg granite; contact not exposed)

Section 2: Falling Creek

Section of Falling Creek Member measured on tributary on south side of Falling Creek beside and east of State Road 667 and along west side of State Road 667, Ashland 7.5-minute quadrangle. Section begins about 50 feet (15.2 m) above the base of the member.

Interval	*Lithology*	*Thickness of bed (feet)*	*Thickness (cummulative) (feet)*
Doswell Formation, Falling Creek Member (290 feet, 88.4 m, top of section covered by alluvium)			
33	Sandstone, very fine-grained, grayish-orange, slightly silty, well-laminated	4	340
32	Sandstone, fine-grained, grayish-orange, slightly silty, well-laminated...........	13	336
31	Siltstone, dusky-red, massive, soft	23	323
30	Siltstone, dusky-red, well-laminated with shaly partings......................	21	300
29	Shale, black, well-laminated, contains compressed fish (*Dictyopyge*)	5	279
28	Shale, dusky-red, well-laminated..	3	274
27	Sandstone, fine-grained, moderate-red, well-laminated	9	271
26	Sandstone, very coarse-grained, moderate-red, poorly laminated...............	8	262
25	Sandstone, fine-grained, moderate-red, well-laminated	12	254
24	Sandstone, fine-grained, moderate-red, well-laminated, with a few interbedded black shale lenses..	16	242
23	Siltstone, medium-gray, massive, micaceous	3	226
22	Shale, black, fissile..	7	223
21	Covered	19	216
20	Sandstone, fine-grained, black, micaceous	2	197
19	Covered	4	195
18	Sandstone, fine-grained, medium-gray, slightly silty, micaceous................	11	191
17	Sandstone, coarse-grained, medium-gray, well-laminated	13	180
16	Sandstone, very coarse-grained, medium-gray, well-laminated.................	11	167
15	Sandstone, fine-grained, light-red, with a few quartz pebbles, slightly cross-bedded	3	156
14	Covered	5	153
13	Sandstone, fine-grained, interbedded with thin very coarse-grained sandstone lenses, dark-gray, well-laminated	6	148
12	Shale, black, slightly silty, fissile.......................................	7	142
11	Sandstone, fine-grained, grayish-orange, interbedded with shale, medium-gray, carbonized wood fragments scattered on some sandstone bedding planes	6	135
10	Covered	4	129
9	Sandstone, fine-grained, dark-gray, slightly silty, well-laminated, micaceous......	10	125
8	Covered	26	115
7	Sandstone, fine-grained, dark-gray, massive, soft	4	89
6	Sandstone, very coarse-grained, light-brown, massive.......................	1	85
5	Covered	6	84
4	Sandstone, fine-grained, moderate-reddish-brown, well-laminated, soft, slightly micaceous, with scattered quartz pebbles..................................	9	78
3	Covered	15	69
2	Sandstone, fine-grained, dusky-brown to dusky-red, slightly silty, well-laminated..	2	54
1	Clay, black to dark-gray, poorly developed partings	2	52
(covered to base by Tertiary gravels and loams)			

Section 3: South Anna River

Section of upper Stagg Creek and Falling Creek members exposed along south side of South Anna River east of Interstate 95, Ashland 7.5-minute quadrangle. Section ends about 60 feet (18.3 m) below top of Falling Creek Member.

Interval	*Lithology*	*Thickness of bed (feet)*	*Thickness (cumulative) (feet)*
Doswell Formation, Falling Creek Member (1093.9 feet, 333.4 meters, section about 60 feet, 18.3 m, short of complete)			
125	Sandstone, fine-grained, dusky-brown, micaceous, iron-oxide cemented	0.25	1093.9
124	Siltstone, dark-gray, massive, breaks up into small (0.2 inch) lumps in some intervals and larger (2 inch) lumps in other portions	13	1093.7
123	Clay, medium-gray, massive	0.5	1080.7
122	Siltstone, brownish-gray, massive and poorly bedded	0.75	1080.2
121	Sandstone, fine-grained, brownish-gray, iron-oxide cemented	0.5	1079.4
120	Sandstone, coarse-grained, moderate-brown, micaceous, poorly iron-oxide cemented	2	1078.9
119	Sandstone, medium-grained, moderate-brown, iron-oxide cemented	0.25	1076.9
118	Siltstone, light-brown, 0.4- to 0.8-inch-thick laminae	2	1076.7
117	Siltstone, moderate-brown, thin-bedded to shaly, some layers contain clam molds and casts	2	1074.7
116	Siltstone, moderate-yellowish-brown, massive, breaks up into 0.4 inch lumps	4	1072.7
115	Sandstone, fine- to medium-grained, medium-gray, well-cemented	2	1068.7
114	Siltstone, brownish-gray, sandy, massive but lumpy	7	1066.7
113	Sandstone, medium-grained, moderate-reddish-brown, poorly cemented by iron-oxide	8	1059.7
112	Conglomerate, light-brown, granular (0.07 inch), poorly sorted, 10-15 percent arkose, poorly cemented	2	1051.7
111	Clay, dark-gray to black, carbonaceous	0.25	1049.7
110	Siltstone, medium-gray, clayey, mottled and lumpy	4	1049.4
109	Siltstone, moderate-brown, sandy and micaceous	1	1045.4
108	Sandstone, coarse-grained, dark-gray, conglomeratic, arkosic, poorly cemented by iron-oxide	0.5	1044.4
107	Sandstone, fine- to coarse-grained, poorly sorted, brownish-gray, conglomeratic, arkosic, poorly consolidated	3	1043.9
106	Sandstone, fine- to coarse-grained, poorly sorted and conglomeratic, light-brown, micaceous, calcareous cement	5	1040.9
105	Covered	6	1035.9
104	Siltstone, brownish-gray, massive	6.25	1029.9
103	Covered	5.75	1023.7
102	Siltstone, brownish-gray, lumpy	6	1017.9
101	Covered	4	1011.9
100	Siltstone, moderate-brown, lumpy	1	1007.9
99	Covered	1	1006.9
98	Siltstone, moderate-green, massive, sandy, hard	2	1005.9
97	Sandstone, medium-grained, moderate-green, jointed at 2- to 4-inch-thick intervals	0.25	1003.9
96	Siltstone, moderate-brown, lumpy, rare calcareous nodules	5	1003.7
95	Sandstone, medium-grained, moderate-brown, micaceous, hard	0.5	998.7
94	Siltstone, moderate-brown, massive, highly micaceous	3	998.2
93	Sandstone, medium-grained, brownish-gray, micaceous, slightly calcareous, weathers to blocky nodules	1	995.2
92	Siltstone, brownish-gray, poorly laminated at 0.8-inch-thick intervals, lumpy where weathered	5.5	994.2
91	Sandstone, fine-grained, medium-gray, massive, slightly calcareous	1.5	988.7
90	Siltstone, brownish-gray, poorly laminated	4	987.2
89	Sandstone, medium-grained, moderate-brown, massive, micaceous	0.5	983.2
88	Siltstone, sandy, moderate-yellowish-brown, lumpy	1.5	982.7
87	Sandstone, fine-grained, brownish-gray, massive	0.5	981.2
86	Siltstone, gray, moderate-brown and moderate-green, lumpy	2	980.7
85	Shale, black and moderate-green interbedded, contains fish scales and fish bones	1	978.7
84	Limestone, fine-grained, medium-gray and massive	0.25	977.7
83	Siltstone, moderate-brown, a few fine-grained moderate-brown sandstone lenses, lumpy	5	977.4
82	Sandstone, medium-grained, moderate-brown, massive	0.5	972.4

81	Sandstone, medium-grained, medium-gray, massive	1	971.9
80	Sandstone, coarse-grained, moderate-yellowish-brown, arkosic, thickly laminated	11	970.9
79	Silt, moderate-brown, clayey, massive	2	959.9
78	Shale, black, contains fish scales	0.17	957.9
77	Silt, moderate-brown, sandy, weathers to 0.02-inch-long lumps	3	957.8
76	Silt, dark-gray, sandy, weathers to 0.02-inch-long lumps	2	954.8
75	Silt, light brown, sandy, weathers to 0.02-inch-long lumps	2.5	952.8
74	Sandstone, fine-grained, light-olive, well-consolidated, massive	1	950.3
73	Covered	8	949.3
72	Silt, light-olive, clayey, poorly laminated, occasional fish scales and clam-shell casts	2	941.3
71	Sandstone, fine- to medium-grained, brownish-gray, slightly micaceous	0.67	939.3
70	Silt, light-olive, clayey, poorly laminated, occasional fish scales and clam-shell casts	5	938.6
69	Sandstone, fine-grained, moderate-yellowish-brown, well-consolidated, impersistent arcuate partings	0.75	933.6
68	Sandstone, fine-grained, moderate-yellowish-brown, poorly consolidated, impersistent arcuate partings	0.5	932.8
67	Sandstone, fine-grained, moderate-yellowish-brown, well-consolidated, impersistent arcuate partings	0.25	932.3
66	Sandstone, fine-grained, moderate-yellowish-brown, poorly consolidated, impersistent arcuate partings	1	932.1
65	Sandstone, fine-grained, moderate-yellowish-brown, well-consolidated, impersistent arcuate partings	0.25	931.1
64	Sandstone, fine-grained, moderate-yellowish-brown, poorly consolidated, impersistent arcuate partings	1.5	930.8
63	Sandstone, medium-grained, moderate-yellowish-brown, well-consolidated, impersistent arcuate partings	0.33	929.3
62	Sandstone, medium-grained, moderate-yellowish-brown, poorly consolidated, impersistent arcuate partings	4.5	929
61	Sandstone, coarse-grained, grayish-orange, micaceous layers make flaggy partings	1	924.5
60	Siltstone, moderate-brown, well-laminated	0.33	923.5
59	Sandstone, coarse-grained, grayish-orange, micaceous layers make flaggy partings	1	923.2
58	Sandstone, medium-grained, moderate-brown, poorly consolidated, 0.8- to 1.2-inch-thick flaggy partings	5	922.2
57	Sandstone, medium-grained, moderate-brown, well-consolidated, massive	3	917.2
56	Sandstone, medium-grained, moderate-brown, poorly consolidated, large mica flakes form 0.8- to 1.2-inch-thick flaggy partings	14	914.2
55	Sandstone, medium-grained to coarse-grained, moderate-brown, well-consolidated, mica layers form flaggy partings	1	900.2
54	Siltstone, moderate-reddish-brown, poorly laminated, slightly micaceous but flakes under 0.04 inch in diameter	2	899.2
53	Sandstone, medium-grained, moderate-brown, slightly micaceous, weathers to lumps	0.67	897.2
52	Siltstone, moderate-yellowish-brown, slightly sandy, massive, slightly micaceous, poorly consolidated	4	896.5
51	Sandstone, coarse-grained, moderate-yellowish-brown, poorly sorted, micaceous, moderately consolidated	1	892.5
50	Covered	42.5	891.5
49	Siltstone, moderate-reddish-brown, soft, well-laminated	1	849
48	Covered	15.5	848
47	Sandstone, medium-grained, grayish-orange, micaceous, poorly bedded	1	832.5
46	Covered	89	831.5
45	Sandstone, fine-grained, moderate-brown, massive, muscovite flakes scattered throughout	5.5	742.5
44	Siltstone, moderate-brown, poorly laminated, muscovite flakes scattered throughout	0.5	737
43	Sandstone, coarse-grained, grayish-orange, massive, micaceous, with pebbles and cobbles of quartz and Petersburg granite in lenses subparallel to bedding, most clasts 0.8 inch in diameter but a few up to 3 inches, rounded to subrounded	10	736.5
42	Siltstone, moderate-brown, sandy, poorly laminated, micaceous	1.5	726.5
41	Sandstone, medium- to coarse-grained, moderate-brown, massive	8	735
40	Sandstone, fine-grained, grayish-orange, 0.4- to 0.8-inch-thick laminae well-developed, partings on muscovite-rich bedding planes, well-laminated	8	717
39	Covered	10	709
38	Sandstone, fine-grained, grayish-orange, with muscovite throughout	3.5	699
37	Shale, dark-gray, silty, calcareous, laminated but poorly developed due to concretion growth	3.5	695.5
36	Sandstone, medium-grained, light-brown, micaceous, massive	2	692
35	Sandstone, fine-grained, light-brown, well-laminated at about 0.4-inch intervals along muscovite-rich bedding planes	1	690

34	Covered	32.5	689
33	Sandstone, coarse-grained, light-brown, massive, with lenses of subrounded quartz pebbles about 0.4 inch in diameter	6	656.5
32	Covered	4	650.5
31	Sandstone, fine-grained, light-brown, well-laminated at about 0.4-inch intervals along muscovite-rich bedding planes	1	646.5
30	Sandstone, fine- to coarse-grained, poorly sorted, micaceous, sporadic pebbles	4	645.5
29	Siltstone, medium-gray, massive, micaceous, soft	4	641.5
28	Sandstone, fine- to coarse-grained, poorly sorted, light-brown, micaceous, kaolinitic, massive except for local areas of poorly developed lamination or quartz-pebble lenses, pebbles about 0.4 inch in diameter	25	637.5
27	Siltstone, moderate-reddish-brown, massive, micaceous	1.5	612.5
26	Sandstone, fine- to coarse-grained, poorly sorted, light-brown, micaceous, kaolinitic, local lenses of poorly laminated sandstone and occasional lenses of quartz pebbles about 0.4 inch in diameter	15	611
25	Sandstone, medium-grained, light-brown, well-laminated at 2- to 4-inch intervals along muscovite-rich bedding planes, very kaolinitic, ripple marks developed in basal foot	8	596
24	Shale, black, noncalcareous, mudcrack patterns of bed beneath extend up into this bed	2	588
23	Sandstone, coarse-grained, moderate-reddish-brown, angular grains, massive	2	586
22	Covered	4	584
21	Siltstone, moderate-brown, soft, poorly laminated, sparsely micaceous	6	580
20	Sandstone, coarse- to fine-grained, poorly sorted, light-brown, micaceous, massive (power line crosses river above this interval)	16	574
19	Conglomerate, gritty, light-brown, massive, poorly sorted with pebbles ranging to sand-size and sporadic cobbles ranging up to 8 inches across, mostly quartz but some Petersburg granite, micaceous	8	558
18	Covered except at very low water when sporadic outcrops of soft silty shale and carbonaceous shale are seen in river bed, but crops are too sparse for detailed description	507	550
17	Sandstone, fine- to coarse-grained, poorly sorted, grayish-orange, no mica, well-cemented, massive	2	43
16	Sandstone, fine- to coarse-grained, poorly sorted, dark-reddish-brown, some scattered muscovite flakes and rounded-quartz pebbles, massive, poorly cemented	18	41
15	Siltstone, pale-red, prominent bedding formed by planes rich in muscovite flakes over 0.04 inch in diameter	4.5	23
14	Sandstone, fine-grained, grayish-orange, 0.04- to 0.06-inch-diameter muscovite flakes scattered throughout, well-laminated, variably cemented	4.5	18.5
13	Sandstone, fine-grained, grayish-orange, 0.04- to 0.06-inch-diameter muscovite flakes scattered throughout, massive and poorly laminated	3.5	14
12	Siltstone, dark- to light-gray in bands, some sandy lenses, bands 0.4 to 6 inches thick	3	10.5
11	Siltstone and silty shale, dark-gray to black, well laminated, contains compressed fish (*Dictyopyge*)	5	7.5
10	Siltstone, medium-gray, highly calcareous, massive, contains armored mudballs and bone fragments	0.5	2.5
9	Siltstone, moderate-green, massive, soft	2	2

Stagg Creek Member (50 feet, 15.2 m, exposed)

8	Sandstone, fine-grained, grayish-orange, massive and well-cemented, faint laminations formed by harder and softer intervals	3	799.5
7	Sandstone, fine- to coarse-grained, poorly sorted, moderate-brown, massive, muscovite flakes scattered randomly throughout	6	796.5
6	Siltstone, moderate-green, clayey, poorly laminated, soft	3	790.5
5	Sandstone, fine-grained, grayish-orange, large (0.8 to 1.2 inch) muscovite flakes on weakly defined bedding planes, well-consolidated	3	787.5
4	Sandstone, fine-grained, medium-gray, large (0.8 to 1.2 inch) muscovite flakes on weakly defined planes, soft	1.5	784.5
3	Sandstone, coarse- to fine-grained, poorly sorted, a few lenses and cross-beds but generally massive, except at base where it is finer and well-laminated, moderately soft	15	783
2	Sandstone, medium-grained, light-brown, well-cemented with soft silty interbed 1/2 to 1 foot thick and a few poorly sorted and coarse interbeds of similar thickness	18	768
1	Covered	750	750

(section ends against Petersburg granite along a faulted contact)

METALLIC MINERALIZATION IN THE BLUE RIDGE PROVINCE OF VIRGINIA[1]

By
Palmer C. Sweet and Stephen C. Bell

CONTENTS

Portions of this publication may be quoted if credit is given to the Division of Mineral Resources. It is recommended that reference to this report be made in the following form: Sweet, P. C., and Bell, S. C., 1980, Metallic mineralization in the Blue Ridge province of Virginia, *in* Contributions to Virginia Geology—IV: Virginia Division of Mineral Resources Publication 27, p. 39-52.

ILLUSTRATIONS

ABSTRACT

Metallic mineralization in the Blue Ridge province consists of two major types. The dividing line of the types of mineralization corresponds to the location of the James River where it crosses the province. Mineralizations, predominantly iron and manganese, in the northern area (Catoctin-type ores) are in the Catoctin Formation. Mineralizations, predominantly iron, copper and arsenic in massive sulfides, in the southern area (Ducktown-type ores) are in volcanic rocks of the Mount Rogers group and the Unicoi Formation. A total of 45 abandoned mines and prospects (23 from the northern area and 22 from the southern area) are specifically located (where possible) and described in this report. Brief description of the mines, including history, rock types, production figures and field observations are included.

INTRODUCTION

The Blue Ridge province in Virginia is bounded on the east by the crystalline rocks of the low, rolling Piedmont province (Dietrich, 1970, fig. 1), and on the west by the sedimentary rocks of the Valley and Ridge province. Differences in the structural styles, lithology, and topography between that portion of the Blue Ridge province lying northeast of the

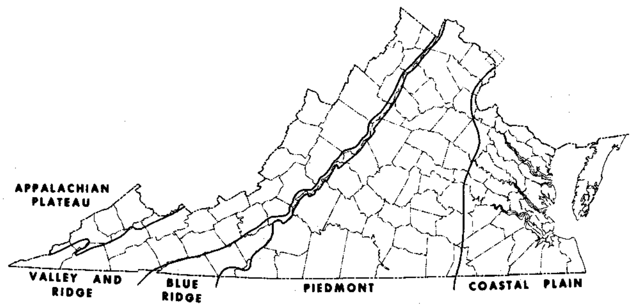

Figure 1. Physiographic provinces of Virginia.

James River and the portion southwest of it (Figure 1) serve as a basis for subdivision of the province. Northeast of the James River the Blue Ridge consists principally of a northeast-trending anticlinorium, the Blue Ridge anticlinorium. The fold is overturned to the west and its trend is locally interrupted by faults. Many of the ridges along the anticlinorium are capped by the Catoctin Formation which consists of a series of greenstones (metabasalts) and interbedded sedimentary units, basalt flows, tuffs, and breccias. The ridges of greenstone on the east-southeastern limb of the anticlinorium, the core (which is composed of the Lynchburg Formation), and some of the Blue Ridge complex rocks are not considered as part of the Blue Ridge province in this paper. In addition, abandoned iron and manganese mines and prospects along the west side of the Blue Ridge, titanium mineralization in the Piney River district (Amherst and Nelson counties), and some other metallic mines and prospects east of the Blue Ridge are not discussed in this paper.

Southwest of the James River, Blue Ridge complex rocks consist mainly of gneissic metasediments, which are cut locally by bodies of foliated ultramafic rocks, such as amphibolites and pyroxenites (Rankama, 1970, p. 22). In this area, the Catoctin Formation is not recognized; however, there are other volcanic rocks here including the Mount Rogers Group and greenstone volcanics in the Unicoi Formation.

METALLIC OCCURRENCES

Most of the metallic mineralization in the Blue Ridge province can be divided into two types, the Catoctin-type and the Ducktown-type; the two types are separated geographically at the James River, the southern limit of the Catoctin Formation and thus reflect the geologic differences between the northern and southern sections of the Virginia Blue Ridge (Figure 2). Northern-section or Catoctin-type mineralizations are found most commonly in the epidotized portions of the greenstones of the Catoctin Formation. Weed (1901, p. 498) noted that the "ores" of this class of deposit do not extend more than 50 or 60 feet (15-18 m) below the surface. Furthermore, he postulated that they were deposited by meteoric waters that percolated through primary deposits. The mineral assemblage that characterizes these deposits consists of small quantities of native copper and in some places cuprite associated with stains and films of malachite and azurite. These minerals are commonly in the epidotized portions of the greenstones, and in many places are associated with small and discontinuous quartz veinlets and stringers; the minerals are also common as films on cleavage planes in the greenstone. Numerous bright stains of the copper carbonates malachite and azurite give an outcrop a good "show." Primary sulfides are rare or absent. Some ore trends may be observed by methods of remote sensing; an example is a north-northwest-trending linear in southern Warren County identifiable on high altitude photographs and LANDSAT images and on the State aeromagnetic map (Rader and Johnson, 1978, p. 96-97). Copper was earlier mined at six localities lying along this trend.

The massive sulfides of the southern section, Ducktown-type occurrences are probably syngenetic and may have been formed by the remobilization of trace sedimentary sulfides and metals leached from the rocks during regional metamorphism (Addy and Ypma, 1977). Massive sulfide occurrences commonly show limonite gossan caps, some of which have produced iron ore. In areas where a gossan cap overlies unaltered massive sulfides consisting of pyrrhotite, there is commonly a zone of secondary alteration. This altered zone, composed mainly of black sulfides, lies between the gossan and the pyrrhotite and is intermixed with unaltered vein material. Deposits in the Gossan Lead of Virginia (Carroll and Grayson counties) are examples of Ducktown-type occurrences.

Sulfide mineralizations in the Virginia Blue Ridge which do not belong to this two-fold classification include the Irish Creek tin deposit in Rockbridge County and the Brinton (United States) arsenic deposit in Floyd County.

The area south of the James River was far more productive than the northern section; copper was the most important single metal. No metallic mines are presently active in the Blue Ridge province of Virginia. In the following sections, quadrangles cited are standard 7.5-minute quadrangles; UTM (Universal Transverse Mercator) coordinates are used for location data.

Northern Section Mines and Prospects

Most of the mining in the area occurred between 1890 and 1910, and though a number of mining corporations were formed, little ore was produced. Brief descriptions of 23 abandoned mines and prospects, arranged alphabetically, follow.

Allen mines—Location: Nelson County, Sherando quadrangle, 2.5 miles (4.0 km) north-northeast of Wintergreen on the southeast side of Crawford Knob (N 4,198,600 E 686,120, Zone 17).

The principal country rocks are chlorite greenstone, schists and phyllites. The rocks have a strike of N75°E and a dip of 30°SE. A main joint has a strike of N42°E and a dip of 74°NW. There are quartz veins up to 12 inches (30 cm) thick that are parallel to the schistosity of the greenstone. The quartz is stained reddish-brown with iron oxide in places and contains chalcopyrite.

Mines were operated from 1885 to 1905. Tunnels were blasted into the mountain with black powder and the ore was taken by tramway down the mountain where it was crushed and smelted. In early 1978, there were six tunnel openings in the main area of the mines, each 3 to 6 feet (1 to 2 m) across at the entrance. A talus-like dump on the mountain side contained chalcopyrite in quartz as well as

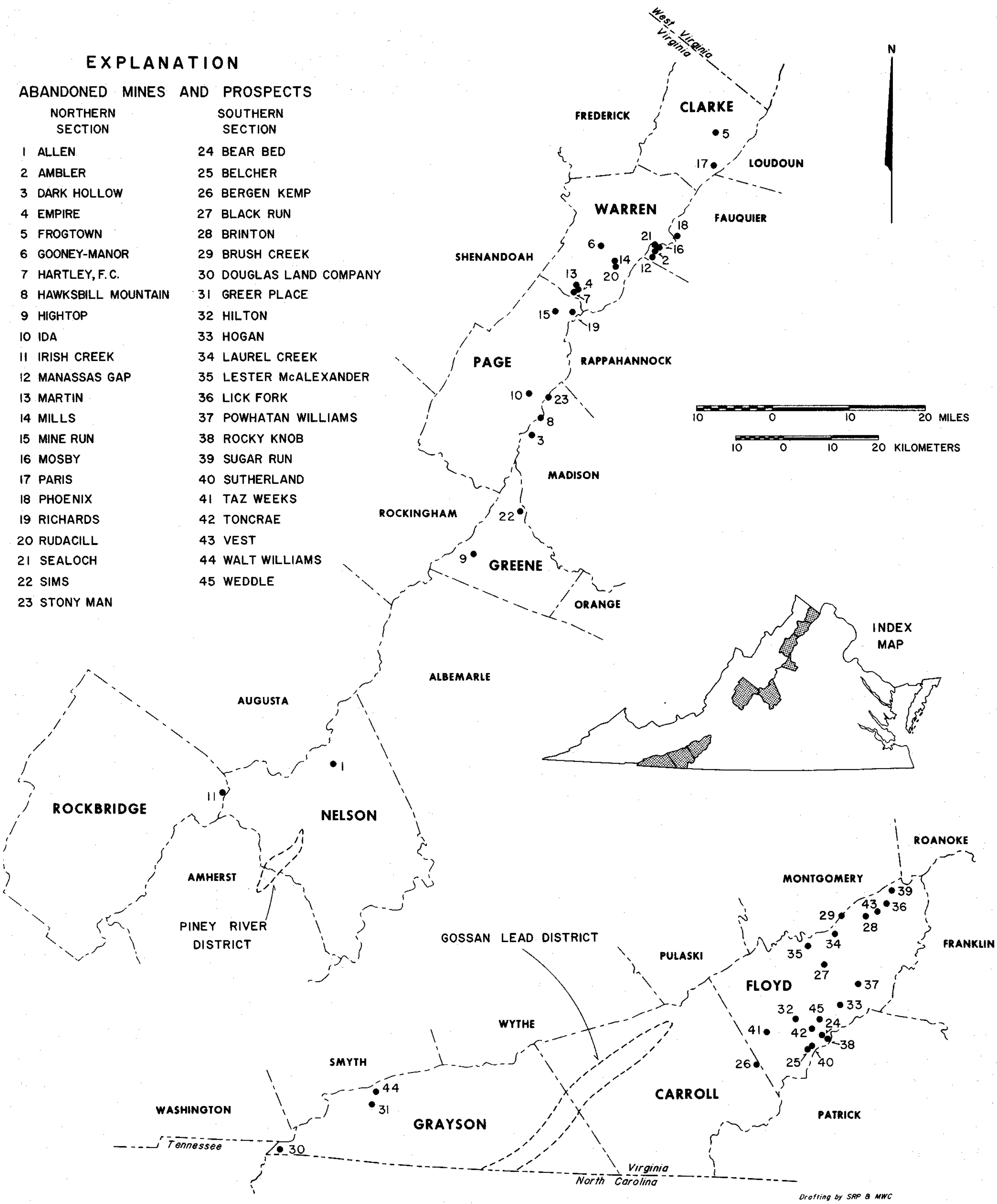

Figure 2. Location map of abandoned metallic mines and prospects in the Blue Ridge province of Virginia.

pieces of greenstone schist and phyllite with malachite stain.

Ambler mine—Location: Fauquier County, Flint Hill quadrangle, about 7.0 miles (11.2 km) northwest of Hume, 0.4 mile (0.6 km) south of Summit Drive approximately 0.3 mile (0.5 km) by road west of its intersection with the Fauquier-Warren County line (N 4,306,510 E 750,620, Zone 17).

The rock is greenstone with some small quartz veins and minor amounts of red jasper; rock attitude is strike N55°E, dip 65°SE. One prominent joint has a strike of N20°W. Mineralization included native copper and bornite in irregular masses in epidotized basalt of the Catoctin Formation. Both Weed, (1911) and Watson (1907) report the Ambler mine as being located in Rappahannock County but Luttrell (1966) states that it is in Fauquier County. After talking with local residents and examining old maps, the authors concluded that the site is in Fauquier County. By 1911, there were two openings in a rocky ledge known as Cottam Rock (Ravensden Rock?) about 1 mile (1.6 km) south of High Knob; a 40-foot (12-m) shaft and an open cut and tunnel were also at the site (Weed, 1911, p. 101). An open cut on the north-northwest slope of Ravensden Rock could still be seen in 1978. There was also a 20-foot-long (6-m) tunnel ending in a 7-foot-high (2-m) opening which contained water and debris. Small amounts of native copper and malachite stain were in a large hillside dump.

Dark Hollow (Blue Ridge Copper Co.) mine—Location: Madison County, Big Meadows quadrangle, 1.5 miles (2.3 km) east of Big Meadows and 0.8 mile (1.3 km) southeast of Fishers Gap in the Shenandoah National Park (N 4,267,280 E 725,840, Zone 17).

Copper mineralization (native copper, cuprite, chalcopyrite, azurite and malachite) formed along joint planes in epidotized Catoctin greenstone near its contact with an intrusive mass of syenite (Weed, 1911, p. 108). Gangue minerals included quartz, calcite, epidote and serpentine. Copper was mined before the Civil War from a shaft sunk a few hundred feet above two main headwater branches. Water was within 20 feet (6 m) of the top of the shaft in 1905 (Weed, 1911, p. 107). The Blue Ridge Copper Company mined the property intermittently in the early 1900's by use of a 42-foot-long (13-m), inclined shaft; a few tons of ore were shipped.

In 1973 there were remains of one small pit and a small concrete foundation at the old mine. A small amount of malachite mineralization was in a small dump of greenstone; most of the old dump was utilized as roadstone on the Appalachian Trail.

Empire prospect—Location: Warren County, Bentonville quadrangle, 3.15 miles (5.07 km) southeast of Bentonville, near the summit of Matthews Arm, about 1.4 miles (2.2 km) east-southeast from the end of State Road 630 (N 4,296,760 E 735,160, Zone 17).

Mineralization was cuprite, bornite and malachite in altered and epidotized basalt; the ore did not average more than 1 or 2 percent (Weed, 1911, p. 101). A shaft was sunk to a depth of 90 feet (27 m) prior to 1905 and in that year several prospect pits were dug. In early 1978, there remained a shallow trench, a caved shaft 15 feet (5 m) in diameter, and a dump of greenstone spread out in the woods. This shaft is southeast of the Matthews Arm summit. No mineralization was seen in the rocks near the shaft. At the summit were shallow depressions, scattered greenstone boulders and amygdaloidal basalt; some of the amygdules contain bornite.

Frogtown prospect—Location: Clarke County, Ashby Gap quadrangle, 2.3 miles (3.7 km) northwest of Frogtown, near the top of the cliffs on a north bend of the Shenandoah River (N 4,330,900 E 243,900, Zone 18).

The Shady Dolomite here contains a trace of copper and lead mineralization (Luttrell, 1966, p. 51). The dolomite, which is fractured and contains calcite veinlets, has a strike of N66°E and a dip of 30°NW. In early 1978, there was an open cut and an open shaft in the high dolomite cliffs. The open shaft, which is 7 feet (2 m) in diameter and about 30 feet (9 m) deep, contained leaves and some timbers in the bottom. There was no mineralization seen in rocks around the old shaft nor at the downslope dump.

Gooney-Manor mine—Location: Warren County, Front Royal quadrangle about 2.9 miles (4.6 km) southwest of the city limits of Front Royal, 0.25 mile (0.40 km) from the southeast side of the U.S. Highway 340, approximately 0.4 mile (0.6 km) by road north of its intersection with State Road 607 (N 4,307,220 E 739,340, Zone 17).

In the early 1900's, the Virginia and Pittsburgh Copper Company owned this mine, in which copper mineralization was mined from crevices and fractures in greenstone. The greenstone is in contact with Ordovician limestones. Copper ores probably formed by concentration of material leached from copper-rich igneous rocks (Rader and Biggs, 1975, p. 46). In 1909 ore assayed at 5 percent copper. In 1975, the site had concrete foundations (Figure 3), hillside pits and excavations; the largest pit is about 40 feet (12 m) by 20 feet (6 m) and is 10 feet (3 m) deep. Mineralization seen at the large dump consisted of chalcopyrite, pyrite, bornite and malachite in small

Figure 3. Concrete foundations for crushing equipment, Gooney-Manor mine, Warren County.

quartz veinlets in the greenstone. The area was partly overgrown with vegetation.

F. C. Hartley prospect—Location: Warren County, Bentonville quadrangle, about 3 miles (5 km) south of Bentonville southwest of the summit of Matthews Arm.

Mineralization was azurite and malachite in epidotized greenstone (Weed, 1911, p. 101). An old shaft on the land of F. C. Hartley was worked, probably in the 1870's. There was no evidence of the shaft nor of a dump when the area was visited in early 1978.

Hawksbill Mountain mine—Location: Madison County, Big Meadows quadrangle, about 4 miles (6 km) northeast of Big Meadows Wayside in the vicinity of Hawksbill Mountain and Hawksbill Gap.

Prospecting took place in the 1800's; there was a water-filled shaft 60 feet (18 m) deep at the site in the early 1900's (Weed, 1911, p. 109). In early 1978, there was no evidence of the old shaft. Remnants of many old greenstone rock slides are on the northeast side of Hawksbill Mountain and dark-green, chloritic slate with malachite copper stain occurs along the Appalachian Trail.

Hightop mine—Location: Greene County, Swift Run Gap quadrangle, south of Swift Run Gap on a spur 1.8 miles (2.9 km) south of Hightop (N 4,243,340 E 712,650, Zone 17). Three adits were also cut into the top of Slaters Mountain, located 3.3 miles (5.3 km) south of Hightop (N 4,240,640 E 714,240; N 4,240,290 E 714,380; N 4,240,300 E 714,150—all Zone 17).

The copper ore (native copper, cuprite, bornite, malachite, azurite and chalcopyrite) was with quartz veinlets in partly epidotized Catoctin greenstone; there was also mineralization along fracture surfaces (Weed, 1911, p. 112-113). In the fall of 1905, the Hightop Copper Company developed stripped ledges, open cuts, and an 80-foot (24-m) shaft with a crosscut, a tunnel and several adits at the top of Slaters Mountain south of the mine. The shaft was water filled in February, 1906 (Phalen, 1906, p. 142). In 1944, there was an unsuccessful attempt to reopen the mine.

In 1974, several openings were at both mine areas. Twin adit entrances (Figure 4) each 6 to 9 feet (2 m to 3 m) in diameter were in the face of the mountain overlooking Bacon Hollow to the west at the main mine; the adits join near the face. Remains of a caved shaft 30 feet (9 m) in diameter and 20 feet (6 m) deep, several small pits, and several concrete foundations, one of which may have supported a small stamp mill, were also on the property. There was a large dump containing epidotized basalt, with quartz stringers and jasper. Malachite and azurite stains were the most abundant mineralization seen, but there was some chalcocite, bornite and chalcopyrite. At Slaters Mountain, the three adits had only minor malachite staining. The longest adit is about 60 feet (18 m). These openings are not mentioned in the literature.

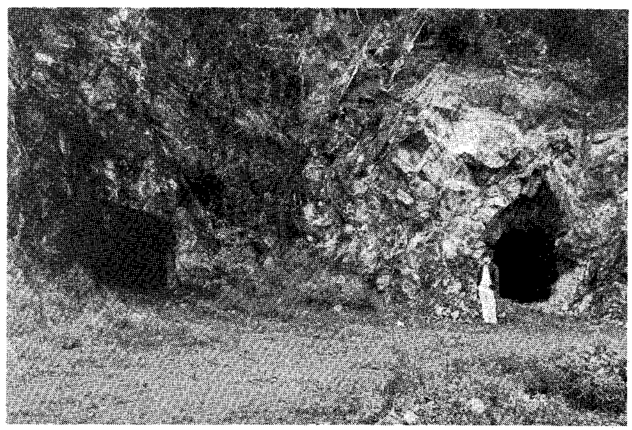

Figure 4. Twin adits in the west fact of Hightop Mountain, overlooking Bacon Hollow. Hightop mine, Green County.

Ida mine—Location: Page County, Big Meadows quadrangle, 1.5 miles (2.4 km) southeast of Cavetown, 0.35 mile (0.56 km) from the west side of State Road 689 approximately 0.55 mile (0.89 km) by road south of its intersection with State Road 668 (N 4,275,690 E 724,120, Zone 17).

Copper mineralization was in the upper part of the Catoctin Formation which consists of a sequence of flows of basalt and amygdaloidal basalt (Allen, 1967, p. 56). The mineralization, consisting of minor amounts of native copper, malachite and azurite, occurred as films and specks with quartz veinlets and in zones of epidotized Catoctin greenstone where

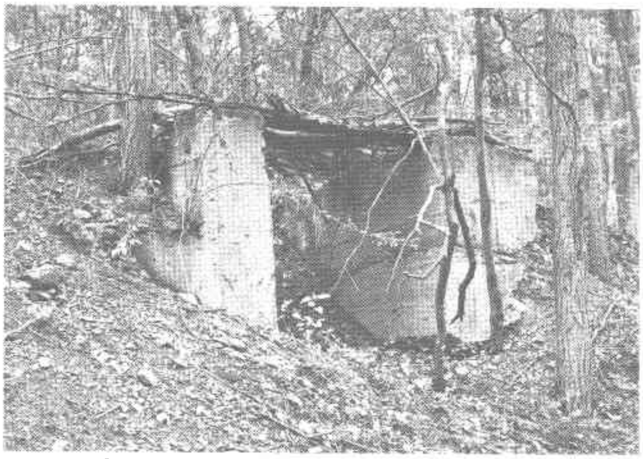

Figure 3. Concrete foundations for crushing equipment, Gooney-Manor mine, Warren County.

quartz veinlets in the greenstone. The area was partly overgrown with vegetation.

F. C. Hartley prospect—Location: Warren County, Bentonville quadrangle, about 3 miles (5 km) south of Bentonville southwest of the summit of Matthews Arm.

Mineralization was azurite and malachite in epidotized greenstone (Weed, 1911, p. 101). An old shaft on the land of F. C. Hartley was worked, probably in the 1870's. There was no evidence of the shaft nor of a dump when the area was visited in early 1978.

Hawksbill Mountain mine—Location: Madison County, Big Meadows quadrangle, about 4 miles (6 km) northeast of Big Meadows Wayside in the vicinity of Hawksbill Mountain and Hawksbill Gap.

Prospecting took place in the 1800's; there was a water-filled shaft 60 feet (18 m) deep at the site in the early 1900's (Weed, 1911, p. 109). In early 1978, there was no evidence of the old shaft. Remnants of many old greenstone rock slides are on the northeast side of Hawksbill Mountain and dark-green, chloritic slate with malachite copper stain occurs along the Appalachian Trail.

Hightop mine—Location: Greene County, Swift Run Gap quadrangle, south of Swift Run Gap on a spur 1.8 miles (2.9 km) south of Hightop (N 4,243,340 E 712,650, Zone 17). Three adits were also cut into the top of Slaters Mountain, located 3.3 miles (5.3 km) south of Hightop (N 4,240,640 E 714,240; N 4,240,290 E 714,380; N 4,240,300 E 714,150—all Zone 17).

The copper ore (native copper, cuprite, bornite, malachite, azurite and chalcopyrite) was with quartz veinlets in partly epidotized Catoctin greenstone; there was also mineralization along fracture surfaces (Weed, 1911, p. 112-113). In the fall of 1905, the Hightop Copper Company developed stripped ledges, open cuts, and an 80-foot (24-m) shaft with a crosscut, a tunnel and several adits at the top of Slaters Mountain south of the mine. The shaft was water filled in February, 1906 (Phalen, 1906, p. 142). In 1944, there was an unsuccessful attempt to reopen the mine.

In 1974, several openings were at both mine areas. Twin adit entrances (Figure 4) each 6 to 9 feet (2 m to 3 m) in diameter were in the face of the mountain overlooking Bacon Hollow to the west at the main mine; the adits join near the face. Remains of a caved shaft 30 feet (9 m) in diameter and 20 feet (6 m) deep, several small pits, and several concrete foundations, one of which may have supported a small stamp mill, were also on the property. There was a large dump containing epidotized basalt, with quartz stringers and jasper. Malachite and azurite stains were the most abundant mineralization seen, but there was some chalcocite, bornite and chalcopyrite. At Slaters Mountain, the three adits had only minor malachite staining. The longest adit is about 60 feet (18 m). These openings are not mentioned in the literature.

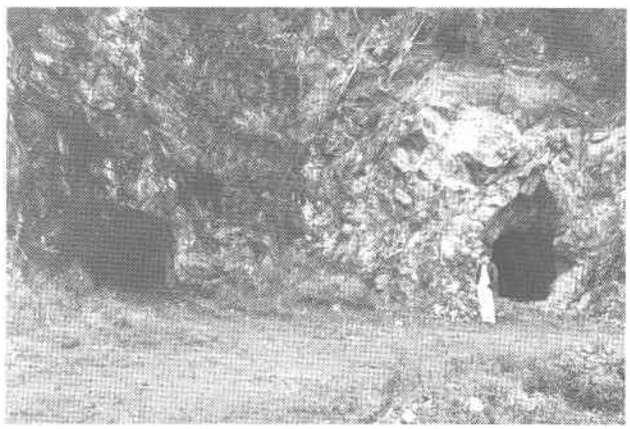

Figure 4. Twin adits in the west fact of Hightop Mountain, overlooking Bacon Hollow. Hightop mine, Green County.

Ida mine—Location: Page County, Big Meadows quadrangle, 1.5 miles (2.4 km) southeast of Cavetown, 0.35 mile (0.56 km) from the west side of State Road 689 approximately 0.55 mile (0.89 km) by road south of its intersection with State Road 668 (N 4,275,690 E 724,120, Zone 17).

Copper mineralization was in the upper part of the Catoctin Formation which consists of a sequence of flows of basalt and amygdaloidal basalt (Allen, 1967, p. 56). The mineralization, consisting of minor amounts of native copper, malachite and azurite, occurred as films and specks with quartz veinlets and in zones of epidotized Catoctin greenstone where joints were reported to have been numerous (Weed, 1911, p. 106). The Virginia Consolidated Copper Company developed the mine from 1902 to 1905 by sinking a 308-foot (94-m) inclined shaft with drifts at three levels; the deepest was at 280 feet (85 m). Production consisted of a few tons of ore from the 30-foot (9-m) level (Weed, 1911, p. 106).

In 1973, there was a caved shaft approximately 25 feet (8 m) deep and 20 feet (6 m) in diameter; the old shaft was water filled. There was also a dump of dark greenstone about 8 feet (2 m) high (Figure 5). Mineralization at the dump was patches, coatings and films of azurite and malachite on fracture surfaces in partially epidotized greenstone and minor mineralization disseminated in quartz veinlets. One sample contained streaks of specularite accompanied by malachite and red to brown jasper in a quartz veinlet. No native copper, cuprite or copper sulfates were at the site, which was partly overgrown.

Figure 5. Tailings pile of dark greenstone, with copper mineralization, Ida mine, Page County.

Irish Creek mine—Location: Rockbridge County, Montebello quadrangle, 1.7 miles (2.7 km) southwest of Montebello, just east of Panther Run, 0.2 mile (0.3 km) from the southeast side of State Road 603 approximately 1.95 miles (3.17 km) by road southwest of its intersection with State Highway 56 (N 4,190,540 E 661,580, Zone 17).

Cassiterite, an ore of tin, occurs as small grains in coarsely crystalline masses of greisen that was formed by replacement of a granodiorite in the Pedlar Formation (Koschmann, Glass and Vhay, 1942, p. 279; Werner, 1966, p. 46); cassiterite was first identified at the site in 1846 (Ferguson, 1918, p. 2). Total production was more than 35,000 pounds of tin (Luttrell, 1966, p. 70). Mining companies which worked the site were: the Virginia Tin Mining and Manufacturing Company, 1884 to 1886; the Lexington Tin Mining Company, 1886; the Boston Tin Mining Company, 1889 to 1892; and the Richards Company, Inc. of Boston, October, 1918 to August, 1919. In 1942, the Bethlehem Steel Company put down about five diamond drill holes (Koschmann, Glass, and Vhay, 1942, p. 285-288). There has been a geochemical reconnaissance survey of the mine area (Fordham, 1978).

Mining remnants in 1972 included the old shaft (No. 1 workings), which was partially caved and about 20 feet (6 m) deep; 2 adits, each containing 12 to 18 inches (30 to 46 cm) of water and the remains of supporting timbers. Parts of the concrete foundations that supported the old mill were just downstream along Panther Run. Exposures of rock were poor except in the wall of the adits. Thick vegetation covered the area, including the dump. Only several small samples of cassiterite were found in the dump, which contained abundant granodiorite.

Manassas Gap mine—Location: Fauquier County, Flint Hill quadrangle and according to Luttrell (1966, p. 89) about 6.5 miles (10.4 km) south of Front Royal on the west slope of Ravensden Mountain, near the stream that forms the headwaters of the Rappahannock River.

Luttrell states that three veins were opened in 1853 by the Manasses Gap Copper Mining Company, also known as the Carter Company according to Weed (1911, p. 102). Luttrell, (1966, p. 89) reports mineralization as native copper and cuprite in epidotized greenstone in masses and seams along joints; disseminated chalcopyrite, bornite and malachite also occur. Weed (1911, p. 102) states that this property was opened at four different localities.

Martin mine—Location: Warren County, Bentonville quadrangle, 2.0 miles (3.2 km) southeast of Bentonville and halfway down the slope of Matthews Arm (N 4,298,810 E 734,810, Zone 17).

The copper mined here was in epidotized Catoctin greenstone as malachite, azurite, and bornite; other minerals included quartz, calcite, chlorite, feldspar and epidote. The greenstone, which is partly stained by iron oxide along fractures, has a strike of N50°E and a dip of 20°SE; one prominent joint has a strike of N32°W and a vertical dip. In the early 1900's a 70-foot (21-m) shaft was sunk on the R. A. Martin tract; the site was intermittently worked in 1903 and 1904 (Phalen, 1906, p. 142).

In early 1978, there was a water-filled shaft 18 feet (5.5 m) by 12 feet (4 m) and a pit 8 feet (2 m) in diameter and 2 feet (1 m) deep. A large dump of dense, dark greenstone present at the site contained malachite stain and some quartz and serpentine.

Mills (Cove Farm) prospect—Location: Warren joints were reported to have been numerous (Weed, 1911, p. 106). The Virginia Consolidated Copper Company developed the mine from 1902 to 1905 by sinking a 308-foot (94-m) inclined shaft with drifts at three levels; the deepest was at 280 feet (85 m). Production consisted of a few tons of ore from the 30-foot (9-m) level (Weed, 1911, p. 106).

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In early 1978, there was a water-filled shaft 18 feet (5.5 m) by 12 feet (4 m) and a pit 8 feet (2 m) in diameter and 2 feet (1 m) deep. A large dump of dense, dark greenstone present at the site contained malachite stain and some quartz and serpentine.

Mills (Cove Farm) prospect—Location: Warren

County, Chester Gap quadrangle, 3.3 miles (5.3 km) north-northeast of Browntown, approximately 1.45 miles (2.34 km) south of the Dickey Ridge Visitor Center, on the east side of the Skyline Drive and the west side of Dickey Hill.

Copper mineralization consisted of native copper, malachite, azurite, chrysocolla and some bornite. In 1905 copper-bearing rock in a ledge 50 feet (15 m) long and 20 feet (6 m) wide about 200 feet (61 m) below the summit of Dickey Ridge was opened by a cut about 7 feet (2 m) wide and 35 feet (11 m) long (Watson, 1907, p. 507).

In early 1978, a 20-foot-wide (6 m) ledge below the summit contained shallow depressions, but no definite openings. The rock on the slope was dense greenstone, epidotized in places. No mineralization was seen.

Mine Run prospect—Location: Page County, Bentonville quadrangle, about 2 miles (3 km) southeast of Compton, on the northwest side of State Road 662 approximately 0.25 mile (0.40 km) southwest of its intersection with State Road 705 (N 4,293,250 E 730,180, Zone 17).

Copper ore was extracted from this site between 1910 and 1920 (Allen, 1967, p. 55). In early 1978 there was no evidence of mining nor of mineralization.

Mosby mine—Location: Fauquier County, Linden quadrangle, 2.5 miles (4.0 km) southwest of Linden, 0.3 mile (0.5 km) from the east side of Summit Drive approximately 1.2 miles (1.9 km) by road east of its intersection with High Knob Drive (N 4,307,100 E 751,500, Zone 17).

Just southeast of the Mosby shelter along the Appalachian Trail is a pit 8 feet (2 m) in diameter and 3 feet (1 m) deep in greenstone schist; the schistosity has a strike of N43°E and a dip of 68°SE. The mine was probably active before 1900. A small dump at the rim of the pit contained schist with some manganese stain; there was no copper mineralization.

Paris prospect—Location: Clarke County, Ashby Gap quadrangle, about 2 miles (3.2 km) northwest of Paris, Fauquier County, approximately 0.6 mile (1.0 km) from the northeast side of combined U.S. Highway 17-50.

This prospect consisted of small seams of native copper associated with malachite in epidotized Catoctin greenstone (Luttrell, 1966, p. 103). Numerous pieces and piles of broken greenstone were at the old site, which is on a hilltop. There was no evidence of mining or of mineralization in the greenstone in early 1978.

Phoenix mine—Location: Fauquier County, in the vicinity of Markham and Linden near the present Fauquier-Warren county line (Austin, 1955, p. E4).

In early 1978, there was no evidence of mine or prospect.

Richards mine—Location: Page County in the Blue Ridge (Luttrell, 1966, p. 111).

In the early 1880's, a mining camp and shops were being put in operation and ore was being readied for shipment to Baltimore for smelting (*The Virginias*, 1882, p. 44). No additional information exists concerning this mine.

Rudacill prospect—Location: Warren County, Chester Gap quadrangle, 3 miles (5 km) north-northeast of Browntown, approximately 1.85 miles (3.08 km) south of the Dickey Ridge Visitor Center, on the east side of the Skyline Drive (N 4,303,480 E 742,550, Zone 17).

Mineralization included native copper, malachite, cuprite, and bornite in epidotized Catoctin greenstone. Rocks include greenstone, some of which is epidotized, and varying amounts of jasper. The Virginia and Pittsburg Copper Company made openings at the site in 1905 (Weed, 1911, p. 100); these consisted of a 75-foot (23-m) cut, a 20-50 foot (6-m to 15-m) shaft and another cut (Watson, 1907, p. 507). In early 1978, there were numerous pits and shallow depressions along the Dickey Hill Trail, on the south side of Dickey Hill. The pits, which did not extend to bedrock, average about 6 feet (2 m) in diameter.

Sealoch (Sealock, Marshall, Ravenswood) mine—Location: Warren County, Linden quadrangle, 2.55 miles (4.11 km) southwest of Linden, 0.2 mile (0.3 km) north of Summit Drive approximately 1.1 miles (1.8 km) by road east of its intersection with High Knob Drive (N 4,307,450 E 750,930, Zone 17).

Copper mineralization included native copper, cuprite, azurite, malachite, chalcopyrite and bornite in quartz lenses and stringers along jointing and schistosity surfaces in epidotized Catoctin greenstone (Luttrell, 1966, p. 118). An early shaft, the Phillips shaft, was 80 feet (24 m) deep (Watson, 1907, p. 506-507). Thirty-five tons of ore averaging more than 10 percent copper were shipped in 1861. In 1904 a 200-foot (61-m) tunnel was driven into the hillside to connect with the Solomon shaft (Weed, 1911, p. 99). The Sealock shaft, which was 1.5 miles (2.4 km) west of the tunnel was 42 feet (13 m) deep (Luttrell, 1966, p. 117).

In early 1978, the only remains of the workings were a pit 7 feet (2 m) in diameter with a large spread-out, rim dump of greenstone; some of the greenstone was epidotized and contained red jasper. The entire areas has been logged over in the last 15 to 20 years and pits and depressions may have been filled with debris. No copper mineralization was seen.

Sims (Bootens Gap, Tunnel Tract, Piedmont Copper Co.) mine—Location: Greene County, Fletcher quadrangle, on southeast flank of the Blue Ridge Mountains, 1.6 miles (2.6 km) north-northwest of Kinderhook and 1.1 miles (1.8 km) west-northwest of Camp Shiloh and about 0.5 mile (0.8 km) west-southwest of the old Fletcher store at the intersection of State Road 667 with State Road 675 (N 4,252,030 E 723,420, Zone 17).

Copper mineralization included native copper, cuprite, chalcopyrite and pyrite as disseminations and masses associated with epidotized rock and quartz lenses along shear zones in Catoctin greenstone. A number of shallow openings and a 30-foot (9-m) shaft were sunk on the Sims property by the Piedmont Copper Company. A 25-foot-long crosscut was driven north at a depth of 30 feet (9 m) (Weed, 1911, p. 113-114).

In early 1978, there was an old trench-cut (possibly a caved adit), 75 feet (23 m) long, 20 feet (6 m) wide and 7 feet (2 m) deep with trend N35°W into the mountainside. A large dump contained dark, dense greenstone with malachite and calcite and quartz with malachite stain. Just to the northeast was a caved shaft (?), 20 feet (6 m) in diameter that was partially filled by debris; its depth was 5 feet (2 m). A small dump of dark, dense greenstone surrounded this opening. Downslope, there was a trench-cut, 40 feet (12 m) by 12 feet (4 m) and 3 feet (1 m) deep.

Stony Man mine—Location: Madison County, Old Rag Mountain quadrangle, 0.95 mile (1.53 km) northwest of Thorofare Mountain Overlook and 1.1 miles (1.8 km) southwest of Stony Man Overlook, in the Shenandoah National Park at stop number 26 on the Stony Man Nature Trail (N 4,275,140 E 728,810, Zone 17).

Copper mineralization (native copper, cuprite, azurite and malachite) occurred as disseminated particles and irregular segregations in joints and fractures of the Catoctin greenstone. These openings were filled with white quartz and adjacent greenstone was epidotized (Weed, 1911, p. 109). Prospecting at this mine began in the 1850's when a 60-foot (18-m) cut, 30 feet (9 m) deep was opened. Some mining also occurred in the early 1900's when the ore was carted about 1.0 mile (1.6 km) to smelting furnaces.

In 1973, there were several pits, 5 feet (1.5 m) by 10 feet (3 m) and 3 feet (1 m) deep. Greenstone in place in the area is dense, fine grained and dark green. No primary mineralization was seen; malachite and minor amounts of azurite were on fracture and joint surfaces.

Southern Section Mines and Prospects

Metallic mineralization in this area is chiefly the Ducktown type; these mineralizations commonly have linear trends, popularly termed "leads." The Gossan Lead in Carroll and Grayson counties is the largest and best known of these. The mines of the Gossan Lead sulfide district are not included in this report because they are the subject of several other studies (Gair, 1978; Kline and Ballard, 1949; Poole, 1973; Stose and Stose, 1957).

Arsenic, iron, and copper are important metals that were produced from the Southern section of the Blue Ridge province. Arsenic occurs as primary deposits of arsenopyrite. Iron and copper are in the limonite gossan caps of many Ducktown-type occurrences. Some of these deposits were mined for iron before their copper content was exploited. Brief descriptions of 22 abandoned mines and prospects, arranged alphabetically, follow.

Bear Bed (Laurel) prospect—Location: Floyd County, Woolwine quadrangle, about 2.4 miles (3.8 km) southwest of Tuggle Gap on the ridge on the west side of State Road 720.

There were large amounts of gossan at the site and magnetite was concentrated in the northern wall of the vein (Luttrell, 1966, p. 15). This mine, which contained large amounts of limonite, is northeast of the Sutherland mine (Fontaine, 1883, p. 192). The property was owned by the Meigs County, Tennessee, and Virginia Mining Company in the 1800's (Fontaine, 1883, p. 192). Dietrich (1959, p. 131) states that the area was covered by vegetation.

In early 1978, there was an overgrowth of small pines and mountain laurel at the probable area of the old prospect. There was several piles of weathered biotite-mica schist on the hillside; no mineralization was in any of the rock material.

Belcher (Weddle, Old Copper mine) prospect—Location: Floyd County, Willis quadrangle, 6.3 miles (10.1 km) southeast of Willis on the south-southwest side of State Road 726 approximately 0.45 mile (0.73 km) by road west-northwest of its intersection with State roads 605 and 777 (N 4,072,460 E 554,010, Zone 17).

This prospect was opened in 1859 by a 68-foot (21-m) shaft into a gossan derived from primary mineralization in quartz-biotite, hornblende and chlorite-garnet schist. The prospect was owned by the Meigs County, Tennessee, and Virginia Mining Company during the 1880's; it was reopened by C. H. Thompson in the late 1930's and early 1940's. In early 1978, a house was on the site of the old shaft. Fragments of chlorite on nearby hills contained no mineralization.

Bergen Kemp prospect—Location: Carroll County, Dugspur quadrangle, 5.6 miles (9.0 km) southeast of Dugspur on the east side of State Road 626 approximately 0.4 mile (0.6 km) by road west-northwest of its intersection with State Road 628 (N 4,070,290 E 542,590, Zone 17).

A quartz vein, about 10-15 feet (3-5 m) wide, which has a strike of N30°E to N40°E, contains manganese oxide with minor amounts of cobalt, copper and nickel oxides. The quartz vein is in gneiss which is probably the Little River gneiss.

Black Run prospect—Location: Floyd County, Floyd quadrangle, 4.5 miles (7.2 km) northwest of Floyd, in the stream bed of Black Run, which empties into Little River, on the northeast side of State Highway 8.

This prospect consisted of a 3- to 4-foot-wide (0.9 to 1.2 m) mineralized quartz vein in mica schist (Sweet, 1971, p. 32); minerals included pyrrhotite, galena and molybdenite. This prospect could not be found in the field.

Brinton (United States) mine—Location: Floyd County, Pilot quadrangle, 0.9 mile (1.4 km) northeast of Terrys Fork and 0.15 mile (0.24 km) on the southwest side of State Road 790 approximately 0.3 mile (0.5 km) by road west-northwest of its intersection with State Road 659 (N 4,101,230 E 566,170, Zone 17).

Mineralization was arsenopyrite, commonly with pyrite, minor cupriferous pyrite, native copper and traces of gold and silver; solutions bearing these ores intruded a quartz-sericite schist (Hess, 1911, p. 209-120). There was interest in this site as early as 1882. The arsenic deposits were found in 1901 by C. R. Brinton (Hess, 1911, p. 205). In 1902 the U.S. Arsenic Mines Company developed the mine with a 215-foot (66-m) shaft; mining continued intermittently until 1917. White arsenic was produced from crude arsenous oxide by volatilization in a reverberatory; the product was 99.75 percent As_2O_3. Total production was 75-100 tons (Dietrich, 1959, p. 123). The mill was removed in 1919-1920.

In 1973, broken portions of foundations (Figure 6) of six buildings, brick and stone walls, an area of waste piles (Figure 7) and several trenches and pits above the mine area remained. Several water-filled pits, a concrete-lined shaft, three large conical tailings piles and a large dump area was near the base of the hillside northwest of these structures. The arsenopyrite is fine- to medium-grained and is disseminated in white to light-green quartz-sericite schist. Bare ground in the area is white to light-green or yellowish-green due to the weathering of the rocks.

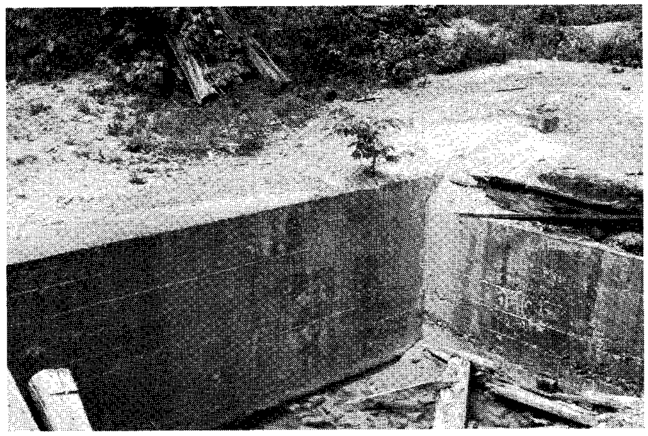

Figure 6. Broken portions of foundations, Brinton mine, Floyd County.

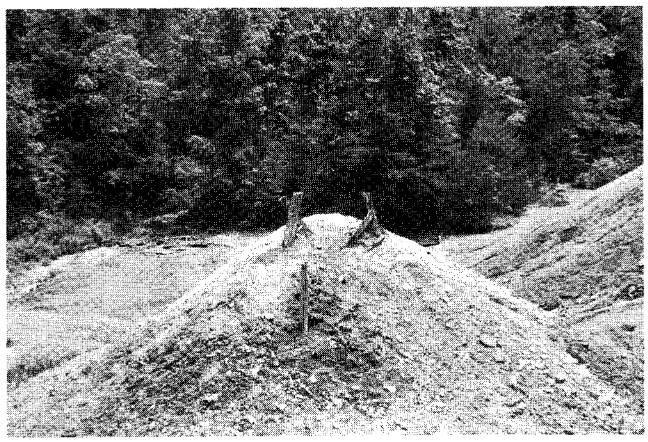

Figure 7. Tailings and waste piles, Brinton mine, Floyd County.

Brush Creek (Walters place) prospect—Location: Floyd County, Pilot quadrangle, east of Pilot, along Brush Creek and its tributaries, northwest of Laurel Ridge and southwest of Pilot Mountain (N 4,100,810 E 561,200, Zone 17).

Placer production of gold began around 1879 and continued intermittently in the 1920's (Sweet, 1971, p. 32). In the mid-1890's a stamp mill was erected. More than $30,000 worth of gold was recovered. The site was prospected in the 1950's. In 1972 there was evidence of the extensive old placer workings along the creek.

Douglas Land Company property—Location: Grayson County, probably on the Grayson quadrangle, south of Big Horse Creek and north of the Virginia-North Caroline state line.

Exploration of copper mineralization (bornite, the Meigs County, Tennessee, and Virginia Mining Company during the 1880's; it was reopened by C. H. Thompson in the late 1930's and early 1940's. In early 1978, a house was on the site of the old shaft. Fragments of chlorite on nearby hills contained no mineralization.

Bergen Kemp prospect—Location: Carroll County, Dugspur quadrangle, 5.6 miles (9.0 km) southeast of Dugspur on the east side of State Road 626 approximately 0.4 mile (0.6 km) by road west-northwest of its intersection with State Road 628 (N 4,070,290 E 542,590, Zone 17).

A quartz vein, about 10-15 feet (3-5 m) wide, which has a strike of N30°E to N40°E, contains manganese oxide with minor amounts of cobalt, copper and nickel oxides. The quartz vein is in gneiss which is probably the Little River gneiss.

Black Run prospect—Location: Floyd County, Floyd quadrangle, 4.5 miles (7.2 km) northwest of Floyd, in the stream bed of Black Run, which empties into Little River, on the northeast side of State Highway 8.

This prospect consisted of a 3- to 4-foot-wide (0.9 to 1.2 m) mineralized quartz vein in mica schist (Sweet, 1971, p. 32); minerals included pyrrhotite, galena and molybdenite. This prospect could not be found in the field.

Brinton (United States) mine—Location: Floyd County, Pilot quadrangle, 0.9 mile (1.4 km) northeast of Terrys Fork and 0.15 mile (0.24 km) on the southwest side of State Road 790 approximately 0.3 mile (0.5 km) by road west-northwest of its intersection with State Road 659 (N 4,101,230 E 566,170, Zone 17).

Mineralization was arsenopyrite, commonly with pyrite, minor cupriferous pyrite, native copper and traces of gold and silver; solutions bearing these ores intruded a quartz-sericite schist (Hess, 1911, p. 209-120). There was interest in this site as early as 1882. The arsenic deposits were found in 1901 by C. R. Brinton (Hess, 1911, p. 205). In 1902 the U.S. Arsenic Mines Company developed the mine with a 215-foot (66-m) shaft; mining continued intermittently until 1917. White arsenic was produced from crude arsenous oxide by volatilization in a reverberatory; the product was 99.75 percent As_2O_3. Total production was 75-100 tons (Dietrich, 1959, p. 123). The mill was removed in 1919-1920.

In 1973, broken portions of foundations (Figure 6) of six buildings, brick and stone walls, an area of waste piles (Figure 7) and several trenches and pits above the mine area remained. Several water-filled pits, a concrete-lined shaft, three large conical tailings piles and a large dump area was near the base of the hillside northwest of these structures. The arsenopyrite is fine- to medium-grained and is disseminated in white to light-green quartz-sericite schist. Bare ground in the area is white to light-green or yellowish-green due to the weathering of the rocks.

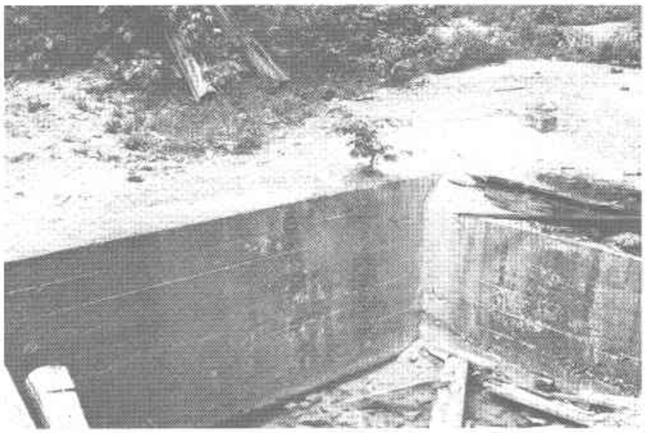

Figure 6. Broken portions of foundations, Brinton mine, Floyd County.

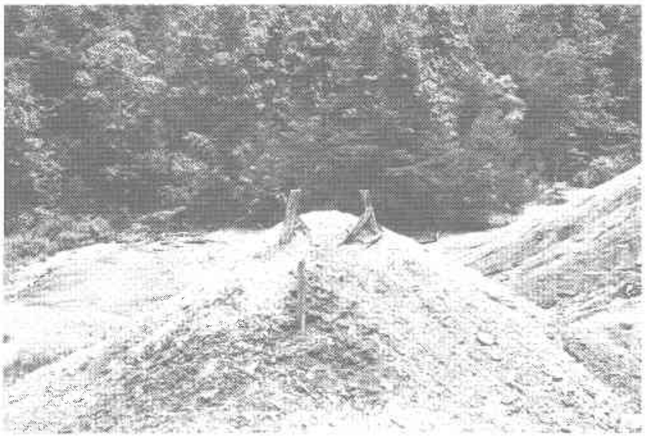

Figure 7. Tailings and waste piles, Brinton mine, Floyd County.

Brush Creek (Walters place) prospect—Location: Floyd County, Pilot quadrangle, east of Pilot, along Brush Creek and its tributaries, northwest of Laurel Ridge and southwest of Pilot Mountain (N 4,100,810 E 561,200, Zone 17).

Placer production of gold began around 1879 and continued intermittently in the 1920's (Sweet, 1971, p. 32). In the mid-1890's a stamp mill was erected. More than $30,000 worth of gold was recovered. The site was prospected in the 1950's. In 1972 there was evidence of the extensive old placer workings along the creek.

Douglas Land Company property—Location: Grayson County, probably on the Grayson quadrangle, south of Big Horse Creek and north of the Virginia-North Caroline state line.

Exploration of copper mineralization (bornite, chalcopyrite and malachite) in green schist near its contact with a porphyry was undertaken in the early 1900's (Watson, 1907, p. 517). Several lead prospects were active in the past and some gold was panned from Big Horse Creek, south of Whitetop (Charles Miller, 1978, personal communication).

Greer Place—Location: Grayson County, Trout Dale quadrangle, about 1 mile (1.6 km) south-southeast of Trout Dale in the area of Fox Creek.

Chalcopyrite was in small grains and large granular masses in a quartz-feldspar porphyry (Watson 1907, p. 517). No other data are available.

Hilton (Hylton) prospect—Location: Floyd County, 3.2 miles (5.1 km) east of Willis, on the northeast side of State Road 771 approximately 1.0 mile (1.6 km) by road south-southwest of its intersection with U.S. Highway 221 (N 4,079,050 E 551,360, Zone 17).

Three shafts and several trenches were in pyrite and supergene copper mineralization (Luttrell, 1966, p. 65). In early 1978, a barn was on the supposed site of a shaft and there was barren vein quartz on the hill near the barn.

Hogan prospect—Location: Floyd County, Floyd quadrangle, about 1.7 miles (2.7 km) south of Floyd in the hillside south of Dodd Creek and 0.2 mile (0.3 km) southeast of the crossing of Dodd Creek and State Highway 8 (N 4,082,230 E 560,580, Zone 17).

Ore was in a 2-foot-thick body of magnetic iron on the land of A. Hogan. A plan to mine the material prior to 1880 was abandoned because the ore was believed to pinch out at a depth of 15 feet (5 m) (Fontaine, 1883, p. 191). In early 1978, a small trench-cut was in the hillside on the south side of Dodd Creek; no mineralization was in fragments of schist on the hill.

Laurel Creek prospect—Location: Floyd County, Pilot quadrangle, about 3 miles (5 km) southeast of Pilot, along Laurel Creek and its tributaries on the southeast side of Laurel Ridge (N 4,097,270 E 560,250, Zone 17).

Placer concentrations of gold from pyritic gold-bearing quartz veins were worked in this area in 1879. In 1972, large trench-cuts and piles of white quartz were remnants of the former extensive placer workings.

Lester McAlexander prospect—Location: Floyd County, Alum Ridge quadrangle, 4.5 miles (7.2 km) northeast of Alum Ridge, near the west side of State Road 617 approximately 0.75 mile (1.21 km) by road north of its intersection with State Highway 8.

Before 1882 gold-bearing stream alluvium was found in a tributary running north into Little River; gold grains ranged from 5 to 80 milligrams in weight (Sweet, 1971, p. 32). In 1975 there were scattered pieces of white quartz on the hillside and in the stream that eventually runs north into Little River (Sweet, 1980).

Lick Fork (MacKusick, Flat Run, John Light's) mine—Location: Floyd County, Check quadrangle, 3.85 miles (6.20 km) west of Copper Hill, on the bank of Lick Fork, 0.1 mile (0.2 km) from the east side of State Road 653 approximately 1.45 miles (2.34 km) by road northeast of its intersection with State Road 660 (N 4,104,060 E 570,730, Zone 17).

Pyrrhotite was reported at the site before the Civil War (Ross, 1935, p. 103). Pyroxene-rich gabbroic dike material was the primary host for pyrrhotite, chalcopyrite, pentlandite, sphalerite and veinlets of violarite mineralization; there were also traces of cobalt (Luttrell, 1966, p. 81). The dike is a light-gray, medium-grained gneiss composed of feldspar, quartz and biotite. An assay showed 1.75 percent nickel, a fraction of 1 percent copper and 0.4 percent cobalt. (Watson, 1907, p. 581). From 1904 to 1907, after the sulfide was found to be nickel-bearing, the Virginia Nickel Corporation, formerly the Fidelity Exploration Company, developed the mine and made openings in four places.

The mine site was visited in 1972, 1973 and 1975 and remains included five pits, a hillside excavation, some concrete foundations, and a drain pipe. The gabbro dike, covered in places with iron-oxide stain, was exposed in the excavation. There is a hillside dump at the site (Figure 8). The only sulfide mineral identified from the dump was pyrrhotite; samples of this mineral did not contain nickel. Nickel is removed from pyrrhotite by natural oxidation (Lindgren, 1932, p. 871) and this process may have removed the nickel from the samples examined.

Powhatan Williams prospect—Location: Floyd County, Floyd quadrangle, 2.6 miles (4.2 km) east-northeast of Floyd on the south side of State Road 860 approximately 0.9 mile (1.4 km) by road southeast of its intersection with U.S. Highway 221 (N 4,086,170 E 564,580, Zone 17).

The Powhatan vein was opened in 1880 with a 30-foot-deep (9 m) cut. A quartz vein in mica schist in the hillside just southwest of the old mill on Pine Creek contained pyrite and minor galena and malachite (Fontaine, 1883, p. 191). When seen in 1972, the old cut was filled in. There were fragments of quartz containing pyrite and limonite and some malachite stain. In early 1978, grass had grown over the site and there was no evidence of the old prospect.

Rocky Knob prospect—Location: Floyd County, Woolwine quadrangle, about 1.9 miles (3.0 km) southwest of Tuggle Gap, probably on the west side

Figure 8. Hillside dump above stream, Lick Fork mine, Floyd County.

of the summit of Rocky Knob and east of the Blue Ridge Parkway.

Limonite gossan was in this area in the 1880's (Fontaine, 1883, p. 192). In early 1978, the slope on the west side of Rocky Knob was mantled by talus consisting of amphibolite and weathered biotite-mica schist. The schist contained quartz and pyrrhotite(?). There were a few soil dumps.

Sugar Run prospect—Location: Floyd County, Check quadrangle, 3.5 miles (5.6 km) west-northwest of Copper Hill, on the north side of Sugar Run, about 350 feet (107 m) along a dirt road on the west side of State Road 865 approximately 0.95 mile (1.53 km) by road west of its intersection with State Road 703 (N 4,106,090 E 571,650, Zone 17).

The sulfide mineralization was in a sheared phase of banded, medium-dark gneiss that is probably the Little River gneiss of Dietrich (1959, p. 145). Several openings made by the Virginia Nickel Corporation during the period 1902-1907 were seen in 1972, including a sloping trench 15-20 feet (5-6 m) long, which apparently was a shaft, and a horizontal adit heading N15°W. The adit, in solid rock, was about 50 feet (15 m) long, 8 feet (2 m) wide and 6 feet (2 m) high; it was two feet above the water level of Sugar Run. There was no dump material and no sulfide mineralization.

Sutherland (Fisher, Hylton, Nowlin) mine—Location: Floyd County, Willis quadrangle, about 6.5 miles (10.4 km) southeast of Willis, on the north side of State Road 720.

Small massive-sulfide lenses of pyrite with sphalerite, chalcopyrite, pyrrhotite and magnetite in a quartz-biotite-garnet schist were prospected in the middle 1880's by Meigs County, Tennessee, and Virginia Mining Company. One hole was drilled and a magnetometer survey was made by the American Metals Company in the 1930's; in 1940, numerous test pits were put down by the Nassog Company. A 50-foot (15-m) adit was opened and 14 holes were drilled in 1943 by the U.S. Bureau of Mines (Grosh, 1948a, p. 2). In early 1978, numerous fragments of quartz and biotite schist as well as pieces of limonite gossan were along the old farm road leading north from State Road 605. The area of the old shaft and adit was virtually inaccessible as it was completely overgrown with rhododendrons.

Taz Weeks prospect—Location: Floyd County, Willis quadrangle, about 2.3 miles (3.7 km) south-southwest of Willis, on the northwest side of State Road 785 and the copper prospect is in a quartz-biotite schist.

Three pits and several trenches were in this area in 1943. It was evident in early 1978 that the area had been logged in the last several years. Several trench-cuts and a few caved pits were at the site. An exposure of quartz-biotite schist and some fragments of brown gossan were along State Road 785.

Toncrae (Toncray, Toncrae-Howard) mine—Location: Floyd County, Willis quadrangle, about 6.2 miles (9.9 km) east-southeast of Willis, about 0.3 mile (0.5 km) from the south side of State Road 605 approximately 1.6 miles (2.6 km) by road south of its intersection with State Road 726 (N 4,075,990 E 555,650, Zone 17).

Mineralization at the mine consisted of a tabular body of massive and disseminated sulfides (pyrrhotite, pyrite, chalcopyrite and sphalerite) and magnetite, with a maximum thickness of about 50 feet (15 m) in a muscovite-biotite-quartz-garnet schist (Espenshade, 1963, p. 2). The body was capped by a limonitic gossan and there was a zone of supergene copper (black aggregate of pyrite, chalcocite and covellite) between the gossan and the sulfides. Iron ore from the gossan was mined from

Figure 8. Hillside dump above stream, Lick Fork mine, Floyd County.

of the summit of Rocky Knob and east of the Blue Ridge Parkway.

Limonite gossan was in this area in the 1880's (Fontaine, 1883, p. 192). In early 1978, the slope on the west side of Rocky Knob was mantled by talus consisting of amphibolite and weathered biotite-mica schist. The schist contained quartz and pyrrhotite(?). There were a few soil dumps.

Sugar Run prospect—Location: Floyd County, Check quadrangle, 3.5 miles (5.6 km) west-northwest of Copper Hill, on the north side of Sugar Run, about 350 feet (107 m) along a dirt road on the west side of State Road 865 approximately 0.95 mile (1.53 km) by road west of its intersection with State Road 703 (N 4,106,090 E 571,650, Zone 17).

The sulfide mineralization was in a sheared phase of banded, medium-dark gneiss that is probably the Little River gneiss of Dietrich (1959, p. 145). Several openings made by the Virginia Nickel Corporation during the period 1902-1907 were seen in 1972, including a sloping trench 15-20 feet (5-6 m) long, which apparently was a shaft, and a horizontal adit heading N15°W. The adit, in solid rock, was about 50 feet (15 m) long, 8 feet (2 m) wide and 6 feet (2 m) high; it was two feet above the water level of Sugar Run. There was no dump material and no sulfide mineralization.

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Small massive-sulfide lenses of pyrite with sphalerite, chalcopyrite, pyrrhotite and magnetite in a quartz-biotite-garnet schist were prospected in the middle 1880's by Meigs County, Tennessee, and Virginia Mining Company. One hole was drilled and a magnetometer survey was made by the American Metals Company in the 1930's; in 1940, numerous test pits were put down by the Nassog Company. A 50-foot (15-m) adit was opened and 14 holes were drilled in 1943 by the U.S. Bureau of Mines (Grosh, 1948a, p. 2). In early 1978, numerous fragments of quartz and biotite schist as well as pieces of limonite gossan were along the old farm road leading north from State Road 605. The area of the old shaft and adit was virtually inaccessible as it was completely overgrown with rhododendrons.

Taz Weeks prospect—Location: Floyd County, Willis quadrangle, about 2.3 miles (3.7 km) south-southwest of Willis, on the northwest side of State Road 785 and the copper prospect is in a quartz-biotite schist.

Three pits and several trenches were in this area in 1943. It was evident in early 1978 that the area had been logged in the last several years. Several trench-cuts and a few caved pits were at the site. An exposure of quartz-biotite schist and some fragments of brown gossan were along State Road 785.

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Mineralization at the mine consisted of a tabular body of massive and disseminated sulfides (pyrrhotite, pyrite, chalcopyrite and sphalerite) and magnetite, with a maximum thickness of about 50 feet (15 m) in a muscovite-biotite-quartz-garnet schist (Espenshade, 1963, p. 2). The body was capped by a limonitic gossan and there was a zone of supergene copper (black aggregate of pyrite, chalcocite and covellite) between the gossan and the sulfides. Iron ore from the gossan was mined from the early 1880's until about 1950; material was smelted at the old Shelor furnace on the west fork of Little River. In 1854-1855, two tunnels were dug into the supergene ore; 32 tons of ore were shipped (Espenshade, 1963, p. 37). The New York and Virginia Copper Company developed the primary ores in 1905 and about 2,500 tons of pyrrhotite ore was produced before the firm shut down in 1908 (Grosh, 1948, p. 2). Intermittent mining took place in 1938, 1944-1945 and 1947. Copper production in 1938 was 43,279 pounds (smelter output), in 1944, 520,000 pounds (smelter output); in 1945 less than 140,000 pounds (mine returns); and in 1947, 10,000 pounds (mine returns) (Sweet, 1976a, p. 27). In 1954 and 1955, Appalachian Sulphides, Inc. drilled 11 diamond-drill holes (the combined footage was more than 5000 feet, 1524 m) and carried out electromagnetic surveys and soil geochemical prospecting (Dietrich, 1959, p. 129). This was probably the most productive copper mine in the Blue Ridge province.

In 1975, the old gossan mine near the top of the hill had trenches, pits and caved shafts, two of which were about 20 feet (6 m) deep. Below the gossan mine were the remains of the old sulfide mine, also present were an old, collapsed, wooden building, a rail retaining-wall, a concrete wall (Figure 9), several concrete foundations, several open shafts, and cuts on the hillside above the waste and slag piles. The valley used as a dump area was without vegetation because of the acidic soil. There were pieces of schist and some pieces of weathered sulfides; sulfides included pyrrhotite, chalcopyrite and galena. There was also some malachite.

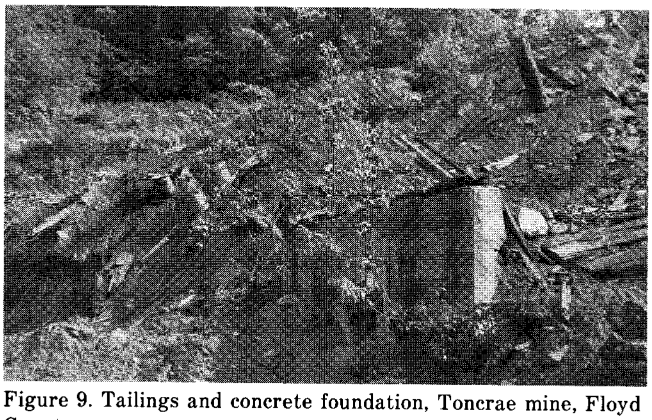

Figure 9. Tailings and concrete foundation, Toncrae mine, Floyd County.

Vest (C. W. Vest, Hemlock) mine—Location: Floyd County, Check quadrangle, 2.5 miles (4.0 km) northwest of Simpson, on the west side of State Road 657 approximately 260 feet (79 m) by road north of its intersection with State Road 659 (N 4,102,290 E 568,140, Zone 17).

The deposit was massive and disseminated sulfides (pyrite and nickel with gold, arsenic, and traces of cobalt) lying parallel to foliation of the quartz-mica schist; this foliation has a strike of N75°E and a dip of 50° to the southeast (Grosh, 1949, p. 2, 3). In the mid-1920's, a 15-foot (5-m) vertical shaft and a 75-foot (23-m) adit were opened. There was nickel in this shaft and in 1936 four (or five?) churn-drill holes were put down in the area (Dietrich, 1959, p. 141). The old shaft was unwatered in early 1943 and in January, 1944, two diamond-drill holes, totaling 320 feet (98 m), were sunk. An analysis of ore taken from the shaft showed 3.2 percent nickel, 0.28 percent cobalt and 0.24 percent copper (Grosh, 1949, p. 3).

In 1972, there were several small pits and trenches in the hillside east and west of the road. Some water was seeping from one of the old drill holes just off the west side of State Road 657. There were small pieces of weathered schist, but no mineralization in the area.

Walt Williams prospect—Location: Grayson County, Trout Dale quadrangle, about 1.1 miles (1.8 km) northeast of Trout Dale, 0.4 mile (0.6 km) from the north side of State Road 603 approximately 0.3 mile (0.5 km) by road east of its intersection with State Road 827 (N 4,062,590 E 462,110, Zone 17).

Gold was mined from this property in the late 1800's. In early 1978 there was a 12-foot (4-m) by 8-foot (2-m), water-filled shaft in the hillside above the level of the stream. The shaft is in a quartz-pebble conglomerate in the Unicoi Formation that has a north-south strike and a dip of 35° to the west. Black iron-oxide stain is on the silica cement between particles; there was no other visible metallic mineralization. There are also some euhedral pieces of feldspar in the conglomerate. Several other exposures of the conglomerate and sandstone are in the area.

Weddle prospect—Location: Floyd County, Woolwine quadrangle, about 2.85 miles (4.59 km) west of Tuggle Gap, 0.25 mile (0.40 km) from the northeast side of State Road 605 approximately 0.15 mile (0.24 km) by road southeast of its intersection with State Road 726 (N 4,078,500 E 556,120, Zone 17).

Pits and shallow shafts were probably in lenses and bands of limonite in quartz-biotite schist on slopes on both sides of a small stream (Luttrell, 1966, p. 141). In early 1978, there were several depressions 15-20 feet (5-6 m) in diameter on the slope on the north side of the stream. These had been filled with white quartz and schist boulders. On the south side of the stream there were numerous piles of boulder-size pieces of white quartz stained red-black by iron oxide.

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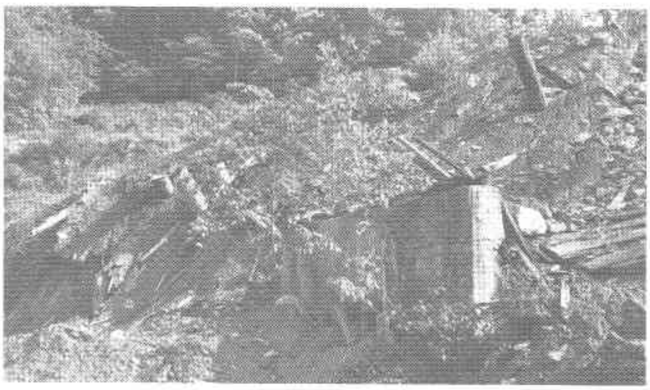

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The deposit was massive and disseminated sulfides (pyrite and nickel with gold, arsenic, and traces of cobalt) lying parallel to foliation of the quartz-mica schist; this foliation has a strike of N75°E and a dip of 50° to the southeast (Grosh, 1949, p. 2, 3). In the mid-1920's, a 15-foot (5-m) vertical shaft and a 75-foot (23-m) adit were opened. There was nickel in this shaft and in 1936 four (or five?) churn-drill holes were put down in the area (Dietrich, 1959, p. 141). The old shaft was unwatered in early 1943 and in January, 1944, two diamond-drill holes, totaling 320 feet (98 m), were sunk. An analysis of ore taken from the shaft showed 3.2 percent nickel, 0.28 percent cobalt and 0.24 percent copper (Grosh, 1949, p. 3).

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Gold was mined from this property in the late 1800's. In early 1978 there was a 12-foot (4-m) by 8-foot (2-m), water-filled shaft in the hillside above the level of the stream. The shaft is in a quartz-pebble conglomerate in the Unicoi Formation that has a north-south strike and a dip of 35° to the west. Black iron-oxide stain is on the silica cement between particles; there was no other visible metallic mineralization. There are also some euhedral pieces of feldspar in the conglomerate. Several other exposures of the conglomerate and sandstone are in the area.

Weddle prospect—Location: Floyd County, Woolwine quadrangle, about 2.85 miles (4.59 km) west of Tuggle Gap, 0.25 mile (0.40 km) from the northeast side of State Road 605 approximately 0.15 mile (0.24 km) by road southeast of its intersection with State Road 726 (N 4,078,500 E 556,120, Zone 17).

Pits and shallow shafts were probably in lenses and bands of limonite in quartz-biotite schist on slopes on both sides of a small stream (Luttrell, 1966, p. 141). In early 1978, there were several depressions 15-20 feet (5-6 m) in diameter on the slope on the north side of the stream. These had been filled with white quartz and schist boulders. On the south side of the stream there were numerous piles of boulder-size pieces of white quartz stained red-black by iron oxide.

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TETRAVALENT MANGANESE OXIDE MINERALS FROM THE RED BRUSH MINE, CRAIG COUNTY, VIRGINIA[1]

By
Christopher R. Halladay[2]

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ABSTRACT

Ore samples collected from the inactive Red Brush manganese mine were examined using X-ray diffraction, electron microprobe and atomic absorption analyses. Five tetravalent manganese oxide minerals, namely cryptomelane, lithiophorite, chalcophanite, cryptomelane-hollandite and coronadite, were identified. The average concentration

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[2] Marline Uranium Corp., Danville, Virginia 24541

of zinc oxide in the ore is 3.05 percent. Zinc not only occurs in chalcophanite, but also substitutes for manganese in significant amounts in lithiophorite (3.35 percent ZnO), cryptomelane (2.76 percent ZnO) and coronadite (1.37 percent ZnO). Nickel and cobalt are concentrated mainly in lithiophorite; the ore contains an average of only 0.44 percent NiO and 0.22 percent CoO.

INTRODUCTION

The abandoned Red Brush manganese mine is located about 5 miles (8 km) northwest of Newcastle in Craig County, Virginia (Figure 1). The deposit lies at the break in slope of the southeastern face of Potts Mountain within the Jefferson National Forest. The site is shown as a "gravel pit" on the Potts Creek 7.5-minute quadrangle topographic map at 37°32′45″ N. latitude and 80°10′51″ W. longitude.

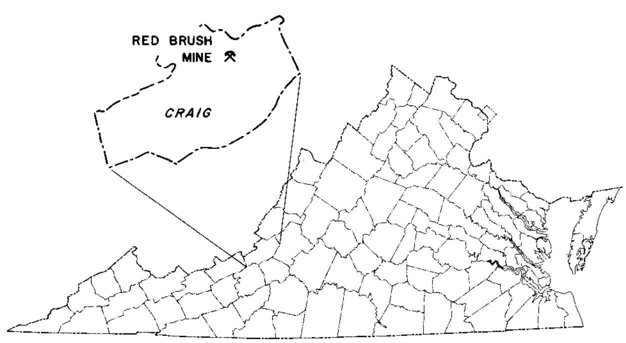

Figure 1. Index map.

Stose and Miser (1922), in their report on manganese deposits of western Virginia, noted that as of 1918, 20 tons of hand-picked ore had been shipped from the Red Brush prospect. Production apparently ceased shortly thereafter, and was revived briefly during World War II. Evidence of former workings consists of a 40-foot-high (12 m) cut in the face of the slope and a 30-foot-long (9 m), northeast-trending trench. Much loose ore lies scattered around the site.

GEOLOGY

The manganese deposit is believed to have been formed by the total replacement of limestone comprising the Tonoloway Formation of Upper Silurian age. Rocks of the Tonoloway Formation are now absent at the mine site, but clean, white-to-pinkish-gray, friable sandstone of the Keefer Formation, which directly underlies the Tonoloway in the region, is present in the cut. The Keefer has a northeast strike and a 20° southeast dip. Dark-reddish-gray, ferruginous sandstone of the Rose Hill Formation (Middle Silurian), which underlies the Keefer, crops out a few meters northwest of the cut. Millboro Shale (Middle Devonian) is exposed about 1300 feet (400 meters) downslope from the mine.

The replacement of the Tonoloway limestone by manganese minerals was probably due to the action of ground water. Manganese is soluble in water under acid and reducing conditions, and is precipitated as manganese oxides or hydroxides from such solutions by suitable increases in pH or oxidation potential, or both (Garrels and Christ, 1965). The pH of manganese-charged, acidic groundwater would have increased as it entered and dissolved the limestone, and the oxidation potential probably increased as the water neared the surface at the break in the slope on the hillside. The effect of these changes in water chemistry would have been to precipitate manganese from solution as the limestone was dissolved.

Polished slabs of ore samples collected from the mine show that original delicate carbonate structures were remarkably preserved during replacement by manganese oxides (Figures 2-4). Features can be seen that resemble shrinkage cracks, "algal" mat and mound structures, microfaults and burrows. In addition, much of the ore is distinctly laminated, which probably is the result of the solution and replacement of carbonate minerals within silty and non-silty laminae in the original rock. Such laminae are characteristic of the upper and lower members of the Tonoloway Formation. Some of the layers in the ore are quartz-free, whereas others contain up to 48 weight percent silica. There is

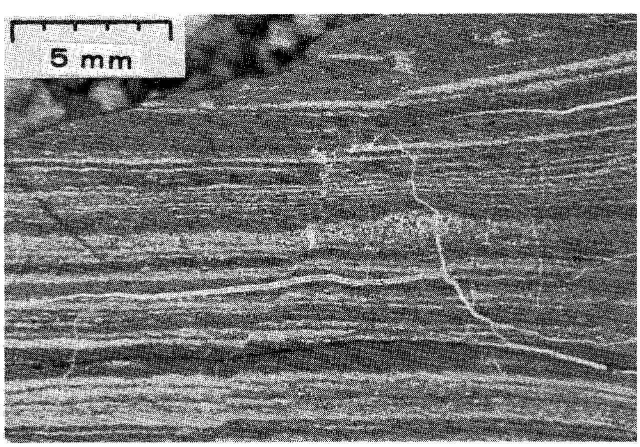

Figure 2. Polished slab showing thin laminae of cryptomelane and quartz resembling "algal" mat structures common to carbonate rocks. Photo by T. M. Gathright, II.

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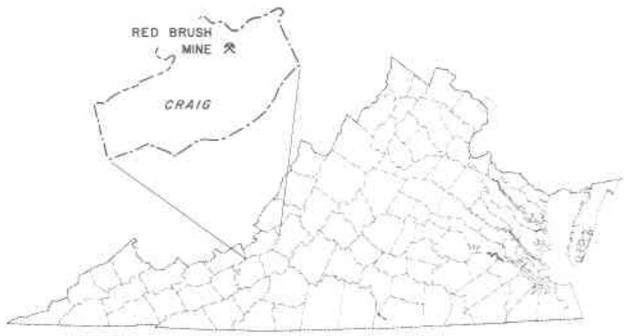

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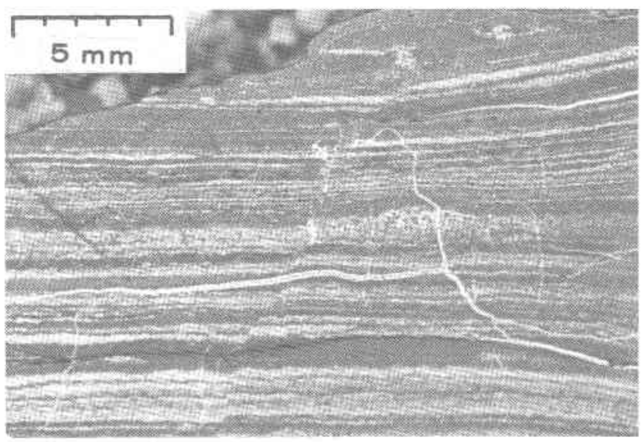

Figure 2. Polished slab showing thin laminae of cryptomelane and quartz resembling "algal" mat structures common to carbonate rocks. Photo by T. M. Gathright, II.

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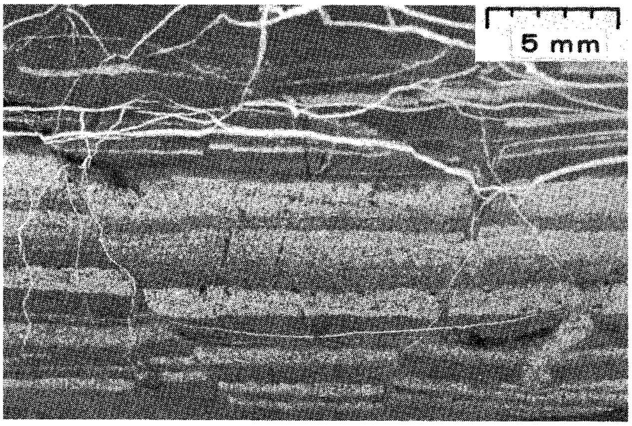


Figure 3. Polished slab showing size-graded laminae which resemble silty layers in the upper and lower members of the Tonoloway Formation. Laminae have been displaced by microfaults. Crosscutting feature at bottom right may be a burrow. Photo by T. M. Gathright, II.

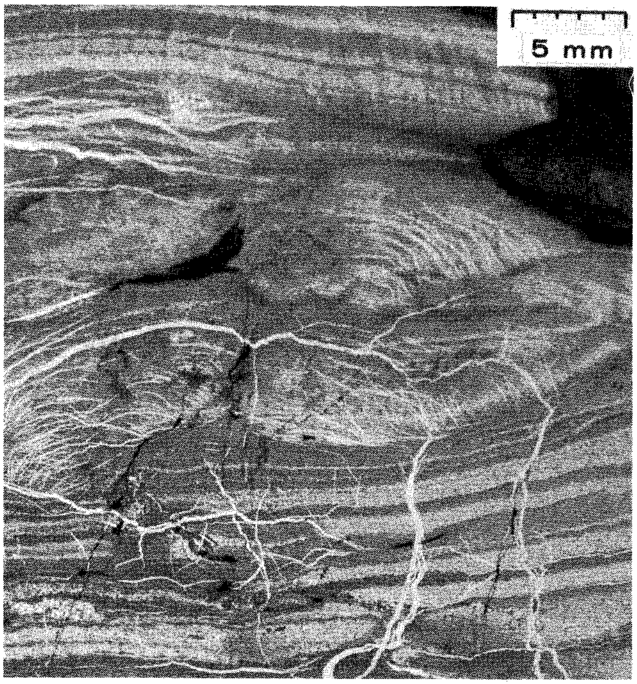


Figure 4. Polished slab showing laminae resembling "algal" mats enclosing a nonlaminated "algal" mound. Photo by T. M. Gathright, II.

generally no difference in manganese mineralogy among the layers; all are composed essentially of cryptomelane. The silica-rich layers, some of which are size-graded, are harder and have higher reflectivities than those low in quartz. Evidence of the laminated structure can be seen on weathered surfaces of turreted ore nodules (Figure 5). Some of the ore has no distinct internal structure and apparently was formed by replacement of the massive middle member of the Tonoloway Formation.

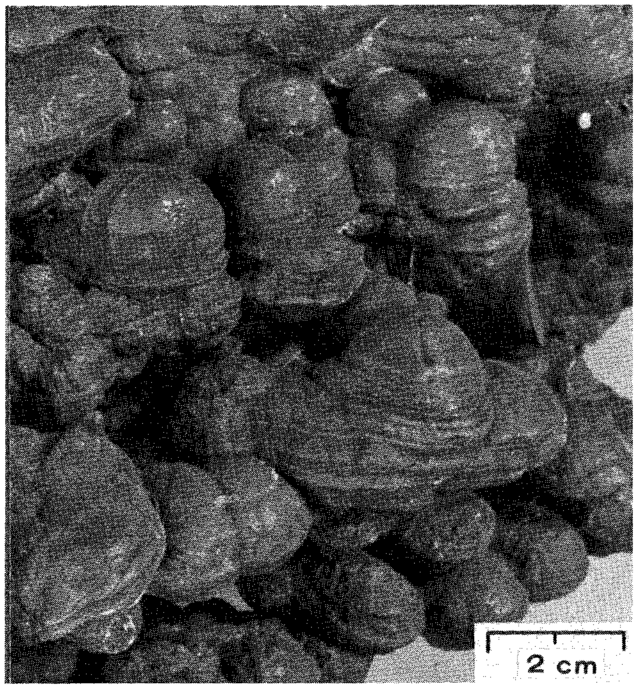


Figure 5. Turreted ore nodules. Banding is due to internal laminated structure. Photo by T. M. Gathright, II.

MINERALOGY

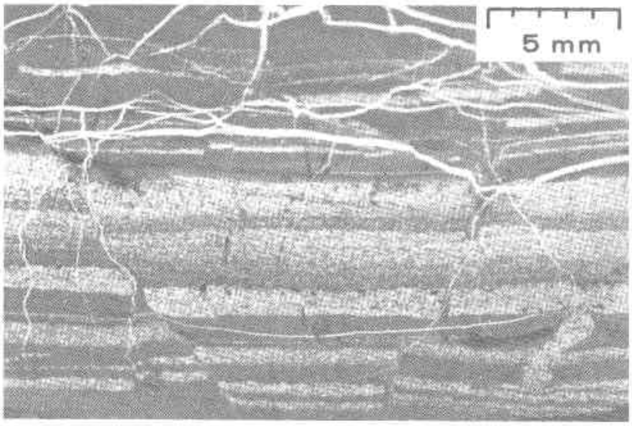
The ore minerals identified in samples from the mine are all fundamentally tetravalent manganese oxides (Table 1). Elemental analyses by electron microprobe and atomic absorption, however, show that they contain nonessential divalent metals. In particular, high concentrations of zinc were found in all the individual manganese minerals and in composites of ore samples. Nickel and cobalt were also detected in most of the minerals but comprise a lower percentage of the ore than does zinc.

Cryptomelane

Cryptomelane is the most abundant manganese mineral in the ore. It occurs in layered nodules and in massive ore, and fills many veinlets and fractures.

Table 1. Manganese oxide minerals identified in Red Brush mine ore samples.

Hollandite group	
Cryptomelane	$KMn_8O_{16} \cdot nH_2O$
Intermediate cryptomelane-hollandite	$(K,Ba)Mn_8O_{16} \cdot nH_2O$
Coronadite	$PbMn_8O_{16} \cdot nH_2O$
Chalcophanite	$ZnMn_3O_7 \cdot 3H_2O$
Lithiophorite	$(Al,Li)MnO_2(OH)_2$



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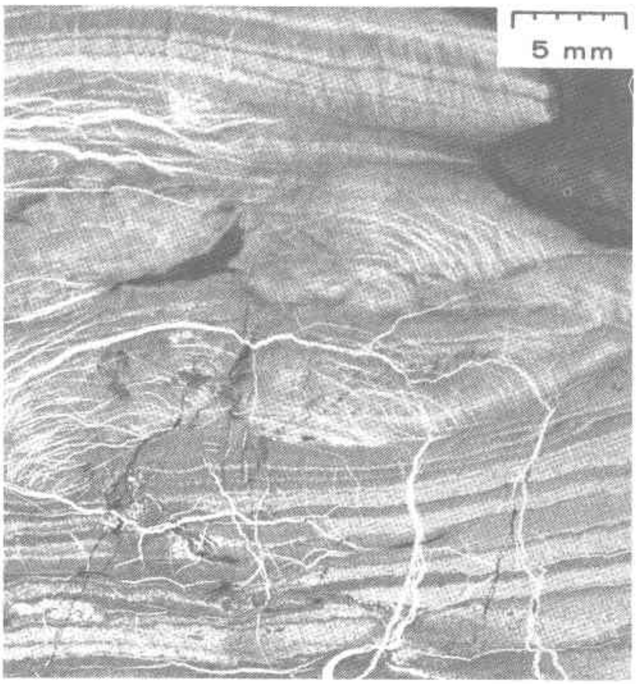

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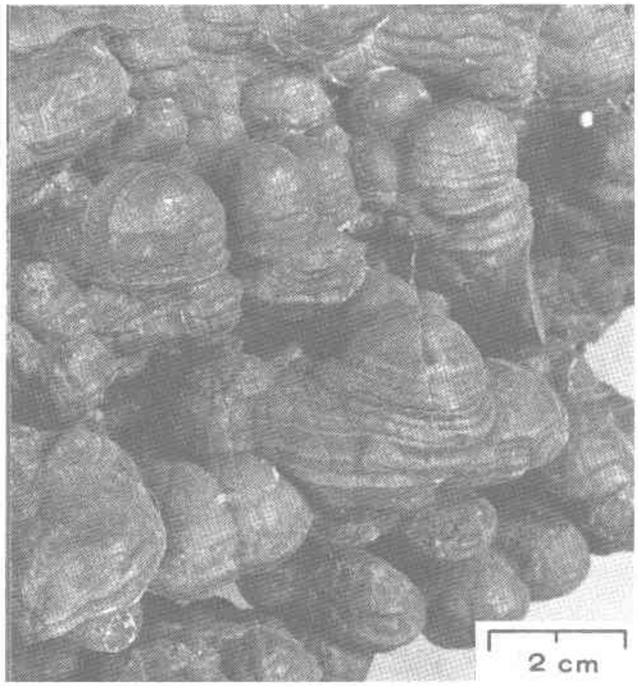

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Lithiophorite	$(Al,Li)MnO_2(OH)_2$

Table 2. Microprobe analyses of cryptomelane

	R23A	R23C	R20A	R20B	R25	R21	Means
MnO_2	81.95[a]	78.78[a]	80.54[a]	81.82[a]	85.57[a]	86.14[a]	76.09[b]
MnO							5.21[b]
NiO	0.00	0.00	0.06	0.08	0.00	0.00	0.02
ZnO	2.85	2.87	2.66	2.54	2.75	3.33	2.83
SiO_2	0.15	0.13	0.11	0.16	0.09	0.13	0.13
BaO	0.20	0.26	0.13	0.11	0.17	0.14	0.17
MgO	0.01	0.00	0.00	0.02	0.01	0.02	0.01
Al_2O_3	0.70	0.77	0.47	0.26	0.56	0.36	0.52
CaO	0.18	0.19	0.22	0.26	0.15	0.15	0.19
K_2O	3.09	2.93	3.59	3.59	3.26	2.56	3.17
Fe_2O_3	0.27	0.26	0.35	0.45	0.33	0.29	0.33
H_2O							11.33[c]
							100.00

[a] All Mn as MnO_2
[b] Mn recalculated as MnO_2 and MnO (see text)
[c] by subtraction from 100%
CuO and PbO not detected

X-ray powder diffraction patterns of many ore samples showed only cryptomelane peaks, and microprobe analyses (Table 2) confirmed the identification of the mineral.

Because the oxidation states of manganese could not be determined by microprobe analysis, the individual percentages of MnO and MnO_2 for the hollandite group minerals, cryptomelane (Table 2), cryptomelane-hollandite (Table 4) and coronadite (Table 5), were estimated using the generalized formula of Frondel, Marvin and Ito (1960) for hollandite-group minerals: $(V_{2-x}A_x)\ (Mn^{4+}_{8-x}Mn^{2+}_x)\ O_{16}\cdot nH_2O$. In this expression, V represents vacant structural sites and A represents various amounts of barium, lead, potassium and other ions. An amount of manganese was assigned as Mn^{2+} equal to the sum of atoms assumed to be in the A site. Nickel and zinc were included in the sum, although it is recognized that they may proxy for manganese. Silicon, aluminum, and iron were not included because they are considered to be present mainly as impurities. The remaining manganese was then calculated as Mn^{4+}. The valence states of iron also were not determined; in the tables all iron is reported as Fe_2O_3.

The concentrations of K_2O in the Red Brush mine cryptomelane samples correspond fairly well to K_2O values in six cryptomelane analyses reported by Hewett and Fleischer (1960, p. 21, p. 29) and in one by Mathieson and Wadsley (1950, p. 100). The mean of these published values is 3.97 percent K_2O. The absence of detectable lead and the low average values of barium in the Red Brush sample are evidence that cryptomelane rather than coronadite or hollandite, the lead and barium manganese oxides isostructural with cryptomelane, is the major phase present.

Some X-ray diffraction patterns, particularly those of soft, black, massive nodules, are characterized by broad cryptomelane peaks of low intensity. These samples thus appear to contain amorphous manganese oxides, but may actually be composed of fine manganese oxide crystallites that are too small to produce interpretable X-ray patterns (Burns and Burns, 1979). Atomic absorption analysis of such material (Table 3) shows that concentrations of nickel and zinc are lower in it than in the ore as a whole.

Microprobe analyses of parts of two samples, R-17 and R-21 (Table 4), revealed a mineral whose composition is similar to that of cryptomelane, but differs from other Red Brush cryptomelane specimens

Table 3. Atomic absorption analysis of "amorphous" manganese oxides.

MnO_2	53.49[a]
NiO	0.01
ZnO	0.59
CoO	0.11
Fe_2O_3	0.93
loss on ignition	7.90
residue	43.40

[a] all Mn as MnO_2
O. M. Fordham, Jr., analyst

Table 4. Microprobe analyses of cryptomelane-hollandite.

	R17	R21	Means	Atomic ratios	Atoms per 16 oxygens
MnO_2	77.66[a]	78.07[a]	73.95[b]	Mn^{4+} .8506	7.60
MnO			3.30[b]	Mn^{2+} .0451	.403
NiO	0.13	0.17	0.15	Ni .0020	.018
ZnO	1.02	1.10	1.06	Zn .0130	.116
SiO_2	0.11	0.27	0.19		
BaO	1.64	1.43	1.55	Ba .0101	.090
MgO	0.10	0.13	0.12	Mg .0032	.029
Al_2O_3	3.15	2.58	2.87		
CaO	0.14	0.25	0.20	Ca .0036	.032
K_2O	1.28	1.19	1.24	K .0263	.235
Fe_2O_3	0.26	1.17	0.72		
H_2O			14.74[c]		7.31
			100.00		

[a] all Mn as MnO_2
[b] Mn recalculated as MnO_2 and MnO (see text)
[c] H_2O by subtraction from 100%
CuO and PbO not detected

by having more barium and less potassium. The mineral is apparently an intermediate cryptomelane-hollandite phase having a potassium/barium ratio of about 2.6 : 1. The "normal" cryptomelane (Table 2) has an average potassium/barium ratio of over 60 : 1.

In sample R-17, cryptomelane-hollandite makes up a narrow veinlet which is cut by a wider seam filled with chalcophanite crystals. In sample R-21 (Figure 6), the mineral occurs adjacent to the cryptomelane-quartz matrix as an irregularly-shaped mass within a cryptomelane vein. An approximate formula for the cryptomelane-hollandite, derived by recalculating the average of the two analyses in Table 4 on the basis of 16 oxygens and neglecting iron, aluminum and silicon, is $(K_{.23}\ Ba_{.09}\ Zn_{.12}\ Ca_{.03}\ Mg_{.03}\ Ni_{.02})(Mn^{4+}_{7.60}\ Mn^{2+}_{0.40})\ O_{16} \cdot 7.3\ H_2O$.

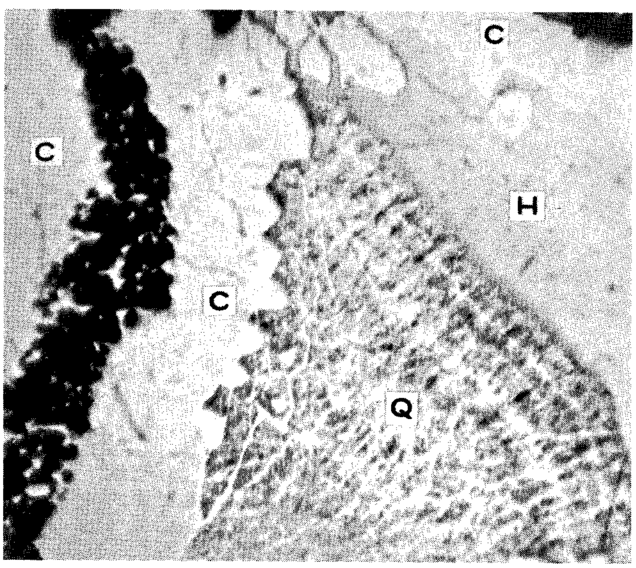

Figure 6. Photomicrograph of cryptomelane-hollandite, sample R-21. C = cryptomelane; Q = cryptomelane and quartz; H = cryptomelane-hollandite. The train of dark patches in the center of the cryptomelane veinlet are sites of chalcophanite crystals plucked out during polishing. Approximately 50x.

Coronadite

A spherical grain less than 1 mm in diameter in a sample composed mainly of cryptomelane was identified as coronadite on the basis of electron microprobe analyses. This is believed to be the first reported occurrence of this mineral in Virginia.

The grain, which is too small to be physically separated from the cryptomelane matrix, consists of a hydrous lead-manganese oxide (Table 5). X-ray powder diffraction analyses of the sample produced patterns that correspond to those of hollandite group minerals. Coronadite and cryptomelane are normally difficult to differentiate by X-ray diffraction alone, but pure coronadite lacks a diffraction peak at 4.93-4.98 angstroms that is found in patterns of cryptomelane and hollandite (Hewett, 1971). The presence of this peak in the patterns of the Red Brush mine sample confirms that cryptomelane is the host mineral but does not preclude the presence of coronadite. The X-ray analyses show no other mineral that would account for the lead content; therefore, it is most probable that the grain is coronadite.

The microprobe analyses show less lead (and consequently more water) than several early published analyses of coronadite. Indeed, the lead value of the

Table 5. Chemical analyses of coronadite

	Microprobe Analyses, Red Brush mine R14	R-Y	Means	Coronadite Mibladen, Morocco[f]	Coronadite Kurgashinkan, U.S.S.R.[f]	"Hydrous Ag-bearing Pb-Mn oxide"[g]
MnO_2	67.64[a]	68.82[a]	60.58[b]	51.89[c]	54.82[c]	63.32[a]
MnO			6.24[b]	5.69[c]	23.98[c]	
NiO	0.16	0.20	0.18			
ZnO	1.35	1.40	1.37			
CuO	0.16	0.06	0.11			2.82
SiO_2	1.29	1.26	1.28	6.00		0.19
BaO	0.57	0.60	0.58	3.55		1.36
PbO	17.29	15.20	16.25	14.19	15.03	15.02
MgO	0.16	0.14	0.15	0.50		0.05
Al_2O_3	1.44	1.45	1.44	1.95		0.09
CaO	0.06	0.06	0.06	4.60	0.80	0.97
K_2O	0.78	0.83	0.80	0.11		0.47
Fe_2O_3	2.37	2.05	2.21	2.31		0.11
H_2O			8.75[d]	8.22	5.20	13.17[d]
other						2.43[e]
			100.00	99.01	99.83	100.00

[a] all Mn as Mno_2
[b] Mn recalculated as MnO_2 and MnO (see text)
[c] MnO_2 and MnO calculated on the basis of excess oxygen
[d] H_2O by subtraction from 100%
[e] includes Sb_2O_3, Ag_2O, and As_2O_3
[f] Hewett, 1971
[g] Radtke et al., 1967

Red Brush grain is similar to that of the "hydrous silver-bearing lead manganese oxide" from the Aurora Mine, Hamilton, Nevada, described by Radtke, Taylor and Hewett (1967) (Table 5). This mineral was not considered to be coronadite mainly because of the differences in lead and water concentrations in it and in a specimen of coronadite reported by Palache and others (1944) to contain 28.68 percent PbO and 1.80 percent H_2O. However, other coronadite analyses compiled by Hewett (1971), two of which are listed in Table 5, have PbO values ranging from 14.19 percent to 27.55 percent, and Hewett and Fleischer (1960) reported coronadite from Chihuahua, Mexico containing 19.3 percent PbO. Thus the percentage of lead in the Red Brush mineral is within the known range of values for coronadite.

The amount of water in the Red Brush coronadite was calculated by subtracting the sum of the measured oxide values from 100 percent. Because the percentage of lead is relatively low, the water value is high in comparison with values in several other coronadite analyses, which generally range from 1 to 5 percent. Water, however, is considered to be non-essential in hollandite-group minerals (Fleischer and Richmond, 1943; Frondel and Heinrich, 1942; Wadsley, 1950) and probably does not occupy well-defined sites in the crystal structure (Potter and Rossman, 1979).

Chalcophanite

Chalcophanite, which makes up about 1 percent of the ore, occurs in nearly all the ore samples collected at the mine as drusy rims and crusts and as vein fillings. It is easily recognized by its silvery metallic luster, tabular form, and softness.

X-ray diffraction patterns of the Red Brush mine chalcophanite correspond well to published patterns of the mineral (Berry and Thompson, 1962; Gulbrandsen and Reeser, 1969). Nine microprobe analyses indicate that the mineral is nickel-rich. Eight of the analyses are very similar, with ZnO values ranging from 15.80 to 19.71 percent and NiO from 0.38 to 0.80 percent (Table 6). The other analysis, of sample R-20, shows more nickel (1.53 percent NiO) and correspondingly less zinc (13.57 percent ZnO). Energy dispersive X-ray analyses did not show significant amounts of cobalt in the mineral. An atomic absorption analysis of a chalcophanite specimen containing 1.06 percent NiO showed only 0.05 percent CoO.

The chalcophanite at the Red Brush mine is slightly deficient in zinc. The ratio of (ZnO + NiO) to

Table 6. Chemical analyses of chalcophanite.

	Microprobe Analyses, Red Bush Mine					
	R20	Means of 8 analyses, excluding R20	Atomic ratios	Atoms per 7 oxygens	Theoretical composition, $ZnMn_3O_7 \cdot 3H_2O$	Chalcophanite[d] Buchan, Victoria
MnO_2	64.31[a]	63.42[b]	Mn^{4+} .7295	3.000	65.82	65.39
MnO		1.57[b]	Mn^{2+} .0221	.091		0.22
NiO	1.53	0.51	Ni .0068	.028 } 1.000		
ZnO	13.57	17.43	Zn .2142	.881	20.54	18.19
SiO_2	0.01	0.01				1.88
Al_2O_3	0.01	0.05				
K_2O	0.04	0.01				
Fe_2O_3	0.24	0.26				0.39
H_2O		16.74[c]			13.64	13.09
		100.00			100.00	99.48

[a] all Mn as MnO_2
[b] Mn calculated as MnO_2 and MnO to make a 3:1 ratio of $Mn^{4+}:(Mn^{2+} + Zn + Ni)$
[c] H_2O by subtraction from 100%
[d] Wasley, 1950
CuO, BaO, PbO, and CaO not detected

MnO_2, which should be 1 : 3 according to the chemical formula, is consistently low for the Red Brush specimens, ranging from 1 : 3.19 to 1 : 3.95. The zinc and nickel deficiency may be compensated for by the presence of small amounts of divalent manganese. By recalculating the average of the manganese values as 1.57 percent MnO and 63.42 percent MnO_2 (Table 6), an exact 1 : 3 ratio between the divalent and tetravalent cations can be established and charge neutrality maintained.

Chalcophanite has been previously reported at one other locality in Virginia, the Price mine near Newport in Giles County, about 27 miles (43 km) southwest of the Red Brush prospect (Hewett and Fleischer, 1960). The mineral from this site is extremely deficient in zinc, containing only 3.5 percent ZnO (Radtke, Taylor and Hewett, 1967). The amount of nickel reported (0.3 percent NiO) is comparable to the nickel concentration in the Red Brush chalcophanite.

Lithiophorite

Lithiophorite was identified in several ore samples by X-ray diffraction. Although the crystallization sequence of the various manganese minerals in most of the ore is obscure or ambiguous, lithophorite is considered for the most part to be a late-forming phase because it fills narrow fractures and veinlets and forms soft black rinds up to 3 mm thick around nodular cryptomelane masses.

Microprobe analyses of the vein-filling lithiophorite show very high average percentages of nickel (5.67 percent NiO) and zinc (3.35 percent ZnO) (Table 7). Significant amounts of these metals and others, particularly cobalt and copper, commonly have been reported in analyses of lithiophorite (Pierce, 1944; Hewett and Fleischer, 1960; Mitchell and Meintzer, 1967; Larson, 1970; Jacobs, 1973). The total concentration of divalent cations (other than Mn^{2+}), however, is higher in the Red Brush lithiophorite than in any other sample reported.

The structure of lithiophorite, consisting of interlayers of MnO_6 and $Al,Li(OH)_6$ octahedra, was determined by Wadsley (1952) and confirmed by Potter and Rossman (1979). Wadsley noted that although the manganese in lithiophorite is predominantly tetravalent, a "considerable fraction" of it exists as ions of lower valency. It can be inferred from lithiophorite analyses published by Van der Walt (1945), Wadsley (1950) and Hewett and Fleischer (1960) that the maximum ratio of Mn^{2+} or other divalent ions to Mn^{4+} is 1 : 5; that is, up to about 17 percent of the Mn^{4+} apparently can be replaced by Mn^{2+}. An approximate 1 : 5 ratio of (Mn^{2+} + Ni + Co + Zn + Cu) to Mn^{4+} appears in at least five published chemical analyses of the mineral. In fact, a formula for lithiophorite derived from the work of Giovanoli and others (1973) incorporated a Mn^{2+}/Mn^{4+} ratio of 1 : 5, as did a tentative lithiophorite formula proposed by Fleischer and Richmond (1943). As can be seen from the atomic

Table 7. Chemical analyses of lithiophorite.

	Microprobe Analyses, Red Brush mine			Atomic ratios		Lithiophorite[d] Gloucester, South Africa	Atomic ratios
	R25I	R25II	Means				
MnO_2	51.00[a]	50.68[a]	50.84[a]	Mn^{4+} .585		48.96	Mn^{4+} .563
MnO						8.20	Mn^{2+} .116
NiO	5.65	5.69	5.67	Ni .076	.117		
ZnO	3.46	3.24	3.35	Zn .041			
Al_2O_3	21.89	22.77	22.33	Al .438		23.84	Al .468
Li_2O			3.36[b]	Li .225		3.30	Li .221
SiO_2	0.01	0.03	0.02			0.30	
MgO	0.02	0.00	0.01				
K_2O	0.03	0.00	0.02				
Fe_2O_3	0.53	0.55	0.54			0.96	
H_2O			13.86[c]			14.60	
			100.00			100.16	

[a] all Mn as MnO_2
[b] Li_2O calculated as LiOH by subtraction from 100%, with Al as $Al(OH)_3$
[c] H_2O by subtraction from 100% after Li_2O calculation
[d] van der Walt, 1945
CuO, BaO, PbO, and CaO not detected

Table 8. Mean concentrations of metals in Red Brush mine manganese minerals.

	Chalcophanite	Coronadite	Cryptomelane	Lithiophorite	Ore composite
ZnO	17.00	1.37	2.76	3.35	3.05[a]
NiO	0.63	0.18	0.03	5.67	0.44[a]
CuO	0.00	0.11	0.00	0.00	n.a.
CoO	0.05[a]	n.a.	0.14[a]	n.a.	0.22[a]
PbO	0.00	16.25	0.00	0.00	n.a.

[a] determined by atomic absorption; O. M. Fordham, Jr., analyst
n.a. = not analyzed

ratios listed in Table 7, the $(Zn + Ni)/Mn^{4+}$ ratio of the Red Brush vein-filling lithiophorite is precisely 1 : 5, assuming that all manganese is Mn^{4+}.

A pure lithiophorite specimen from Gloucester, South Africa which was analyzed by van der Walt (1945) contains 48.96 percent MnO_2 and 8.20 percent MnO. Comparison of the atomic ratios for this sample with those calculated for the Red Brush lithiophorite (Table 7) shows that the sum of zinc and nickel (0.117) is nearly identical to the amount of Mn^{2+} (0.116) in the South African specimen.

The substitution of divalent ions for Mn^{4+} necessitates a compensatory change in the lithium/aluminum ratio in the Al, $Li(OH)_6$ octahedral units. That the lithium content of lithiophorite is variable is well documented by published chemical analyses, and nearly lithium-free lithiophorite (0.2 to 0.3 percent Li_2O) has been reported from Charlottesville, Virginia (Mitchell and Meintzer, 1967).

The positive charge deficiency created by a $(Ni + Zn)/Mn^{4+}$ ratio of 1 : 5 would be compensated by a lithium/aluminum ratio of 1 : 2. This is the lithium/aluminum ratio in the South African lithiophorite analyzed by van der Walt (Table 7). Although lithium was not determined by the microprobe analyses of the Red Brush samples, an estimate of the lithium content was made by adding the oxide percentages determined by microprobe (with aluminum represented as $Al(OH)_3$) and subtracting this sum from 100 percent. If the difference (5.38 percent) is considered to be due solely to Li(OH), the calculated lithium/aluminum ratio is 1 : 1.95, and the charge deficiency caused by nickel and zinc substitution is almost exactly compensated.

CONCLUSIONS

Minerals of the Red Brush prospect, like those of many manganese deposits in the Southern Appalachians, were first studied before X-ray diffraction was widely used for mineral identification. As a result, the only manganese mineral mentioned by

Stose and Miser in their 1922 report on the Red Brush prospect was "psilomelane." The true identity of the manganese minerals and the abundances of metals such as cobalt, nickel, zinc and copper are becoming known upon reinvestigation of the deposits.

The Red Brush ore differs from that of many other deposits in that zinc is the most abundant metal other than manganese and iron. Lithiophorite is the only mineral at the mine that contains more nickel than zinc. A composite of the ore was found to contain 3.05 percent ZnO and only 0.44 percent NiO and 0.22 percent CoO (Table 8). Copper was not detected by any of the microprobe analyses of cryptomelane, chalcophanite or lithiophorite, and the mineral identified as coronadite contains an average of only 0.11 percent CuO. The relative abundance of zinc in the ore is due not only to the presence of chalcophanite, but also to the high concentrations of zinc in cryptomelane and coronadite.

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