# Middle Ordovician Rocks of the Tellico-Sevier Belt Eastern Tennessee

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*By* ROBERT B. NEUMAN

A SHORTER CONTRIBUTION TO GENERAL GEOLOGY

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*Description of rocks of the outcrop belt containing the type sections of the Tellico and Sevier formations, with interpretations of their sedimentary environment*

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## MIDDLE ORDOVICIAN ROCKS OF THE TELLICO-SEVIER BELT, EASTERN TENNESSEE

By Robert B. Neuman


### ABSTRACT

The southernmost outcrop belt that exposes a complete section of rocks of Middle Ordovician age in eastern Tennessee contains the type sections of Tellico sandstone (Keith, 1896a) and Sevier shale (Keith, 1895). Study of a 50-mile segment of this belt reveals the necessity for reclassification of these deposits. The new classification and the probable environments of deposition of these rocks are summarized as follows:

| Keith, 1895, 1896a | Classification of present report | Description | Tectonic environment |
|---|---|---|---|
| Bays sandstone | Bays formation | Red calcareous mudrock and siltstone, with nonred sandstone and claystone rare; 400–1,000 feet. | Elevated, deeply weathered source area; deposition in shallow water that was occasionally drained. |
| Sevier shale, upper part | Sevier formation (revised usage), with Bacon Bend member (new) at top. | Bacon Bend member is interbedded gray and red calcareous shale and siltstone, with some nonred beds possessing submarine slump structures; main body of formation is gray silty calcareous shale, calcareous sandstone, and calcarenite; total formation thickness, 1,500–2,200 feet. | Source area generally of low relief; basin of deposition shallow, sediments subject to stirring and sorting by marine currents. Closing phase contains transition to Bays environment. |
| Sandstone lentil in Sevier shale. | Chota formation (new) | Gray calcarenite, most with quartz-sand grains; 550–900 feet. | Little new material from source area; subsidence of area of deposition uniform, slow; a littoral or offshore bar deposit. |
| Sevier shale, lower part, Tellico sandstone, and Athens shale, upper part. | Tellico formation (revised usage). | Gray silty sandy calcareous shale, with lenses of gray feldspathic calcareous sandstone in middle part; 2,700–4,500 feet. | Maximum relief between source area and depositional basin: source area of high relief; deposition below wave base. |
| Athens shale, lower part, and Chickamauga limestone, upper part. | Blockhouse shale (new), with Toqua sandstone member (new) and Whitesburg limestone member. | Dark-gray calcareous shale with graptolites, with lateral equivalent of gray fine- to coarse-grained calcareous sandstone; basal member is argillaceous limestone; 150–950 feet. | Lower limestone is unstable shelf associate; shales accumulated in poorly ventilated basin; terrigenous sands carried into basin by streams. |
| Chickamauga limestone, lower part. | Lenoir limestone with Mosheim member and basal Douglas Lake member. | Gray argillaceous limestone, with lateral equivalent of light-gray aphanitic limestone; basal member composed of various kinds of clastic limestones; 30–100 feet. | Negligible contributions from land areas; initial deposits on debris-littered erosion surface; remainder are unstable shelf limestones: chemical precipitates formed in enclosed basins, some redeposited in shallow open sea. |

## INTRODUCTION

This report describes the southeasternmost complete section of rocks of Middle Ordovician age in eastern Tennessee and clarifies their stratigraphic classification. The report is based on field study of a 50-mile segment of the outcrop belt that lies along the northwest edge of the Great Smoky Mountains and Chilhowee Mountain, or from east of the city of Sevierville on the northeast to the Tellico River on the southwest (pl. 27). In this belt, here called the Tellico-Sevier belt, Middle Ordovician rocks are about 7,500 feet thick. In most of this area the rocks possess a homoclinal structure in which the sequence is complete from the Lower Ordovician rocks below to the unconformity at the base of the Chattanooga shale (Devonian and Carboniferous) above. Within the belt of homoclinal structure, stratigraphic units may be traced along the strike for long distances, and their lateral variations may be worked out. The results may be applied to the remainder of the area studied and to other parts of the Middle Ordovician rocks of East Tennessee, where the structural features are much more complex.

The area studied includes the Tellico River on the southwest along which is exposed the type section of the Tellico sandstone of Keith (1896a, p. 3). Farther northeast it also includes the type area of the Sevier shale of Keith (1895, p. 4) in Sevier County at the northwest foot of Chilhowee Mountain. Northeast of the area studied, the belt expands into a wide synclinorium of complex structure that extends into Virginia. On one of the anticlinal uplifts within the synclinorium is the type section of the Mosheim limestone (Ulrich, 1911; Wilmarth, 1938, p. 1427), and along its northwest edge is the type section of the Whitesburg limestone (Ulrich, 1929, p. 2).

Other type sections of units commonly used in the Middle Ordovician of East Tennessee, such as Lenoir limestone, Holston marble, Athens shale, and Ottosee shale (fig. 22), lie in outcrop belts northwest of this one. Inasmuch as these outcrop belts are separated by thrust faults, direct correlation cannot be made.

## FIELDWORK AND ACKNOWLEDGMENTS

The investigation on which this report is based is part of a geological study of the Great Smoky Mountains area. Between 1949 and 1951 about 16 months were devoted to fieldwork on the Middle Ordovician rocks, during which their outcrops were mapped on topographic quadrangle maps on a scale of 1:24,000. Persistent beds were traced, and fossils were collected; about 200 square miles were mapped. The investigation was under the supervision of Philip B. King who gave much help in the preparation of the manuscript.

G. A. Cooper, of the U. S. National Museum, assisted the investigations in many ways, including aid in the field, making available his own notes and collections from the area, identification or confirmation of the writer's collections of brachiopods and trilobites, and generous consultation on many problems; in addition, he prepared the photographs of plate 25 of this paper. John Rodgers, then of the Geological Survey, and the late Josiah Bridge also visited the writer in the field; Bridge made or confirmed the writer's collections of graptolites and critically reviewed the manuscript. Jean Berdan identified the ostracodes cited generically.

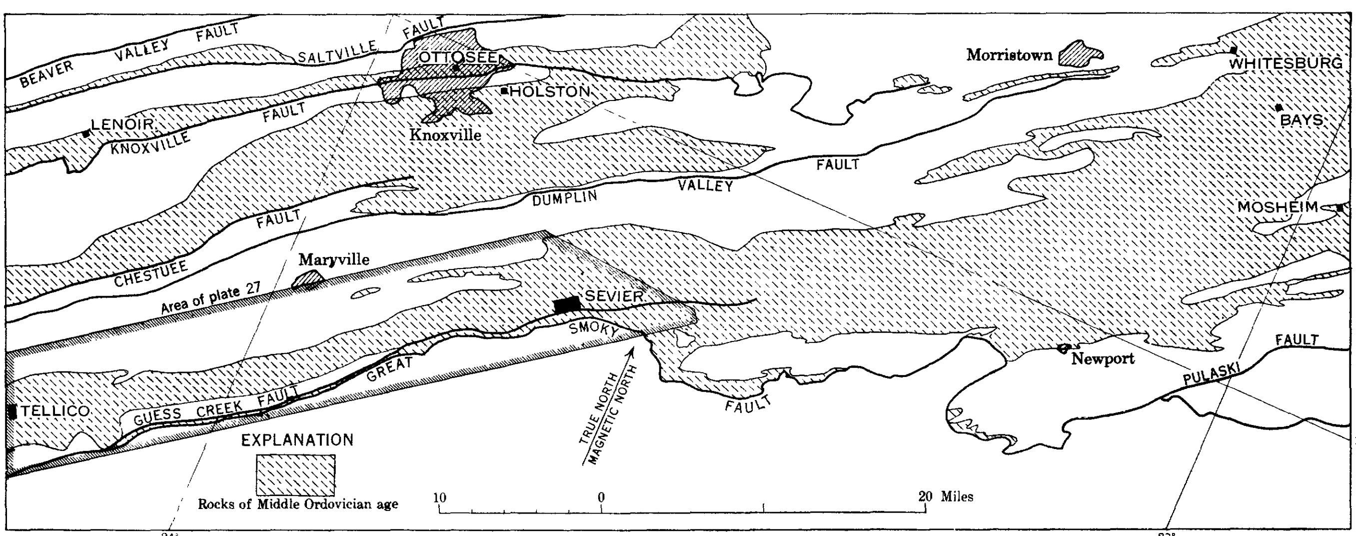



FIGURE 22.—Map showing distribution of Middle Ordovician rocks in part of eastern Tennessee. Solid blocks indicate type localities of Middle Ordovician formations. Adapted from Rodgers, 1952.

## ANALYSIS OF STRATIGRAPHIC NOMENCLATURE

### HISTORICAL BACKGROUND

#### EARLY WORK

Early geologic work in eastern Tennessee may be divided into three phases: (1) that of Safford (1869) and of Safford and Killebrew (1876 and later); (2) that of the U. S. Geological Survey reported in Folios of the Geologic Altas of the United States by Campbell, Hayes, and Keith (see classification below); and (3) the work of E. O. Ulrich and his associates.

Safford (1869, p. 246–250) designated the outcrop belt dealt with in this report as the "Gray belt" of "the upper member of the Trenton and Nashville series, "in contrast to the "Red belt" of beds of the same age adjacent to the northwest. Within the Gray belt he recognized two details that are important in making present-day correlations: the occurrence of black shale with graptolites at the base of the shale section, and a gradual change in rock color from gray or "Sky-blue" in the northeast to dominant red in the southwest. Safford gave the thickness of the shale between the "Clinch Mountain Sandstone" (Bays formation) and the "Maclurea Limestone" (Lenoir limestone) as 1,982 feet. Safford and Killebrew (1876, p. 108, 130) introduced the term Lenoir limestone, the oldest term still applied to rocks of Middle Ordovician age in the Appalachian area, for blue, argillaceous limestone near Lenoir City which previously was designated the Maclurea Limestone by Safford (1869).

Folios of the U. S. Geological Survey covering many quadrangles in the southern Appalachians were prepared by several geologists working simultaneously in different areas, all under the general supervision of Bailey Willis. The earliest were published between 1894 and 1896, although some results of the work were published by Willis in 1893. Stratigraphic terminology of the Middle Ordovician rocks differs from one folio to another, probably because of progressive refinement of correlation and nomenclature. Because of a delay in publication of some folios, some names first appeared in quadrangles far from their type areas.

The Estillville folio (Campbell, 1894) largely in southwestern Virginia, contains the names Chickamauga limestone, Sevier shale, and Bays sandstone, the first based on outcrops in the Ringgold (Georgia) quadrangle (Hayes, 1891, 1894a), the second on outcrops in the Knoxville quadrangle (Keith, 1895), and the third on outcrops in the Morristown quadrangle (Keith, 1896b). In the Cleveland folio (Hayes, 1895), equivalents of the Sevier shale as defined in the Estillville folio were termed the Athens shale and Tellico sandstone, the first from outcrops within the quadrangle, the second from outcrops in the Loudon quadrangle (Keith, 1896a). The name Athens had, however, been used earlier in the Kingston folio (Hayes, 1894b) for supposedly equivalent shales now known to be of Late Ordovician age.

All five of these names appear in a single section in the subsequent Knoxville and Loudon folios (Keith, 1895, 1896a), where the Sevier was restricted to the upper part of the rocks assigned to it in the Estillville folio, and the names Athens and Tellico were used for its lower part. However, the term Tellico was apparently not found to be regionally applicable, as it was not used in the adjacent Morristown folio (Keith, 1896b), where the Sevier was shown as lying directly on the Athens.

Keith's lithologic descriptions of these formations southeast of Bays Mountain in the Knoxville folio may be summarized as follows:

*Bays sandstone.*—Red calcareous and argillaceous sandstone, with some feldspathic sandstone beds; 300–1,100 feet thick.

*Sevier shale.*—Light-blue calcareous shale with two units of bluish-gray and gray calcareous sandstone. Average thickness from top to bottom of the 5 units: shale 550 feet; sandstone 300 feet; shale 550 feet; sandstone 575 feet; shale 625 feet; "The

*Early classification of Middle Ordovician rocks in eastern Tennessee*

| Safford, 1869 | Hayes, 1894, Ringgold folio | Hayes, 1895 Cleveland folio (eastern part) | Campbell, 1894 Estillville folio (Holston River outcrop belt) | Keith, 1895 Knoxville folio (southeast of Bays Mountain) |
|---|---|---|---|---|
| Clinch Mountain Sandstone.[1] | Rockwood formation. | Rockwood formation. | Clinch sandstone. | Clinch sandstone. |
| Trenton and Nashville series<br>Lenoir limestone.[2] | Chickamauga limestone. | Sevier shale.<br>Tellico sandstone.<br>Athens shale.<br>Chickamauga limestone. | Bays sandstone.<br>Sevier shale.<br>Chickamauga limestone. | Bays sandstone.<br>Sevier shale.<br>Tellico sandstone.<br>Athens shale.<br>Chickamauga limestone. |
| Knox dolomite. | Knox dolomite. | Knox dolomite. | Knox dolomite. | Knox dolomite. |

[1] Beds directly above the Middle Ordovician; no correlation of Clinch sandstone with Rockwood formation is implied.
[2] Proposed by Safford and Killebrew, 1876, p. 130.

shales are precisely like the Athens shale, and the sandstones are very similar to the Tellico sandstone."

*Tellico sandstone.*—Bluish-gray and gray calcareous sandstone and sandy shales, closely interbedded; these weather to a porous sandy rock with a strong red color; 800–900 feet thick.

*Athens shale.*—Black graptoliferous shales near the base, passing up into thin light-blue shaly limestone; 1,000–1,200 feet thick.

*Chickamauga limestone.*—Massive blue and gray and argillaceous limestone; 0–50 feet thick.

In his subsequent revision of the folio terminology, Ulrich distinguished the Mosheim limestone below the Lenoir limestone (Ulrich, 1911). He later (*in* Gordon, 1924) introduced the term Whitesburg limestone for beds between the Lenoir (Chickamauga) limestone and the Athens shale. The term Ottosee shale, which he substituted for Sevier shale as mapped in the northwest part of the Knoxville quadrangle (Keith, 1895), was never applied to the southeasternmost belt. Similarly, the Holston marble, noted as discontinous lentils by Keith in the Knoxville and Loudon folios, but given formational rank by Ulrich, was not recognized in the southeastern belt. Ulrich's classification of rocks of Middle Ordovician age in this belt was as follows:

Bays sandstone
Sevier shale (=Ottosee shale of northwestern belts)
Tellico formation (Holston marble of northwestern belts absent)
Athens shale
Whitesburg limestone
Lenoir limestone
Mosheim limestone

## LATER WORK

A complex classification of rocks of Middle Ordovician age was adopted in Virginia by Butts (1940), and formation names that had their origins in Tennessee were extended into Virginia.

B. N. Cooper and C. E. Prouty (Cooper and Prouty, 1943, Cooper, 1944) investigated in detail the Middle Ordovician rocks of southwestern Virginia. Their work disclosed that the classification of Butts was untenable, and they therefore established a new one. As the rocks of this area are relatively fossiliferous, detailed zonation is possible, and this section may be used as a standard for correlation and classification elsewhere. The units of the southwestern Virginia section are as follows:

Moccasin formation
Witten limestone
Bowen formation
Wardell formation
Gratton limestone
Benbolt limestone
Peery limestone
Ward Cove limestone [1]
Lincolnshire limestone
Five Oaks limestone
Blackford formation

Subsequent work (B. N. Cooper, 1950) shows that the Gratton is a partial lateral equivalent of the Wardell limestone, and that the Elway limestone is a unit of formational rank that had been included at the top of Blackford formation.

C. E. Prouty extended these concepts into Tennessee. His earlier paper (Prouty, 1946) contains no reference to the southeasternmost belt other than to note the correspondence of the Sevier shale to the Ottosee shale and the Ottosee shale to the Benbolt limestone.

In a later paper (Prouty, 1948, p. 1612–1613) he makes the following statements:

> The Lincolnshire limestone thickens from Virginia into Tennessee by addition at the base, resembling in appearance the more shaly Lenoir limestone facies of Tennessee, a partial equivalent of the Lincolnshire. The overlying Thompson Valley clastic limestone occurs throughout the southeast belts in Virginia and Tennessee, being partly equivalent of the commercial "Holston" marble of the Knoxville, Tennessee, area (Farragut limestone). The upper Cliffield (Ward Cove and Peery formations) thins from Virginia into Tennessee, disappearing entirely in southwest Virginia and northeast Tennessee.
>
> * * * From Virginia into Tennessee * * * the most pronounced change * * * is in the grading of the Benbolt-Gratton-Wardell facies into the Sevier shale facies. The Sevier is best developed southeast of Clinch Mountain (and the Tazewell axis) * * *, the interval thinning from more than 4,400 feet in the Bays Mountain area southeast of Knoxville, Tennessee, to less than 800 feet northwest of the axis near the Cumberland escarpment. The Farragut limestone ("Holston marble") thins northwestward and disappears northwest of the arch. The Tellico sandstone shows offlap relationship to the Farragut, thinning out on the southeast flank of the axis. The lower Sevier shaly limestone overlaps the Tellico toward the arch. The middle Sevier * * * thins out directly northwest of the axis. The upper Sevier * * * and the overlying Bowen formation show offlap relationships with the lower Sevier, possibly due to pre-Witten erosion.

Cooper and Cooper (1946, p. 51–53), however, showed that the Mosheim and Lenoir limestones are at least partly equivalent, forming a unit that underlies the Lincolnshire limestone. Elsewhere in their paper (p. 78–80) they suggest the equivalence of the Whitesburg limestone to the Botetourt member of the Edinburg formation, and they proposed (p. 78) use of the term Liberty Hall facies of the Edinburg limestone (a revival of the term Liberty Hall limestone of Campbell, H. D., 1905) for the black shales and platy limestones long referred to as the Athens shale or limestone in Virginia.

The work of Rodgers, G. A. Cooper, B. N. Cooper, and the writer in East Tennessee indicates that Keith's

[1] The Ward Cove, Lincolnshire, Five Oaks, and Blackford were originally (Cooper and Prouty, 1943) classed as members of the Cliffield formation. In later publications (for example, Cooper, 1945, p. 43) these units were given formation rank, and the term Cliffield formation was abandoned.

Athens shale, Tellico sandstone, Sevier shale, and Bays sandstone of the southeastern belt under discussion are equivalents of Keith's Chickamauga and Moccasin limestones of the northwestern belts. The broader outlines of this relation have been shown diagrammatically by King (1950, fig. 9, p. 660). Some differences in the interpretation of the details exist between the different geologists and are presented in their reports. (Rodgers, 1953, p. 66; B. N. Cooper, 1953, p. 3; G. A. Cooper, 1955.)

The graptolites of the Athens shale have been the subject of extensive study by C. E. Decker (1952). In the southern Appalachians, Deckér accepts the stratigraphic classification of the older folios. His graptolite collections from many sections of this unit are significant contributions to our knowledge.

### NECESSITY FOR A REVISED CLASSIFICATION

Two published geologic maps on a scale of 1:125,000 embrace the area of this report: Keith (1895) and Rodgers (1953). The classification of rocks of Middle Ordovician age on neither map conforms with the findings of the present writer.

Keith's (1895) classification below can be recognized in the field, but several of the units of that classification seem arbitrary and unnatural. The Tellico sandstone seems to have been drawn on the basis of its topographic expression, which is quite marked. The Sevier shale contains several units that can be recognized individually, the lowest of which contains a fauna that is notably different from the remainder of the formation.

Rodgers (1953, p. 76–82) briefly described and discussed the rocks on which the present report is based. He distinguished most of the named units of the present report, but named and classified them differently. In the writer's opinion Rodgers' introduction of the terms Ottosee shale and Holston formation and the continued use of the Athens shale here give these terms time-stratigraphic rather than rock-unit status. Observations made after the preparation of Rodgers' report changed many of the present author's views on correlation. He now accepts the correlation of the thick sandy formation, here termed the Chota formation, with the "Holston formation of the standard belt" of Rodgers.

The writer desires to present an accurate description of the stratigraphy in as much detail as is practical, by means of a rock-unit classification based primarily on the rocks of his map area. This classification is compared with those of Keith and Rodgers below. In the treatment of the individual units to follow, a summary of the nomenclatural status of the formation precedes discussion of the unit itself so that problems of terminology are dealt with as they arise.

*Classification of Middle Ordovician rocks of the type Tellico-Sevier belt*

| Present report | Keith, 1895 | Rodgers, 1953 |
|---|---|---|
| Bays formation. | Bays sandstone. | Bays formation.[1] |
| Sevier formation: | | |
| Bacon Bend member. | Not differentiated from main body of Sevier shale. | Not differentiated from main body of Ottosee shale. |
| Sevier formation, main body. | Sevier shale, upper part. | Ottosee shale.[1] |
| Chota formation. | Sandstone lentil in Sevier shale. | Holston formation.[1] |
| Tellico formation. | Includes lower part of Sevier shale, all of Tellico sandstone, and upper part of Athens shale. | Athens shale.[1] |
| Blockhouse shale: | | |
| Dark shale member. | Athens shale, lower part. | |
| Toqua sandstone member. | Not differentiated from Athens shale. | Sandstone layers of Sand Mountain, near Etowah, Tenn. (p. 80). |
| Whitesburg limestone member. | Not differentiated from Chickamauga limestone. | Whitesburg limestone. |
| Lenoir limestone: | | Lenoir limestone: |
| Argillaceous limestone member. | Chickamauga limestone. | Mosheim member. |
| Mosheim member. | | Basal layers with chert fragments and dolomite breccia (p. 78). |
| Douglas Lake member. | | |

[1] Units mapped by Rodgers.

346880—55——2

Each formation of this classification is mappable on scales of 1:62,500 or larger. The designation member is applied to two types of rock units: those so thin that they cannot conveniently be shown on scales smaller than 1:24,000, and those that are lateral equivalents of part or all of a named formation. For the latter type formation rank is given to the units having the most common lithic features and member rank is applied to those having the less well known features.

Older names have been retained where ambiguity seems unlikely. Reasons for departures from previous usages are given in discussions of the individual units below.

New names are given to units that have not previously been recognized or named and to some units whose old names imply a lithic identity which in the writer's view is not present.

## MIDDLE ORDOVICIAN SECTION

The thickness of the Middle Ordovician section in the Tellico-Sevier belt averages 7,500 feet. All the rocks are calcareous—calcareous shale, calcareous siltstone, calcareous mudrock, calcareous sandstone, calcarenite, and limestone. (An exception is a thin quartzite at the top of the section.) The adjective "calcareous" will often be omitted hereafter to avoid unnecessary repetition.

Limestone, 30 to 100 feet thick, forms the base of the section, overlying interbedded dolomite and limestone of the Knox group of Late Cambrian and Early Ordovician age. The limestone is succeeded by dark-gray shale or gray sandstone. The rest of the sequence is a succession of interbedded shale and sandstone to the uppermost unit of maroon mudstone, siltstone, and sandstone. Black Chattanooga shale of Devonian and Carboniferous age overlies the rocks of Middle Ordovician age.

A stratigraphic diagram (pl. 28) is based on the writer's mapping of rocks of Middle Ordovician age; it shows the relations of the rock units encountered. The diagram is an exaggerated downdip view of the outcrop belt. The vertical scale is twice the horizontal scale of the diagram. Churches and schools whose names appear on the topographic maps are plotted on the diagram and properly located with respect to the rock units on which their foundations lie. This diagram can be used, therefore, together with the appropriate topographic maps, to find localities in the area. Fossil localities and other noteworthy points mentioned in the text are indicated by appropriate symbols.

## STRUCTURE OF THE TELLICO-SEVIER BELT

Through most of the area of this investigation rocks of Middle Ordovician age form a homocline in which the beds have an average strike of N. 45° E. and an average dip of 45° SE. In the southwestern part of the area (pl. 27), near the Little Tennessee River, two anticlines define a structural anomaly. The northernmost of these (north of Union Grove Church) brings to the surface rocks of Early Ordovician age in its core, and its axis plunges gently to the southwest, widening the outcrop belt of part of the section. To the southeast a gentle anticline lies athwart the general northeast-southwest structural grain of the area; the Little Tennessee River follows closely the crest of this structure. These two anticlines are apparently not related, for beds may be traced between them without apparent deflection.

In the northeast part of the area, the outcrop belt widens as the homocline passes into a synclinorium. This structure as defined by the limestone and lower shale units is little faulted, but in the higher sandstone and shale units many faults and much complex folding appear. Although it was not possible here to work out stratigraphic relations of the sort determined farther southwest, the complex structure aided stratigraphic work by bringing some fossiliferous beds to the surface at many places across the strike.

## ROCKS UNDERLYING MIDDLE ORDOVICIAN

### KNOX GROUP (LATE CAMBRIAN AND EARLY ORDOVICIAN)—RELATIONS WITH OVERLYING ROCKS

Limestones and dolomites of the Knox group underlie rocks of Middle Ordovician age. The limestones are gray and blue gray, very fine grained, and most are marked by many thin irregular clay partings. Dolomite beds form less than half of the highest few hundred feet of Knox; these are usually light gray, finely crystalline, and well laminated to platy. Fossils showing that these rocks are correlative with the Mascot dolomite have been found at several places.

The contact of the Lenoir limestone (the lowest formation of the Middle Ordovician sequence) with the Knox group is disconformable. Relief on the upper surface of the Knox is indicated by the lenticularity of the Douglas Lake member at the base of the Lenoir limestone. Fragmental material derived from rocks of the Knox group and incorporated in the Douglas Lake member is evidence that the upper surface of the Knox was littered with debris as a result of subaerial exposure. Outcrops are inadequate to make determinations of the relief of this surface within the area studied, but Bridge (1955) found relief of about 140 feet at this contact in the excellent exposures near Douglas Lake a short distance to the northeast.

## LENOIR LIMESTONE

### GENERAL FEATURES

The term Lenoir limestone is here applied to limestones of several distinctive types that comprise the basal part of the Middle Ordovician section. The main part of the formation consists of gray cobbly argillaceous limestone with which the name Lenoir is associated by many geologists from Virginia to Alabama, regardless of its exact stratigraphic position or fossil content. Also included in the Lenoir of this report is dove-gray aphanitic limestone termed the Mosheim member, and a discontinuous basal unit characterized by several kinds of detrital limestone to which the term Douglas Lake member is applied.

The name, Lenoir limestone, was proposed by Safford and Killebrew (1876, p. 130–131) to replace the term "Maclurea Limestone" of Safford (1869). Lenoir limestone is used in preference to Chickamauga limestone (Hayes, 1891) because the former has priority. The type section of the Lenoir limestone near Lenoir City, Tenn., has been described by Cooper and Cooper (1946, p. 52), and their description is summarized as follows:

| | *Thickness* |
|---|---|
| Limestone, dark-gray, medium-grained, sparsely cherty; *Maclurites "magnus"* feet | 100–125 |
| Limestone, impure; *Mimella nucleus* (Butts), *Valcourea* sp., *Hesperorthis* sp feet | 25–45 |
| Mudrock, dolomitic do | 7.5 |
| Limestone, shaly; crowded with *Rostricellula pristina* (Raymond) inches | 2–18 |
| Limestone, dove-gray, aphanitic feet | 4–9 |

Wherever there are exposures, the Lenoir, with a thickness ranging from 26 to 95 feet, intervenes between the basal beds of the Blockhouse shale and the highest beds of the Knox group. This fact is emphasized because Keith in his maps of the area (Keith, 1895, 1896a) showed the Athens shale resting directly on the Knox in most places. Measured sections of the Lenoir and its component members are given in table 1. The members are shown on plate 28 also, but the small scale of that diagram precludes accurate representation of thicknesses.

### DOUGLAS LAKE MEMBER

The term Douglas Lake member of the Lenoir limestone was proposed by Bridge (1955) for unusual beds exposed at the base of the Lenoir on the north shore of Douglas Lake about 2 miles east of Douglas Dam. These exposures are in the Tellico-Sevier belt about 25 miles northeast of the area of the present study.

The Douglas Lake member contains several kinds of clastic and impure limestone, the most common of which are yellow and salmon-pink silty limestone, pink and gray calcarenite, and medium- to coarse-grained limestone conglomerate that locally contains abundant fragments of chert. The fragments contained in the conglomerate are angular and many are lithologically similar to beds in the underlying Knox group.

These detrital limestones and limestone conglomerates are found in five small isolated bodies within the area studied; the locations of two of these are shown on plate 28 (VO 4 and TA 5B). All are at the base of the Lenoir limestone but at considerable distances from one another. None is sufficiently well exposed to permit accurate tracing of its outlines, but the deposits are assumed to be lenticular and to lie in depressions on the upper surface of the Knox group, as they do at Douglas Lake according to Bridge.

### MOSHEIM MEMBER

The term Mosheim limestone was first used by Ulrich (1911). At its type section along the Southern Railroad 0.9 mile south-southwest of Mosheim, Tenn., about 60 feet of thick-bedded dove-gray aphanitic limestone is exposed, with *Maclurites magnus* Lesueur in the upper 10 feet. Between the aphanitic beds and the dolomitic beds of the Knox group is a gray cobbly limestone, 2 feet thick, with large leperditiid ostracodes. Overlying the aphanitic limestone is "5–10 feet of impure, granular, crumbly-weathering limestone containing a few orthid brachiopods, *Mimella* and *Valcourea*, and trilobites, which correlate these beds with the middle beds of the type Lenoir" (Cooper and Cooper, 1946, p. 51).

The Mosheim member of the Lenoir limestone in the Tellico-Sevier belt is identical lithologically with the aphanitic limestone in the Mosheim section. Some beds flecked with numerous calcite crystals are calcarenites (lime sandstones) in which the grains and most of the matrix are composed of the same aphanitic material; some of the filling between grains, however, is crystalline calcite. Because of the purity and massiveness of the Mosheim limestone beds, their weathered surfaces are characteristically fluted.

### ARGILLACEOUS LIMESTONE MEMBER

Gray to dark-gray fine-grained argillaceous limestone forms the main body of the Lenoir in the Tellico-Sevier belt. The argillaceous material concentrated between nodules of limestone gives the rock its distinctive appearance on weathered surfaces. Chert is sparingly present. Small crystals of pyrite are commonly disseminated through the rock, and freshly broken rock has a strong odor of sulfur dioxide.

Within the area of this study, most sections of the Lenoir limestone contain both the argillaceous limestone member and the more pure Mosheim member. In all these the Mosheim is overlain by the argillaceous limestone. In some sections, however, one or the other of these members occupies the whole interval between the Knox group and the overlying Blockhouse shale (see table 1).

Cooper and Cooper have found sections in which rock types that resemble the Mosheim and argillaceous limestones are interbedded, and they conclude: "probably the type Mosheim is a calcilutite facies representing a substantial part of the true Lenoir" (1946, p. 52). It is in this sense that these terms are used here.

The top of the Lenoir limestone appears as a sharp and planar contact. The overlying beds (Whitesburg limestone member of the Blockhouse shale) are similar lithologically to the argillaceous limestone member of the Lenoir, but the darker color of the Lenoir beds readily permits discrimination at most places, and there is no gradation between them.

#### FOSSILS

The Douglas Lake member of the Lenoir limestone has yielded many specimens of a small tumid rhynchonellid brachiopod, identical with or very similar to *Rostricellula pristina* (Raymond) (pl. 25, figs. 38, 39). One specimen of *Lingula fostermontensis* Butts and a few specimens of leperditiid ostracodes were also collected.

From the argillaceous limestone have come "*Rafinesquina*" *champlainensis* (Raymond) (pl. 25, fig. 37), *Valcourea strophomenoides* (Raymond), and a species each of *Hesperorthis* and *Mimella*.

The Mosheim member contains only gastropods. Two forms, identified from calcite-filled cross sections, are *Lophospira* sp. and *Maclurites magnus*? Lesueur.

The faunas and stratigraphy of the Lenoir limestone of the Tellico-Sevier belt correspond well with those at Lenoir City and Mosheim, Tenn., and leave little doubt that all should be assigned to the Lenoir limestone of the type section.

#### SOILS AND TOPOGRAPHIC EXPRESSION

The Lenoir limestone does not form a distinct soil in this area. Its outcrop belt is narrow and its content of insoluble residues is low compared to the thick formations adjacent to it, so that in most places its outcrop is concealed by colluvial deposits from the neighboring formations. Nevertheless, the Lenoir has a definite, although subtle, topographic expression. Many small streams follow it closely, and elsewhere a gentle depression marks its trace.

## BLOCKHOUSE SHALE

#### GENERAL FEATURES

Dark-gray calcareous shale with thin beds and lenses of dark-gray dense limestone forms the main body of a unit of formational rank, 150 to 950 feet thick, here given the name Blockhouse shale. In the southwestern part of the area studied these fine-grained rocks are partly replaced by fine- to coarse-grained sandstone, named Toqua sandstone member in this report. Thin argillaceous limestone forms a basal member of the Blockhouse shale, and the term Whitesburg limestone member is applied to it.

#### NAME

The Blockhouse shale as defined in this report was included by Keith (1895) and Rodgers (1953) in the lower part of the Athens shale. The writer departs from this usage for two reasons: the rocks of this area do not have many significant characters in common with the rocks at the type section of the Athens shale, and the dark-gray shale and associated rocks, here called the Blockhouse, form a distinct mappable unit that warrants recognition as a formation.

TABLE 1.—*Thicknesses, in feet, of constituent units at measured sections of the Lenoir limestone*

[Locality numbers refer to points indicated on plate 28]

| Locality no. | WD 41 | WD 2 | BL 9 | BL 5 | BL 4 | BN 3 | BN 5 | TA 5 | VO 8 | VO 22 |
|---|---|---|---|---|---|---|---|---|---|---|
| Distance between sections, in miles | 6.6 | 2.2 | 3.2 | 0.9 | 6.0 | 1.9 | 2.7 | 2.6 | 4.5 | |
| Argillaceous limestone member | 14 | 15 | 3 | 40 | 10 | 45 | | 40 | 45 | 10 |
| Light-gray pure limestone (Mosheim member) | 12 | 55 | 50 | 45 | 60 | | 45 | | | 30 |
| Basal clastic limestone (Douglas Lake member) | 3 | | | | | | | 55 | 20 | |

Typical Athens shale at the town of Athens, Tenn., was described by Rodgers (1952b) as "blue, nodular, calcareous and argillaceous rock that is more nearly shaly limestone than true shale. * * * Black shale, which is supposedly typical of the Athens, does not occur in this area."

The term Athens shale has been widely extended to include black calcareous shale (Keith, 1895; Ulrich, 1911; Butts, 1940; Decker, 1952 and others); but, in the author's opinion, refined stratigraphic nomenclature requires that this and other terms be confined to one type of rock, contiguous or demonstrably contemporaneous with the unit at its type section. Local names have been given to equivalent rocks of different facies in other parts of the stratigraphic column. The terms Copper Ridge dolomite and Conococheague limestone, for example, are applied to different lithofacies of the same Upper Cambrian interval (Howell, chm., and others, 1944), and this practice contributes to clear stratigraphic nomenclature. Thus the term Athens should be applied only to rock comparable to that of the type section.

*Geologic section 1. Type section of the Blockhouse shale, Blockhouse quadrangle, Blount County, Tenn.*

[The base of this section is 800 ft southwest of Bench Mark F 132Y (elevation 972 ft) extending southeastward up a gullied hillside. Attitude of bedding somewhat variable, strike averaging N. 40° E., dip 50° SE.]

Tellico formation, lower shale division: Gray, brown and buff-weathering silty shale, sandy shale, 2 ft thick, about 50 ft above base.

| | Feet |
|---|---|
| Blockhouse shale: | |
| Dark shale member: | |
| 4. Shale, fissile, chocolate-brown weathering, without silt, interbedded with buff-weathering silty shale | 20 |
| 3. Shale, fissile, chocolate-brown weathering, without silt | 30 |
| 2. Shale, dark-gray; brown-weathering, with intercalated cobbles and beds, 2 to 6 in. thick, of dense, dark-gray limestone; no fossils seen | 150 |
| 1. Shale, calcareous, fissile, dark-gray, gray-brown weathering, weathered chips paper-thin, crunchy underfoot; fragments of graptolites in all but basal 25 ft | 200 |
| Whitesburg limestone member: | |
| Limestone, light-gray, cobbly, upper 2 to 5 ft interbedded with dark-gray shale | 5–20 |

Lenoir limestone at base of section.

## WHITESBURG LIMESTONE MEMBER

### NAME

The Whitesburg limestone was named by Ulrich (1929, p. 2, footnote) for dark crystalline limestone between the dark calcareous Athens shale and the Lenoir limestone. The type locality was designated as 2 miles southeast of Whitesburg, Hamblen County, Tenn. (fig. 22), where the thickness was stated to be 500 feet.

Cooper and Cooper (1946, p. 54) say "the type Whitesburg is composed of black limestone and intercalated graptoliferous shales with an aggregate thickness of 500 feet * * * "

The writer found few exposures at this type section. Above the dolomites of the Knox group are scattered exposures of cobbly limestone that probably belongs to the Lenoir limestone. These are overlain by about 5 feet of granular limestone that contains brachiopods and abundant fragmental trilobite remains. Overlying these beds is dark-gray thin-bedded to slabby very fine grained limestone with interbedded dark-gray shale that contains graptolites.

G. A. Cooper (oral communication, 1949) pointed out a locality about 6 miles north-northeast of the Whitesburg section where similar granular limestone about 400 feet thick contains the same fossils as the 5-foot unit of the type section. This thick unit of granular limestone is also overlain by dark-gray graptolite shale, with intercalated light-gray calcarenite. The variability of thickness of the granular limestone, therefore, appears to be very great here, from 5 feet to 400 feet in 6 miles.

Separation of the graptolite-bearing shale and limestone from the granular limestone with trilobites and brachiopods seems warranted. The writer has therefore applied the term Whitesburg limestone member of the Blockhouse shale to the granular beds. The limestone is considered a basal member of the graptolite-bearing beds because of the gradational contact between them. Keith (1895, 1896a) undoubtedly included the beds here classed as the Whitesburg in his Chickamauga limestone, as he did in the vicinity of Whitesburg (Keith, 1896b).

### LITHIC FEATURES

The Whitesburg limestone member of the Blockhouse shale contains two contrasting phases: light-gray fine-grained argillaceous cobbly limestone and dark-gray granular ferruginous siliceous argillaceous, and commonly oolitic, limestone that occurs in even beds averaging about 2 inches in thickness. These two phases have been found in the same exposure, but in most places only one is present.

The cobbly bedded rock is exposed in fresh outcrops at only a few places; where fresh it is not easily distinguished from the argillaceous limestone member of the underlying Lenoir limestone. The Whitesburg is, however, lighter colored than the Lenoir, slightly more argillaceous, and contains much more fragmental organic debris. Weathering of this phase of the Whitesburg is most effective on the shaly matrix that encloses the cobbles, commonly freeing them to litter the surface of the ground.

Fresh rock of the even-bedded granular phase is very hard and tough, difficult to break with a hammer. It weathers to a reddish-yellow compact saprolite in which many fossils are well preserved as molds. At one outcrop in the Vonore quadrangle (VO 4, pl. 28) the rock contains sufficient iron to weather a deep hematitic red. Much of this rock in the southwestern part of the area studied contains scattered small well-rounded quartz grains.

The cobbly bedded fine-grained rock occurs in the central part of the area studied, from about the Sevier-Blount County line southwestward to the area between localities BL 5 and BN 4 of plate 28. In this area the member is from 3.5 to 20 feet thick (table 2). The even-bedded granular limestone is from 10 to 21 feet thick; it occurs in both the northeastern and southwestern parts of the area and along the limbs of the narrow syncline that parallels the main belt in the eastern part of Blount County.

### DARK SHALE MEMBER

#### LITHIC FEATURES

The dominant rock of the Blockhouse shale is dark-gray finely laminated calcareous shale. Parallel laminae spaced at intervals of from 1 to 4 millimeters set apart somewhat differently colored rock. Where slightly weathered, the laminae form closely space planes of fissility.

In the upper half of the Blockhouse, gray dense fine-grained limestone forms beds and lenses within the shale. Many are plainly marked by shrinkage cracks. The thicker limestone beds are from 6 to 8 inches thick and may be traced along outcrops for considerable distances; most, however, are only 2 or 3 inches thick and are not persistent. The limestone beds do not have the laminations of the enclosing shale.

Although the shales that characterize the Blockhouse have often been referred to as black, they are actually dark gray and distinct from such black noncalcareous shales as form the Deepkill shale of New York or the Chattanooga shale of Tennessee.

Weathered Blockhouse shale is gray brown or chocolate brown, in contrast to the buff, yellow, and ochrous shades of higher shales of this Middle Ordovician section. Weathering reduces the rock to brittle thin leaves that produce a characteristic crunchy noise when walked upon.

### TOQUA SANDSTONE MEMBER

#### NAME

The term Toqua sandstone member of the Blockhouse shale is here given to fine- to coarse-grained gray calcareous sandstone that occurs in the lower part of the formation in the southwestern part of the area of this study. The name is taken from Toqua Church, Vonore quadrangle, Monroe County, Tenn. (see type section, Geologic section 2).

The presence of a sandstone at this horizon is not indicated in the Loudon folio (Keith, 1896a), and the area encompassing the outcrop of this rock was mapped as the Athens shale in that folio and by Rodgers (1953, pl. 8).

#### LITHIC FEATURES

The Toqua sandstone member of the Blockhouse shale is formed of light-gray fine- to coarse-grained calcareous sandstone. The finer grained sandstone is well laminated, crossbedded, and occurs in beds 4 to 12 inches thick that are separated by thinner beds of dark-gray graptoliferous shale. The coarser grained rock is poorly laminated and forms beds 10 to 20 inches thick which are set apart by poorly defined bedding plane partings that do not contain shale. Poor sorting characterizes the coarse-grained sandstone: particle size ranges from clay size to rock fragments as large as 30 millimeters in diameter. The average large size of quartz grains is from 1 to 1.5 millimeters, and the largest fragments are rounded pebbles of dense gray limestone.

An unusual but rare component of the rock throughout the Toqua are fragmental graptolites that remain uncrushed.

Weathered rock of the Toqua is greenish brown or olive; its saprolite is yellow brown to ochrous. These colors contrast with the dark brown and red colors of weathered sandstone units higher in this section.

TABLE 2.—*Thickness and type of bedding at measured sections of the Whitesburg member of the Blockhouse shale*

| Locality no | WA 2 | WD 41 | WD 2 | BL 7 | BL 5 | BN 3 | TA 5 | VO 4 | VO 22 |
|---|---|---|---|---|---|---|---|---|---|
| Distance between sections, in miles | 3.0 | 6.6 | 2.2 | 3.2 | 6.9 | 3.6 | 1.9 | 4.9 | |
| Type bedding | Even | Cobbly | Cobbly | Cobbly | Cobbly | Even | Even | Even | Even |
| Thickness, in feet | 21 | 3.5 | 5 | 6 | 5–20 | 14 | 10 | 10 | 10 |

*Geologic section 2.—Type section of the Toqua sandstone member of the Blockhouse shale*

**[Section measured 1.15 miles southeast of Toqua Church, Vonore quadrangle, Monroe County, Tenn., near the southeast bank of the Tellico River, along and near a wagon road. Strike averages N. 65° E., dip 25° SE.]**

*Portion of section exposed near wagon road*

| | Feet |
|---|---|
| Blockhouse shale: | |
| Dark shale member: | |
| 20. Shale, dark-gray, finely laminated, calcareous, silt-free; seen only in abundant float and in a few small outcrops about 500 ft northeast of wagon road; about | 200 |
| Toqua sandstone member, about 400 ft thick: | |
| 19. Sandstone, fine-grained, and dark-gray shale, interbedded; poorly exposed in cultivated fields about 500 ft northeast of wagon road; about | 150 |
| 18. Sandstone, fine-grained, and silty shale, interbedded; here deeply weathered to saprolite; sandstone is thin bedded in units from 6 in. to 2 ft thick, forming about one-third of the total thickness of this part of the section; exposed in gullies about 200 ft northeast of the wagon road; about | 100 |
| *Portion of section exposed along wagon road* | |
| 17. Sandstone calcareous, medium- to coarse-grained, with small rounded fragments of fine-grained limestone; beds from 6 in. to 2 ft thick | 20 |
| 16. Covered in gully | 10 |
| 15. Sandstone calcareous, light-gray, weathers to greenish-brown; fine- to coarse-grained, poorly sorted; beds about 1 ft thick, with laminations about 1 in. apart; uncrushed graptolites: *Climacograptus* sp., *Diplograptus* sp., *Glossograptus* sp | 20 |
| 14. Sandstone, fine- to medium-grained; weathered and poorly exposed | 15 |
| 13. Claystone, fissile, ochrous, punky; saprolite of shale | 1 |
| 12. Sandstone, weathered, fine- to medium-grained; weathers to yellow-brown | 2 |
| 11. Shale, weathered, chocolate-brown; lacks silt | 0.5 |
| 10. Sandstone calcareous, light-gray, weathers to greenish-brown; mostly fine grained and platy; fragmental uncrushed graptolites | 6 |
| 9. Shale, weathered, chocolate-brown, fissile, silt-free; abundant graptolites: *Nemagraptus gracilis* (Hall), *Dicellograptus moffatensis* var. *alabamensis* Ruedemann, *Didymograptus sagitticaulus* Gurley, *Climacograptus* sp., *Diplograptus* sp | 1.5 |
| 8. Sandstone calcareous, light-gray, fine- to medium-grained; most of the unit is fine grained and platy, with a few coarser grained beds as much as 1.5 ft thick without laminae | 14 |
| 7. Sandstone calcareous, light-gray, fine-grained, platy, crossbedded, with a few medium-grained nonlaminated beds | 28 |
| *Portion of section exposed on hillside to north of wagon road* | |
| 6. Sandstone calcareous, light-gray, weathers to greenish-brown, with gray surfaces; beds about 1 ft thick with faint parallel laminae from ½ to 1 in. apart | 10 |
| 5. Siltstone, light-gray, platy; small detrital mica flakes in some bedding planes | 20 |
| Whitesburg limestone member, 15 ft thick: | |
| 4. Limestone, dark-gray, granular, argillaceous; weathers to dark-brown; *Christiania subquadrata* Hall and Clarke, and other fossils | 10 |
| 3. Limestone, gray, granular, with irregular clay partings; much fragmental fossil remains | 5 |
| Lenoir limestone, 40 ft thick: | |
| 2. Limestone, fine-grained, argillaceous, nodular | 10 |
| 1. Limestone, aphanitic, dove-gray, with flecks of crystalline calcite (Mosheim member) | 30 |
| Limestone of Knox group at base. | |

## STRATIGRAPHIC RELATIONS

### INTERNAL STRATIGRAPHY

The Blockhouse shale as a whole ranges in thickness from 150 feet (BN 2) to about 950 feet (TA 5A); the average for the formation is about 400 feet, the thickness of the type section.

The contact of the Whitesburg limestone member with the dark shale member is gradational. Where these relations are best seen (loc. BL 5 at Blockhouse, pl. 28) the cobbly beds of the Whitesburg thicken from 5 to 20 feet along 750 feet of strike distance, and in the thickened portion includes tongues of dark-gray shale 6 inches to 2 feet thick.

The contact of the Whitesburg with the Toqua sandstone member, however, is sharp and without interbedding. Where the Toqua overlies the Whitesburg, the Whitesburg commonly contains scattered grains of quartz in shaly partings between limestone strata.

Dark-gray shale forms the full thickness of the formation above the Whitesburg in the northeastern segment of the belt. The Toqua sandstone member forms the lower part of the formation toward the southwest. The section near Mint (BN 2, same as Decker, 1952, Geologic section 7, p. 34) displays the interrelations of the shale and sandstone facies and is the northeasternmost exposure of the sandstone facies. A lower shale unit, here 55 feet thick, contains a few sandy beds each about 2 inches thick. This is overlain by beds of coarse- and fine-grained sandstone, some as much as a foot thick without laminae, separated by shaly partings (Toqua sandstone member), forming a unit about 20 feet thick. The overlying unit, about 85 feet thick, is composed of dark-gray shale with thin beds of fine-grained dark-gray limestone near the top. The dark-gray shale is overlain by medium-gray buff-weathering silty shale of the Tellico formation.

# PLATE 25

[Photographs by G. A. Cooper. All figures natural size except where otherwise indicated]

FIGURES 1–3. *Pionodema* sp. Bacon Bend member of Sevier formation, locality TA 29A, 0.14 mile northeast of Fourmile Church, Tallassee quadrangle.
1. Impression of part of pedicle exterior from mold, × 2, USNM 117343b.
2. Mold of brachial interior, × 2, USNM 117343m.
3. Mold of pedicle interior, × 2. Counterpart of fig. 1.

4, 5. *Sowerbyella* sp. Sevier formation, upper shale division, locality BN 11, 0.53 mile east-southeast of Old Kagley Church, Binfield quadrangle.
4. Mold of brachial interior, 2 specimens, × 2, USNM 123579b.
5. Mold of pedicle interior (lower specimen) and brachial exterior (upper specimen); mold of pedicle interior of *Glyptorthis* sp. at left center, × 2, USNM 123579a.

6–8. *Dinorthis transversa* Willard. Sevier formation, middle sandstone division, locality KZ 11, 1.57 miles southwest of Rocky Branch, Kinzel Springs quadrangle.
6. Impression from mold of brachial exterior, USNM 118024b. Note branching costae.
7. Mold of brachial interior, USNM 118024f.
8. Mold of pedicle interior, USNM 118024a.

9. "*Camerella*" *longirostris* Billings. Sevier formation, middle sandstone division, locality TA 25, 0.28 mile northwest of Fourmile Church, Tallassee quadrangle.
Pedicle exterior, × 2, USNM 117096a.

10–13. *Zygospira* sp.
10. Several specimens partly buried in matrix, × 2, USNM 123577b.
11, 12, 13. Pedicle, brachial, and anterior views, × 3, USNM 123577a. Bacon Bend member of Sevier formation, locality B 35, 0.27 mile southeast of Christie Hill School, Blockhouse quadrangle.

14–16. Gen. and sp. aff. *Zygospira acutirostris* (Hall). Sevier formation, 8 miles south of Cleveland, Tenn., 0.5 mile southeast of Hambright mine. This fossil is common in the Chota formation.
Pedicle, brachial, and anterior views, × 3, USNM 117189a.

17–19. *Oligorhynchia* sp. Sevier formation, west side of Guthrie Gap, 2 miles south-southeast of Whitehorn, Bulls Gap quadrangle.
Pedicle, brachial, and anterior views, × 3, USNM 118017.

20, 21. *Sowerbyites* sp. Tellico formation, upper shale division, locality WA 45, Chapman Highway, 1.58 miles east-northeast of Cusick, Walden Creek quadrangle.
20. Pedicle exterior, partly exfoliated, USNM 123578a.
21. Brachial exterior, partly exfoliated, USNM 123578b.

22, 23. *Cyrtonotella* sp. Tellico formation, upper shale division, locality B 136, at bench mark LHT 1366, 1 mile southeast of Chilhowee View School, Blockhouse quadrangle.
22. Mold of pedicle interior, USNM 123574a.
23. Mold of brachial interior, USNM 123574b.

24–27. *Paurorthis catawbensis* Butts. Tellico formation, upper shale division, locality VO 21, 1.6 miles south-southeast of Toqua School.
24, 25. Brachial view, × 1 and × 2, USNM 117278a.
26. Brachial interior of silicified specimen, × 2, USNM 117278b.
27. Two molds of pedicle interior and fragment of external mold, × 2, USNM 117275.

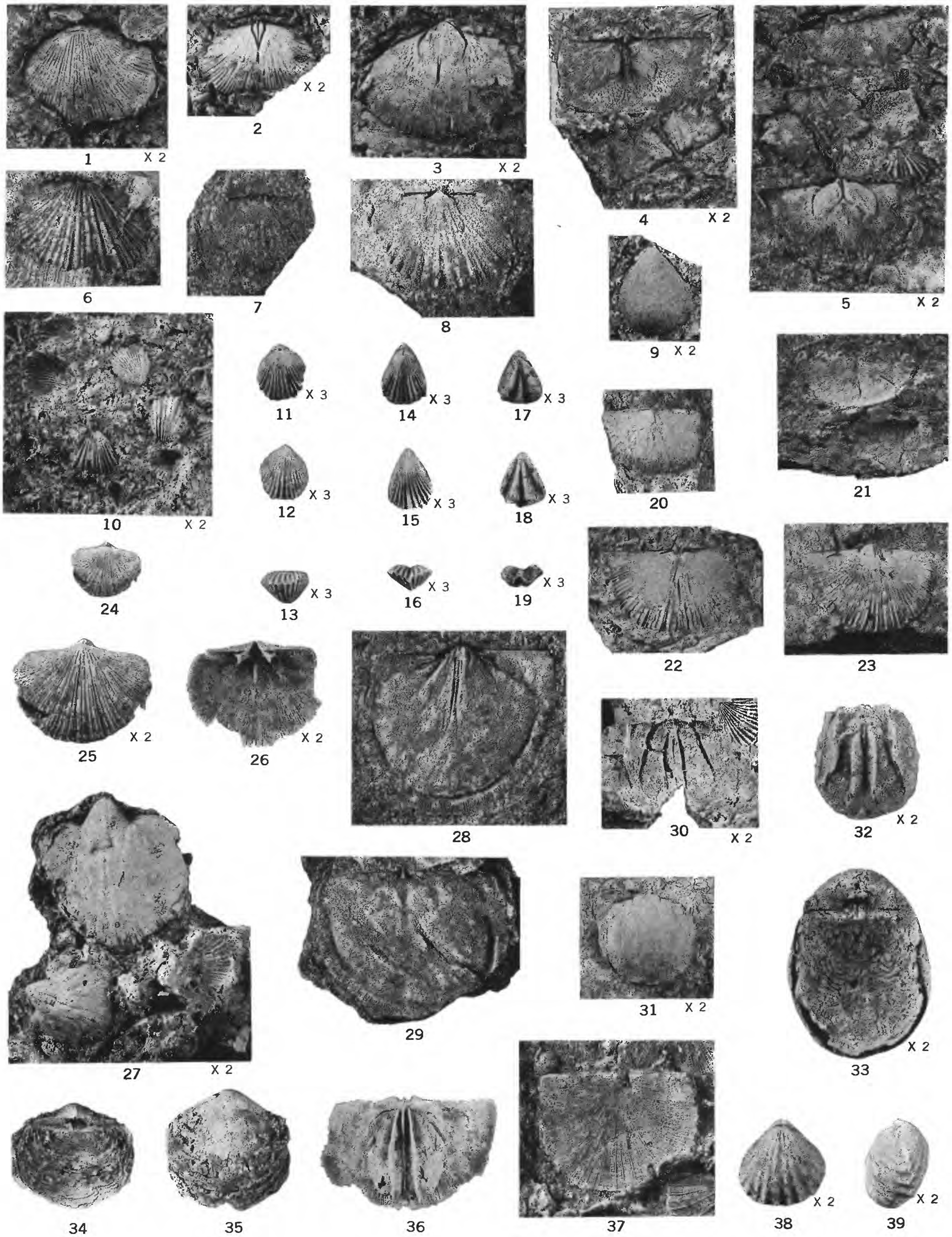
28, 29. "*Strophomena*" *tennesseensis* Willard. Tellico formation, middle sandstone division, locality WD 6, 0.3 mile northwest of Cold Spring Church.
28. Mold of pedicle interior, USNM 123580a.
29. Mold of brachial interior, USNM 123580b.

30–33. *Christiania subquadrata* Hall and Clarke. Figs. 30 and 31 from Whitesburg limestone member of Blockhouse shale; figs. 32 and 33 from "Upper" Lenoir limestone, a quarter of a mile southeast of Friendsville, Concord quadrangle.
30. Mold of brachial interior, × 2, USNM 123575a.
Locality BN 4, 0.8 mile southeast of Centenary Church, Binfield quadrangle.
31. Mold of pedicle interior, immature specimen, × 2, USNM 123576a. Locality TA 3, U. S. Highway 129, 1 mile north of Wellsville, Tallassee quadrangle.
32. Brachial interior of silicified specimen, × 2, USNM 117580j.
33. Brachial view of silicified specimen, × 2, USNM 11016a.

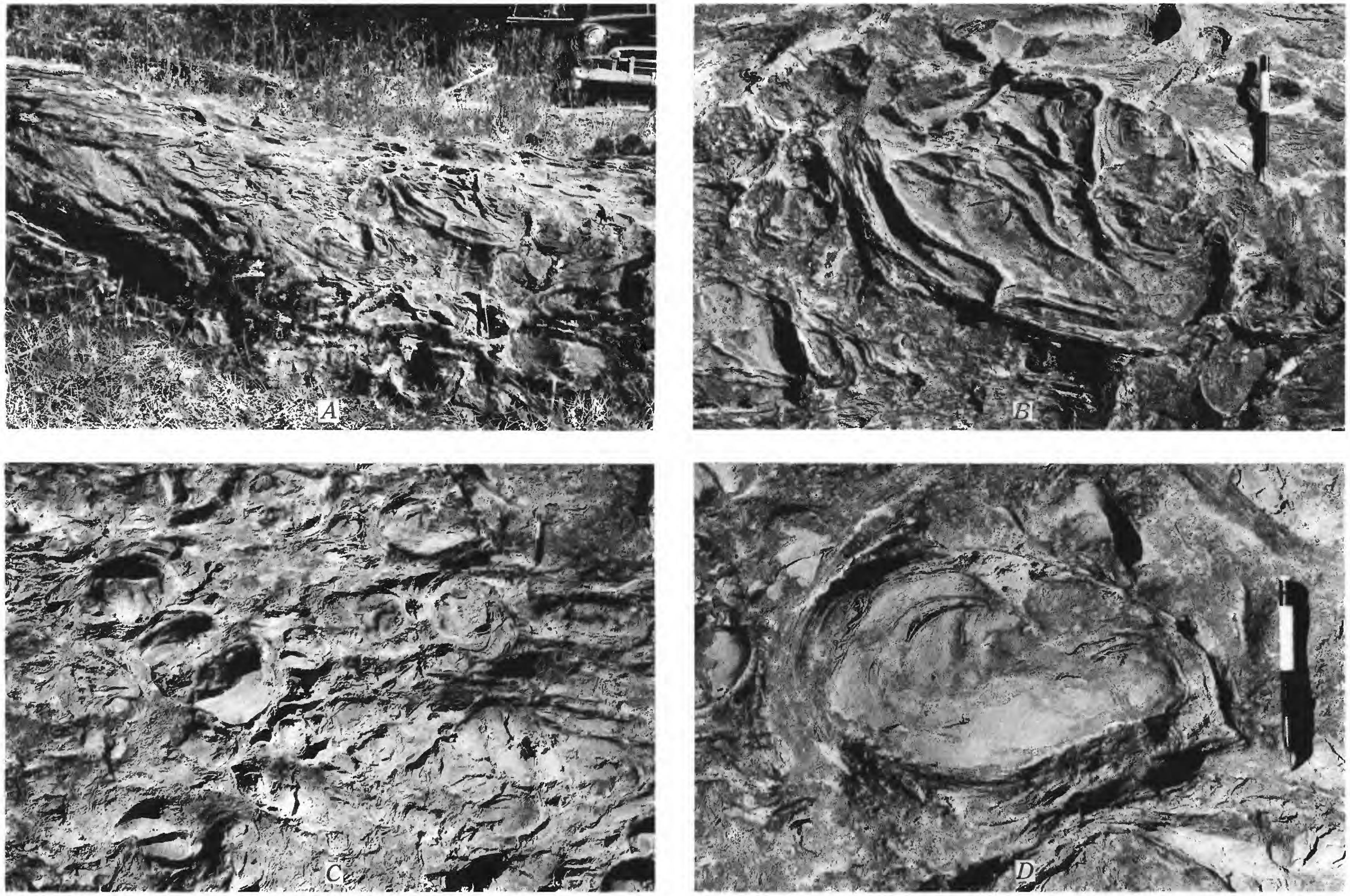
34–36. *Bimuria superba* Ulrich and Cooper. "Upper" Lenoir limestone.
34. Pedicle view of silicified specimen, USNM 108201.
Between Friendsville and Christiansburg, Tenn.
35. Brachial view of silicified specimen, USNM 108200a.
36. Brachial interior of silicified specimen, USNM 108200h.
A quarter of a mile southeast of Friendsville, Concord quadrangle, Tennessee.

37. "*Rafinesquina*" *champlainensis* (Raymond). Lenoir limestone, locality WD 45, 0.1 mile southwest of triangulation station 37 SH, Wildwood quadrangle.
Brachial view.

38, 39. *Rostricellula* cf. *R. pristina* (Raymond). Douglas Lake member of Lenoir limestone, locality TA 5, 0.65 mile southwest of Williamson Chapel, Tallassee quadrangle.
Brachial and lateral views of a specimen, × 2, USNM 117238b.




REPRESENTATIVE BRACHIOPODS FROM ROCKS OF MIDDLE ORDOVICIAN AGE IN THE TELLICO-SEVIER BELT




CONTORTED BED IN THE BACON BEND MEMBER OF THE SEVIER FORMATION

Four views of unit 5 of Geologic section 6, Tallassee quadrangle, 0.25 mile southwest of Fourmile Church. Photographs taken by H. E. Malde. In all views the smoother depressed areas are formed of relatively massive silty limestone; the remainder of the rock is contorted calcareous shale. Bed dips 30° SE; the longest axis of most deformed nodules parallel the strike, N. 55° E. *A*, General view downdip; *B*, Closer view of part of *A*, showing details of hooked shapes and abrupt termination of laminations at the border of shapes; *C*, View of bedding surface; *D*, Closer view of part of *C*, showing detail of a shape in which laminations nearly follows its outline.

Southwest of the section at Mint the dark-gray shale and the Toqua sandstone member thicken. The maximum thickness of the formation, including all members (about 950 feet), is attained near locality TA 5A (pl. 28); southwest of that point the entire formation thins very gradually. The Toqua sandstone member thickens to the maximum observed at the southwestern edge of the area studied (Geologic section 2), where the sandstone measured 400 feet in thickness and is overlain by about 175 feet of dark-gray shale.

#### CONTACT WITH THE TELLICO FORMATION

The upper contact of the Blockhouse shale is gradational through a zone that in most places is about 20 feet thick. In this zone beds of dark-gray silt-free shale, 4 to 10 inches thick, alternate with beds of lighter colored silty shale of comparable thickness, the proportion of lighter colored beds to darker ones increasing upward to the final exclusion of the darker ones. The writer believes that to designate any horizon in this gradational zone as the contact would be unnatural; for mapping, however, the lowest appearance of lighter colored shale was chosen as the contact.

#### FOSSILS

The Whitesburg limestone member of the Blockhouse shale is moderately fossiliferous. Fossils weather out on the surfaces of the loose cobbles, or molds may be found in the saprolite of the evenly bedded rock. Following is a synoptic list of the forms that have been identified in it:

Trilobites:
- *Acrolichas* sp.
- *Cybiloides*, sp.
- *Pliomerops* sp.
- *Ampyx* sp.

Brachiopods:
- *Paurorthis* sp.
- Gen. and sp. aff. *Leptella pseudoretroflexa* Reed
- *Dactylogonia* sp.
- *Leptellina* sp.
- *Christiania subquadrata* Hall and Clarke (pl. 25, figs. 30, 31)
- *Paleostrophomena* sp.
- *Clitambonites* sp.
- *Skenidioides* sp.
- *Orthambonites* sp.
- *Glyptorthis* sp.
- *Schizotreta* sp.
- *Lingulasma* sp.
- *Lingula* sp.

Numerous ostracodes, bryozoans, and much encrinal debris remain to be identified.

G. A. Cooper (oral communication, 1953), on the basis of extensive work by himself and B. N. Cooper, recognizes the faunule listed above as an assemblage characteristic of the Whitesburg limestone of the type area, which they relate to the Ward Cove limestone of southwestern Virginia.



The dark shale and the Toqua sandstone members have yielded only graptolites. In the shale these fossils have been crushed, but several uncrushed specimens have been found in the sandstones.

A list of all forms identified by the writer and Josiah Bridge follows:

*Nemagraptus gracilis* (Hall)
*Dicellograptus moffatensis* var. *alabamensis* Ruedemann
  cf. *D. sextans* (Hall)
*Diplograptus* (2 species)
*Didymograptus sagitticaulus* Gurley
*Cryptograptus tricornis* var. *insectiformis* Ruedmann
*Glossograptus* sp.
*Climacograptus* sp.

Decker (1952, p. 35) reported the following graptolites from his section 7 which corresponds with locality BN 2 of this paper.

*Climacograptus antiquus* var. *lineatus* Elles and Wood
  *modestus* Ruedemann
  *scharenbergi* Lapworth
*Cryptograptus tricornis* (Carruthers)
*Dicellograptus forchammeri* var. *flexuosus* Lapworth
  *forchammeri* var. *diapson* Gurley
*Didymograptus sagitticaulus* Gurley
  *serratulus* (Hall)
*Diplograptus* (*Amplexograptus*) *maxwelli* Decker
  (*Glyptograptus*) *euglyphus* Lapworth
    *vespertinus* Ruedemann
  (*Orthograptus*) *calcaratus* var. *acutus* Lapworth
  *calcaratus* var. *alabamensis* Ruedemann
  *calcaratus* var. *incisus* Lapworth
*Nemagraptus gracilis* (Hall)
*Glossograptus quadrimucronatus* var. *maximus* Decker
  *ciliatus* Emmons
  *whitfieldi* (Hall)

This graptolite faunule corresponds to that of the middle zone of the Athens shale of Decker (1952, p. 76) and to the Liberty Hall facies of the Edinburg formation in Virginia (Cooper and Cooper, 1946, p. 78–86).

#### SOILS AND TOPOGRAPHIC EXPRESSION

The small thickness of the Whitesburg limestone member of the Blockhouse shale precludes its having much effect on the soils or topography. Through most of their belts of outcrop the Whitesburg and the Lenoir limestones crop out in the same gentle topographic depression. The more ferruginous and siliceous phase of the Whitesburg imparts a deep red color to the soil and contributes abundant blocky fragments to the residuum—a feature that led Safford (1869, p. 232) to name this rock the "Block Limestone." These cap a gentle topographic swell between depressions underlain by the purer limestone below and the weaker shale above.

The dark shale member of the Blockhouse shale roduces a thin compact soil, which, in many places, has been completely removed by erosion. The soil is clayey because the rock contains a few particles larger than clay size. These particles pack closely so that the soil has low permeability; water does not soak in but runs off, carrying with it much of the loose fine material, keeping the soil thin.

On the manuscript soils map of Sevier County by the U. S. Soil Survey (Hubbard and others, 1948) the outcrop area of the Blockhouse shale in the vicinity of Knob Creek (pl. 27) stands out plainly, the distinctive soils formed on it being classed in the Needmore and Dandridge series; those formed on adjacent formations are classified as an undifferentiated complex of Litz and Dandridge soils.

A subdued rolling topography is formed on this shale, in contrast with the knobs to the southeast that are supported by more resistant beds of the overlying Tellico formation.

Soils formed from the Toqua sandstone member of the Blockhouse shale are light brown, thick, friable, and sandy. Where the Toqua is 20 to 100 feet thick it forms a low ridge; where its thickness is greater than 100 feet it supports a ridge that stands about 150 feet above the adjacent lowlands underlain by shale.

## TELLICO FORMATION

### GENERAL FEATURES AND NAME

The term Tellico formation is here applied to a sequence of gray silty, sandy calcareous shale and calcareous sandstone 2,700 to 4,500 feet thick. The dominant rock of the formation is shale, in which sandstone forms lenticular units. In general, sandstone units are concentrated near the middle of the formation, and it is to this part that Keith originally applied the term Tellico sandstone.

The Tellico formation as used in the present report includes rocks above and below those originally included in the term by Keith (1895, 1896a). As herein defined it includes the upper part of the Athens formation, the Tellico formation, and that part of the Sevier formation beneath the "sandstone lentil" of the Knoxville and Loudon folios.

### LITHIC FEATURES

#### CALCAREOUS SHALE

Most of the Tellico formation is composed of light-gray, silty, and sandy calcareous shale. The rock commonly splits into parallel plates and slabs 10 to 20 millimeters thick along planes that are coated with finely divided mica. Between these are more closely spaced laminae that result from slight variations in composition. Laminations of the more argillaceous rock are even and parallel, but with increasing amounts of silt and sand laminations become wavy, with less regular and wider spacing. Contrasted with the dark-gray shale member of the Blockhouse shale below, the shale of the Tellico formation is lighter colored, less finely laminated, and contains silt and sand which is lacking in the lower shale. Weathered shale of the Tellico formation is yellow and buff in contrast with the brown colors of weathered Blockhouse shale.

Cobbles of light-gray very fine grained limestone are contained in the shale in a few places in the upper part of the formation. These cobbles are commonly very fossiliferous, and most of the fossils listed below from the upper part of the formation were collected from them. Where deeply weathered the limestone cobbles are represented only by pockets of red clay surrounded by soft weathered yellow shale. At one place (VO 26) limestone cobbles weather free from their shale matrix and litter the surface of the ground.

#### CALCAREOUS SANDSTONE

Calcareous sandstone of the Tellico formation is medium gray to bluish gray, fine to medium grained, and generally even textured. The most common detrital constituent is quartz that occurs in subrounded grains. Abundant angular grains of sodic plagioclase are contained in many beds. Calcium carbonate occurs as fossil shells, detrital grains including abraded organic debris, and as crystalline interstitial cement. Iron oxide and unidentified clay minerals together form as much as 25 percent of the rock.

Individual sandstone strata are from 2 to 8 inches thick and form units as much as 250 feet thick composed of a sequence of thin sandstone strata separated by shaly partings. The shale partings are from ½ to 2 inches thick and are commonly uniform and parallel. The individual sandstone strata between shale partings are uniform, without laminae, crossbedding, or graded bedding.

The sandstone weathers brown, reddish brown, and yellow brown; most outcrops have a distinct weathered rind. Deeply weathered rock from which calcium carbonate has been completely removed retains much of its cohesiveness, some being barely friable.

Associated with the sandstone at a few places are layers of light-gray and pink argillaceous calcarenite as much as 20 feet thick. This rock is composed of detrital calcium carbonate formed mostly from fragmental organic materials, largely crinoidal, but containing fragments of bryozoan colonies and fragmental brachiopods. Where weathered, this rock leaves a saprolite of porous clay which retains many structures of the fresh rock.

Thin beds of siliceous ferruginous limestone conglomerate are interbedded with sandstone layers at a few places. The conglomerates are made up of rounded fragments of very fine grained limestone of unrecognized stratigraphic origin; these average about 15 millimeters in diameter, and they are embedded in a calcareous sandstone matrix.

### STRATIGRAPHIC RELATIONS

#### INTERNAL STRATIGRAPHY

The Tellico formation is 2,700 to 4,500 feet thick. The maximum thickness is in the northeastern part of the area studied, northeast of Blockhouse; the minimum is near Union Grove Church (pls. 27, 28).

Contacts of the individual sandstone strata with shale are well defined; those that define the mappable sandstone units, however, are gradational. At these, thin beds of sandstone are interleaved with shale through zones 5 to 50 feet thick. Distal edges of sandstone units pass into sandy shale and shaly sandstone and cease to be traceable.

Units of sandstone occur as lenses of widely varying dimensions from about 500 feet above the base of the formation to within 200 feet of its top. The thicker and more persistent ones are concentrated near the middle of the formation, and it is to this part of the section that the term Tellico sandstone was originally applied (Keith, 1895, 1896a). Only those sandstone units more than 75 feet thick were mapped and are shown on plate 28.

Three areas characterize three modes of occurrence of the mappable sandstone units: (1) the central and northeastern parts where two to four sandstone units can be mapped; (2) to the southwest, in the vicinity of Wellsville, where there is only one thick sandstone; and (3) the Tellico River section where there are several relatively thin sandstone units. The positions, limits of traceability, and relative thicknesses of these units are shown on plate 28. That part of the formation in which sandstone units are concentrated may be considered to form a middle sandstone division that intervenes between a lower and an upper shale division. In order to identify the stratigraphic position from which fossils were collected, these general subdivisions are shown on plate 28 and are indicated in the faunal list that follows and in the range chart of brachiopods (fig. 23).

#### CONTACT WITH CHOTA FORMATION

The Chota formation conformably overlies the Tellico formation. The contact with the shale below and the quartzose calcarenite of the Chota formation above is exposed at only a few places, but where it was seen it was sharp and abrupt. No conglomerate or other evidence of disconformity was noted at this contact. At Hawkins Bridge over the Tellico River, 45 feet of pink crossbedded calcarenite of the type usually associated with the Chota formation is separated from the main body of the Chota formation by 75 feet of gray shale. A similar calcarenite also occurs at a somewhat lower horizon a short distance to the northeast. Elsewhere the shale sequence is fairly uniform within about 250 feet beneath the contact.



### FOSSILS

Fossils were collected from 22 localities in the Tellico formation, some of which yielded only one identifiable specimen. Particular emphasis was placed on the collecting of brachiopods because the work of G. A. Cooper makes them most useful for stratigraphic correlation. Only a few trilobites were seen, and most of these belong to long-ranging nondiagnostic genera. Bryozoans are the most common fossils, but so little is known about them that no attempt was made to collect or study them. A few ostracodes, graptolites, sponge spicules, and some crinoidal debris are also present.

Fossils are few in the finely laminated shales. Most of the evenly bedded sandstones contain at least a few fragments of organic remains. Calcarenites are largely composed of organic material: encrinal fragments, bryozoans, and brachiopods, but little of this material is identifiable. Irregularly bedded shaly sandstone commonly contains fossils, and the shale-and-limestone cobble units in the upper part of the formation affords the best collecting.

The following fossils were identified:

Upper shale division:
- Ostracodes:
  - *Aparchites*? sp.
- Trilobites:
  - *Calymene* sp.
  - *Isotelus* sp.
  - N. gen. and sp. aff. *Lychas* sp.
  - *Trinodus* sp.
  - *Calliops* sp.
- Brachiopods:
  - *Paurorthis catawbensis* Butts (pl. 25, figs. 24–27)
  - "*Strophomena*" *tennesseensis* Willard
  - Gen. and sp. aff. *Öpikina* sp.
  - *Leptellina* sp.
  - *Bimuria superba* Ulrich and Cooper (pl. 25, figs. 34–36)
  - *Ptychoglyptus virginiensis* Willard
  - *Sowerbyites* sp. (pl. 25, figs. 20, 21)
  - *Sowerbyella ampla* (Raymond)
  - *Paleostrophomena* sp.
  - *Oxoplecia* cf. *O. holstonensis* Willard
  - *Mimella* sp.
  - *Multicostella saffordi* (Hall and Clarke)
  - *Dinorthis* sp.
  - *Vellamo*? sp.
  - *Glyptorthis* sp.
  - *Cyrtonotella virginiensis* Butts (pl. 25, figs. 22, 23)

| Species | Tellico-Sevier belt: Douglas Lake mbr. | Lenoir ls. | Whitesburg ls. mbr. | Blockhouse sh. | Tellico fm.: Lower shale div. | Tellico fm.: Middle shale div. | Tellico fm.: Upper shale div. | Chota fm. | Sevier fm.: Lower shale div. | Sevier fm.: Middle ss. div. | Sevier fm.: Upper shale div. | Sevier fm.: Bacon Bend mbr. | Bays fm. | Southwestern Virginia (Cooper and Prouty, 1943): Lenoir ls. (E. Tenn.) | Blackford fm. and Elway ls. | Lincolnshire ls. | Ward Cove ls. | Benbolt ls. | Wardell fm. | Bowen fm. and Witten ls. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ptychoglyptus virginiensis Willard | | | | | | | X | | | | | | | | | | — | | | |
| "Strophomena" tennesseensis Willard | | | | | | X | X | | | | | | | | | | ···— | — | | |
| gen. and sp. aff. Öpikina sp. | | | | | | X | X | | | | | | | | — | — | — | — | — | —→ |
| "Rafinesquina" champlainensis (Raymond) | | X | | | | | | | | | | | | — | | | | | | |
| Dactylogonia sp | | | X | | | X | | | | X | X | | | — | — | — | — | — | — | — |
| Leptellina sp | | | X | | | X | X | | | | | | | — | — | — | — | — | — | —→ |
| Gen. and sp. aff. Leptella pseudo-retroflexa Reed | | | X | | | | | | | | | | | | | | — | — | | |
| Christiania subquadrata Hall and Clarke | | | X | | | | | | | | | | | | | | — | — | | |
| sp | | | | | | | | | | | X | | | | | | — | ··· | ··· | ···→ |
| Bimuria superba Ulrich and Cooper | | | | | | | X | | | | | | | | | | — | — | | |
| Sowerbyella ampla (Raymond) | | | | | | | X | | | | | | | | | | — | | | |
| negritus (Willard) | | | | | | X | | X | | | | | | | | | — | | | |
| sp | | | | | | | | | X | X | X | | | | | | | — | — | |
| Sowerbyites sp | | | | | | | X | | | | | | | | | — | —·- | | | |
| Gen. and sp. aff. Sowerbyites sp | | | | | | | | | | | X | | | | | | | | | |
| Paleostrophomena sp | | | X | | | X | X | | | | | | | | | | — | | | |
| Gen. and sp. aff. Zygospira acutirostris (Hall) | | | | | | | | X | | | X | | | | | | | — | | |
| Zygospira sp | | | | | | | | X | | | X | X | | | | | | | | — |
| Protozyga sp | | | | | | | | X | | X | | | | — | — | — | — | — | — | —→ |
| "Camerella" longirostris Billings | | | | | | | | | | X | X | | | | | | | — | | |
| Oxoplecia holstonensis Willard | | | | | | | | | | | | | | | | | — | | | |
| cf. O. holstonensis Willard | | | | | | X | X | | | | X | | | | | | | | | |
| Oligorhynchia sp | | | | | | | | X | | | | | | | | — | — | — | — | — |
| Rostricellula rostrata Ulrich and Cooper | | | | | | | | | | | X | X | | | | | | | — | |
| pristina (Raymond) | | | | | | | | | | | | | | — | | | | | | |
| cf. R. pristina (Raymond) | X | | | | | | | | | | | | | | | | | | | |
| Camerella sp | | | | | | X | | | | | X | | | — | — | — | — | — | — | —→ |
| Paurorthis sp | | | X | | | X | | X | | | | | | | | — | — | — | | |
| catawbensis Butts | | | | | | | X | | | | | | | | | | — | | | |
| Skenidioides sp | | | X | | | X | | | | | | | | — | — | — | — | — | — | — |
| Pionodema sp | | | | | | | | | | | | X | | | | | | | | — |
| Fascifera sp | | | | | | | | | | X | | X | | | | | — | — | — | |
| Doleroides sp | | | | | | | | | | | X | X | | | | | | ··· | — | — |
| Mimella superba Butts | | | | | | | | | | | X | | | | | | | — | | |
| | | X | | | | X | X | X | | | | | | — | — | — | — | — | | |
| Dinorthis transversa Willard | | | | | | | | | | X | | | | | | | | — | | |
| sp | | | | | | | X | | | | | | | | — | — | — | | | |
| Multicostella saffordi (Hall and Clarke) | | | | | | | X | | | | | | | — | — | — | | | | |
| bursa (Raymond) | | | | | | | | | | | | | | | | | — | | | |
| cf. M. bursa (Raymond) | | | | | | X | | | | | | | | | | | | | | |
| | | | | | | | | X | | | | | | — | — | — | — | — | | |
| Valcourea strophomenoides (Raymond) | | X | | | | | | | | | | | | — | — | — | | | | |
| Vellamo? sp | | | | | | | X | | | | | | | — | — | — | | | | |
| Glyptorthis sp | | | X | | X | X | X | X | | | X | | | — | — | — | — | — | — | — |
| Ptychopleurella sp | | | | | | | | X | | | X | | | — | — | — | — | — | | |
| Cyrtonotella virginiensis Butts | | | | | | | X | | | | | | | | | — | — | | | |
| sp | | | | | | X | | | | | | | | | | — | — | — | | |
| Hesperorthis sp | | X | | | | | | | | | | | | — | — | — | — | — | — | — |
| Orthambonites sp | | | X | | | X | X | | | | | | | — | — | — | — | — | — | — |
| Schizotreta sp | | | X | | | | X | | | | | | | — | — | — | — | — | — | — |
| Lingulasma sp | | | X | | | | X | | | | | | | — | — | — | — | — | — | — |
| Lingula fostermontensis Butts | X | | | | | | | | | | | | | — | | | | | | |
| spp | | | X | | | | X | X | | | | | X | ←— | — | — | — | — | — | —→ |

**FIGURE 23.—Range chart of brachiopods listed from Middle Ordovician rocks in the Tellico-Sevier belt and southwestern Virginia. Prepared with the aid of G. A. Cooper.**

Upper shale division—Continued
- Brachiopods—Continued
  - *Orthambonites* sp.
  - *Schizotreta* sp.
  - *Lingulasma* sp.
  - *Lingula* sp.
- Graptolites:
  - *Nemagraptus gracilis* (Hall)
  - *Climacograptus* sp.
  - *Didymograptus* sp.
- Cystoid:
  - *Echinosphaerites* sp.

Middle sandstone division:
- Brachiopods:
  - *"Strophomena" tennesseensis* Willard (pl. 25, figs. 28, 29)
  - Gen. and sp. aff. *Öpikina* sp.
  - *Dactylogonia* sp.
  - *Sowerbyella negritus* (Willard)
  - *Leptellina* sp.
  - *Paleostrophomena* sp.
  - *Oxoplecia* cf. *O. holstonensis* Willard
  - *Camerella* sp.
  - *Paurorthis* sp.
  - *Skenidioides* sp.
  - *Mimella* sp.
  - *Multicostella* cf. *M. bursa* (Raymond)
  - *Glyptorthis* sp.
  - *Cyrtonotella* sp.
  - *Orthambonites* sp.
- Graptolites:
  - *Climacograptus* sp.
  - *Dicellograptus* sp.
  - *Dicranograptus* sp.

The stratigraphic occurrence of the brachiopods is plotted on figure 23. There are many similarities between these fossils and those of the Whitesburg limestone member of the Blockhouse shale. These affinites supplement the stratigraphic observations that indicate very close relations between the Blockhouse shale and the Tellico formation. Correlation of the Blockhouse shale and the Tellico formation with the Ward Cove limestone of southwestern Virginia is suggested. Further remarks concerning correlation will be made in the section "Correlation of the Tellico-Sevier belt with other belts of the southern Appalachians."

#### SOILS AND TOPOGRAPHIC EXPRESSION

Residual soils formed from the shales of the Tellico formation are generally thin, dominantly yellow to light brown, waxy, silty or sandy, and vary with changes in bedrock. The sandstone forms a deep-red, thick, loose, and sandy soil that contains fragments of weathered porous sandstone. Because these soils have developed on ridges, they have crept downslope into valleys underlain by shale, obscuring the shale in many places.

The concentration of sandstone in the middle part of the formation is also reflected topographically. The shale of the lower part of the formation supports steep-sided ridges and spurs that are elongate at right angles to the strike of the beds; here erosion has been controlled by steeply dipping transverse joints. Effective barriers to much erosion on transverse joints are sandstone beds 100 feet or more thick. These form ridges which are not breached for a mile or more and which have received local names, such as Woodpecker Knobs, Black Sulphur Knobs, and Chestnut Ridge.

Valleys and saddles parallel to the strike of the beds are formed on the shale of the upper part of the formation because it is less resistant to erosion than the sandstone units above and below. Individual sandstone beds form low ridges, but few of these are as prominent as those supported by adjacent sandstone units. Alternation of weaker and stronger beds, together with faults, folds and joints, produce the fine-grained knobby topography called Slate Knobs in the Walden Creek quadrangle (pl. 27).

### CHOTA FORMATION

#### GENERAL FEATURES AND NAME

The name Chota formation is here given to a unit which is formed dominantly of quartzose calcarenite, 550 to 900 feet thick, and is underlain by the Tellico formation and overlain by the Sevier formation. It is the same unit as the "sandstone lentil of the Sevier formation" of Keith (1895, 1896a), and the Holston formation of Rodgers (1953), as mapped in this area.

The name is taken from the Chota School, Vonore quadrangle, Monroe County, Tenn. (Geologic section 3)

#### LITHIC FEATURES

The quartzose calcarenite is gray, dark gray, and reddish gray and has small well-rounded quartz grains disseminated through the rock. Coarse encrinal debris embedded in coarse crystalline calcite forms more than half the volume of the rock. This debris is little abraded, although most plates are disarticulated. Calcarenite lacking quartz grains but otherwise similar to the quartzose calcarenite is also common in the Chota formation.

The quartzose calcarenite of the Chota formation differs from the calcareous sandstone of the Tellico formation in two important respects: the proportion of noncalcareous materials, including detrital grains and clay, is much higher in the Tellico formation, and no feldspar grains are known from the Chota formation.

The Holston marble, described by Dale (1924), is similar to, and perhaps closely related to, the calcarenites of the Chota formation. Dale concluded (p. 126) that the coarsely crystalline calcite was formed by solution of fine-grained material and redeposition to form a coarsely crystalline fabric—a process termed calcspathization by Sander (1951, p. 24).

Wavy thin partings of sandy silty, argillaceous material closely parallel bedding and separate strata of quartzose and quartz-free calcarenite 2 to 6 inches thick. Seams of similar appearance, parallel to the strike of the beds, but nearly perpendicular to their dip, impart a characteristic appearance to many outcrops, but their origin is not understood. In contrast to the even-bedded sandstones of the Tellico formation, bedding-plane partings of the Chota formation are wavy, and the strata that they set apart are commonly crossbedded. At many exposures the cross laminae of alternating beds dip in opposite directions, producing a "herringbone" structure (Shrock, 1948, p. 246).

Little of the calcarenite contains sufficient insoluble materials to retain its cohesiveness after calcium carbonate has been dissolved. The weathered rock, therefore, rarely has a porous rind, and the saprolite exposed in road cuts is soft and friable; in many places deep weathering has produced a collapsed residuum rather than a saprolite. In places where the saprolite and residuum have been completely removed a pinnacled surface similar to those formed on other limestones is revealed.

The Chota formation also contains a few beds of gray, fine-grained argillaceous limestone with nodular weathered surfaces that are very similar to the argillaceous member of the Lenoir limestone at the base of the Middle Ordovician section. At a few places gray, yellow-weathering shale is also present, but it forms only a small part of the formation.

*Geologic section 3.—Type section of the Chota formation, near Chota School, Vonore quadrangle, Monroe County, Tenn.*

[Section measured north of Tennessee Highway 72; see sketch map, fig. 24]

| *Exposures on hillsides southeast of Diamond Branch* | *Feet* |
|---|---|
| Sevier formation, lower shale division: Lower 100 ft composed of gray, brownish-yellow weathering calcareous siltstone and shale; fissility weak where fresh, good where weathered; no fossils seen. | |
| Chota formation, about 900 ft thick: | |
| 5. Calcarenite, light-gray, with a few grains of pink crystalline calcite; small rare well-rounded quartz grains; most of the rock composed of medium-size angular grains of gray limestone and organic debris, with crystalline calcite between detrital grains; *Sowerbyella negritus* (Willard) and ostracodes | 30 |
| 4. Limestone, fine-grained, gray and light-gray, argillaceous; limestone cobbles weather free from more argillaceous rock; contains lens of gray aphanitic limestone (loc. CH 5, fig. 24). Brachiopods (CH 8, fig. 24); *Acrolichas* sp., *Illaenus* sp., *Paurorthis* sp., *Ptychopleurella* sp., other brachiopods and bryozoans | 20 |
| 3. Calcarenite and oolitic limestone, gray, clay partings thin to obscure; many stylolites; current-bedding; encrinal debris, bryozoans, *Oligorhynchia* sp. and *Mimella* sp | 25 |
| 2a. Calcarenite, quartzose gray and reddish-gray; sandy partings weather to prominent ribs; current bedding | 10 |
| Covered interval beneath alluvium of Diamond Branch, about | 100 |
| *Exposures on hillside, 20 to 40 feet above road level* | |
| 2. Calcarenite, quartzose dark-gray, and dark reddish-gray, medium-grained; red tints from pink calcite grains and ferruginous clay; quartz grains small- to medium-size, rounded, seldom in contact with each other; weathered surfaces mostly dark reddish gray with sandy partings projecting in relief; most beds show current bedding; a few bedding surfaces have symmetrical ripples; gen. and sp. aff. *Zygospira acutirostris* (Hall), ostracodes, bryozoans (loc. CH 3, fig. 24) | 500 |
| Covered, in creekbed and flood plain | 50 |
| *Exposures at road level and on hillside up to 20 feet above road* | |
| 1. Calcarenite, quartzose light-gray and gray; small well-rounded sand grains; carbonate greenish-gray, gray and pink limestone, and crystalline calcite; wavy partings of silt and fine sand; current bedding; *Mimella* sp., gen. and sp. aff. *Zygospira acutirostris* (Hall), ostracodes, bryozoans (locs. VO 13, CH 2, fig. 24). To base of member at road intersection | 150 |

Basal contact not exposed; covered interval of 10 ft separates lowest 10 ft of quartzose calcarenite and highest shale in lane and on hillside opposite house at BM LHT 1328.

Tellico formation, upper shale division: Gray silty shale and lenticular calcareous siltstone, weathers to yellow-brown, fissile to irregularly bedded; no fossils seen; about 50 ft well exposed.

## STRATIGRAPHIC RELATIONS

### INTERNAL STRATIGRAPHY

The Chota formation is thinnest in the northeast part of the homocline, where it measured 550 feet (KZ 4). It thickens to the northeast to 650 feet (WD 35) 3 miles southwest of its truncation by the Guess Creek fault. Its widest outcrop is near Liberty Church (B9 A), where outcrops are scarce and there is some possibility of structural repetition. However, the thickness at Nelson Chapel (TA 24), 675 feet, the type section (VO 13), 900 feet, and at the Tellico River (VO 34), 750 feet, accurately reflect the magnitude and variation of the unit as a whole.

The quantity of quartz grains in the calcarenite decreases very gradually from northeast to southwest. Exposures near the Little River are notably more quartzose than those near the Little Tennessee and Tellico Rivers, but the gradation between these is imperceptible as the beds are traced along their strike.

Quartz-free calcarenite occurs at various levels through the formation. Its distribution does not appear to follow the pattern of increasing quartz content along the strike, except for beds near the top

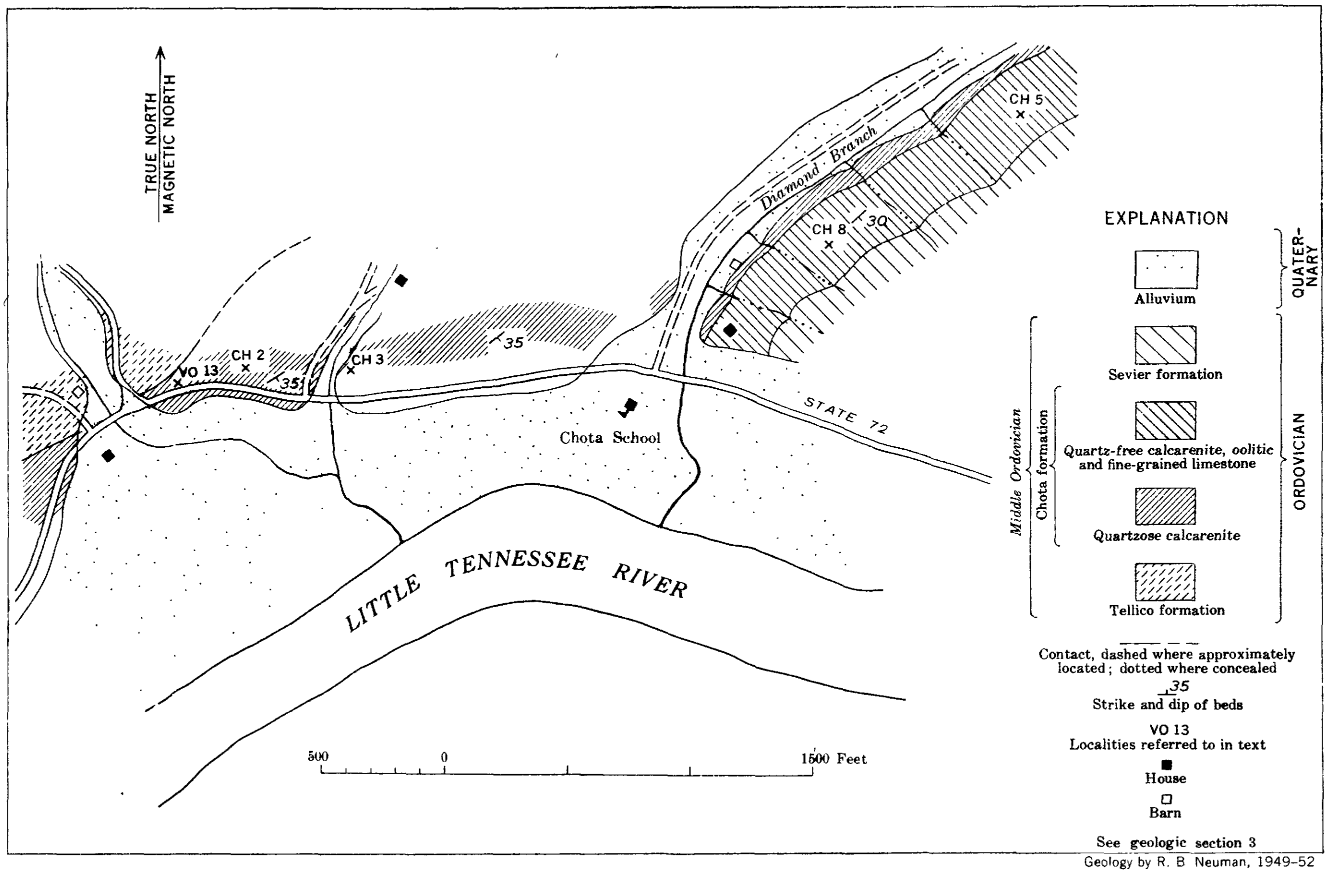



FIGURE 24.—Geologic sketch map of the type section of the Chota formation, vicinity of Chota School, Vonore quadrangle, Monroe County, Tenn.

which appear to be continuous through the southwestern most 12 miles of outcrop.

Three well-exposed sections of the formation are known in addition to the type section (Geologic section 3). At the southwestern limits of the area studied, beginning at Hawkins Bridge over the Tellico River and continuing southeast along the county road, are excellent exposures of quartzose calcarenite; about 50 feet of dark-gray argillaceous limestone are exposed at the top of the formation in wooded fields southwest of the road.

About one-half mile southwest of Nelson Chapel (TA 24) the uppermost beds, gray nodular limestone, are underlain by characteristic ledges of quartzose calcarenite exposed in a field and an old quarry on the west side of the creek that breaches the ridge.

Northeast of Law Chapel (KZ 4) calcarenite and fine-grained gray limestone are exposed at the top of the formation and are underlain by a thin unit of gray shale. Gray and maroon sandstone and quartzose calcarenite are exposed through 360 feet to the base of the section.

#### CONTACT WITH THE SEVIER FORMATION

The Chota formation is overlain by the lower shale division of the Sevier formation. In most places this contact is between calcarenite, with or without quartz, and nodular limestone below and brown-weathering shale and sandy shale above. Beds of the type commonly associated with the Chota formation occur within a few feet of the base of these shales at many places, and the contact seems to be gradational.

#### FOSSILS

Identifiable fossils in the Chota formation are very few. Bryozoans are locally abundant, and debris from them and from crinoids and cystoids locally forms a large proportion of the rock. The following trilobites and brachiopods were identified:

*Illaenus* sp.
*Acrolichas* sp.
*Paurorthis* sp.
Gen. and sp. aff. *Zygospira acutirostris* (Hall) (pl. 25, figs. 14–16)
*Protozyga* sp.
*Oligorhynchia* sp. (pl. 25, figs. 17–19)
"*Strophomena*" *tennesseensis* Raymond
*Sowerbyella negritus* (Willard)

*Mimella* sp.
*Multicostella* sp.
*Glyptorthis* sp.
*Ptychopleurella* sp.
*Lingula* sp.

Few of these fossils are well enough preserved to permit specified identification, and the generic assignments do not indicate the affinities of this formation. Many lithologic characters of the Chota formation are the same as parts of the overlying Sevier formation and distinct from the underlying Tellico formation. The underlying beds contain a diagnostic faunal assemblage (Ward Cove age), and the fossils of overlying beds are distinctly younger (Benbolt and Wardell age), but further work will be required to relate the Chota formation to either of these with confidence. Correlations between belts are discussed in the section, "Correlation of the Tellico-Sevier belt with other belts of the southern Appalachians."

#### SOILS AND TOPOGRAPHIC EXPRESSION

The Chota formation produces a deep-red soil composed of a mixture of sand and clay. This soil does not contain lumps of weathered rock that characterize the soils developed from the Tellico formation.

A line of knobs and elongate ridges parallels the strike of the Chota formation. Summits average 50 to 100 feet below those supported by sandstones of the Tellico formation. The ridges and knobs are markedly asymmetrical, the slope of the scarp face far exceeding that of the dip slope. Water gaps through this line of ridges are formed by a few streams that parallel the transverse joint system; most saddles are at the heads of gullies that are controlled by the same structure.

## SEVIER FORMATION

### GENERAL FEATURES

The term Sevier formation is here applied to a sequence of calcareous shale, calcareous sandstone, and calcarenite about 1,800 feet thick. At the top of the formation is a distinctive unit, 40 to 165 feet thick, characterized by slump-bedding structures, here named the Bacon Bend member. The main body of the Sevier formation is similar to the Tellico formation, having beds and lenses of sandstone and calcarenite interbedded with shale.

### NAME

Keith applied the term Sevier formation to interbedded sandstone, shaly limestone, and shale northwest of Chilhowee Mountain in Sevier County. In describing the formation, Keith (1895, p. 4) commented: "The shales are precisely like the Athens shale, and the sandstones are very similar to the Tellico sandstone."

Keith divided the formation into three parts: two shale divisions separated by a sandstone lentil. In the present report the shale division beneath the sandstone lentil is assigned to the Tellico formation, the sandstone lentil is termed the Chota formation, and the Sevier formation is restricted to the shales and sandstones that lie between the Chota and Bays formations.

Review of Keith's mapping by the present writer indicates that Keith was not entirely consistent in tracing the top of the Sevier formation. In the Knoxville folio (Keith, 1895, p. 4) the upper part of the Sevier is described as a shale, and its contact with the Bays formation is drawn essentially where the writer would place it. In the Loudon folio (Keith, 1896a) the Sevier-Bays contact was mapped at a considerably lower level. Bluffs along the Little Tennessee River in this quadrangle are mapped as entirely within the Bays formation, but the present writer has found that these bluffs include prominent exposures of the upper part of the Sevier formation including the Bacon Bend member.

### LITHIC FEATURES OF MAIN BODY

#### CALCAREOUS SHALE

The calcareous shale of the main body of the Sevier formation is dull gray, but it has a greenish cast in many places. Most of the rock is a clay shale, but it contains varying amounts of silt and sand like the shale of the Tellico formation. Its fissility is slightly weaker than the shale of the Tellico formation; a distinctive feature of some beds is their property of breaking along curved surfaces into fragments that have the appearance of desiccation polygons. The more silty beds are irregularly laminated, and many contain fossil bryozoans and brachiopods distributed along bedding surfaces and in small aggregations. At some places the shale passes into dove- and greenish-gray aphanitic limestone containing abundant bryozoans and a few brachiopods. On weathering, these rocks become yellow, greenish-yellow, and buff.

Interbedded with shale in the upper part of the formation is a lens of red calcareous mudrock about 25 feet thick and 2.5 miles long (Geologic section 4). This mudrock forms nonlaminated beds about 10 inches thick and includes beds of buff mudrock that differs from the red rock only in color.

#### CALCAREOUS SANDSTONE

Calcareous sandstone forms mappable units in the Sevier formation much like those of the Tellico formation. The rock is gray, but tints of green and red are common. The grains of quartz are very fine (0.62–0.125 mm) and angular; feldspar grains are rare. Individual beds are from 2 to 12 inches thick and are commonly cross laminated. Thin coatings of finer grained material with prominent flakes of detrital mica form partings between sandstone beds. Opposite dips of cross laminae commonly produce a herringbone pattern, but some dip regularly southeastward more steeply than true bedding. Bedding planes of many beds in the upper part of the formation have rounded symmetrical ripple marks; these have an amplitude of about three-fourths of an inch and a distance between crests of from 6 to 10 inches. Associated with sandstone are beds of gray, pink, and maroon calcarenite, dove- and brownish-gray aphanitic limestone, and a few beds of greenish- and reddish-gray intraformational conglomerate. The conglomerates are from 4 to 8 inches thick, with angular to subrounded limestone pebbles about one-half inch in average diameter, lithologically similar to adjacent beds.

The weathered surfaces of sandstone beds are ribbed, formed as a result of the contrasting weathering properties at different levels within the bed. The weathered rock is brown or yellow-brown and friable. The calcarenite has smooth weathered surfaces and on thorough weathering leaves a dark-red waxy residuum.

### STRATIGRAPHIC RELATIONS

#### INTERNAL STRATIGRAPHY

The average thickness of the Sevier formation, exclusive of the Bacon Bend member, is about 1,800 feet. The maximum thickness observed is about 2,100 feet in the central part of the area studied. The variation of thickness and distribution of dominant rock types are shown on plate 28.

A persistent sandstone unit near the middle of the formation makes possible an informal threefold subdivision of the main body of the formation. Accordingly, this sandstone is termed the middle sandstone division, separating the dominantly shaly lower and upper parts of the sequence. The three subdivisions are shown on plate 28 and are indicated in the faunal lists and in the brachiopod range chart (fig. 23).

The middle sandstone division at the northeastern edge of the outcrop belt is about 75 feet thick and lies well below the middle of the formation. Traced to the southwest it thickens and appears to rise in stratigraphic position. It reaches its maximum thickness of 500 feet southeast of Nelson Chapel, but to the southwest a shale tongue intervenes, splitting the sandstone into two tongues. The lower of these reappears as thin discontinuous lenses, but the upper extends to the southwestern edge of the area studied, where it is 450 feet thick and includes the middle of the formation.

Intertonguing of shale and sandstone near Nelson Chapel makes sharp and formal differentiation of the subdivisions impossible. The lower part of the formation, however, throughout the outcrop belt, is shale with little lithologic variety.

Shale forms most of the upper division in the northeastern part of the outcrop belt, but sandstone and calcarenite beds increase in number and thickness to the southwest, forming three-fourths of the division at the southwestern edge of the area. Much of this sandstone occurs in a thick unit at the top of the formation; in the central part of the area this unit is divided into two parts by a shale tongue, and only the much-thinned lower one persists to the northeast.

Red calcareous mudrock, similar to that of the overlying Bays formation, occurs near the middle of the upper division in the southwest part of the area (Geologic section 4). Rocks of this kind are uncommon in this part of the section.

*Geologic section 4.—Part of the upper division of the Sevier formation*

[Section measured about half a mile S. 15° E. of Nelson Chapel, Tallassee quadrangle, Blount County; bedding strikes N. 45°-50° E., dips 30°-40° SE. Section starts at intersection of wagon road and county road, 0.58 mile S. 15° E. of Nelson Chapel]

| | *Feet* |
|---|---|
| 16. Sandstone, calcareous, gray and reddish-gray; thin beds set apart by wavy shaly partings; clay-filled cross fractures parallel to strike but normal to dip; weathers dark-brown and reddish-brown | 150 |
| 15. Limestone, fine-grained, greenish-gray, argillaceous; bedding structures obscure; brachiopods poorly preserved, rare; bryozoans better preserved, abundant | 15 |
| 14. Covered | 20 |
| 13. Calcarenite, quartzose, light-gray, crossbedded; thin, wavy clay partings 2 to 4 in. apart (in creek bottom) | 40 |
| 12. Covered; abundant yellow shale chips in soil to foundations of dismantled house | 150 |
| 11. Mudrock, calcareous and siltstone, red; beds 2 to 10 in. thick, without laminae | 6 |
| 10. Covered | 10 |
| 9. Shale, fissile, weathered yellow | 3 |
| 8. Shale, fissile, maroon | 2 |
| 7. Shale and mudrock, yellow-weathered; not fissile in lowest 6 in | 5 |
| 6. Mudrock calcareous, red, in beds 1 to 4 in. thick | 5 |
| 5. Sandstone calcareous, reddish-gray, weathers brown | 2 |
| 4. Covered; brown shaly sandstone chips in soil | 12 |
| 3. Shale, light-gray, silty, with thin lenses of silty limestone; weathers greenish-yellow; *Sowerbyella* sp. at 3 ft and 35 ft below top of unit; continuous outcrops to cover in gulley | 100 |
| 2. Covered | 70 |
| 1. Shale, light-gray, weathers greenish-yellow as above; outcrops continuous in vicinity of old barn; to base of exposures | 125 |
| Total | 715 |

#### CONTACT WITH BACON BEND MEMBER

The rock types that characterize the main body of the Sevier formation persist into the Bacon Bend member. The distinguishing features at the base of the upper member are the structures which probably were formed by movement of the sediments before their lithification. Because it is improbable that the first of these movements was recorded simultaneously everywhere, a contact drawn at the lowest of these should probably be considered a special kind of conformable contact.

#### FOSSILS

Identifiable fossils are very rare in the Sevier formation. The fine-textured evenly laminated shaly rocks are almost completely lacking in organic remains. Many of sandy beds and calcarenites contain abundant bryozoans and encrinal debris and a few brachiopods were found.

Lower shale division: Only one collection was obtained; It (BL 57) contained *Sowerbyella* sp.
Middle sandstone division contains:
- Brachiopods:
  - *Dactylogonia* sp.
  - *Sowerbyella* sp.
  - *"Camerella" longirostris* Billings (pl. 25, fig. 9)
  - *Dinorthis transversa* Willard (pl. 25, figs. 6–8)
  - *Fascifera* sp.
  - *Protozyga* sp.
- Ostracodes:
  - *Eurychilina* sp.
  - *Aparchites*? sp.

Upper division contains:
- *Dactylogonia* sp.
- *Christiania* sp.
- *Sowerbyella* sp. (pl. 25, figs. 4, 5)
- *Zygospira* sp.
- Gen. and sp. aff. *Zygospira acutirostris* Hall
- *Camerella* sp.
- *Oxoplecia* cf. *O. holstonesis* Willard
- *"Camerella" longirostris* Billings
- *Rostricellula rostrata* Ulrich and Cooper
- *Ptychopleurella* sp.
- *Mimella superba* Butts
- *Mimella* sp.
- *Glyptorthis* sp.
- *Doleroides* sp.

The species of *Sowerbyella* (pl. 25, figs. 4, 5) that is present through the member is a large papillate shell, 10 to 15 millimeters wide. *Sowerbyella* of this type, specimens of which are in the collections of the National Museum, is common in the Benbolt and Wardell limestone of southwestern Virginia and their equivalents (G. A. Cooper, oral communication, 1951). *Rostricellula rostrata* Ulrich and Cooper, and species of the genera *Doleroides* and *Fascifera* also range through these formations. *Mimella superba* Butts and *Dinorthis transversa* Willard are known elsewhere only from the Benbolt limestone of Cooper and Prouty (1943) in the southwestern Virginia section. Other species listed from the member are either long-ranging types or species not well enough preserved to permit more than generic identification. The occurrence of the genus *Christiania* in these beds is not surprising, because it is known to occur in the Whitesburg limestone member of the Blockhouse shale and its equivalents (*C. subquadrata* Hall and Clarke), and in the much younger Oranda formation in Virginia (*C. trentonensis* Ruedemann) (Cooper and Cooper, 1946, p. 88).

#### SOILS AND TOPOGRAPHIC EXPRESSION

Residual soils developed from rocks of the Sevier formation are varied in character and spotty in distribution. Dark-brown and reddish-brown friable lumpy soils form on sandstone beds; thin silty soils form on shale; and red compact waxy soils are derived from more limy beds. The soils developed from shale and limestone are very similar to those formed on the upper shale division of the Tellico formation. The sandstone soils are a richer and redder brown than those formed on other sandstone units in this sequence and are intermediate in texture between soils of the middle sandstone division of the Tellico formation and those of the Chota formation.

Lines of elliptical knobs are supported by sandstone beds of the Sevier formation. The weaker shale beds and the transverse joint system govern the drainage, producing a trellis pattern.

### BACON BEND MEMBER

#### GENERAL FEATURES AND NAME

The name Bacon Bend member of the Sevier formation is here given to the unit at the top of the formation in which gray calcareous shale and sandstone have submarine slump structures; the Bacon Bend also contains even-bedded beds of gray and red calcareous mudrock. The name is taken from the meander neck of that name on the Little Tennessee River (Vonore quadrangle), Monroe County, Tenn. Rocks of the Bacon Bend member are exposed at the southeast end of prominent bluffs that overlook the river; the type section was measured about 1 mile northeast of these exposures (Geologic section 5).

*Geologic section 5.—Type section of the Bacon Bend member of the Sevier formation*

[Section measured on the southeast side of an unnamed creek, 0.63 mile, northeast of Jones Cemetery, and 0.2 mile northeast of a small dam on Fourmile Creek and Tennessee Highway 72, Tallassee quadrangle, Monroe County. Section measured in pasture and woods; bedding strikes N. 50° E., dips 30° SE.]

| | Feet |
|---|---|
| Bays formation: | |
| 13. Mudrock, calcareous, red, and siltstone; nonlaminated beds 8 to 12 in. thick; weathers hackly; exposed in woods. | |
| 12. Covered | 10 |

| | Feet |
|---|---|
| Sevier formation: | |
| Bacon Bend member, about 90 ft thick: | |
| 11. Limestone, shaly, reddish-gray, fine-grained, with closely spaced red clay laminae | 0.5 |
| 10. Covered | 1.0 |
| 9. Limestone, silty, gray and reddish-gray, fine-grained; layers of contrasting silt content, 1–2 in. thick; less silty beds interrupted by crosscutting partitions of more silty and shaly limestone—"pull-apart" structure | 6 |
| 8. Covered | 20 |
| 7. Mudrock and chalky limestone, light-red to salmon-pink, with gray and greenish-gray layers and lenses; laminated to shaly; poorly preserved orthid brachiopods and gastropods 10 ft above base | 16 |
| 6. Mudrock, greenish-gray, laminated; weathers yellow | 1 |
| 5. Mudrock, greenish-gray, with nodules of slightly more pure limestone in twisted and contorted shapes, 1 to 4 in. in average diameter | 2 |
| 4. Mudrock, greenish-gray, with a few thin interrupted beds of more pure limestone | 5 |
| 3. Covered, yellow shale chips in soil | 15 |
| 2. Sandstone calcareous, gray, fine-grained, irregularly bedded; contorted structures in basal 2 ft; forms lip of small waterfall | 25 |
| Main body, upper division: | |
| 1. Sandstone calcareous, gray, fine-grained, thin-bedded; crossbedded; to creek bottom. Similar beds crop out northwest of creek | 75+ |

Outcrops along Tennessee Highway 72 just 0.2 mile to the southwest supplement this section. The uppermost beds of the Bacon Bend member (unit 11) are red shaly limestone whose full thickness of 2 feet is exposed. Twenty-one feet of gray and reddish-gray silty limestone (unit 9) including a contorted bed 2 feet thick is exposed, but the base of this unit is concealed in a covered interval. Twelve feet below the lowest exposure of unit 9 light-red and pink laminated mudrock and limestone of unit 7 is 17 feet thick and is underlain in turn by greenish-gray, yellow-weathering shaly mudrock to the base of exposures.

#### LITHIC FEATURES

Most of the Bacon Bend member is formed of rocks similar to those of the main body of the Sevier formation, with intercalations of red and buff calcareous mudrock. The gray and greenish-gray calcareous sandstone and shale of the Bacon Bend are distinguished from those of the main body of the Sevier formation by their bedding structures. Many of the beds of the Bacon Bend member possess contorted and disrupted structures that have been associated with submarine slump (Fairbridge, 1946; Kuenen, 1953).

Photographs of a good exposure of well-developed slump structures are shown on plate 26. Elongate, oblate, hooked, and irregular shapes of silty limestone are enclosed in a contorted shaly matrix. The maximum elongation of shapes is in a northeast-southeast direction, here parallel to the strike of the bed. Elongation is most apparent normal to bedding surfaces (pl. 26*A*), but it is also distinct on bedding surfaces (pl. 26*C*). The shapes themselves are formed of laminated rock; in some the laminations are moderately to strongly bent, and these may terminate sharply at the edge of the shape (pl. 26*B*), or nearly follow the outline of the shape, intersecting its borders at acute angles (pl. 26*D*). Some shapes, however, show no signs of deformation (pl. 26*A*, lower right), and others have a closely spaced system of parallel fractures that are filled with the shaly material of the matrix.

Beds with these contorted structures are interbedded with evenly bedded rock. Closely interleaved siltstone and shale in which the siltstone layers are 1 to 3 inches thick and the shales are somewhat thinner are suggestive of the predeformation character of the contorted beds. In many of these the more massive siltstone layers are broken at 3- to 6-inch intervals, and shaly material fills the breaks, similar to "pull-apart" structures (Natland and Kuenen, 1951, p. 89–90).

In addition, there is more ordinary calcareous sandstone, siltstone, and shale. Reddish and greenish-gray silty limestone with bryozoans and brachiopods lies near the base of the member at several places. Coarser grained, crossbedded calcareous sandstone that is indistinguishable from similar beds of the main part of the Sevier formation also forms a minor part of the Bacon Bend member.

Red laminated mudrock and impure limestone form the top of the Bacon Bend member at every exposure; the color of these beds is like that of the Bays above, but the rock differs in being laminated rather than massively bedded. Similar laminated red rock forms the middle part of the Bacon Bend in the southwestern part of the area, but it does not persist at this horizon into the Blockhouse quadrangle.

#### STRATIGRAPHIC RELATIONS

The Bacon Bend member of the Sevier formation is 40 to 165 feet thick. Silty and sandy beds with disturbed layers form the lower part of the member; red and yellow silty limestone and mudrock dominate the upper part. Red color predominates through a larger portion of the member in the southwestern part of the belt (Tallassee and Vonore quadrangles), but the rocks that are associated with red beds persist through the area. Variations in thickness, therefore, appear not to be due to local erosion at contacts; rather, it is thought that the movements that produced the structures which identify the base of the member occurred at different horizons from place to place.

#### CONTACT WITH BAYS FORMATION

The upper contact of the Bacon Bend member of the Sevier formation with the Bays formation is sharp, marked by the appearance of nonlaminated red mudrock and siltstone. The Bacon Bend has the appearance of a transitional zone between the Sevier formation below and the Bays formation above. No evidence of an interruption of deposition was seen; the contact, therefore, seems to be conformable.

#### FOSSILS

Encrinal and bryozoan debris form a large part of the basal sandy portion of the Bacon Bend member but do not characterize the member. Brachiopods are not common, but the following were identified:

*Rostricellula rostrata* Ulrich and Cooper
*Pionodema* sp. (pl. 25, figs. 1–3)
*Fascifera* sp.
*Doleroides* sp.
*Zygospira* sp. (pl. 25, figs. 10–13)

A few very large specimens of the gastropod genus *Hormatoma* were seen in the red rocks of this member.

This small faunule indicates only that the Bacon Bend member should be considered a part of the Sevier formation. The stratigraphic position of the member indicates its correlation with the Wardell formation of southwestern Virginia (see p. 167).

#### SOILS AND TOPOGRAPHIC EXPRESSION

Most soils developed from the Bacon Bend member are indistinguishable from those of the main body of the Sevier formation. In places, however, red mudrock imparts a red color to the soil similar to that of the Bays formation above.

A gentle depression is formed on the outcrop of the Bacon Bend. This depression in most places is filled with alluvium and colluvium derived from the steep-sided hills of the adjacent Bays formation.

## BAYS FORMATION

### GENERAL FEATURES AND NAME

Red calcareous mudrock and siltstone characterize the Bays formation. The term was first used (as Bays sandstone) by Willis (1893, pls. 60, 61), who gave its thickness for several sections but did not describe the rocks. It was subsequently used in the Estillville (Campbell, 1894), Knoxville (Keith, 1895), Morristown (Keith, 1896b), and Greeneville (Keith, 1905) folios; the latter two contain the type locality of the formation: "Bays Mountain of Hawkins and Greene counties, Tennessee" (Keith, 1895, p. 4). In the latter two folios the name was also applied erroneously in the Clinch Mountain belt to a unit of Upper Ordovician rocks now known as the Juniata formation (Wilmarth, 1938, p. 130).

The outcrops of Bays formation here considered are in the same structural belt as the type area of the formation, and, although the two outcrop areas are not connected, there is little question concerning the identity of the units.

The designation Bays formation (Rodgers, 1953) is preferred to Bays sandstone because mudrock and siltstone are characteristic; only part of the unit is sandy, and true sandstone beds are few.

Willis (1893) and Keith (1896b, 1905) assigned a white quartzite at the top of the Bays formation in the Bays Mountain area to the Clinch sandstone, and the same correlation was made by Keith in the Knoxville and Loudon folios. This quartzite is certainly a part of the Bays formation, and rocks of Medina age are not present in this section (Prouty, W. F., 1936).

### LITHIC FEATURES

By far the dominant rock in the Bays formation is red calcareous mudrock and siltstone. This forms beds 6 inches to 2 feet thick which are set apart by prominent bedding planes. Each bed is nearly uniform in character, and bedding laminae are often not evident in the fresh rock, although in many places they are revealed by weathering. Most of the constituent particles of the mudrock are too small to be distinguished with a hand lens, but grains are visible in the siltstone. Some prominent minor features of the rock include scattered green mottling and short rods of crystalline calcite about two-tenths of an inch in diameter and 1 inch long. Most of these beds show jointing and cleavage; joints parallel to the strike but normal to the dip in many places are more prominent than bedding planes.

The upper part of the formation contains several beds that are not red. Among these are layers of buff claystone and buff siltstone that is interleaved with thin beds of red mudrock. Many of these beds contain large ostracodes. This rock has the superficial appearance of metabentonite that occurs in the formation in other areas. Although it may contain admixtures of volcanic material, it lacks a silicified zone that normally underlies metabentonites, it contains marine fossils and large well-rounded quartz grains in thin layers, and the buff rock is closely interbedded with red mudrock—all of which are features not normally associated with metabentonites.

Greenish-gray fine-grained sandstone beds, each about 1 foot thick, some of which contain poorly preserved pelecypods, occur at various horizons. The upper part of the formation also contains a few beds of gray medium-grained feldspathic sandstone. Nearly white quartzite in four bodies at the top of the formation are outlined on plate 28. The quartzite is introduced as interbeds with the normal red rocks of the formation. It is medium- to coarse-grained and is composed almost exclusively of rounded quartz grains, with a sprinkling of feldspar grains, cemented by vitreous silica. Fresh rock is light gray, but it is nearly white where weathered.

#### STRATIGRAPHIC RELATIONS

The Bays formation thickens from 400 feet at the northeastern end of these exposures to about 1,000 feet at the southwest. The general subdivisions that comprise the formation extend through the outcrop belt, suggesting that variation of thickness involves the entire unit.

The Bays formation is overlain by the Chattanooga shale of latest Devonian and Carboniferous age. The Bays-Chattanooga contact, therefore, is the largest disconformity in the Paleozoic sequence of the southern Appalachians. The upper part of the Middle Ordovician, Upper Ordovician, Silurian, and perhaps the entire Devonian are missing from the section.

#### FOSSILS

The Bays formation yielded one species of *Lingula*, two species of ostracodes, and some very poorly preserved pelecypods. The *Lingula* is a large, inflated shell, pentagonal in outline, that occurs abundantly in the lower 25 feet of the formation in many places. The pelecypods, too poorly preserved for identification, were found at several horizons.

Species of the ostracode genus *Isochilina* were collected at two horizons, one about 200 feet above the base of the formation in the northeastern part of the belt (BL 68), the other in the upper third of the formation in its southwestern outcrops. These fossils were examined by Miss Jean Berdan, who reported (memorandum, March 1, 1950) that the lower form appears to be conspecific with specimens collected by R. S. Bassler from the Bays of Bays Mountain at Bulls Gap, Tenn., about 75 feet above the first appearance of red sediments; it is an undescribed species allied to *Isochilina armata* Walcott from the Lowville limestone of New York. Berdan (memorandum, July 28, 1950) said that the higher species is similar to an undescribed species figured by Butts (1942, pl. 94, figs. 24, 25), from the Eggleston limestone of Virginia.

These three forms, of little importance for correlation, are suggestive of the environment in which the formation was deposited. The modern *Lingula* and many modern pelecypods live in burrows that they make for themselves. Many ostracodes are capable of burrowing beneath the surface of bottom sediments. These forms, therefore, seem capable of escaping drying out from occasional subaereal exposure of the sea floor on which they live, and the ancient forms may have had the same capabilities.

#### SOILS AND TOPOGRAPHIC EXPRESSION

The soils of the Bays formation are maroon, silty, thin, and easily eroded where the natural cover of vegetation has been removed. A large part of the outcrop area is woodland, but rock crops out abundantly in clearings.

The quartzite crops out as ledges in many places. On some spurs, however, nearly fresh blocks form a jumbled mass at the surface, and actual outcrops are not present. In some road cuts, however, the quartzite has weathered to friable sand.

The Bays formation forms a line of dissected ridges and knobs whose summits are 20 to 60 feet lower than those supported by the calcareous sandstones to the northwest. Inasmuch as the quartzite bed lies at the foot of a prominent ridge supported by rocks of Mississippian age (Little and Short Mountains), it has only a slight topographic expression, forming subordinate northeast-southwest trending spurs at the base of spurs of the higher Mississippian ridges to the southeast.

## ROCKS OVERLYING MIDDLE ORDOVICIAN

### CHATTANOOGA SHALE (LATE DEVONIAN AND CARBONIFEROUS)

Black noncalcareous shale, for which the name Chattanooga shale (Hayes, 1891, p. 143) has long been used, overlies the Bays formation. In most places its lower part is intensely sheared, but at one undeformed section the shale is 25 feet thick. At this section the Chattanooga rests on quartzite of the Bays formation, and a basal bed about 5 inches thick is very sandy. The remainder of the section is fissile black silty shale, and the same rock characterizes undeformed parts of the formation at all exposures.

Because of deformation, thicknesses of the Chattanooga in this belt cannot be determined. The width of its outcrop belt is constant, and observations around the Nashville dome (L. C. Conant, oral communication, 1952) show that its thickness there varies within narrow limits and is comparable to that of this belt.

The Chattanooga shale is succeeded by a thick section of clastic rocks of Mississippian age.

## CORRELATION OF THE TELLICO-SEVIER BELT WITH OTHER BELTS OF THE SOUTHERN APPALACHIANS

The purpose of this paper is to describe the rocks of the Tellico-Sevier belt and to clarify the older terminology that is based on sections within this belt. The writer has insufficient firsthand knowledge of outcrop belts other than this to make authoritative correlations between them. The work of two geologists has been devoted to these rocks in recent years. Rodgers' work is presented in the Explanatory Text that accompanies the Geologic map of East Tennessee (Rodgers, 1953). G. A. Cooper has studied the brachiopods from rocks of Middle Ordovician age throughout the United States, and his report, with much stratigraphic information, is currently being prepared for publication. The writer has benefited from the exchange of much information with these geologists and has accepted certain of their correlations as a basis for a correlation of the rocks of the Tellico-Sevier belt.

### CORRELATION WITH TAZEWELL COUNTY, VA.

A classification proposed by Cooper and Prouty (1943) for rocks of Middle Ordovician age in southwestern Virginia supersedes those of Ulrich (1929) and Butts (1940) in that area. Subsequent work by Cooper and Cooper and others has proved this classification to be a natural one for these rocks and has led them to recommend that the section of Tazewell County, Va., be adopted as the standard Middle Ordovician section for the southern Appalachians—if not for a greater area.

The occurrence of brachiopods in the stratigraphic units discussed in this study is recorded in figure 23. The range of identical or most closely related forms in the sequence in southwestern Virginia is also given. Beneath the sequence of units in southwestern Virginia a column labelled "Lenoir" has been added for fossils known from that formation in eastern Tennessee but not known from the Virginia section. Evidence from this chart and stratigraphic data are used to suggest the correlations of table 3.

Concerning these correlations the following qualifications are needed:

1. The Lenoir limestone of eastern outcrop belts may be older than any part of the Tazewell County section, or it may be correlative with the Elway. Cooper (1950, p. 33) notes the absence of Chazy fossils from the Elway but expresses his belief that the Elway is of Chazyan age. Blackford equivalents (Cooper, 1950, p. 30) contain *Rostricellula pristinia* (Raymond) (pl. 25, figs. 37, 38) and probably are to be correlated with the Douglas Lake member of the Lenoir limestone.

2. The Lincolnshire limestone and its correlatives are present in western and northeastern outcrop belts in the Appalachian Valley but have no apparent representatives in the Tellico-Sevier belt. It is probable that

TABLE 3.—*Correlation of Middle Ordovician rocks of the Tellico-Sevier belt with the Friendsville-Knoxville belt and southwestern Virginia*

<table>
<tr><th>Tellico-Sevier belt</th><th>Friendsville-Knoxville belt compiled from information supplied by B. N. Cooper, G. A. Cooper, J. M. Cattermole</th><th>Southwestern Virginia compiled from Cooper and Prouty, 1943, and Cooper, 1950</th></tr>
<tr><td>Bays formation (400–1,000 ft).</td><td>Bays formation (500 ft).</td><td>Witten limestone and Moccasin formation (total 425 ft).</td></tr>
<tr><td>Bacon Bend member of Sevier formation (40–165 ft).</td><td rowspan="2">Ottosee shale (800 ft).</td><td>Wardell formation (35–200 ft).</td></tr>
<tr><td>Sevier formation, main body (1,400–2,100 ft).</td><td rowspan="2">Benbolt limestone (400 ft).</td></tr>
<tr><td>Chota formation (500–900 ft).</td><td>"Tellico sandstone" and "Holston marble" (800 ft).</td></tr>
<tr><td rowspan="2">Tellico formation (2,700–4,500 ft).<br>Blockhouse formation (150–950 ft).</td><td rowspan="2">"Lenoir limestone," upper part (400 ft).</td><td>Peery limestone (60 ft).<br>Ward Cove limestone (225 ft).</td></tr>
<tr><td>Lincolnshire limestone (150 ft).</td></tr>
<tr><td>Lenoir limestone including Mosheim member (25–100 ft).</td><td rowspan="2">Lenoir limestone, lower part (200 ft).</td><td>Five Oaks limestone (45 ft).<br>Elway limestone (40 ft).</td></tr>
<tr><td>Douglas Lake member of Lenoir limestone (0–55 ft).</td><td>Blackford formation (100 ft).</td></tr>
</table>

none were deposited here, and that the Lenoir-Whitesburg contact marks a minor disconformity.

3. The Blockhouse shale and the Tellico formation are correlated with the Ward Cove limestone on the basis of comparable faunas that are particularly well developed in the Whitesburg limestone member of the Blockhouse formation and in the upper shale division of the Tellico formation. A brachiopod that closely resembles *"Strophomena" tennesseensis* Willard (pl. 25, figs. 28, 29) occurs commonly in the upper two-thirds of the Tellico formation; elsewhere this fossil has been found only in rocks of Benbolt age (G. A. Cooper, oral communication, 1951).

4. The restricted faunas of the Chota and Sevier formations furnish only small support for correlation of these units with the Benbolt limestone. Most of the fossils are known from both the Benbolt limestone and Wardell formation of Cooper and Prouty (1943). However, *Mimella superba* Butts and *Dinorthis transversa* Willard (pl. 25, figs. 6, 7, 8), found in the main body of the Sevier formation, are confined to the Benbolt limestone and its equivalents. The occurrence of these species and the marked stratigraphic contrast of the Chota and Sevier formations with the underlying beds lend weight to this correlation.

5. The Bacon Bend member of the Sevier formation may be equivalent to the Wardell limestone of southwestern Virginia. The lithic character of the Bacon Bend closely resembles that of the younger Bowen formation and the Witten limestone of that area (Cooper and Prouty, 1943) although the latter lacks slump structures. However, in northwestern belts interbedded nonred and red rocks in this general stratigraphic position are much thicker than the Bacon Bend member. Rodgers and Kent (1948, p. 39–42) cite a total thickness of 613 feet for their units G, H, I, and J of the Lowville and Moccasin limestones, and in their observations of the regional distribution of these facies (p. 39) they point to the increasing amount of blue limestone and corresponding decrease in proportion of red rocks in western belts. It is therefore probable that the stratigraphic interval that contains the equivalents of these rocks in the Tellico-Sevier belt lies within the Bays formation, and that the initial red deposits here are older than those of northwestern belts.

6. The Bays formation is correlated with the Witten limestone and Moccasin formation of Prouty (1946) on the basis of their similar lithic character and comparable stratigraphic position. The tongues of yellow-weathering shale of northwestern belts contain most of the fossils known from these rocks, but similar fossiliferous beds were not found in the Bays formation in the Tellico-Sevier belt.

### CORRELATION WITH FRIENDSVILLE-KNOXVILLE BELT

The outcrop belt that is just northwest of the Tellico-Sevier belt passes through Friendsville, Tenn., and south of Knoxville. B. N. Cooper and G. A. Cooper have examined these rocks near Friendsville, and J. M. Cattermole has studied them in the Knoxville metropolitan area. The following generalized section of the Middle Ordovician rocks in this belt is drawn from personal communication with these geologists.

*Bays formation.*—Red calcareous mudrock and siltstone, about 500 ft.

*Ottosee shale.*—Gray shale and calcareous sandstone containing lenses of calcarenite including the Meadow and Vestal marbles; total about 800 ft.

*"Tellico sandstone" and "Holston marble"*—Light-pink quartz-free coarse-grained calcarenite (150 ft), overlain by thin calcareous shale (50 ft), and quartzose calcarenite above (600 ft).

*"Lenoir limestone".*—Gray argillaceous nodular limestone, the upper 400 ft bearing the *Christiania subquadrata* (Hall and Clarke) fauna; the lower part with *Maclurites magnus* Lesueur and other fossils of Chazy aspect; between this rock and the Knox there is generally from 30 to 75 ft of dove aphanitic limestone (Mosheim member); total, about 600 ft.

A correlation of the Friendsville-Knoxville belt with the southwestern Virginia section and the Tellico-Sevier belt is suggested in table 3. These correlations are based on faunal comparisons, lithologic resemblance, and stratigraphic position, and are in general accord with correlations made by Rodgers, and Cooper and Cooper. They are not proposed here as a contribution to the knowledge of these rocks, but as a guide in discussing the place of the Tellico-Sevier belt in the history of sedimentation in the Appalachian Valley of eastern Tennessee during Middle Ordovician time.

## SEDIMENTARY ENVIRONMENT OF THE DEPOSITS

As has been shown in this report, the rocks of Middle Ordovician age in the Tellico-Sevier belt contain more detrital material and are thicker than rocks of the same age to the northwest. The contrast in total thickness is striking: those in the Tellico-Sevier belt average 7,500 feet, compared with their correlatives in southwestern Virginia that average 1,500 feet.

In the section that follows features of formations that have been described are interpreted to determine their sedimentary environment. In addition to those features that indicate relative proximity to an eastern source area, each formation possesses features that permit interpretation of some aspects of Middle Ordovician paleogeography and paleotectonics of the region.

In broad terms three phases of a sedimentary and tectonic cycle can be recognized:

Initial phase: Erosion of low-lying lands and deposition on an adjacent shelf.

Active phase: Deepening of the sedimentary basin with accompanying elevation of the bordering land.

Closing phase: Filling of the basin and reduction of relief on the bordering land.

In the succeeding pages these changes and the evidence for them are traced through the successive intervals of Middle Ordovician time.

### BLACKFORD AND ELWAY TIME

Initial Middle Ordovician rocks (Douglas Lake member of the Lenoir limestone) were deposited on a surface of limestones and dolomites of Early Ordovician age which had been subject to subaerial erosion. Solution cavities of large size had been developed (Laurence, 1944), and residual deposits of chert, limestone and dolomite fragments, and mud had accumulated in depressions on that surface. These materials were incorporated into the basal conglomeratic member of the Lenoir limestone.

Following the initial deposits, lime muds of two types accumulated: those of exceptional purity in which only gastropod remains have been found (Mosheim member of the Lenoir limestone), and argillaceous deposits with a normal brachiopod fauna (argillaceous limestone member of the Lenoir limestone). Present knowledge does not permit the distinction of a pattern of areal distribution of these facies. Cloud and Barnes (1948, p. 45) considered that some limestones of the Lower Ordovician Ellenburger group, which are similar to the Mosheim, were precipitated chemically, and that their deposition was comparable to the formation of calcium carbonate muds accumulating now in the Bahamas. Black (1933, p. 457) showed that these Bahaman muds are accumulating in shallow areas that served as vast evaporating pans, in which increasing temperatures drive off carbon dioxide, thus reducing the solubility of calcium carbonate. These precipitated muds are inhospitable to most forms of life, but they contain patches where bottom conditions permit the growth of abundant mollusks (Cloud and Barnes, 1948, p. 59). Descriptions of the Bahamas deposits, however, do not provide an analogy for the argillaceous limestones of the typical phase of the Lenoir limestone. It seems reasonable to postulate that these deposits were formed in more freely circulating waters where conditions for the growth of brachiopods were more favorable. One important factor would certainly be a higher concentration of carbon dioxide in open water that would favor the growth of phytoplankton which probably furnished food for brachiopods.

The contrast in clay content between the two rock types suggests that the Mosheim member was precipitated from clear waters, whereas the argillaceous limestone member of the Lenoir was deposited from more turbid water.

It is therefore possible to interpret the close association of the argillaceous with the more pure limestones of the Lenoir as simultaneous deposits beneath a sea whose bottom stood at different depths from place to place. In the more shallow waters deposition may have been restricted to chemically precipitated calcium carbonate; in deeper waters circulation was probably better, conditions more suitable for marine life, and the more easily transported terrigenous clays could become mixed with lime muds.

The tectonic environment of these deposits may be that of an unstable shelf (Krumbein and Sloss, 1951, p. 361–363), characterized by mild subsidence with the addition of little detrital material.

### LINCOLNSHIRE TIME

The unstable shelf environment (Krumbein and Sloss, 1951, p. 361–363) persisted through Lincolnshire time. Although no rock unit in the Tellico-Sevier belt can be correlated with the Lincolnshire, to the northwest the Lincolnshire limestone is a nodular argillaceous rock, similar to the Lenoir and characteristic of this environment. In the Tellico-Sevier belt the contact between the Lenoir limestone and the Blockhouse shale is interpreted as a disconformity that marks interruption of deposition spanning Lincolnshire time. Interruption of deposition that results from changes in sea level or from local warping should also be associated with the unstable shelf environment.

### WARD COVE TIME

Evidence of the transition from the initial phase to the active geosynclinal phase is shown by Ward Cove equivalents in the Tellico-Sevier belt. The great contrast in thickness of the rocks of Middle Ordovician age in northwestern and southeastern outcrop belts is largely accounted for by rocks of Ward Cove age. In the Tellico-Sevier belt rocks correlated with the Ward Cove limestone of Cooper and Prouty (1943) are about 4,000 feet thick; in the Friendsville, Tenn., area to the northwest, they are 1,200 feet thick, and the Ward Cove limestone in its type area in southwestern Virginia is only 175 to 225 feet thick (Cooper, 1945, p. 46). The sedimentary environment of the individual rock units is suggested below.

The earliest sediments of Ward Cove age (Whitesburg limestone member of the Blockhouse shale) are fine-grained argillaceous limestone with a fauna of brachiopods, bryozoans, and trilobites that represent a continuation of the unstable shelf environment that prevailed in earlier Middle Ordovician time.

The succeeding rocks record a change to geosynclinal sedimentation culminating with deposition of the Tellico formation. This change brought progressively greater quantities of terrigenous materials to the site of sedimentation accompanied by deepening of the sedimentary basin. The transition seems to reflect a change in crustal relief and stability from minimum relief and maximum stability in early Ward Cove time to maximum relief and considerable instability recorded in the deposits of the Tellico formation.

In the Tellico-Sevier belt dark-gray calcareous shale with a graptolite fauna (dark shale member of the Blockhouse shale) overlies the argillaceous limestone with gradational contact. Rocks believed to be correlative with these shales have spatial relations that are suggestive of their depositional environment. A progression from shale in the southeastern outcrop belts to limestone in those of the northwest points to a southeastern source of terrigenous materials. The conglomeratic sandstone (Toqua sandstone member of the Blockhouse shale) that intertongues with the dark shale is further evidence of this source.

At several places in the southeastern area (for example, Boyds Creek and St. Clair, Tenn.) beds of calcarenite intercalated with dark shale suggest that marine currents derived carbonate detritus from an offshore source and redeposited it as bars or submerged sills.

Poor ventilation and quiet bottom conditions are requirements for the accumulation of dark finely laminated shale (Kuenen, 1950, p. 9–14). Poor ventilation occurs in land-locked seas in which the entire body of water is nearly stagnant, in lagoons in which seaward circulation is confined to inlets, and in areas in which the circulation of upper and lower layers differ—the upper layers unrestricted, but the lower ones protected by sills or other obstructions to circulation on the bottom layers.

The presence of limestone beds contemporaneous with the shale to the northwest suggests that the dark shales of the Blockhouse shale were not deposited in a land-locked basin. The bars or sills recorded by the calcarenite may have been barriers to marine circulation that prevented thorough ventilation in the area of dark-shale sedimentation.

The depths at which marine circulation was inhibited may be indicated by the occurrence of graptolites in limestone that also contains brachiopods, trilobites, and other elements of a normal benthonic fauna. Several geologists (G. A. Cooper, H. B. Whittington, and A. J. Boucot) have found this association of fossils in rock that they had dissolved with hydrochloric acid. Graptolites are believed to have lived near the surface of the water, suspended from floats of their own making or attached to floating materials such as seaweed (Ruedemann, 1947, p. 15–23). It therefore seems that the surface layers over areas of both limestone and dark-shale sedimentation were sufficiently alike to support the same graptolite faunas. The present writer concludes that waters at shallow depth circulated freely, but that beneath them, in areas of dark-shale sedimentation, circulation was restricted.

Shrinkage cracks that mark some limestone beds within the dark-shale sequence do not necessarily indicate subareal exposure. Shrinkage cracks may also form as a result of loss of volume because of diagenetic crystallization of calcium carbonate without subareal exposure (Pettijohn, 1949, p. 144).

Lithic features of the Toqua sandstone member shed additional light on the sedimentation of the Blockhouse shale. The common occurrence of crossbedding in the sandstone, the rock fragments that it contains, and the limited distribution of this rock suggest to the writer that it was deposited at the mouth of a major stream. Intercalation of shale and sandstone suggests that fluvial distributaries entered the area of poor ventilation where shales were being deposited. Occasionally when these distributaries were operative, shale deposition was replaced by sandstone deposition. These distributaries so little altered the general environment that the special conditions required to produce the shale resumed immediately after they ceased to flow.

The writer believes, therefore, that the Blockhouse shale (exclusive of the Whitesburg limestone member) accumulated in a position intermediate between an area of limestone sedimentation that lay to the west and land on the east. The waters were sufficiently deep to have protected the bottom from subareal exposure, but no evidence was seen that suggests a maximum depth of these waters. The area of sedimentation was protected from bottom circulation, probably by submerged sills that accumulated on the shoreward side of the area of limestone sedimentation.

The shales and sandstones of the Tellico formation that overlie the Blockhouse shale do not have the nearshore and confined aspect of the lower beds. Although these shales and sandstones are only sparingly fossiliferous, the fossils that have been found are brachiopods and bryozoans, which make up an assemblage comparable to that in the limestones of outcrop belts to the northwest.

The lighter shades of gray that characterize the shales of the Tellico formation indicate oxidation of the carbonaceous material that was deposited with them. The parallel laminae of this rock shows that it was not disturbed by wave turbulence, but varying amounts of silt and sand contained in the shales suggest that bottom currents were actively distributing materials. Continuing subsidence through the span of time represented by the Tellico formation is inferred by the essential uniformity of the shales of the formation throughout its thickness.

Conclusions on the sedimentary environment of the sandstone lenses which form the middle division of the Tellico formation are much more difficult to reach. Bottom currents competent to move particles of the sizes involved commonly show their presence and direction by crossbedding. Turbidity currents leave their marks in graded bedding and convolute structures. Only a small part of the sandstones of the Tellico formation are crossbedded, and the structures that indicate transport by turbidity currents are totally lacking. A possible niche for these sandstones may lie near the front of a mass of material that was transported by turbidity currents.

Conglomeratic sandstones with convolute structures that are probably correlative with the Tellico formation occur east of Bristol, Tenn., in Virginia (sandstone facies of the Athens formation of Butts, 1940, p. 163), and similar rock that may also be correlative has been reported to the southwest of the area of this study, east of Etowah, Tenn. (J. M. Kellberg, oral communication, 1953), and near Cisco, Ga. (Munyan, 1951, p. 67). These occurrences indicate that there was a large supply of sandy material available for redistribution, either by currents of normal marine circulation or by turbidity currents. Thus, when these currents were advantageously fed, or flowed into the area that is now the Tellico-Sevier outcrop belt, sands were deposited; but when these conditions were interrupted, only the finer grained clays and silts were deposited.

The feldspar content of the sandstone of the Tellico formation indicates a source that was highly feldspathic, subject to weathering that permitted preservation of this mineral. The feldspar grains may have been derived from granitoid rocks, or from highly feldspathic sandstone similar to those of the Ocoee series (King, 1949, p. 633). Preservation of feldspar is possible when the source area is subject to weathering under an arid or semiarid regimen, or under humid conditions with considerable relief (Pettijohn, 1949, p. 385). Ferrous iron and clay in sandstone of the Tellico formation suggest the second alternative: that solution and hydration were active processes in the source area, but that oxidation and hydration of the transported material was not completed before burial. It is concluded, therefore, that the source area for the sediments of the Tellico formation was tectonically active (Kay, 1951, p. 14–15), and that a humid climate prevailed there.

### BENBOLT TIME

The closing phase of the cycle recorded by rocks of Middle Ordovician age in the Tellico-Sevier belt begins with rocks of Benbolt age. During this time thicker and coarser grained rocks were deposited in the southeast, but the contrast with equivalent beds in outcrop belts farther northwest is not as conspicuous as it is in rocks of Ward Cove age. Thicknesses increase from 400 feet of the Benbolt limestone of Cooper and Prouty (1943) in southwestern Virginia to about 1,000 feet in the Friendsville-Knoxville belt and to 2,000 feet of the Chota formation and the main body of the Sevier formation.

Evidence of uniform and slow depression of the basin of deposition and of a persistent pattern of marine currents in it are shown by the calcarenite of the Chota formation. Disarticulation and abrasion of the organic debris that forms a large part of this rock points to extended agitation and transport. The uniform size and rounding of the quartz grains of this rock furnishes information of the same kind, as does the current bedding that is ubiquitous through the formation.

The overlying interbedded shale and sandstone indicates a departure from this uniformity. The small size of the sand grains in these beds, together with the virtual absence of feldspar grains, indicates that weathering of the source area was more advanced than that which produced the sands of the Tellico formation. The complex interrelations of this terrigenous detritus with shale may have resulted from one or more of the following factors: (1) Contributions of new materials to the sedimentary basin may have been concentrated into a few pulses that are recorded as sandstone units; (2) minor shifts in the strand line may have effected the distribution of sandstone and shale; (3) minor changes in the bathymetry produced by tectonics or reef-building organisms may have governed the distribution of bottom currents and hence their ability to deposit material; and (4) paleoclimatological factors that may also have effected the course of marine currents. Probably only minor variations were required to effect a change from shale to sandstone or calcarenite deposition, and it is impossible, in the light of current knowledge, to select any single con trolling factor.

The depth of water in which the rocks of the Sevier formation was deposited was probably less than that which prevailed during deposition of most of the

Tellico formation. The common occurrence of large colonies of bryozoans and other organisms indicates relatively shallow water, as do most occurrences of current bedding and ripple marks.

### WARDELL TIME

If the correlation of the Bacon Bend member of the Sevier formation with the Wardell formation of Cooper and Prouty (1943) of southwestern Virginia is correct, thickening is toward the northwest, perhaps as a result of mass movement (Fairbridge, 1946, p. 88). The Bacon Bend ranges from 40 to 165 feet in thickness, and the Wardell in its type locality ranges from 35 to 200 feet (Cooper and Prouty, 1943, p. 875). The northeast-southwest elongation of the nodules of the deformed beds of the Bacon Bend further suggests basinward movement.

Introduction of red mudrock into this sequence suggests that the conditions that culminated to produce the overlying Bays formation were being established. Thus, in the source area conditions became comparable to those that prevailed during deposition of the Bays formation, but conditions of deposition were somewhat different, as may be seen in the contrast in fossil content and in minor differences in bedding structure. Red mudrock of the Bacon Bend contains orthid brachiopods and gastropods in contrast with the Bays fauna of animals that could protect themselves from exposure to the air by burrowing. The transition thus recorded is one of increasing supply of terrigenous material into a shallowing marine basin.

### WITTEN AND MOCCASIN TIME

Eastward thickening and coarsening of detrital material is again observable in rocks of Witten and Moccasin age. The Bays formation in the Tellico-Sevier belt contains considerable siltstone and sandstone, in contrast with yellow shale and blue limestone equivalents to the northwest. The thickness of the Bays formation, reduced an indeterminate amount by post-Bays erosion, is 400 to 1,000 feet; in southwestern Virginia, where the interval is not punctuated by erosion, the Witten and Moccasin formations total about 425 feet in thickness (Cooper and Prouty, 1943, p. 878–880).

Van Houten (1948), concluded that the red early Cenozoic deposits of the Rocky Mountain region were derived from red soils developed on a terrane of complex bedrock and deposited as red rocks in "tectonic basins which sank rapidly enough to maintain a lowland environment" (p. 2103). Red soils develop under a warm humid climate, on topography that is well drained (p. 2117). Chemical weathering must be effective to produce these soils, permitting iron-bearing minerals to be thoroughly oxidized. Thus the rate of weathering of the source area exceeded denudation, and erosion was seldom so great as to permit complete stripping of the weathered mantle.

These red muds were probably deposited in shallow mud flats that seem to have been drained intermittently. The well-marked bedding planes that separate the thick and obscurely laminated beds and the fauna of linguloid brachiopods, large thick-shelled ostracodes, and pelecypods, all of which were probably burrowing forms, are considered evidence for this environment.

The clean quartz sandstone that is preserved in lenticular bodies at the top of the Bays formation may be a much-washed beach sand. Rock of this type was classed as a postorogenic deposit by King (1950, p. 661).

### BLOUNTIAN OROGENY

Rodgers (1953, p. 94) gave the name Blountian orogeny to the crustal disturbance that was the ultimate cause for the accumulation of the thick section of rock described in this paper. Rodgers stated his belief that the climax of this orogeny is represented in the Bays formation.

The writer believes that the maximum relief between source area and sedimentary basin is recorded in sandstones of the Tellico formation, and that the conglomerates referred to by King (1950, p. 661) as evidence for the orogeny are equivalent to part of that formation. The succeeding formations are believed to contain evidence of continuing denudation of the source area with attendant filling of the basin. Volcanism, recorded by metabentonite at several horizons in outcrop belts to the northwest, is held by some as evidence of an orogenic climax, but volcanism is also associated with the waning stages of orogeny (Turner and Verhoogen, 1951, p. 201). Further evidence of igneous activity associated with this event are the pegmatites of Spruce Pine, N. C., for which Middle Ordovician age assignments have been made (Rodgers, 1952a, p. 420), but it is not possible to relate these with any specific stratigraphic unit.

It is not yet possible to indicate the nature and extent of the source area that was undergoing orogenesis. It may have been a landmass of the kind commonly included in the concept of Appalachia; Kay (1951, pl. 1) has conceived of an island chain, and King (1950, p. 659) has described the source area as "fold ridges that were raised in the interior zones of the mountain system * * * ."

### ADDITIONAL COLLECTING LOCALITIES

Locations of points at which fossils were collected supplemental to those already described. Descriptions of localities are with reference to named geographic points that are identifiable on the U. S. Geological

Survey-Tennessee Valley Authority topographic quadrangle concerned. Where collections from more than one formation are cited from the same locality, its location is given only with the lower formation.

Lenoir limestone:
- Vonore quadrangle:
  - VO 4. Lane and pasture 0.5 mile southeast of Howard Bridge. *Rostricellula* cf. *R. pristina* (Raymond), *Lingula fostermontensis* Butts; Douglas Lake member.
- Tallassee quadrangle:
  - TA 5. Lane and abandoned quarry, 0.65 mile southwest of Williamson Chapel. *Rostricellula* cf. *R. pristina* (Raymond); Douglas Lake member. *"Rafinesquina" champlainensis* Raymond; Lenoir limestone.
- Binfield quadrangle:
  - BN 3. Abandoned quarry, 0.2 mile southeast of road "Y" at Mint. *Valcourea strophomenoides* (Raymond), *Mimella* sp., *"Rafinesquina" champlainensis* Raymond; Lenoir limestone.
- Blockhouse quadrangle:
  - BL5 A. Pasture, 0.2 mile southwest of road "T" at Blockhouse. *Valcourea strophomenoides* (Raymond); Lenoir limestone.
- Wildwood quadrangle:
  - WD 41. Abandoned quarry, 0.94 mile northwest of Ellejoy Church. *Valcourea strophomenoides* (Raymond); *"Rafinesquina" champlainensis* Raymond; Lenoir limestone. *Maclurites magnus* Lesueur; Mosheim member.
  - WD 45. Pasture, 1.45 miles north of Ellejoy Church *Hesperorthis* sp., *"Rafinesquina" champlainensis* Raymond; Lenoir limestone.
  - WD 46. Pasture, 1.46 miles northwest of Ellejoy Church *Rostricellula* cf. *R. pristina* (Raymond), leperdidiid ostracodes; Douglas Lake member.

Blockhouse shale:
- Vonore quadrangle:
  - VO 4. *Schizotreta* sp., Whitesburg limestone member.
- Tallassee quadrangle:
  - TA 3. Road cut, U. S. Highway 129, 0.58 mile east of Lanier School. *Orthambonites* sp., *Glyptorthis* sp. *Paleostrophomena* sp., *Paurorthis* sp., *Ampyx* sp., Whitesburg limestone member.
  - TA 5. *Skenidioides* sp., *Schizotreta* sp., Whitesburg limestone member.
- Binfield quadrangle:
  - BN 4. Cultivated field, 0.65 mile southwest of Mt. Olive Church. *Orthambonites* sp., *Skenidioides* sp., *Christiania subquadrata* Hall and Clarke; Whitesburg limestone member.
  - BN 3. *Glyptorthis* sp., *Orthambonites* sp. ,*Christiania subquadrata* Hall and Clarke; Whitesburg limestone member.
- Blockhouse quadrangle:
  - BL 5. Pasture, 0.15 mile southwest of road "T" at Blockhouse. *Orthambonites* sp., *Glyptorthis* sp., *Clitambonites* sp., *Leptellina* sp., *Dactylogonia* sp., *Paurorthis* sp., *Lingula* sp., *Lingulasma* sp., *Ampyx* sp., *Acrolichas* sp., *Cybiloides* sp., *Pliomerops* sp., Whitesburg limestone member.
  - BL 10. Drainage ditch, north side of county road, 0.25 mile south of Pine Level Church *Diplograptus* sp.,

Blockhouse shale—Continued
- Blockhouse quadrangle—Continued
  - *Glossograptus* sp.; Blockhouse shale, 75 ft above the top of the Whitesburg limestone member.
- Wildwood quadrangle:
  - WD 39. Gully, north side of county road, 1.15 miles east-northeast of Prospect crossroads. *Nemagraptus gracilis* (Hall) *Diplograptus* sp.; Blockhouse shale, about 250 ft above the top of the Whitesburg limestone member.
- Walden Creek quadrangle:
  - WA 2. Road cut, county road, 0.62 mile southeast of Harrison Chilhowee Academy. *Orthambonites* sp., *Skenidioides* sp., *Christiania subquadrata* Hall and Clarke, gen. and sp. aff. *Leptella pseudoretroflexa* Reed, *Oxoplecia* sp.; Whitesburg limestone member.
  - WA 27. Road cut, south side of county road at turn, 0.53 mile north of Knob Creek Church. *Diplograptus* sp., *Dicellograptus moffatensis* var. *alabamensis* Ruedemann, *D. sextans* (Hall), *Cryptograptus tricornis* var. *insectiformis* Ruedemann(?); Blockhouse shale.
  - WA 29. Road cut, northwest side of lane (Reagan Branch), 0.45 mile northeast of Knob Creek Church. *Diplograptus* sp., *Dicellograptus moffatensis* var. *alabamensis* Ruedemann, *D. sextans* (Hall); Blockhouse shale.

Tellico formation:
- Vonore quadrangle:
  - VO 26. Abandoned quarry, 0.25 mile north of Hawkins Bridge. *"Strophomena" tennesseensis* Willard; upper shale division.
  - VO 26A. North side of road "Y," 0.2 mile north of Hawkins Bridge. *Mimella* sp., *Multicostella* sp.; upper shale division.
  - VO 37. Road cut, lane, 0.88 mile north-northeast of Hawkins Bridge. *Orthambonites* sp., *Glyptorthis* sp., *Paleostrophomena* sp. ceraurid trilobites; middle sandstone division.
  - VO 20. Wooded ridge crest and saddle, 1.12 miles south-southeast of Toqua School. *Orthambonites* sp., *Multicostella* sp., *Cyrtonotella* sp.; middle sandstone division.
  - VO 21. Pastures, 1.6 miles south-southeast of Toqua School. *Orthambonites* sp., *Mimella* sp., *Dinorthis* sp., *Paleostrophomena* sp., *"Strophomena" tennesseensis* Willard, *Paurorthis catawbensis* Butts, *Schizotreta* sp., aparchitid ostracodes, *Calliops* sp., *Calymene* sp.; upper shale division.
  - VO 15. Road cut, west side of county road, 0.47 mile west-northwest of Chota School. *Glyptorthis* sp., *Multicostella* sp., *Mimella* sp., *Cyrtonotella* sp., gen. and sp. aff. *Öpikina*, *Paurorthis catawbensis* Butts; upper shale division.
- Tallassee quadrangle:
  - TA 28. Lane, 1.0 mile southwest of bridge at Wellsville. *Glyptorthis* sp., *Calliops* sp.; upper shale division.
- Binfield quadrangle:
  - BN 7. Road cut, west side of county road, 0.35 mile north of Old Kagley Church. *Multicostella* cf. *M. saffordi* (Hall and Clarke), *Orthambonites*, gen. and sp. aff. *Öpikina*; upper shale division.

Tellico formation—Continued

Blockhouse quadrangle:

BL 18. Wooded hillside and crest, 0.42 mile west of Old Piney Church. *Glyptorthis* sp., *Multicostella* cf. *M. bursa* (Raymond), *Cyrtonotella* sp., "*Strophomena*" *tennesseensis* Raymond, *Sowerbyella negritus* (Willard), *Leptellina* sp., *Dactylogonia*, sp., *Camerella* sp., *Oxoplecia* cf. *O. holstonensis* Willard, gen. and sp. aff. *Öpikina*; middle sandstone division.

BL 28. East side of lane, 0.69 mile southeast of Piney Grove Church. *Dicranograptus* sp.; middle sandstone division.

BL 136. Road cut, north side of road "T" at BM 1366, 1.0 mile southeast of Chilhowee View School. *Glyptorthis* sp., *Cyrtonotella virginiensis* Butts, *Paleostrophomena* sp., *Paurorthis catawbensis* Butts, n. gen. and sp. aff., *Lychas* sp., *Isotelus* sp., *Trinodus* sp.; upper shale division.

BL 36. Road cut, east side of county road, 0.85 mile southeast of Chilhowee View School. *Orthambonites* sp., *Skenidioides* sp., *Glyptorthis* sp., *Paleostrophomena* sp., *Paurorthis* sp.; middle sandstone division.

Kinzel Springs quadrangle:

KZ 8A. Road cut, lane in Spicewood Branch, 1.42 miles west-southwest of Rocky Branch School. "*Strophomena*" *tennesseensis* Raymond; middle sandstone division.

Wildwood quadrangle:

WD 7. Pasture on ridge, 0.45 mile northwest of Cold Springs School. *Orthambonites* sp., *Mimella* sp., "*Strophomena*" *tennesseensis* Raymond; middle sandstone division.

WD 6. Road cut and pasture east of lane, 0.3 mile northwest of Cold Springs School. *Orthambonites* sp., "*Strophomena*" *tennesseensis* Raymond; middle sandstone division.

WD 22. Pasture at ridge crest, 0.65 mile east-northeast of Cold Springs Church. *Orthambonites* sp., "*Strophomena*" *tennesseensis* Raymond; middle sandstone division.

WD 23. Pasture on ridge, 0.55 mile east-northeast of Cold Springs Church. "*Strophomena*" *tennesseensis* Raymond, gen. and sp. aff. *Öpikina*; middle sandstone division.

WD 27. Stream bed, 1.0 mile east-northeast of Cold Springs Church. *Sowerbyella negritus* (Willard), *Oxoplecia* cf. *O. holstonensis* Willard; middle sandstone division.

Walden Creek quadrangle:

WA 42. Road cut and low hill on both sides of Chapman Highway (U. S. 411, 441, and Tenn. 71), 0.34 mile north-northwest of Pitner School. *Sowerbyites* sp., "*Strophomena*" *tennesseensis* Raymond, *Leptellina* sp., *Bimuria superba* Ulrich and Cooper, *Paurorthis* sp.; upper shale division.

WA 45. Abandoned quarry, northeast of intersection of county road with Chapman Highway, 0.64 mile northeast of Pitner School. *Sowerbyites* sp.; upper shale division.

WA 58. Wagon road, 0.38 mile north-northwest of Sugarloaf Church. "*Strophomena*" *tennesseensis* Raymond, *Paurorthis* sp.; upper shale division.

Tellico formation—Continued

Walden Creek quadrangle—Continued

WA 61. Road cut, north side of Chapman Highway, 1.0 mile southwest of Zion Hill Church. *Vellamo*? sp., *Cyrtonotella* sp., *Sowerbyella ampla* (Raymond), *Paleostrophomena* sp., *Ptychoglyptus virginiensis* Willard; upper shale division.

WA 60. Abandoned quarry, south bank of Knob Creek, 0.7 mile northeast of Pitner School. *Echinosphaerites* sp., *Climacograptus* sp., *Multicostella* sp., *Dinorthis* sp., "*Strophomena*" *tennesseensis* Raymond, *Sowerbyites* sp.,*Leptellina* sp., *Oxoplecia* cf. *O. holstonensis* Willard; upper shale division.

WA 67. Pasture in valley, 0.6 mile east-southeast of Sugarloaf Church. Asaphid trilobite fragments; upper shale division.

WA 70. Road cut, north side of Chapman Highway, 0.36 mile north-northwest of Pleasant Hill Church. Asaphid trilobite fragments; upper shale division.

Pigeon Forge quadrangle:

PF 24. Road cut, north side of Chapman Highway, 1.9 miles northwest of New Era Church. *Nemagraptus gracilis* (Hall), *Climacograptus* sp., *Didymograptus* sp; upper shale division.

Chota formation:

Vonore quadrangle:

VO 34. Wooded hillside 0.35 mile south of Hawkins Bridge. *Nidulites*? sp., *Echinosphaerites*? sp., *Ptychopleurella* sp., *Glyptorthis* sp., *Paurorthis*? sp., *Lingula* sp.; limestone at top of formation.

Tallassee quadrangle:

TA 24. Pasture on hillside and abandoned quarry, 0.42 mile southwest of Nelson Chapel. *Multicostella* sp., *Oligorhynchia* sp., n. gen. aff. *Zygospira acutirostris* (Hall); upper third of formation.

Blockhouse quadrangle:

B 9A. Road cut, east side of county road, 0.3 mile southeast of Liberty Church. *Mimella* sp.; middle part of formation.

BL 54. Abandoned roadway, 1.24 miles east-northeast of Old Piney Church. *Protozyga* sp.; uppermost 100 ft of formation.

BL 71. Lane, 0.24 mile southwest of Law Chapel. *Mimella* sp.; middle part of formation.

Walden Creek quadrangle:

WA 5. Road cut, lane east side of Carter Branch, 0.7 mile southwest of Dripping Springs School. "*Strophomena*" *tennesseensis* Raymond; middle part of formation.

Sevier formation:

Vonore quadrangle:

VO 35. Pasture, 0.68 mile southwest of Howard School. *Mimella* sp., *Multicostella* sp., *Camerella* sp., *Rostricellula rostrata* Ulrich and Cooper, *Sowerbyella* sp.; upper shale division.

VO 35A. Same pasture as VO 35, 100 ft southeast *Mimella* sp., *Rostricellula rostrata* Ulrich and Cooper, *Sowerbyella* sp.; upper shale division.

Tallassee quadrangle:

TA 41. Old railroad cut, north side, 0.06 mile northwest of north landing of Jones Ferry. *Doleroides* sp., *Rostricellula* sp.; upper part of upper shale division.

Sevier formation—Continued

Tallassee quadrangle—Continued

TA 42. Hillside beneath power transmission line, 0.58 mile northwest of north landing of Jones Ferry. *Pionodema* sp.; Bacon Bend member.

TA 51. Abandoned quarry, north side of Tenn. Highway 72, 1.55 miles west-northwest of the intersection of Tenn. Highway 72 with U. S. Highway 129. *Doleroides* sp., *Rostricellula rostrata* Ulrich and Cooper, *Dactylogonia* sp., *Sowerbyella* sp.; upper shale division.

TA 48. Creekbed, 0.5 mile north-northeast of Jones Cemetery, *Rostricellula rostrata* Ulrich and Cooper, *Sowerbyella* sp.; upper shale division.

TA 46A. Lane, west side of Spradling Branch, 0.91 mile northeast of Jones Cemetery. *Doleroides* sp.; Bacon Bend member.

TA 26. Gully on ridge crest, 0.43 mile west of Fourmile Church. *Camerella* sp., *Oxoplecia* cf. *O. holstonensis* Willard, *Christiania* sp., *Sowerbyella* sp., *Calliops* sp.; upper shale division.

TA 25. Creekbed, 0.28 mile northwest of Fourmile Church. *"Camerella" longirostris* Billings, *Protozyga* sp.; middle sandstone division.

TA 29A. Road cut, north side of county road, 0.13 mile northeast of Fourmile Church. *Fascifera* sp., *Rostricellula* sp.; Bacon Bend member.

TA 24X. Ledges southeast of road "Y," 0.45 mile southwest of Nelson Chapel. *Protozyga* sp., *Eurychilina* sp., *Aparchites*? sp.; middle sandstone division.

TA 18A. Road cut, east side of lane, 0.55 mile south-southeast of Nelson Chapel. *Glyptorthis* sp.; upper shale division.

TA 20. Road cut, west side of lane, west side of Fourmile Creek, 1.15 miles east-northeast of Fourmile Church. *Conularia* sp., *Doleroides* sp., *Rostricellula rostrata* Ulrich and Cooper; Bacon Bend member.

TA 13. Pasture, west side of Clear Creek, 0.62 mile south-southwest of Kagley Chapel. *Hormotoma* sp., *Doleroides* sp.; Bacon Bend member.

TA 16. Bluffs west of Clear Creek, 0.28 mile southeast of Kagley Chapel. *Glyptorthis* sp., *Mimella superba* Butts, *Dactylogonia* sp., *Sowerbyella* sp.; upper shale division.

TA 16A. Same section as TA 16, 300 ft southeast of *Sowerbyella* sp.; upper shale division.

TA 6. Road cut, east side of lane, 0.5 mile east-northeast of Kagley Chapel. *Ptychopleurella* sp., *"Camerella" longirostris* Billings, *Sowerbyella* sp.; upper shale division.

TA 2. Creekbed, 0.8 mile east-southeast of Kagley Chapel. *Glyptorthis*, *Rostricellula rostrata* Ulrich and Cooper, gen. and sp. aff. *Zygospira acutirostris* (Hall); upper shale division.

Binfield quadrangle:

BN 11. Road cut, east side of lane, east bank of Sixmile Creek, 0.52 mile east-southeast of Old Kagley Church. *Glyptorthis* sp., *Doleroides* sp., *Camerella* sp., *Sowerbyella*, n. gen. aff. *Sowerbyites;* upper shale division.

Blockhouse quadrangle:

B 35. Road cut, southeast side of county road, 0.27 mile southeast of Christie Hill School. *Pionodema* sp., *Zygospira* sp., *Rostricellula rostrata* Ulrich and Cooper; Bacon Bend member.

Sevier formation—Continued

Blockhouse quadrangle—Continued

B 22. Creekbed, 0.4 mile southeast of Sixmile Cemetery. *Glyptorthis* sp., *Fascifera* sp., *Dactylogonia* sp.; middle sandstone division.

B 17. Creekbank 0.91 mile south-southwest of Old Piney Church. *Mimella* sp., *Glyptorthis* sp.; upper shale division.

BL 57. Road cut, east side of county road, 1.7 miles southeast of Chilhowee View School. *Sowerbyella* sp.; upper shale division.

BL 70. Hillside in pasture, 1.08 miles southwest of Law Chapel. *Doleroides* sp., *Rostricellula rostrata* Ulrich and Cooper; upper shale division.

Kinzel Springs quadrangle:

KZ 2. Creek bottom, 0.32 mile southeast of Law Chapel. *Rostricellula rostrata* Ulrich and Cooper, *Zygospira* sp.; upper shale division.

KZ 11. Creekbank, north side of creek and county road, 0.45 mile southwest of Rocky Branch School. *Dinorthis transversa* Willard; middle sandstone division.

Bays formation:

Tallassee quadrangle:

TA 46. Lane, west side of Spradling Branch, 0.91 mile northeast of Jones Cemetery. *Lingula* sp.; lower 20 ft of formation.

TA 43. Old Lane, 1.1 miles southwest of Fourmile Church. *Lingula* sp.; lower 20 ft of formation.

Blockhouse quadrangle:

B 36. Trail, 0.45 mile southeast of Mountain View School. Pelecypods, poorly preserved in gray, friable-weathered sandstone.

BL 68. South bank of creek, 1.87 miles southeast of Old Chilhowee School. *Isochilina* aff. *I. armata* Walcott; middle part of formation.

BL 68A. Road cut, east side of county road, 0.46 mile east-southeast of site of Birchfield Church. *Lingula* sp.; 15 ft above base of formation.

BL 46. East side of lane, 0.87 mile south-southeast of Law Chapel. *Lingula* sp.; lower 20 ft of formation.

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[Italic numbers indicate stratigraphic descriptions

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