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To the Graduate Council:

I am submitting herewith a dissertation written by Melvin O. Smith entitled "Stratigraphy and Structure of the Middle Ordovician Rocks in the Vicinity of Calhoun, McMinn County, Tennessee." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Geology.

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STRATIGRAPHY AND STRUCTURE OF THE MIDDLE ORDOVICIAN ROCKS IN THE VICINITY OF CALHOUN, MCMINN COUNTY, TENNESSEE

A Dissertation

Presented for the

Doctor of Philosophy

Degree

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Melvin O. Smith

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To my family whose sacrifices, understanding and staunch support knew no bounds, I can only say, "God bless, and now it's your turn."

ABSTRACT

The units of the Chickamauga Group in the vicinity of Calhoun, Tennessee, are lithologic entities within a depositional framework representing complex, inter-related marine carbonate environments receiving varying amounts of terrigenous clastics. Environments represented by the various lithologies include intertidal carbonates, lagoonal carbonates and shales, subtidal, shallow shelf, calcarenite and oolite banks and bars, and deeper water fine clastics and basin carbonates. Modern analogues occur along the west coast of Florida and in the Persian Gulf on the Qatar Peninsula and along the Trucial Coast.

Tectonic episodes controlled sedimentation, at least on a minor local scale, and produced pebble conglomerates and facies boundary shifts in an otherwise stable shelf environment. Structural deformation may have been contemporaneous, in part, with sedimentation where minor facies changes occur in close association with minor folds.

Detailed mapping has permitted a reinterpretation of the stratigraphy and structure in which three newly designated (this paper) mappable members of the Ottosee are delineated and the structural interpretation of a north-plunging, breached anticline within the Athens syncline as shown on the Tennessee state geological map (Hardeman, et al., 1966) is rejected. The structure of the area is reinterpreted to be an asymmetric syncline with the southeast limb having the higher dips and being the most distorted. Several previously unmapped klippen were delineated and are interpreted as having possibly

originated as slices which occurred as a result of fault plane folding and refracturing to separate the mass from the underside of the allochthonous block.

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CHAPTER I

INTRODUCTION

I. GENERAL DISCUSSION

The Valley and Ridge Province of East Tennessee exhibits several elongate belts of strata separated by major thrust faults as shown in Figure 1. The area included in this study lies between two of the faults: the Knoxville fault to the northwest and the Chestuee fault to the southeast; this is the "Main Red Belt" of Safford (1869). The area includes a considerable portion of central McMinn County, parts of eastern and northern Bradley County, and the northwestern most part of Polk County. Further, all or portions of seven 7-1/2 minute topographic maps (scale: 1/24,000) are included in the study. They are the Calhoun, Riceville, Etowah, Benton, Charleston, Athens, and East Cleveland quadrangles of the Tennessee Valley Authority series as shown in Figure 2. The portion of the Athens quadrangle is slightly modified after Rodgers (1952) and the portion of the East Cleveland quadrangle is from Swingle (1959) (see Plate I in map pocket).

This investigation was undertaken to study and resolve apparent discrepancies between published data and observed field relationships relative to the Chickamauga units in the vicinity of Calhoun, Tennessee, and to relate the mapping by Swingle in the East Cleveland area with that of Rodgers in the Athens area.



Figure 1. Study area outlined on a portion of the Geologic Map of Tennessee (Hardeman, et al., 1966).

Stratigraphic units are colored only within the study area.

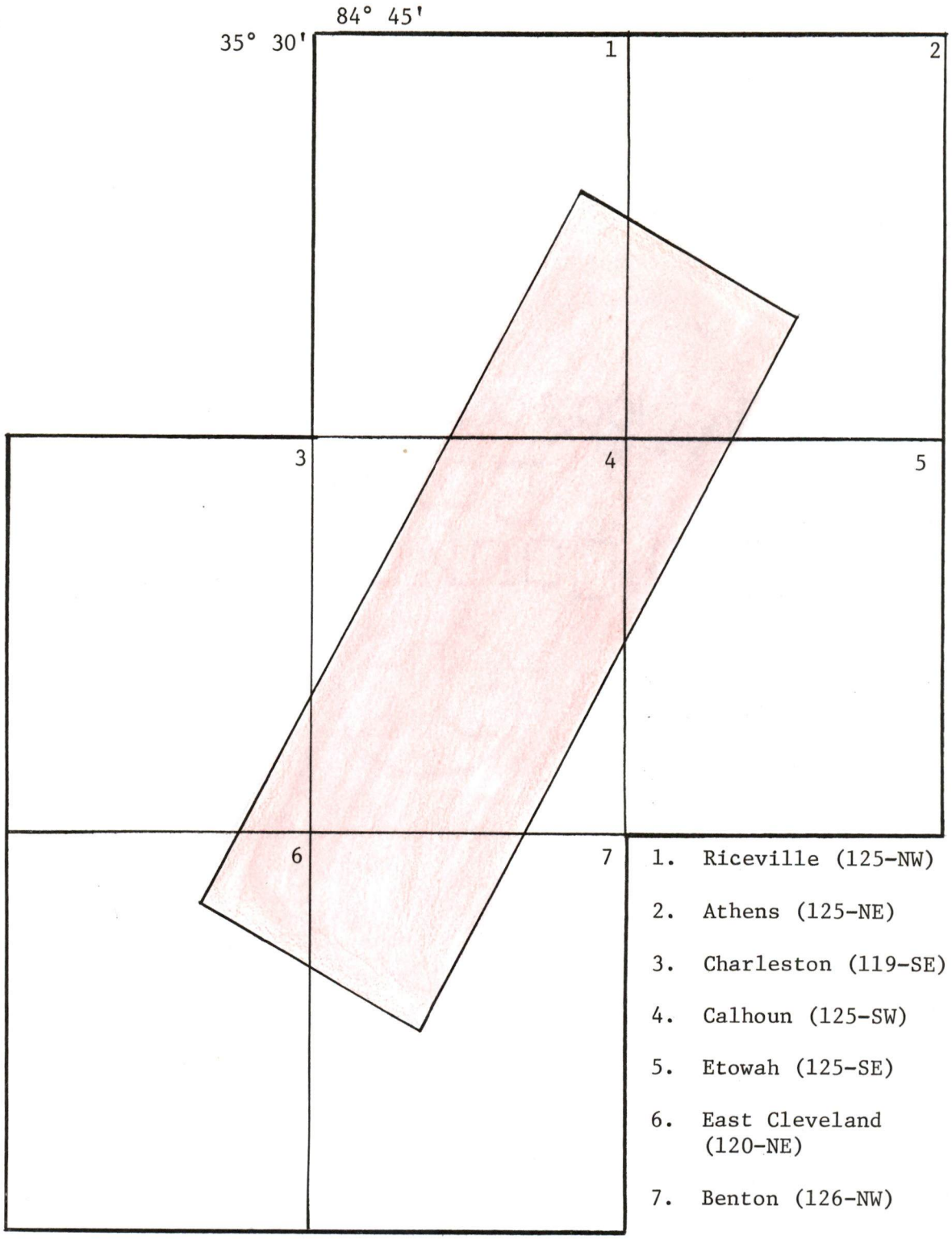


Figure 2. Quadrangle index map (all 7-1/2 minute quadrangles) with study area in red.

This report is mainly concerned with rocks of the Chickamauga Group of Middle Ordovician age. Key aspects of the study include three previously undescribed, mappable members of the Ottosee Shale, two oolitic limestone members and a very sandy fossiliferous limestone member. Although similar lithologically to the Chapman Ridge Formation of Cattermole (1958), the sandy limestone member of the Ottosee is not equivalent to the Chapman Ridge as it occurs several hundred feet higher in the stratigraphic section than the Chapman Ridge of the Calhoun area. Another factor which drew the writer's attention to the area was a discrepancy between the published structural interpretation and observed field data. Figure 3 illustrates the interpretation shown on the Geologic Map of Tennessee, East-Central sheet (Hardeman, et al., 1966). Section C-C' (Plate II) illustrates the interpretation of this report and is found in the map pocket.

Detailed geologic mapping was done in an area of 100 square miles in an effort to delineate the distribution and structural attitudes of all units, including the newly described lithologic units, and to ascertain their relationship to units previously mapped.

An attempt has been made to compare the Middle Ordovician rocks of this area to modern depositional patterns.

Nomenclature of earlier workers was applied where practical and where it complimented the presentation of the geologic situation. Nomenclatural changes were made and new names proposed as dictated by geologic data as shown in Figure 4 and Table I.

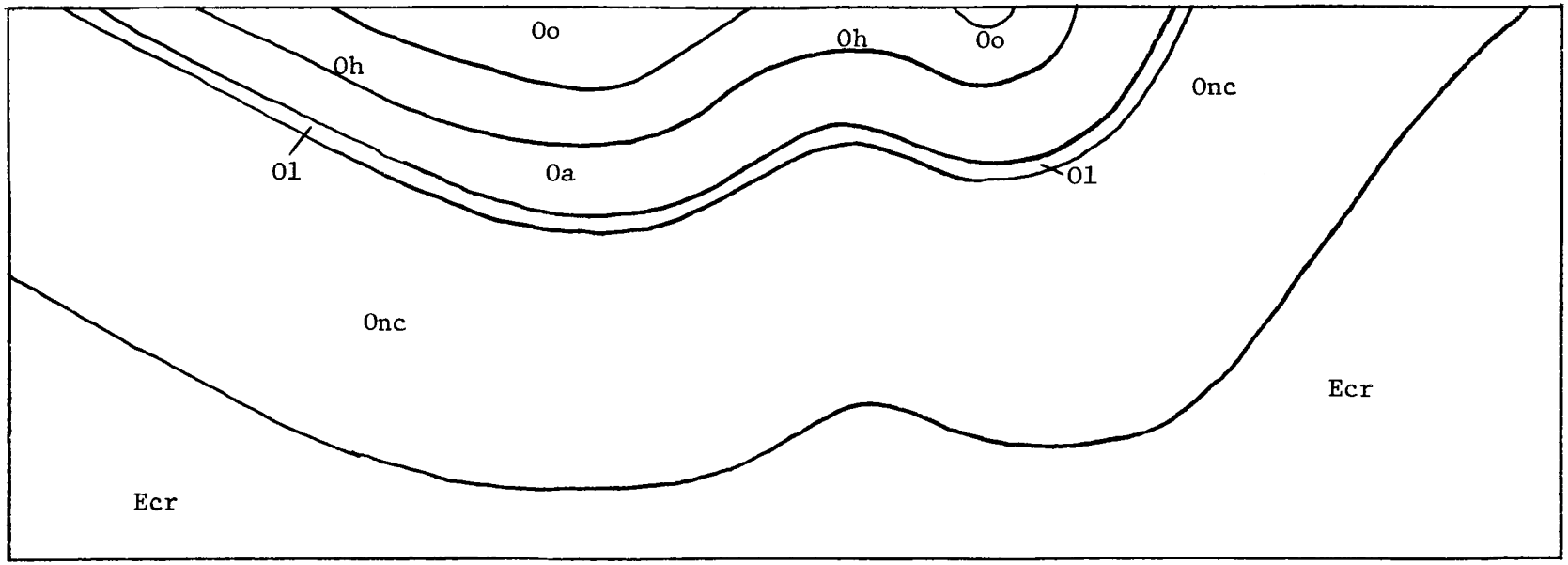


Figure 3. Generalized section across the Athens syncline generally paralleling the railroad tracks east of Calhoun, Tennessee.

The interpretation is that shown on the state geologic map (Hardeman, et al., 1966). Contacts are taken from the Calhoun geologic quadrangle (this report). Compare with structure section C-C' (Plate II in map pocket) along the same general line.

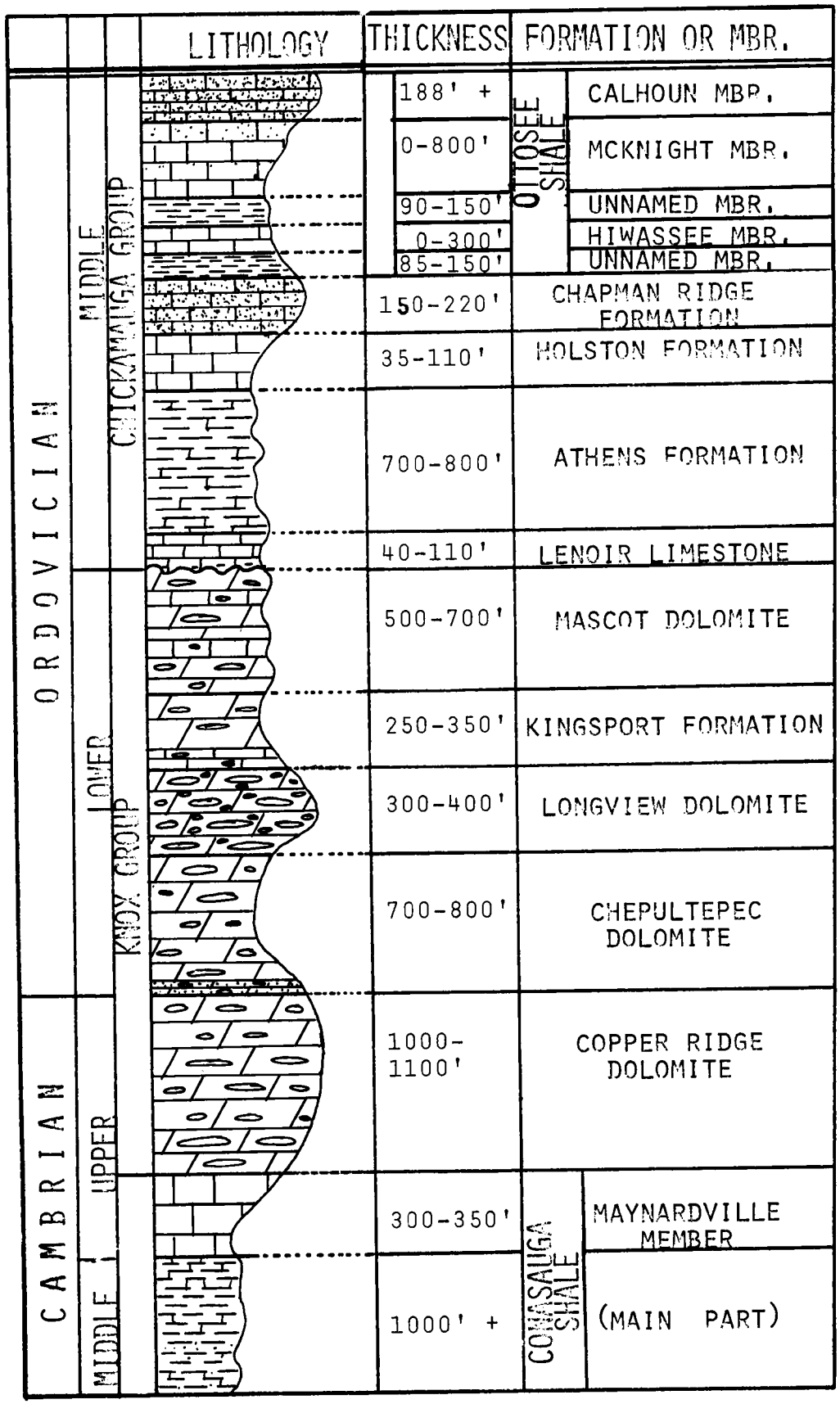


Figure 4. Columnar section.

TABLE I

NAMES AND TYPE LOCALITIES OF FORMATIONS AND MEMBERS

Age	Group	Formation		Name and Type Locality
Ordovician, Middle	Chickamauga	Ottosee Formation Ulrich, E. O., 1911, G. S. A. Bull. V. 22	Calhoun Member	New, this report. Named for exposures near Calhoun, McMinn County, Tennessee
			McKnight Member	New, this report. Named for exposures in the vicinity of McKnight Hollow near Calhoun, McMinn County, Tennessee
			Unnamed Member	
			Hiwassee Member	New, this report. Named for exposures on the Hiwassee River near Calhoun, McMinn County, Tennessee
			Unnamed Member	
		Holston Formation		Hayes, C. W., 1895. USGS Atlas, Folio 16, map. Named for the Holston River northwest of Knoxville, Tennessee
		Athens Formation		Hayes, C. W., 1894. USGS Atlas, Folio 4, p. 2. Named for the town of Athens, McMinn County, Tennessee
		Lenoir Limestone		Safford, J. M. and Killebrew, J. B., 1876. Named for exposures at Lenoir City, Loudoun County, Tennessee

TABLE I (Continued)

Age		Group	Formation		Name and Type Locality
Ordovician	Lower	Knox	Mascot Dolomite		Oder, C. R. L. and Miller, H. W., 1945. Named for exposures at Mascot, Knox County, Tennessee
			Kingsport Formation		Oder, C. R. L. and Miller, H. W., 1945. Named for exposures at Kingsport, Sullivan County, Tennessee
			Longview Dolomite		Butts, Charles, 1926. Named for exposures at Longview, Shelby County, Alabama
			Chepultepec Dolomite		Ulrich, E. O., 1911. Named for exposures at Chepultepec, Blount County, Alabama
Cambrian	Upper		Copper Ridge Dolomite		Ulrich, E. O., 1911. Named for Copper Ridge at Thorn Hill, Grainger County, Tennessee
	Middle		Conasauga Shale	Maynardville Member	Oder, C. R. L., 1934. Named for exposures at Maynardville, Union County, Tennessee
					Hayes, C. W., 1891. Named for the Conasauga River in northwest Georgia.

CHAPTER II

STRATIGRAPHY AND STRUCTURE

I. STRATIGRAPHY

Introduction

The stratigraphic relationship of the various units included within the Chickamauga Group of Middle Ordovician age has long been a topic of discussion at geologic meetings throughout the southeastern United States. The difficulties associated with establishing some reasonable, widely-accepted, regional framework, especially between strike-belts in the Valley and Ridge Province, are well documented and have been expounded upon by many authors. Rodgers (1953, p. 64) stated that "Probably more controversy has raged over the stratigraphy of the Chickamauga limestone and equivalent units in the southern Appalachians than over that of any other major unit."

The writer feels that the problems are closely related, at least in part, to a more or less piecemeal geographic approach and a penchant for inspecting and correlating a few scattered, well-exposed sections which were not always ideally placed. Further, the situation was undoubtedly worsened by a paucity of detailed, large-scale, geologic maps and a general lack of consistency in data used for unit recognition. The problems should respond favorably to a coordinated effort involving analysis of depositional environments, biostratigraphic methods and detailed lithostratigraphic mapping.

The first phase of this study was the preparation of a detailed geologic map (Plate I in map pocket). Subdivision of strata was accomplished via lithologic character, and map units are therefore lithostratigraphic units mappable (at a scale of 1/24,000) on the basis of physical parameters.

General Discussion

The Chickamauga rocks in the vicinity of Calhoun, Tennessee crop out within and along the limbs of the southwestern extension of the Athens syncline. The maximum thickness of approximately 2700 feet occurs just north of the Louisville and Nashville railroad one and three-fourths miles east of Calhoun. Section thickening, caused by multiple folding and distortion, was observed in several units so that true maximum thickness may be somewhat less.

Exposures are limited and scattered owing to a deep residual soil developed over limestone units and the tendency of the shales toward rapid disintegration into yellow, chippy soils. The shales tend to produce the thinnest soils so that outcrops are generally more abundant in the more shaly units. Each unit of the Chickamauga has a more or less characteristic soil except for two different oolitic limestone members of the Ottosee which produce soils of great similarity.

Cross-sections depicting subsurfaces aspects of the Chickamauga and Knox Groups are based on surface data projected into the subsurface with the aid of data gleaned from shallow water wells, farmers, and well drillers. No deep wells, such as oil, gas, or mineral exploration tests, have been drilled within the Chickamauga outcrop belts.

Knox stratigraphy was not a primary concern of this study. However, Knox units underlie the Chickamauga everywhere in the study area and, as certain lithologies such as the "Mosheim" type are seen to be apparent repetitions of some upper Knox lithologies, a brief review is included.

Knox Group

According to Rodgers (1953), the Knox Group, or portions of it, underlie more or less continuously every major strike-belt in the Valley and Ridge Province. The usual contact with overlying units in the Calhoun area is an uncomformable surface exhibiting some relief and carbonate and chert breccias. Overall, exposures of the Knox were too limited to measure the amount of erosional relief of the unconformity. Fragments of Knox incorporated in the overlying unit, as shown in Figure 5a and 5b, are evidence that the upper surface of the Knox was subjected to subaerial exposure and the lenticularity of the deposits indicates at least some relief.

The Knox Group was named by Safford (1869) for exposures at Knoxville and Knox County. Various subdivisions, redefinitions, and recombinations have been proposed and used since Safford's work. Oder (1934) and others have pointed out the existence of two lithologic phases in the Knox: a northwestern, dominantly cherty, dolomite phase and a southeastern, less cherty, dominantly limestone phase. The area of this report apparently lies somewhere between these two extremes as evidenced by the presence of locally developed limestone zones as much as thirty feet thick interbedded with the thick-bedded dolomites, especially in the upper three formations of the Knox.

a.



b.

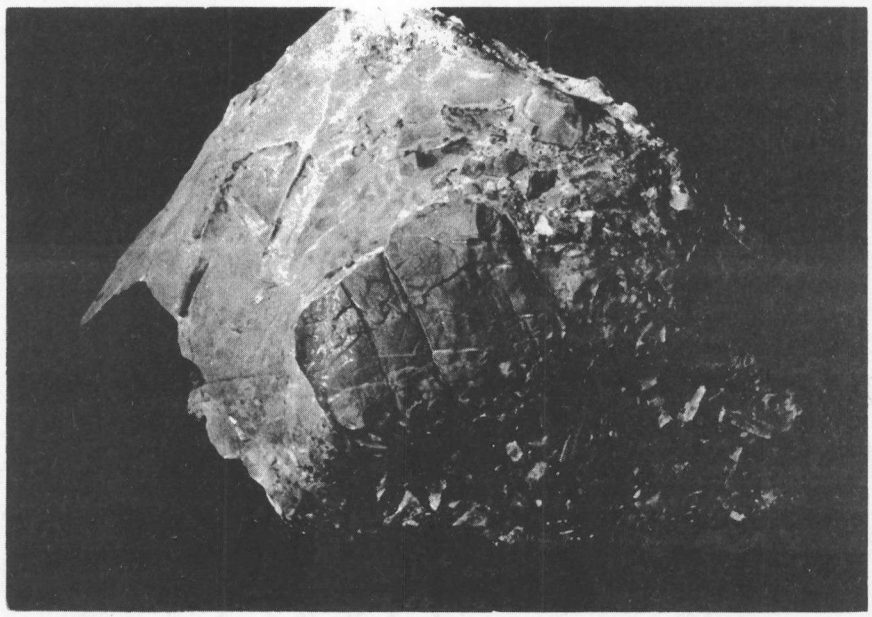


Figure 5. Post-Knox sedimentary breccia block from the Chatata Creek klippe area near the southern border of the map.

Lithology included in base of Lenoir for mapping purposes. Note the smoother matrix of dolomite in the upper right portion of the lower photo.

The great quantity of siliceous material in the residuum, described by Swingle (1959) in the Cleveland area, was also observed in the Calhoun area and was used as a basis for differentiation of the Knox units in the absence of exposures, as is the case for most of the area. Much chert of the Knox type was found scattered across the area of Chickamauga outcrops and is interpreted by the writer as having been let down during weathering of the Chestuee overthrust sheet. Several klippen attest to the overthrust nature of the fault. None of the Knox-type chert was found in situ in any of the Chickamauga formations.

Knox-Chickamauga Unconformity

The unconformity between the Knox Group of Early Ordovician age and the Chickamauga Group of Middle Ordovician age has been described and documented by many workers in the Valley and Ridge Province. Bridge (1956, p. 57) stated that in East Tennessee the uppermost formation of the Knox Group was the Mascot Dolomite and that nowhere had post-Early Ordovician erosion completely removed it. Finlayson and Swingle (1962) described an angular relationship between these two groups where their contact is exposed on Norris Lake.

In the Calhoun area the unconformity is not well-exposed and "exact" contacts between Knox and Chickamauga units are rare. Where the contact is exposed it is usually a disconformity, with occasional deposits of red to green, mottled, very thinly laminated, silty dolomites and dolomitic shales intervening between typical Knox and typical Chickamauga units. Some sedimentary breccia also occurs at this

contact with carbonate and chert fragments of Knox type commonly embedded in a red silty dolomitic mudstone (Figure 5a and 5b). The best exposure of this breccia is on the northwest portion of the Benton quadrangle, adjacent to the north end of a large klippe. The breccia does not occur within the klippe but in the overridden rocks. These post-Knox deposits are not peculiar to the Calhoun area. Bridge (1955) recognized similar deposits along the north shore of Douglas Lake some two miles from Douglas Dam east of Knoxville. The writer followed convention and placed these sporadically distributed deposits in the lower Lenoir Limestone for mapping purposes.

Chickamauga Group

General discussion. The term Chickamauga was first applied by Hayes (1891, p. 143) to a sequence of rocks in the valley of West Chickamauga Creek, Hamilton County, Tennessee. Thickness was given as "about 1600 feet" and included rock units ranging in age from Early Ordovician to the Maysville stage of the Late Ordovician according to Butts and Gildersleeve (1948). Subsequent workers such as Rodgers (1953) restricted the term to include rocks above Knox and below the Reedsville Shale (or Martinsburg). Others used the term in an even more restricted sense or advocated its abandonment altogether (Cooper, 1956). Further, the Chickamauga has been elevated to supergroup status in the type area (Milici and Smith, 1969). It is difficult on the basis of available data to evaluate the supergroup status for the Chickamauga of the Calhoun area. Group status is retained for the present.

Correlation of Chickamauga subdivisions in widely separated geographic localities without benefit of detailed mapping generated confusion because of repetitive lithologies and the non-definitive, recurrent nature of certain faunal assemblages. Criteria for recognition of any individual unit within the Chickamauga ranged from use of paleontological data through lithologic similarities to stratigraphic position. This practice of changing recognition criteria from locality to locality magnified possible error when correlating between strike-belts or between adjacent states.

Lenoir Limestone. In addition to the previously described breccias, this lowermost unit of the Chickamauga Group consists of shales, dolomites, and medium to dark gray, light gray-weathering, nodular argillaceous to shaly, fossiliferous limestone. The argillaceous fraction is de-emphasized on weathering as it decomposes first, leaving a concentration of nodular limestone on the outcrop surface. The argillaceous material occurs as discontinuous, discrete, thin beds and laminations separating nodules and fossils. Casual checks of this argillaceous material indicate that it is probably greater than 90% carbonate fraction. Fossils are abundant in most limestone beds and include brachiopods, bryozoans, pelmatozoan debris, scattered sponges and an occasional coral. Algal material in the form of oncolites is locally abundant. The Lenoir also includes sporadic and discontinuous lenses and beds of dove-gray, aphanitic limestone containing calcite augen which weather dark in a lighter matrix, giving rise to a peculiar "birdseye" appearance. This lithology is commonly referred to as

"Mosheim" type. Thicker, more continuous occurrences of similar rock have been mapped by numerous workers in East Tennessee as the Mosheim Member of the Lenoir Limestone. The Mosheim lithology is not mappable in the Calhoun area and is included in the Lenoir. Cooper and Cooper (1946) reported sections in this strike-belt where the Mosheim lithology was interbedded with Lenoir lithology, a situation not observed in the study area, and concluded that the Mosheim was a facies of the Lenoir.

Regionally Lenoir grades northeastward from the Calhoun area into a more limey section where Lenoir type limestones thicken at the expense of the Athens. This facies relationship was first noted by Keith (1896) who observed that the two lithologies graded one into the other near the Monroe-McMinn County line some 15 to 20 miles north of Calhoun. Rodgers (1953) stated

> It is difficult to understand how Keith's field observations could have been so long ignored and overlooked while the attempt was made to fit the Athens shale into the column above the Holston instead of below.

Farther north toward Knoxville in this strike-belt the Holston overlies Lenoir lithologies and the Athens of the Calhoun area is present only as a thin tongue in the lower third of the Lenoir Formation (Kenneth R. Walker, personal communication, 1976).

Although the Lenoir becomes slightly less argillaceous and thicker in a northeasterly direction from the Calhoun area, the lithologic characteristics and thickness range of 50 to 100 feet is persistent in the study area except near the northwest corner of the

Etowah quadrangle. Here less than 15 feet of Lenoir is present and it contains thin beds of red silty to sandy limestone and calcareous sandstone not seen elsewhere in the study area.

The Christiania and Maclurites fauna of the Knoxville area, generally considered characteristic of this part of the stratigraphic section, were not observed in the Calhoun area.

The Lenoir Limestone commonly occupies a topographic position just below the crest of a line of low rounded hills capped by rocks of the Athens Formation.

Athens Formation. The term Athens has been widely used since Hayes (1894) first applied the name in the Kingston folio to a shale section between the Chickamauga of Ordovician age and the Rockwood formation of Silurian age. He later used the term (Hayes, 1895, p. 3) to describe a shale unit between the Chickamauga Limestone and his Tellico Sandstone. The formation was named for the town of Athens on the Athens topographic quadrangle that adjoins the Calhoun quadrangle to the northeast. The unit was described as being laterally equivalent to the top portion of the Lenoir and as increasing in thickness to the east as its character changed to include a "bed of calcareous sandstone from 250 to 700 feet thick about 500 feet from the base of the formation" (Hayes, 1895, p. 3). Hayes' applications of the term Athens were later found to be inconsistent as the shale unit so named in the Kingston folio was later assigned to the Reedsville Shale of Late Ordovician age by Rodgers (1953) and the shale unit so named in the

Cleveland folio (Hayes, 1895), which contains the type locality, was assigned a Middle Ordovician age and described as occurring between the Lenoir Limestone and the Holston Formation (Swingle, 1959, p. 30). Following Hayes' (1894, 1895) inconsistent usage of the term, Butts (1940) applied the term "Athens Shale" to a unit of which he said "Thickness varies from a few feet on western margins to perhaps 5,000 to 10,000 feet in a large area in southern Washington County, Virginia and northern Sullivan County, Tennessee." Furthermore, he described three distinct facies in his "Athens," none of which corresponds to the lithologic character of the Athens of the type locality. In addition Butts (1940) showed the Athens and Whitesburg units as being above the Holston of Virginia while in the type area of the Athens it is below the Holston, and the Whitesburg lithology is absent. Decker (1952) apparently had some problems with selecting the lithologic unit to be called Athens and in reality described a biostratigraphic unit based on an Athens graptolite faunal zone as is illustrated by his statement "In general the Athens graptolites occur almost wholly in the lower part of the formation, and the base of the formation occurs at different stratigraphic horizons in different regions" (Decker, 1952, p. 47). Keith (1895 and 1896) further confused the issue by stating in reference to the Athens that "It is everywhere composed of blue and black shales, which do not vary in appearance," a description that does not apply in the type locality.

The examples presented above illustrate the inconsistent application and description of the Athens and indicate a need to follow the

suggestion of Neuman (1955) that "The term Athens should be applied only to rock comparable to that of the type section." Furthermore, since the Athens unit is not a shale in the type locality, the writer proposes the adoption of Athens "Formation" as a more appropriate and less confusing name for the unit.

Exposures at the type locality are limited, and poorly-exposed partial sections are the rule. Rodgers (1952, p. 74) suggested an alternate "pieced-together" section in the immediate type area as being better than the type section. The writer suggests a reference section measured along the south side of the Hiwassee River at a locality known as Henegar Bluff in Bradley County approximately two miles east of the town of Charleston. Here new roadcuts along the Upper River Road expose almost all of the Athens in relatively unweathered outcrops. The section is also relatively free from minor folding.

In the Calhoun area and in the type area, the Athens is a light to medium gray, light gray-weathering, argillaceous, sparsely fossiliferous limestone with interbedded stringers and lenses of very calcareous shale. The limestone comprises as much as 85% of the upper half of the unit according to information furnished by George Thomas (personal communication, 1973) who at one time owned part of a now defunct rock quarry located in the Athens Formation at Henegar Bluff. Insoluble residue from several grab samples dissolved by the writer showed general agreement with Mr. Thomas' information although unintentional high grading of samples may have increased the average limestone content by 10 to 15%. Partial weathering produces a peculiar

cobbly appearance, Figure 6, which alters to a dimpled appearance, Figure 7a, where the cobbles fall from more or less vertical faces. This characteristic can be used to assist in the identification of the Athens in the Calhoun area because the cobbles are confined to the Athens except for a few isolated beds in the Ottosee, where the cobbles are much less numerous and smaller, and for an occasional bed in the quartzose Chapman Ridge Formation immediately below the Ottosee.

The Athens is sparsely fossiliferous except for occasional thin, fine grained limestone stringers which contain bryozoans, pelecypods, gastropods, and brachiopods.

Advanced weathering of the Athens produces a tough, yellow, clayey residuum containing abundant yellow to ocher shale chips showing no trace of the original cobbly nature of the fresher rocks.

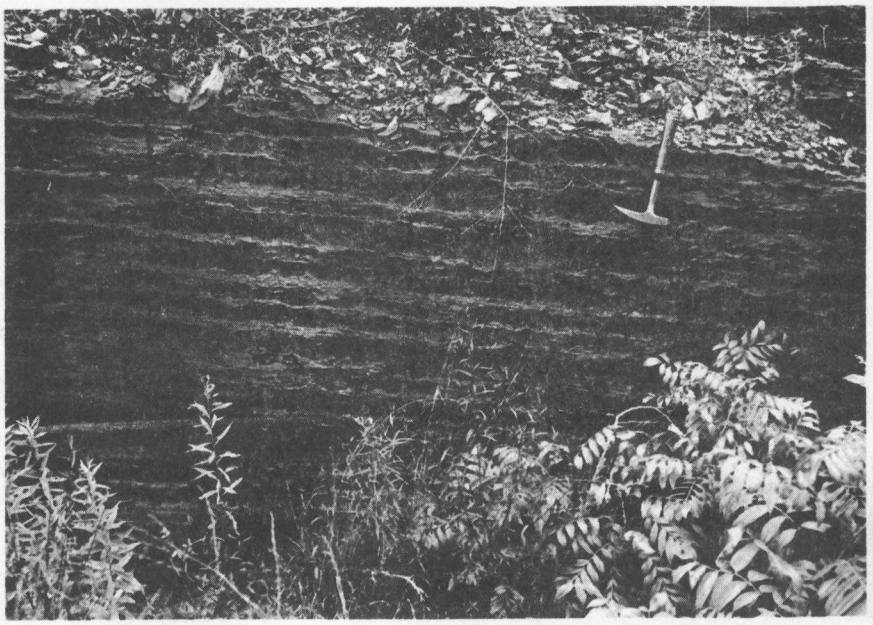
Where the Athens is well-exposed as at Henegar Bluff, a crude cyclic or rhythmic pattern can be seen in the size and occurrence of the cobbles, shown in Figure 7b. Near the base of the cycle the cobbles are larger (up to one foot in diameter) and occur in more or less continuous beds. The cobbles become gradually smaller, more profuse, and less well-bedded upward. Then, beginning above the small-size (1/2 inches) cobble bed, large-size cobbles are present and the pattern is repeated. It is possible that this pattern is related to bed thickness as the upper and lower bed surfaces are tangential to the cobbles. The pattern does not seem to be related to structural factors.



Figure 6. Cobbly Athens Formation at Section WB-2 east of Calhoun, Tennessee.

Relatively unweathered cobbly layers appear light colored.

a.



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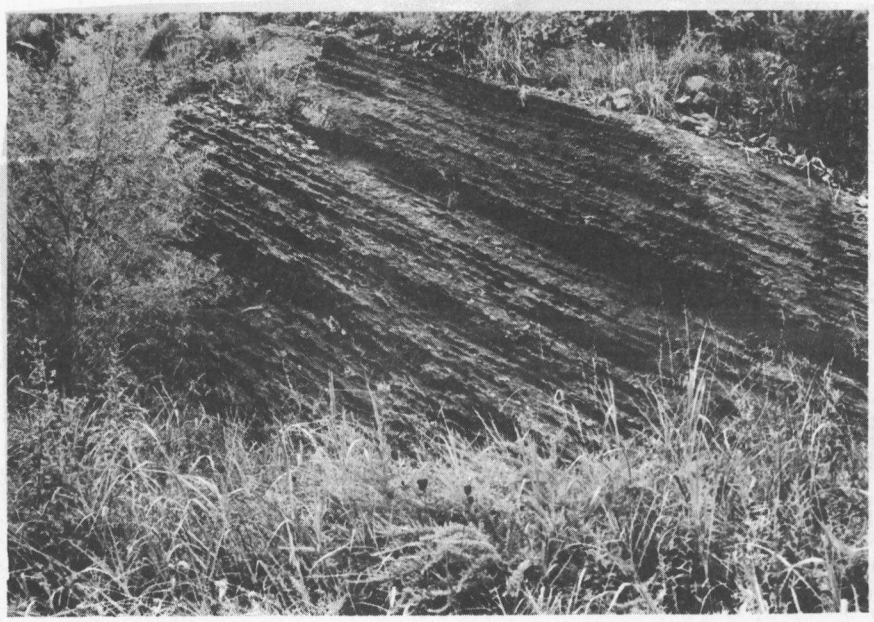


Figure 7. Weathered outcrops of the Athens Formation at Section WB-2 east of Calhoun, Tennessee.

Note well-developed dimpled character of outcrop that appears as cobbles weather free from the steep face in (a) and the decrease in cobble size upward in (b).

Near the top contact, the Athens locally becomes more sandy. A few discontinuous, thin beds of calcareous sandstone, grading laterally and vertically to sandy limestone, are scattered through the upper five feet. These sandy beds locally grade upward into the lowermost beds of the overlying coarse calcarenites of the Holston Formation. The contact is gradational over an interval of less than ten feet. Near the southermost edge of the map area in one outcrop the sandy transitional zone is missing and the Athens and Holston lithologies are interbedded through an interval of five to ten feet. The Holston interbeds are thin (less than one foot) and contain as much as 10% argillaceous appearing material.

The lower contact of the Athens is gradational and is placed at the base of the yellow-weathering, chippy shales and cobbly limestones and above the nodular-weathering, argillaceous-appearing, fossiliferous limestones of the Lenoir.

Thickness values for the Athens Formation are difficult to establish because of poor exposures and complex folding that tends to thicken the section. However, in the section at Henegar Bluff where deformation is at a minimum, the Athens was measured to be approximately 750 feet thick.

Topographic expression of the Athens is quite variable in that it appears as areas of low irregular hills and slopes with intricate drainage patterns and also caps some small, isolated hills that stand higher than the rest of the Athens. A low strike ridge is exhibited near the base of the Athens Formation where it forms the crest of the low hills above where the Lenoir crops out.

Holston Formation. The Holston Formation was named by Keith (1895) for exposures along the Holston River northeast of Knoxville, Tennessee. The unit included beds above the Lenoir Limestone and below the Tellico (Chapman Ridge of present day terminology) Sandstone. The term has since been variously applied in both nearby and widely separated areas to include any one of a number of calcarenites bearing the industry name "Tennessee Marble." This unrestricted usage, together with redefinition, redescription, and the general confusion related to the application of the same nomenclature to both overlying and underlying formations has caused some writers (Prouty, 1946; Cooper, 1956; Kashfi, 1971) to propose that the term be abandoned. Swingle, et al. (1967), however, have re-established the validity of the Holston as a lithologic map unit and rejected calls for abandonment of the term as well as its redefinition by Rodgers (1953). The writer has mapped the Holston as a separate unit in the vicinity of the Calhoun quadrangle immediately southwest of the Athens quadrangle where Rodgers (1952) included the overlying Tellico Sandstone (Chapman Ridge of this report) in his Holston Formation. The writer has restricted the Holston to the non-sandy carbonates which are separated from the overlying calcareous, highly ferruginous sandstones of the Chapman Ridge by a five to 15 feet thick silty to sandy unit, Figure 8, containing large algal-appearing structures, perhaps large oncoliths, in conjunction with small corals, bryozoans in growth position and great numbers of orthocones in apparent random orientation. This unit is termed the "Orthocone zone" and mapped with the

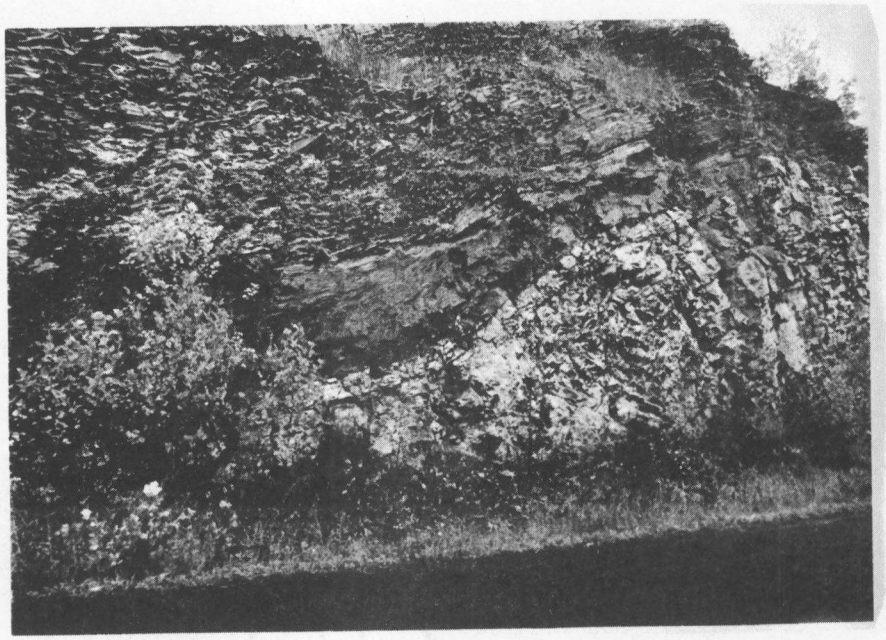


Figure 8. Orthocone zone at Henegar Bluff.

The massive appearing, approximately ten feet thick unit, near the center of the picture is the orthocone zone with the light colored Holston below and the Chapman Ridge Formation above.

Chapman Ridge Formation. Numerous fragments and scattered whole shells of a large gastropod very similar to Maclurites magnus Lesueur are found at this horizon. They were not observed in any other unit. The shell material appears slightly abraded and could have been transported short distances. Maclurites magnus Lesueur is considered characteristic of the Lenoir Limestone. If these gastropods are non-transported specimens of Maclurites magnus then the silty to sandy unit in which they occur is probably the lateral equivalent of some part of the Lenoir, if they are truly limited to the Lenoir. If they are transported specimens then either the environments of Lenoir and this silty to sandy unit were co-existent or Lenoir Limestone was exposed to erosion during the deposition of the silty to sandy unit. Burk McWilliams (personal communication, 1974) has stated that this or a similar silty to sandy, orthocone horizon is present in the same strike-belt in the vicinity of Knoxville. The unit may therefore represent the "lower tongue of Ottosee" of Cattermole (1955) although extensive mapping is needed to establish this as a fact. The unit does represent the persistent "middle-shale member" of the Ottosee of Rodgers (1952).

Butts (1940) placed the Holston between the Lenoir and Whitesburg Limestones of Virginia where he also placed the Athens Shale above the Whitesburg. This would imply that the Holston occurs below the Athens which is not true in the Calhoun area or in the type localities of either the Athens or Holston Formations. Butts (1940, p. 148) further stated that in the Athens belt in the vicinity of Athens, Tennessee,

the Holston is absent and the Athens rests on Lenoir. The Athens does rest on Lenoir at Athens, Tennessee, and the Holston lithology occurs above the Athens Formation. It is difficult to understand how Butts, who well knew the Holston lithologic characteristics (Butts, 1940, pp. 148-158), could have failed to recognize the Holston lithology in the vicinity of Athens, Tennessee. Hayes (1895) also apparently failed to recognize the Holston unit in the vicinity of Athens because the lithology is not mentioned in the Cleveland folio.

In the Tellico-Sevier belt to the southeast, Neuman (1955) equated the Chota Formation (Neuman, 1955, new) which was placed above his (Neuman's) redefined Tellico with the Holston of Rodgers (1953). Neuman (1955, p. 166) also correlated the Chota Formation with the "Holston marble" and the "Tellico sandstone" of the Friendsville-Knoxville strike-belt, the strike-belt of this study. Rodgers (1953, p. 75) apparently agreed with this correlation; in fact Neuman (1955, p. 145) cited Rodgers as having first proposed the correlation. Therefore, the Holston and Chapman Ridge Formations of this report are the southwestern extensions of the "Holston" and "Tellico" of earlier workers (see Figure 9 for comparison of stratigraphic terminology) and the northwestern equivalent of the Chota Formation of Neuman (1955).

In the study area the Holston Formation is a coarse grained, fossil-fragmental, very thick-bedded (see Appendix for measurement conventions used) limestone, locally crossbedded and styolitic as shown in Figure 10. The unit exhibits a wide range of colors from cream to buff to pink to red and reddish-brown. Some beds, especially

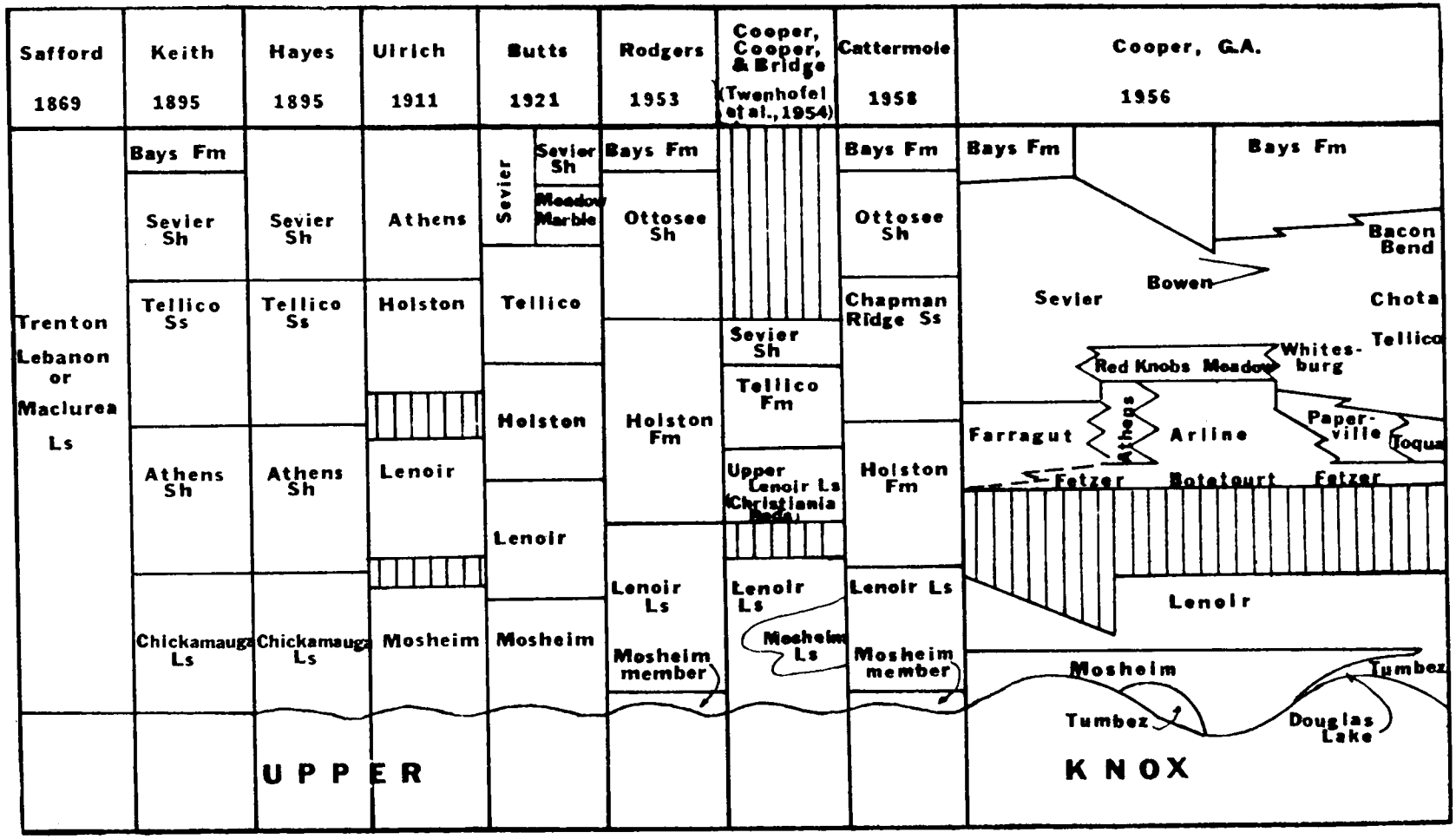


Figure 9. Comparison of Middle Ordovician stratigraphic terminology applied in the middle and eastern belts in East Tennessee (from McLaughlin, 1973).

Each column represents the stratigraphic units used by that worker in his area of interest and does not necessarily imply temporal correlation from column to column.

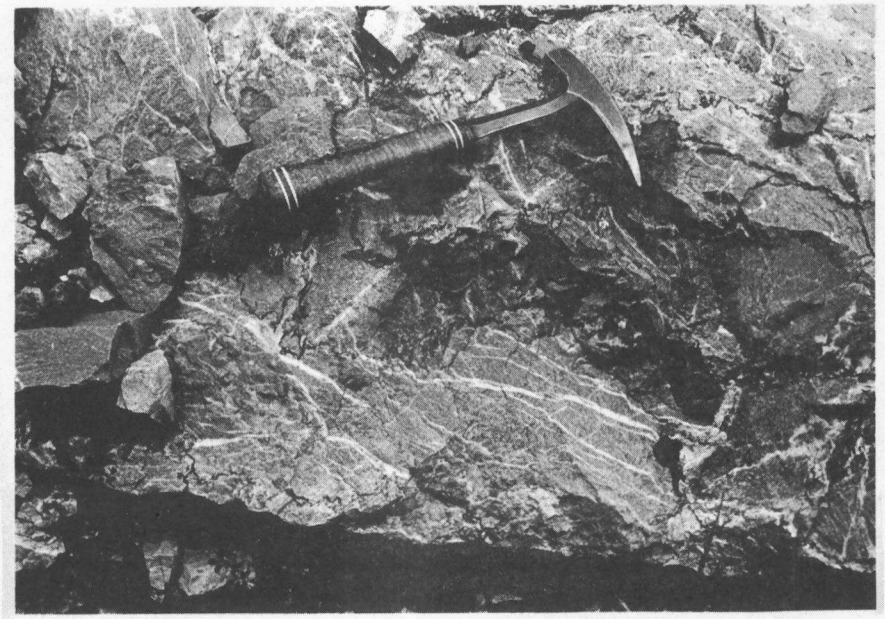


Figure 10. Holston Formation showing stylolites and calcite rehealed fractures common to all of the thicker beds of this unit; exposure in Carruth Hollow east of Mile 10 of Oostanaula Creek.

near the base, are light to medium-light gray with faint pinkish overtones. Fossil fragments include pelmatozoan debris, bryozoans, and brachiopods (those whole shells observed were usually less than 1/2 inch in diameter). Much of the fossil debris is highly disarticulated and extensive thin-section work by a competent paleontologist would seem needed to contribute significantly to the paleontological knowledge of the Holston.

Quartz sand grains were not observed in the Holston calcarenites except for the previously described basal transition zone and an occasional bedding plane surface which has a few scattered, quartz sand grains on it.

The contact with the overlying Chapman Ridge Formation is generally sharp. However, exposures are generally poor and in a few localities the two lithologies appear to be interbedded through a vertical interval of perhaps ten feet.

Thickness of the Holston along the northwest limb of the syncline ranges from 50 to 125 feet. Along the southeast limb the thickness is generally 20 to 35 feet except for one small exposure near the southernmost part of the map area where the Holston lithology thins to less than ten feet. Thickness variations different from those mentioned may be present but poorly exposed contacts due to vegetation cover and thick residuum generally prohibit accurate measurements. Seventy feet of Holston were measured at sections WB-1 (see Appendix) at Henegar Bluff on the southside of the Hiwassee River east of Charleston, Figure 11. The contacts there are well-exposed, display the gradational lower contact, sharp upper contact, and the overlying "orthocone-gastropod" zone.

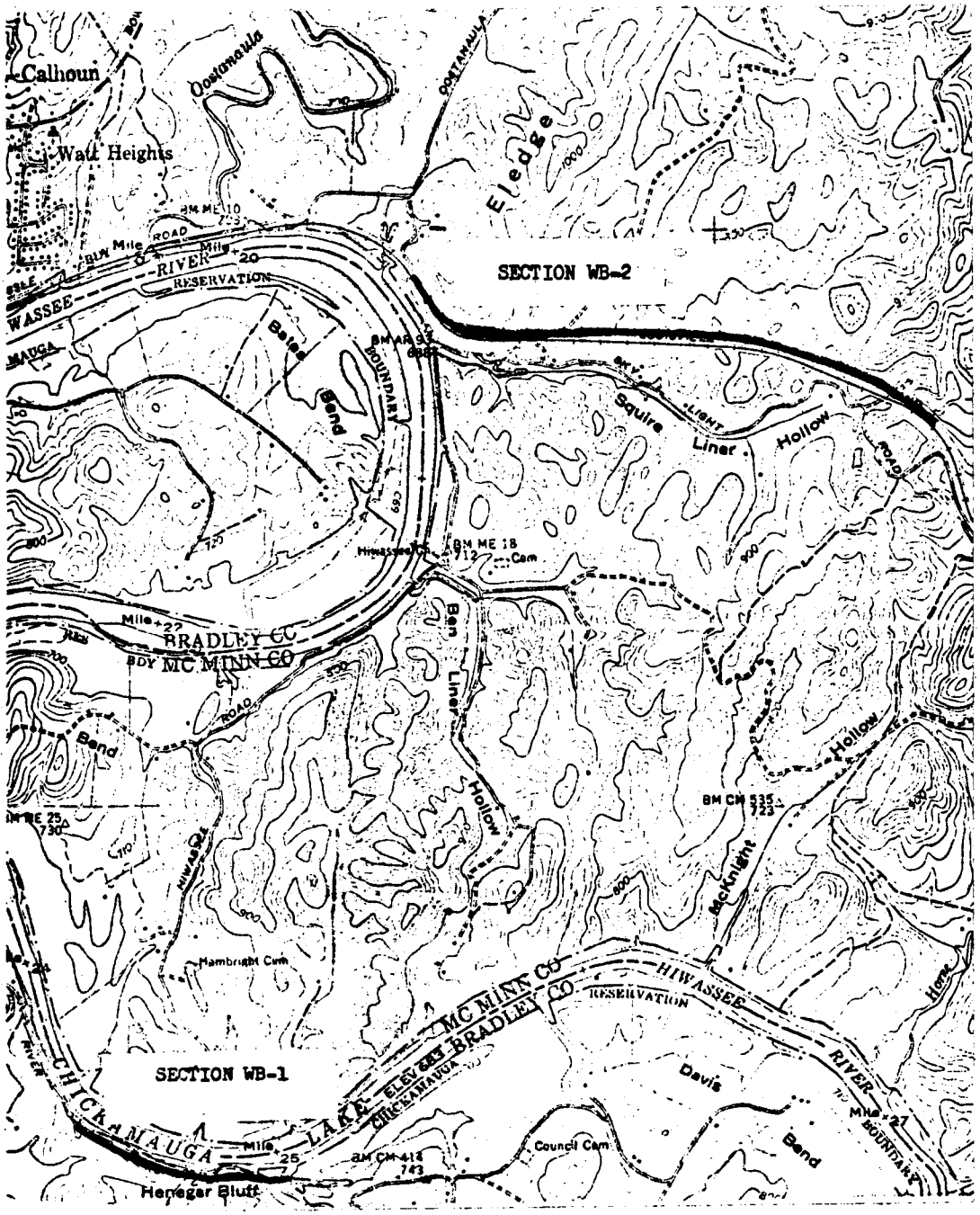


Figure 11. Location of measured sections (Calhoun 1:24,000 topographic map).

Chapman Ridge Formation. The unit here called Chapman Ridge (Cattermole, 1955) was mapped as the Tellico by Hayes (1895) and the upper part of the Holston by Rodgers (1952). LeRoux (1974) considered the Chapman Ridge as equivalent to part of the Chota Formation in the next strike-belt to the southeast which contains the type section of the Tellico of Hayes (1895) and the redefined Tellico of Neuman (1955). The writer has followed Catermole's usage because the Chapman Ridge Formation of the Calhoun area is essentially continuous, laterally, with that of Catermole in the Knoxville area. A correlation with the Tellico type section in the next belt to the southeast is unlikely. A major problem has been that of correlating from belt to belt or section to section without benefit of detailed knowledge of the intervening units present, their areal distribution, or the repetitious nature of the lithologies. This view is in part substantiated by the apparent lack of awareness of previous workers of the existence of an upper red sandy limestone, the Calhoun Member of this report, very similar to the Chapman Ridge lithology but considerably higher in the stratigraphic section. Neuman's Chota may be the lateral equivalent of the Chapman Ridge (plus the Holston) or it may be the equivalent of the Calhoun Member or of the McKnight Member and the Calhoun Member of the Ottosee Formation of this report. The writer does not have sufficient evidence to make a belt to belt correlation but recognition of the presence of an upper red sandy limestone in the Calhoun area is considered vital to any correlation proposals.

The Chapman Ridge Formation where fresh consists of blue-gray fossiliferous, very sandy limestone, grading both laterally and vertically to very calcareous, quartzose sandstone. Both limestones and sandstones contain thin dark bands or layers of highly ferruginous limey sandstone that weather in positive relief. These dark bands are especially prominant when they occur in cross-bedded units, Figure 12. These thin dark layers pinch and swell laterally and are, for the most part, discontinuous within any one outcrop. The sandy limestone and calcareous sandstone phases are locally interbedded and both lithologies are fossiliferous and crossbedded. The Chapman Ridge weathers to a deep, dark red soil, and dark red, iron-stained outcrops on topographically flatter areas. On steeper slopes, especially in areas of steeper dips and steep slopes, the Chapman Ridge sandstones weather to protruding ledges of red to red-brown, punky, porous, low-density blocks and fragments of quartz sand cemented with hematite and limonite, Figure 13. The limestones tend to weather more deeply and leach more completely than the sandstones, leaving a blocky, pale red, sandy, tough clay soil between the protruding sandstone ledges, Figure 14. This differential weathering is seen even on the fresher surfaces and is especially noticeable where the Chapman Ridge beds are steeply dipping. Thin interbeds and lenses of chippy-weathering, shaly material yield a yellow clayey soil similar to that produced by weathering of the Athens Formation. These shaly interbeds are more numerous and laterally more continuous near the top of the Chapman Ridge although they do not comprise more than 20% of any 10-foot interval. The upper

a.



b.

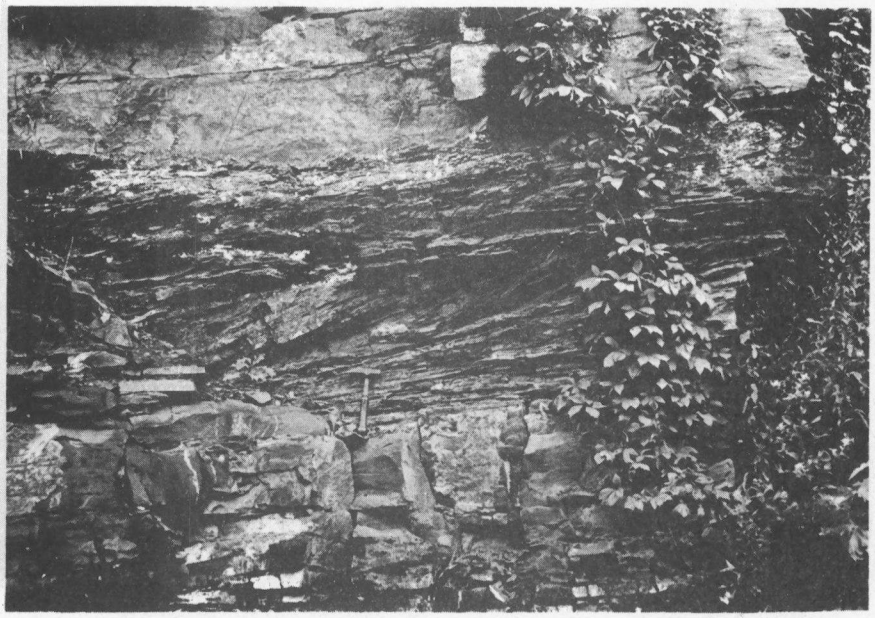


Figure 12. Crossbedded Chapman Ridge Formation near Mile 25 of the Hiwassee River and crossbedded Chapman Ridge Formation at Henegar Bluff.

Note the dark bands (thickest is approximately 1/2 inch) weathering in relief; also note the crossbeds terminate against the dark bands in (a).

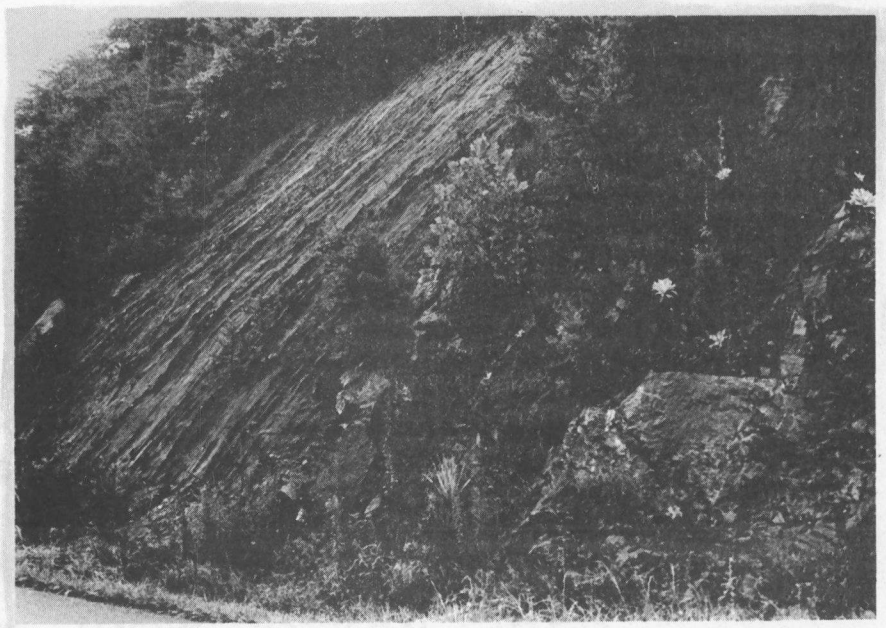


Figure 13. Punky-weathering ferruginous Chapman Ridge Formation near Council Church east of Section WB-1.

The thicker beds (thickest approximately four feet) are more ferruginous and more quartzose.

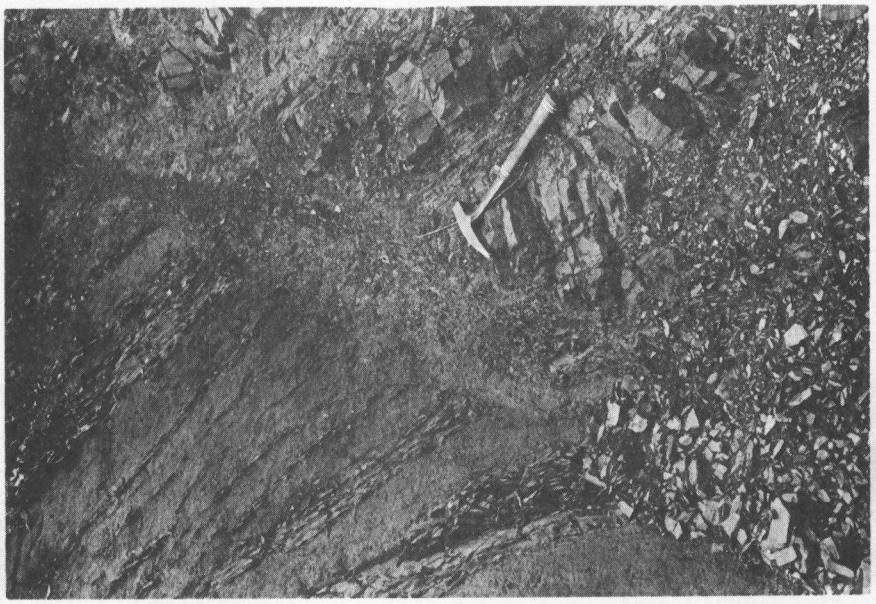


Figure 14. Chapman Ridge Formation west of the crossing of Sky Light Road and the Louisville and Nashville railroad showing differential weathering character of the more ferruginous beds.

Note small fault near the head of the hammer.

contact of the Chapman Ridge is usually gradational over some 20 to 30 feet but is locally sharp. For mapping purposes the upper contact is placed at the top of the highest red-weathering sandstone or limestone and below the dominantly calcareous shales of the Ottosee which contain a few thin beds of tan to brown weathering limestone and limey sandstone. These lower limestones and limey sandstones of the Ottosee are not ferruginous and weather to a buff to light ocher soil. The top of the Chapman Ridge, as drawn on the red-weathering limestones and sandstones, is coincident with a topographic break that is usually obvious even in dense pine woods where no other evidence of the contact is visible.

Well-exposed sections of the Chapman Ridge are relatively uncommon; well-exposed contacts are even more rare. A section at Henegar Bluff on the Hiwassee River (WB-1, see Appendix) consists of approximately 159 feet of typical red sandstones and limestones above the orthocone-gastropod horizon. Distortions due to folding and minor faulting preclude exact measurements. However, a section measured along the railroad tracks east of Calhoun (WB-2, see Appendix) has essentially the same thickness. The unit exhibits a thickness range in this area from approximately 150 to 225 feet. The greatest variations in thickness occur on the southeast limb of the Athens syncline and this may in part be related to structural effects and the asymmetry of the fold. Thickness variations do not appear to be related to thickness changes in the underlying Holston.

Ottosee Formation. The formation in the Calhoun area, mapped as Ottosee by the writer, was called the Sevier shale by Hayes (1895). Rodgers (1953, pp. 76-81) stated that the Ottosee and Sevier are in part of different ages and that the Sevier as originally defined included all rocks between a thin Chickamauga limestone and the Bays Formation. As such he felt that the Sevier included equivalents of the Lenoir, Athens, Holston, and Ottosee (see Rodgers, 1953, Figure 4 opposite p. 66). The writer has chosen to use the name Ottosee for these beds because they are of very similar lithology, occupy the same stratigraphic position, are in the same strike-belt and are physically continuous with the Ottosee shales of the type locality at Knoxville, Tennessee. Further, the Ottosee shales are not known to be physically continuous with the Sevier shales in any of the strike-belts to the east and southeast and correlation of the two units is tenuous.

The Ottosee in the Calhoun area is similar to the Athens Formation but is more dominantly shale, has fewer and thinner cobbly beds, and contains more sand in the form of very thin to medium-bedded sandy to very sandy limestones and local thin beds of very calcareous sandstones, all of which weather to light browns and tans. This weathering characteristic of the Ottosee arenites is significantly different from that of the underlying Chapman Ridge which almost invariably weathers red. Nowhere in the Calhoun area are these brown and tan weathering layers of the Ottosee interbedded with the red weathering layers of the Chapman Ridge. The sandstones in the

Ottosee are more fossiliferous, containing more whole fossils than the Chapman Ridge, especially near the distal edges of these Ottosee sandstones and sandy limestones where they grade laterally into argillaceous limestones and finally into calcareous shales. Bryozoans and brachiopods are most common but crinoids and corals are fairly abundant.

The Ottosee consists dominantly of calcareous shales and thin limestones and sandstones but in addition contains three readily mappable limestone members, herein named, in ascending order: the Hiwassee Member (present only on north limb of Athens syncline), the McKnight Member, and the Calhoun Member. Shales of variable thickness are present below and above the Hiwassee Member but the Calhoun Member lies directly on the McKnight Member without any significant amount of shale between them except in the Athens quadrangle. The Hiwassee and McKnight Members are commonly oolitic to very oolitic with scattered occurrences of red ooids in a sparry matrix, especially near the distal edges of the oolitic limestone members. Oolitic limestones in the Ottosee have also been noted in the vicinity of Knoxville by the writer and described by recent workers, including Walker and Ferrigno (1973a), and in the next belt to the southeast by LeRoux (1974) and Kashfi (1971, p. 36). The Calhoun Member is a fossiliferous sandy limestone grading laterally and vertically to fossiliferous calcareous sandstone commonly crossbedded and ripple marked.

The maximum thickness of the Ottosee Formation in the Calhoun area is approximately 1700 feet. Minor folding and faulting probably

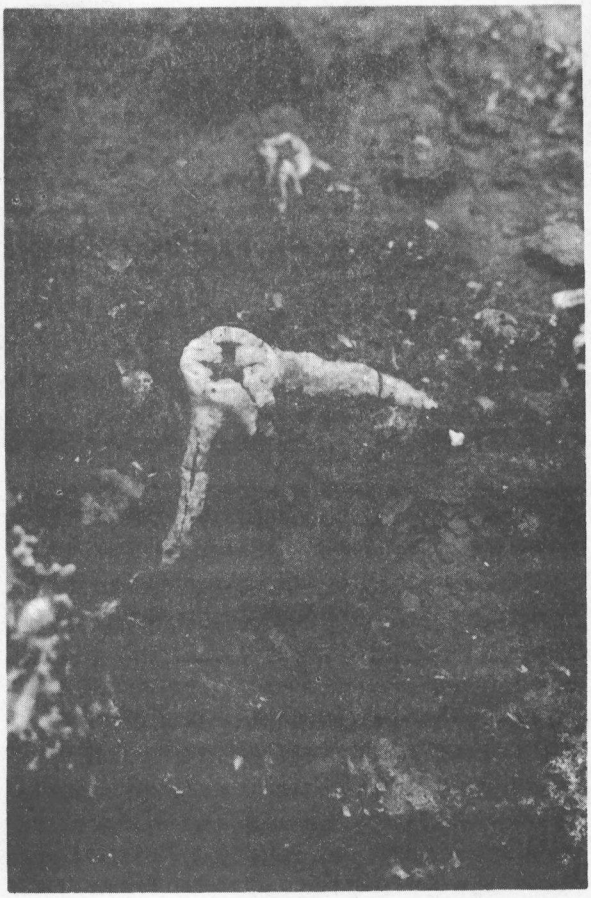
causes some thickness variation but this is difficult to evaluate because outcrops consist of partial exposures and are sporadic in occurrence.

Lower Unnamed Shale Member. This unit consists of typical Ottosee which is light to medium gray, calcareous, thinly laminated, ocher-weathering shale and contains thin sporadic beds and lenses of calcareous and fossiliferous brown-weathering sandstones and thin fossiliferous limestones. The thickness of this member ranges from 85 to 150 feet.

Hiwassee Member. The Hiwassee Member is named for Hiwassee Church which is located immediately southeast of the type section which was measured along the Louisville and Nashville railroad tracks approximately two miles east of Calhoun, Tennessee and approximately 1/2 mile east of the railroad cut through Eledge Ridge (Section WB-2, Figure 11, page 31).

Lithologically, the Hiwassee Member of the Ottosee Formation is a light gray, fine to coarse-grained oolitic limestone, mostly oosparite and oomicrite, with interbeds and laminations of fossiliferous oolite and oolitic fossil-fragmental calcarenite. Near the top and bottom contacts and near the distal ends where the above described lithology phases into shale, the Hiwassee Member includes discontinuous lenses and lentils of argillaceous to shaly, very fossiliferous limestones with pelmatozoan "holdfast" structures in growth position, Figure 15. These limestones grade laterally into thin, very calcareous, argillaceous, sandstone units which in turn

a.



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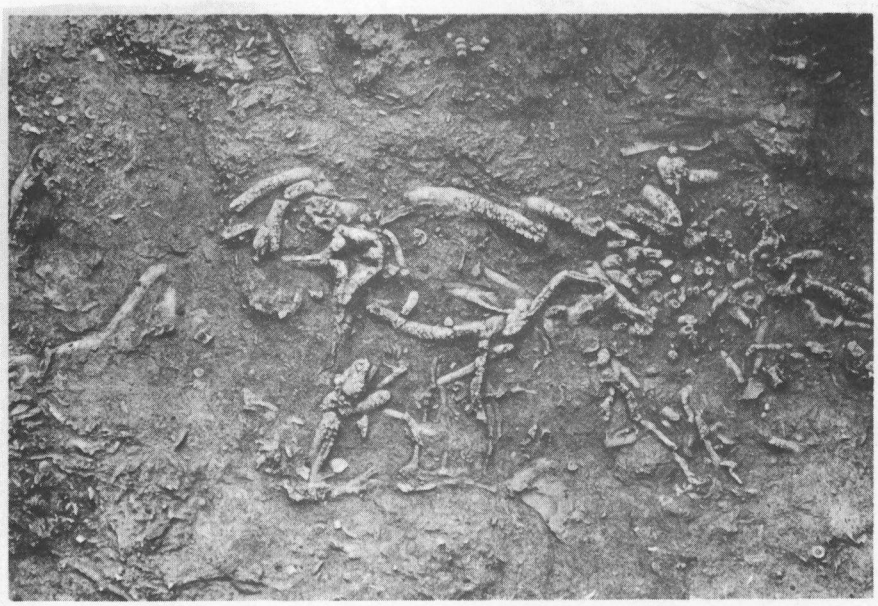


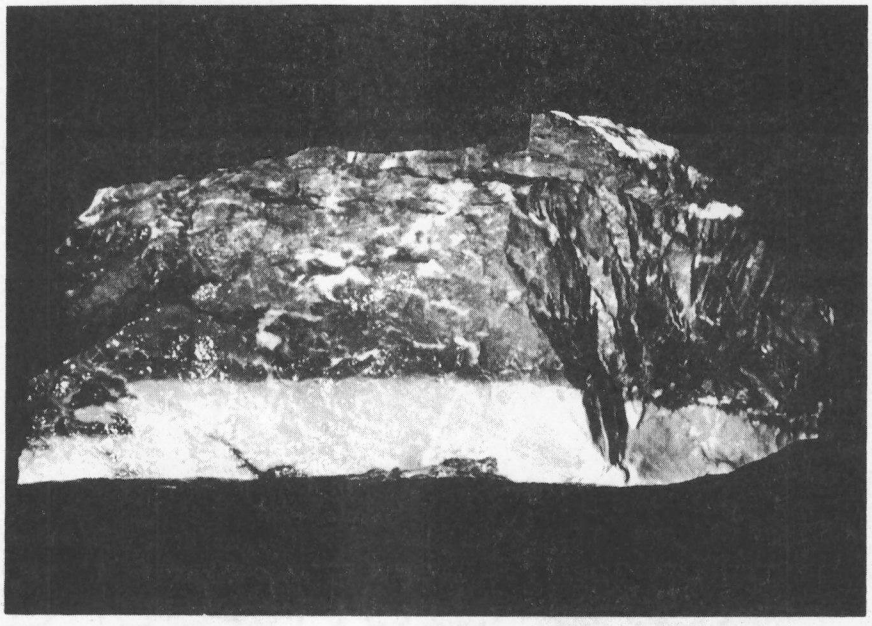
Figure 15. Pelmatozoan holdfasts in growth position in the Hiwassee Member of the Ottosee Shale.

Stem is approximately 1/2 inch in diameter in (a). Largest stem is approximately 1/2 inch in diameter in (b).

grade laterally into typical Ottosee shales. This facet of the Hiwassee can be seen south of Ben Liner Hollow (see the geologic map). Persistent color changes accompany the lithologic changes from oosparite through calcareous argillaceous, fossiliferous sandstones to fossiliferous, calcareous shales. The oolites change lithologically, both laterally and vertically, where they are intercalated with shales, and change colors from white to gray to pinkish-gray to red, with some mottling, in a direction away from the main oolitic mass. The intercalated shales and argillaceous limestones exhibit the same general color change with the addition of greens and ochers and much mottling. The different colors in the mottled areas have sharp boundaries which do not coincide with any observable lithologic change, Figure 16. The sandstone units do not display mottling.

The ooids are gray to tan, most spherical (Figure 17) and generally have fossil fragments as nuclei. Sand grain nuclei are also present but rare in some beds and even dominant in other thin beds close to lenses of pebble conglomerate at several localities (Figure 18). Red ooids, in a sparry matrix, occur at several localities along the outcrop belt of the Hiwassee Member as along Meadow Fork Creek. These red oosparites can be traced laterally into light dove-gray, dense oomicrites and biosparites. The ooids are red even when the matrix material laterally changes to tans and grays. Stylolites are common.

a.



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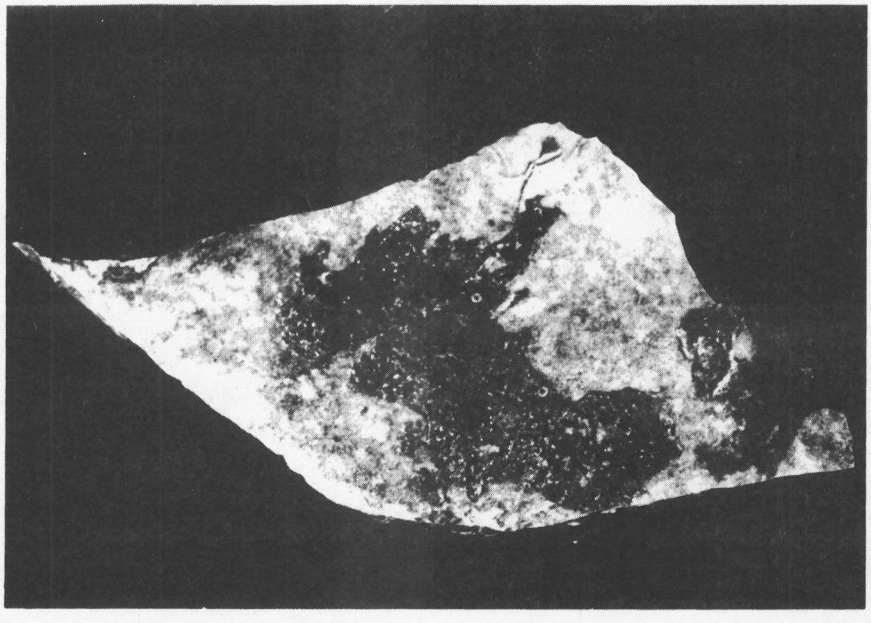


Figure 16. Color mottling of carbonates near shale-carbonate interface.

Note the very sharp boundary of the colors. Darker color is red and lighter color is pale green. Color changes do not reflect a lithologic change. Lower photo shows color mottling as above but on a bedding plane containing a fossil hash. Many of the fossils are also red.

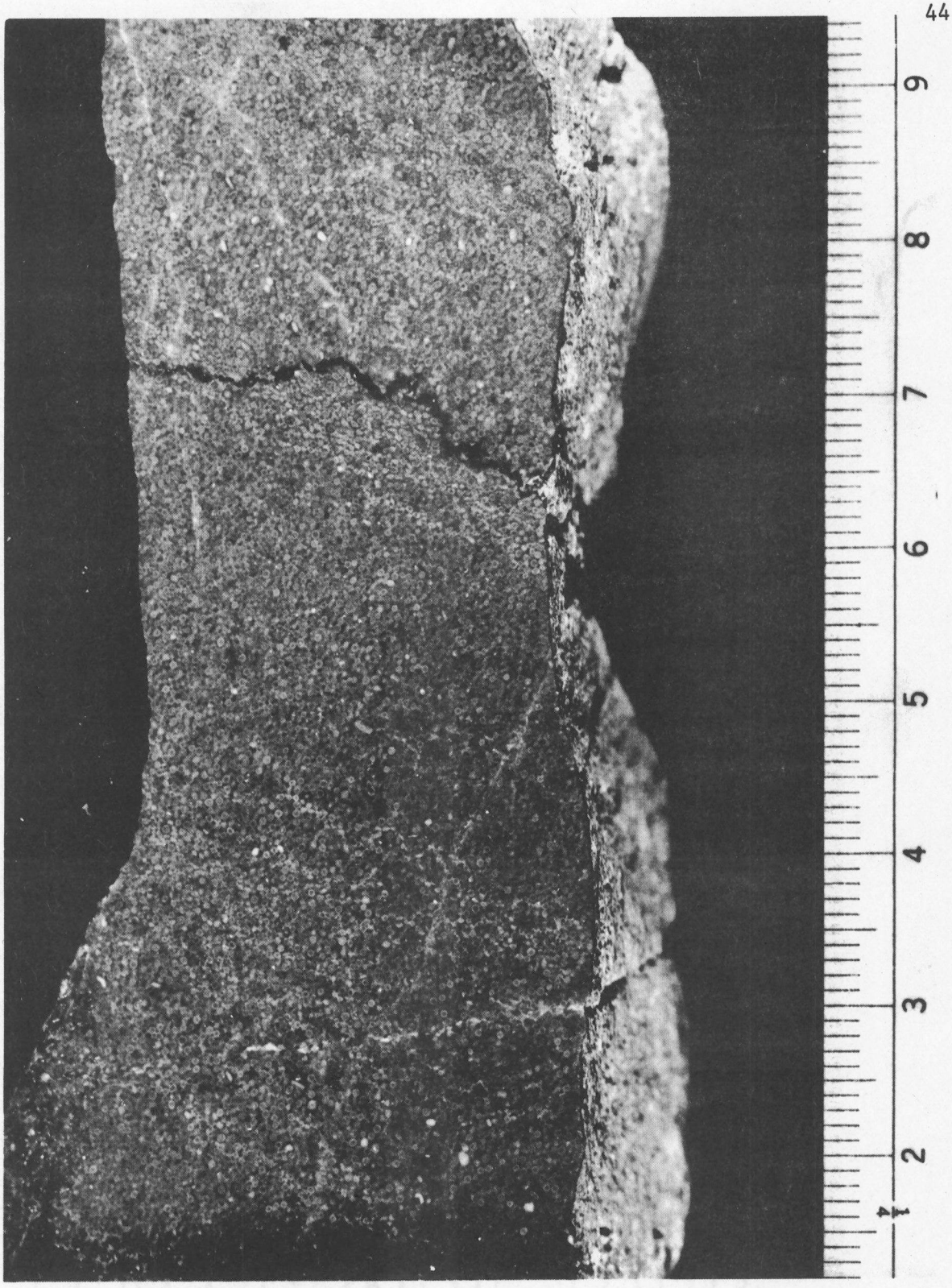


Figure 17. Ooids in the Hiwassee Member of the Ottosee Shale with mostly quartz sand grain nuclei.

Note the stylolite, a common feature in this lithology. Scale is in inches.

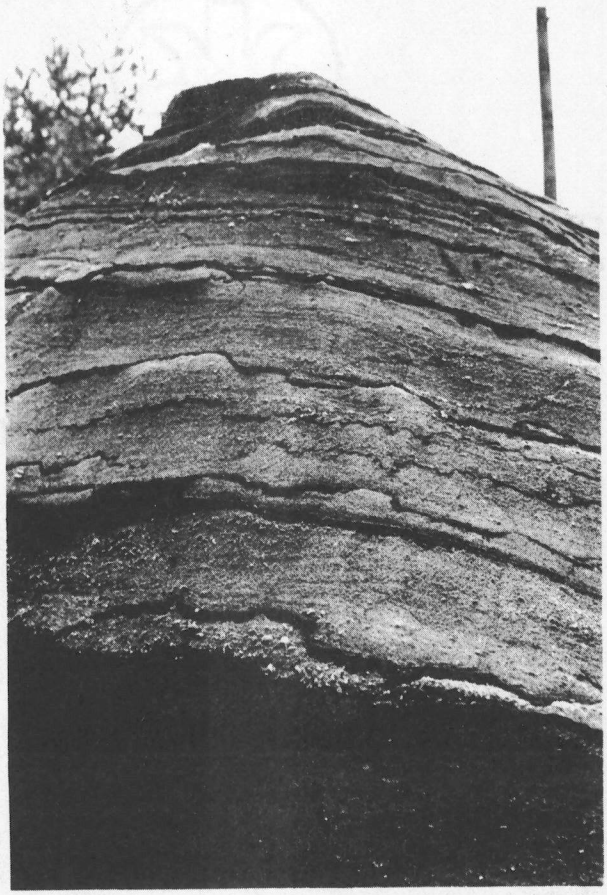


Figure 18. Pebble conglomerate outcrop of Hiwassee Member of the Ottosee Shale at Section WB-2 east of Calhoun, Tennessee.

Largest pebbles are approximately 3/4 inch maximum diameter. Note the stylolitic appearance of the dark bands.

Pebble conglomerate beds are poorly and sporadically exposed which makes it difficult to determine if they are laterally continuous or if they are discontinuous lenses which do not persist from outcrop to outcrop. The writer suggests that they may represent two or at most three horizons in this unit. Pebble composition ranges from milky quartz, medium blue-gray quartz, tan to light brown chert, sandstone, quartzite and peculiar, dense, "greenstone" type pebbles of unknown origin, Figure 19. These pebble horizons contain materials ranging in size from fine sand to pebbles one inch by 1-1/2 inches in diameter. Most commonly they are less than 1/4 inch in maximum diameter and tend to be equidimensional. Most exposures show a general decrease in pebble size upward. The pebbles are mostly subrounded but range from angular to rounded with the chert fraction persistently exhibiting the more angular appearance.

Pebble and boulder conglomerates have been described by Kelberg and Grant (1956) from Chickamauga outcrop belts to the east and southeast near the Great Smoky Fault. It is not presently known if the conglomerates of the Calhoun area are related to those described by Kelberg and Grant. The writer suggests that they may be time equivalent and related to the same sporadic tectonic episodes.

The Hiwassee Member weathers light gray to very light gray in the more massive limestone beds, which locally exceed six feet in thickness with only stylolites to disrupt the lithologic continuity. The ooids tend to weather a slightly different color than the matrix so that the ooids are more readily seen in weathered outcrops. Beds greater

a.

b.

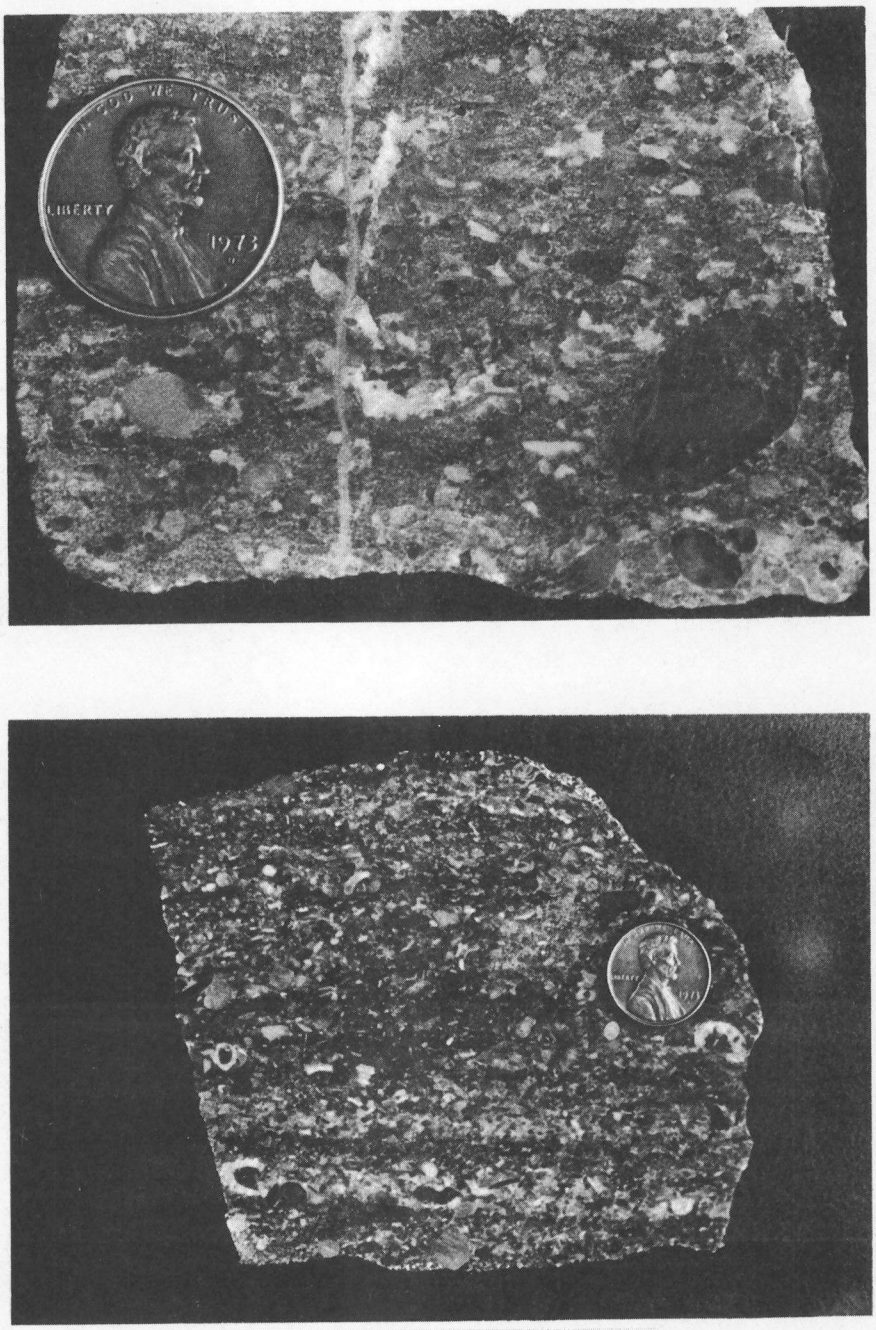


Figure 19. Sawed section of pebble conglomerate (a) and sawed section of pebbles associated with coarse bioclastic limestone (b) in the Hiwassee Member of the Ottosee Shale.

Note the variety of pebble lithologies and the calcite rehealed fracture in (a) and the dark, fine to medium quartz sand grains in (b).

greater than two feet thick tend to weather into large, rounded, fluted masses that are often nearly buried in red residual soils that become a lighter red color with advanced maturation, as shown in Figure 20.

Cross-bedding is common but sporadic in distribution along strike. Some beds with well-developed crossbedding weather into thin sheets in a manner which closely resembles spalling.

The Hiwassee Member is 209 feet thick at the type section along the Louisville and Nashville railroad tracks northeast of the Hiwassee Church (see Appendix, Section WB-2). The section is thinner than in the area farther to the north between the railroad and Bowater Road. A paucity of outcrops precludes the possibility of establishing a measured section in that area but the unit is probably approximately 350 feet thick.

The unit was traced southward from the type section to where it "pinched out" into typical Ottosee shales north of the Hiwassee River near Henegar Bluff. The Hiwassee is exposed only on the northwestern limb of the Athens syncline and apparently pinches out to the southeast across the syncline. A facies relationship with the typically shaly Ottosee possibly explains the disappearance of the unit. However, as the Ottosee section below the McKnight Member thins with the loss of this unit and because there is a general lack of significant transition zones, the term pinchout is preferred.

Northward from the type section the Hiwassee is continuous, although of variable thickness, along the northwest limb of the Athens syncline into the Athens Quadrangle (Rodgers, 1952). Rodgers mapped



Figure 20. A typical outcrop of oolitic limestone in the Hiwassee Member of the Ottosee Shale at Section WB-2 east of Calhoun, Tennessee.

Note the coarser materials toward the base which are pebbles and very coarse fossil fragments. Outcrop is approximately five feet high.

scattered exposures of quartz-free crystalline limestone or "marble" separate from the main body of the Ottosee on both the north and south limb of the Athens syncline and designated them Oom. The writer has traced the Oom beds on the north limb of the syncline into the Hiwassee Member and the Oom along the southeast side are equivalent to the McKnight Member (Plate I, in map pocket). The writer has modified the southwestern portion of Rodger's map of the Athens Quadrangle to show a more continuous distribution of the Hiwassee Member.

The Hiwassee Member becomes generally non-oolitic northward near the Riceville-Etowah road although occasional outcrops of fossil-fragmental limestone in this area contain ooids. Some of these scattered oolitic exposures are crossbedded and contain red ooids in a sparry matrix, Figure 21. No oolites were observed north of Long Hollow Road near South Liberty although the associated fossil-fragmental limestones persist northeast into the Athens quadrangle.

This unit is lithologically quite similar to the lower portion of the McKnight Member and would be separated from it only with great difficulty should the intervening shale unit phase or pinch out. These two oolitic limestone members were not observed in contact anywhere in the study area or adjacent areas to the northeast.

The soils from the Hiwassee and McKnight Members are light to deep red, blocky, tough, clayey, plastic soils that crack into polygonal patterns on dessication, Figure 22. These soils are easily distinguishable, for the most part, from the yellow to ocher, clayey soils of the Ottosee shales and from the red to dark red sandy, loose, uncompacted soils of the Calhoun Member which overlies the McKnight Member.

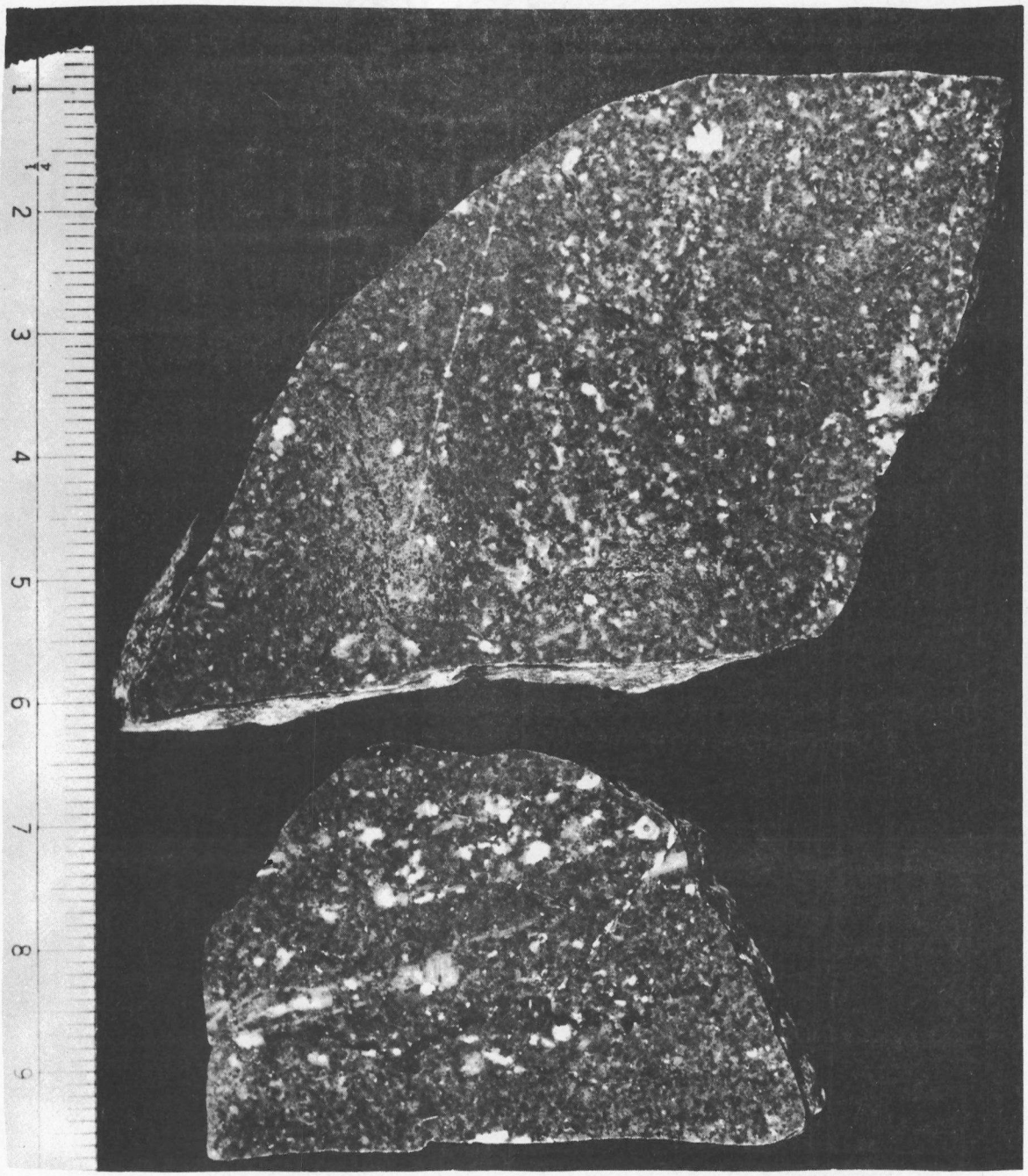


Figure 21. Red ooids with fine quartz sand grain and fossil fragment nuclei: Hiwassee Member of Ottosee Shale.

Note stylolites. Scale is in inches.

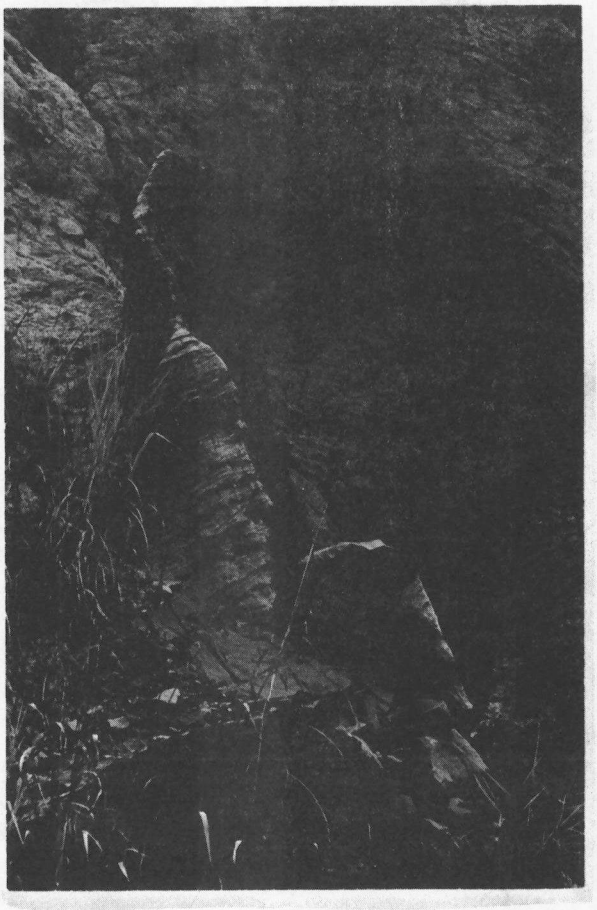


Figure 22. Blocky textured soils developed on the Hiwassee Member of the Ottosee Shale at Section WB-2 east of Calhoun, Tennessee.

Fluted remnant in deep residual soil is typical of this member.

Unnamed Middle Shale Member. This unit is mostly shale, medium to light gray with scattered small cobbles. Shale is calcareous, locally fissile and silty to sandy in thin beds. This shale member ranges in thickness from 90 to 150 feet.

McKnight Member. This member was named for McKnight Hollow, approximately 2-1/2 miles southeast of Calhoun, McMinn County, Tennessee, where the unit is well-developed. The type section is located along the Louisville and Nashville railroad tracks (Section WB-2, Figure 11, page 31) east of the type section of the Hiwassee Member. The McKnight Member is 702 feet thick at the type section. Oosparites and oomicrites are the dominant lithologic types although fossil-fragmental limestone lithologies occur as interbeds and as bioclastic-oolitic admixtures. Whole brachiopods are common in these beds. Locally, light gray to light dove-gray oosparite without fossil fragments is interbedded with the other major lithologic types. Red ooids in either sparry or fossil fragmental matrix are well-developed just southwest of the cemetery behind the Meadow Fork Church. The lower contact with the middle Ottosee shales is usually sharp; however, the lowermost limestone beds are argillaceous and shaly through an interval of approximately five feet. These argillaceous limestones are very fossiliferous and contain bryozoans, brachiopods, pelmatozoan "holdfasts" in growth position and an occasional coral fragment. This zone is similar to the oolite-shale contact zones for the Hiwassee Member, as described above, including the lateral and vertical color changes.

Near the southwestern edge of the map area the McKnight Member is absent because of erosion of the plunging southwest end of the Athens syncline. Northeastward along the southeastern limb of the Athens syncline the unit is almost continuous, with variable thickness but generally thins northward toward the Athens quadrangle. In the Athens quadrangle it includes Rodgers "marble" (Oom) of the southeast limb of the Athens syncline (see Plate I in map pocket). Along the northwest limb of the syncline the McKnight Member thins through erosion and one mile northeast of the Old Swafford Cemetery north of Meadow Fork Road the unit is completely removed exposing typical underlying Ottosee shale. Removal of these oolitic limestone beds is apparently closely related to an oblique anticlinal wrinkle across the Athens syncline (see map pocket, Plate II, Section A-A'). Several smaller folds are associated with this anticlinal wrinkle and collectively affect the depth of water and the resulting depositional pattern with regard to the lateral continuity of otherwise persistent oolitic limestone layers which seem to become more erratic where the member crosses this anticlinal structure. Cooper (1954) also suggested structural control of local facies in the Southern Appalachians. The continuity of oolites or persistent limestone layers is not re-established northeastward of this structure. Near the northeast corner of the Calhoun quadrangle near South Liberty, the McKnight Member grades through apparent facies changes into discontinuous Ottosee-type dark blue-gray, sandy limestone and finally becomes indistinguishable as a unit in typical Ottosee shales. The McKnight

Member on the northwest limb of the Athens syncline could not be traced into the Athens quadrangle except for a small isolated patch near Mile 20 of Oostanaula which was mapped northeastward into the Athens quadrangle. Rare, small float fragments and small patches of red blocky soil suggested occasional recurrences of this lithology along strike, perhaps at the same horizon.

Two pebble conglomerate zones, each approximately three feet thick, were measured at the type section and noted in several additional outcrops during mapping. Pebble sizes range up to 3/4 inches, maximum diameter, although the average was approximately 1/4 inch. These conglomerates are poorly exposed and it is not definitely known if the zones are laterally continuous. They do seem to occur at the same stratigraphic horizon and are so similar lithologically as to suggest continuity. Pebble composition is variable, ranging from milky quartz to blue-gray quartz through quartzite, sandstone, tan to light brown chert, and as in the Hiwassee Member, to an occasional peculiar "greenstone" type pebble of unknown origin.

The McKnight Member is directly overlain by the Calhoun Member in an apparently conformable relationship over most of the study area. Near the northeastern border of the map (see Section A-A' in map pocket) and in the Athens quadrangle a shale unit, similar to those separating the Chapman Ridge and Hiwassee units and the Hiwassee and McKnight Members, separates the McKnight and Calhoun Members. Where the Calhoun lies directly on the McKnight the contact is gradational through some five to ten feet. The top of the McKnight Member

is picked at the top of the dominantly sandy oolitic limestone layers and below the lowest highly ferruginuous, red-weathering, arenaceous and fossil fragmental limestone beds of the Calhoun Member. Where the McKnight and Calhoun Members are separated by shale the contacts are similar to the shale-limestone contacts of the Hiwassee Member. The McKnight and Calhoun units are easily separated in the field except where colluvium from the Calhoun Member masks the contact.

Karst topography has developed within the outcrop pattern of the McKnight Member. Although sinkholes are common in the other limestone members, those in the McKnight Member are different because some of them are very deep and steep-sided.

Calhoun Member. The Calhoun Member of the Ottosee Formation is recognized chiefly in the central portion of the Athens syncline on the Calhoun quadrangle. Rodgers (1952) mapped several small occurrences of red, semicrystalline to crystalline limestone (Calhoun-type lithology), some of which are located northeast of Oostanaula Creek on the Athens quadrangle, and assigned a map symbol "Oou" for this upper member. Rodgers (1952) also mapped a small isolated occurrence of Calhoun-type lithology in the southwestern part of the Athens quadrangle (about 1-1/2 miles N. E. of the S. W. corner of the map) and assigned the lithology to his "Holston." The writer suggests that these beds may be the lateral equivalent of the Calhoun Member. The lateral continuity of these beds has not been established and the suggested equivalency is based strictly on stratigraphic position and similar lithologic characteristics as no outcrops

were found between the two units.

The type section of the Calhoun Member is located approximately 2-1/2 miles east of Calhoun at the deep cuts on the Louisville and Nashville railroad spurline to Benton, Figure 11, page 31, Section WB-2. A thickness of 188 feet was measured at this site but it is only a partial section as the top has been eroded. This is the maximum exposed thickness for the unit in the area. North of the Bowater-Etowah road, 1-1/2 miles northeast of the type section, erosion has breached the Calhoun Member, exposing the underlying McKnight Member and isolating two relatively small remnants of Calhoun lithology to the northeast.

The Calhoun Member is composed of sandy, dense, fossil-fragmental limestones grading locally both laterally and vertically, to calcareous, fossil-fragmental, very ferruginous, quartz sandstones which weather bright red to red-brown, punky, porous, sandstone remnants and finally into a red to dark red, very sandy, blocky textured, loamy soil. These soils are almost always well-developed and deep even where the beds are steeply dipping or on end. Bedrock exposures are scattered and discontinuous but the interval is well-marked in areas of no outcrop by strong soil contrasts, the non-sandy, more clayey, tough, plastic soils of the McKnight Member below and the dark red, sandy, loamy-textured, ferruginous soils of the Calhoun Member above.

Bioclastic debris is generally co-mingled with quartz sand although some beds are locally quartz-free. Size ranges for all clastics are fine to coarse with occasional small zones or lenses

of fine to coarse poorly sorted, quartz sand and fossil fragments. All of the quartzose sandstones of the Calhoun Member are fossiliferous. Crossbedding is common to all lithologies but is better developed in the more quartzose layers of the Calhoun Member. Ripple marks are common and well-developed in the quartzose sandstones, especially those with the higher iron content, Figure 23. Ripple marks were not observed in the quart-free bioclastic beds. Bedding features are more obvious on weathered outcrops because the bioclastic material is preferentially removed from between the more quartzose darker layers, Figure 24.

Dark bands, up to one inch thick, weather in positive relief on some beds in the Calhoun Member. These bands are similar to those in the Chapman Ridge Formation and contain abundant dark brown to black, very fine, clayey, non-laminated material. The dark bands tend to parallel bedding planes, terminate cross-bedding sets or run sub-parallel to stylolites, Figure 25. LeRoux (1974) collected similar dark material samples from rocks in the next belt to the southeast, with lithologies similar to the Calhoun Member, and inferred that they were organic in origin probably derived from algal materials.

Scattered loose pebbles in the residuum from the Calhoun Member suggest the occurrence of pebble conglomerate zones similar to those in the Hiwassee and McKnight Members. However, these pebbles were not observed in place and may be exotic to the residuum from this unit. Zones of abundant discoidal shale intraclasts occur sporadically throughout the Calhoun Member (Figure 26) and are interpreted by the

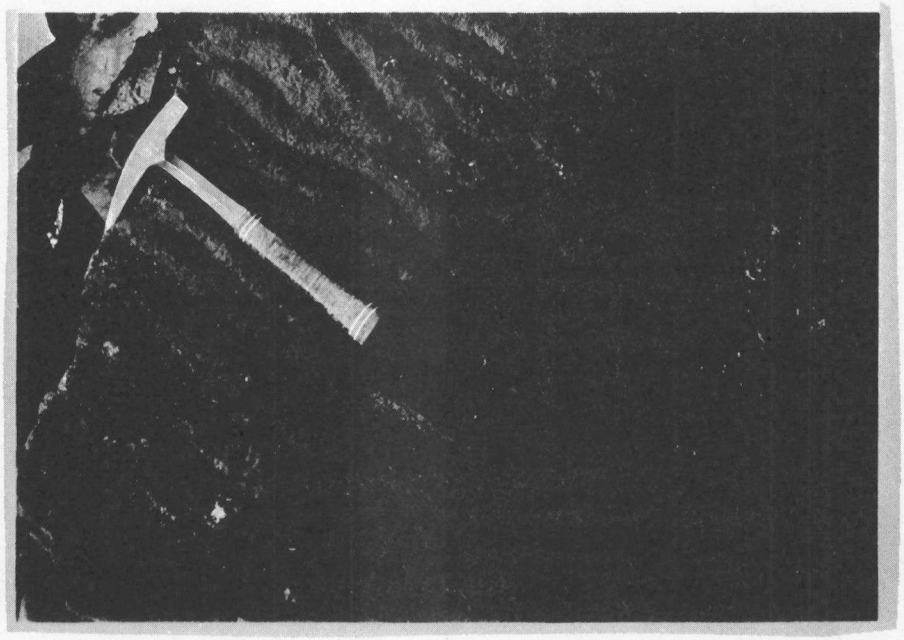


Figure 23. Oscillation ripple marks in the Calhoun Member of the Ottosee Shale.

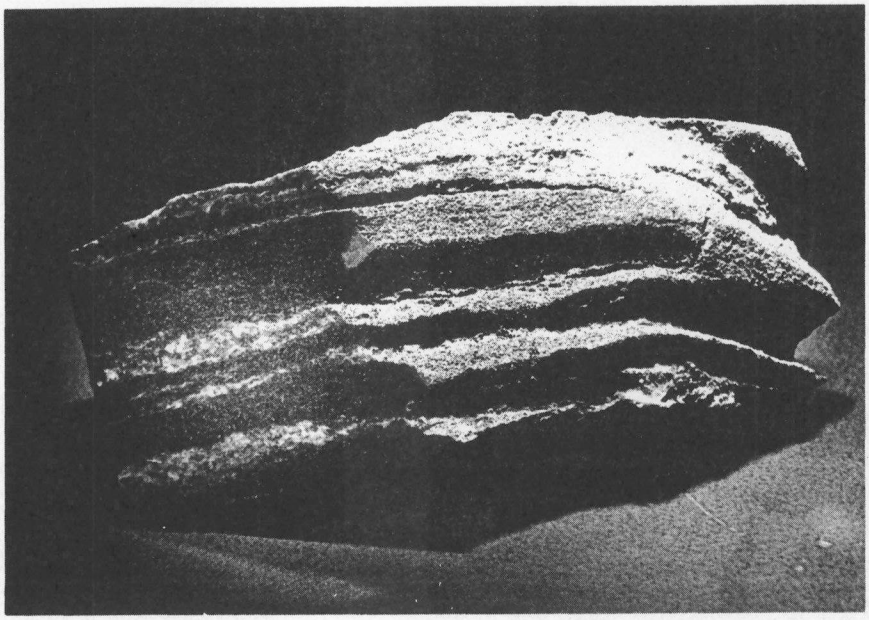


Figure 24. Differential weathering of interbedded bioclastic and sandy layers in the Calhoun Member of the Ottosee Shale.

Note pitted surface of sandy layers. Specimen is approximately eight inches long.



Figure 25. Dark, ferruginous bands in a more calcareous portion of the Calhoun Member of the Ottosee Shale at Section WB-2 east of Calhoun, Tennessee.

Thickest dark bank is approximately 1/2 inch thick.

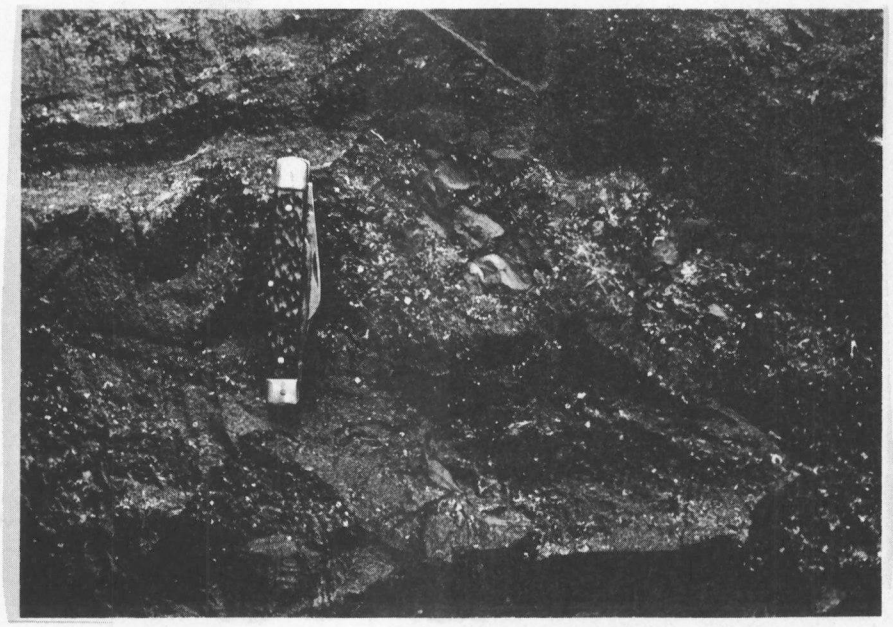


Figure 26. A zone of discoidal shale intraclasts in the Calhoun Member of the Ottosee Shale.

as "rip up" fragments associated with periodic storms. The shale clasts range up to two inches, maximum diameter, but average approximately 1/2 inch.

Discontinuous shale lenses and lentils in the Calhoun Member are suggested by the presence of yellow to pale red, mottled, clayey soils which occur in isolated exposures within the outcrop area of this unit. These soils contain numerous chips of shaly material typical of Ottosee Shale soils. Limestone outcrops near these soil occurrences exhibit color changes and the same argillaceous to shaly, very fossiliferous character similar to the two underlying Hiwassee and McKnight oolitic members when exposed adjacent to similar shale pods or lenses. Profuse pelmatozoan "holdfasts" in growth position also occur in the Calhoun Member in the distal zones where carbonates and calcarous sandstones grade into discontinuous patches of Ottosee-type soils. Isolated exposures of these "holdfast" beds are so similar to those of the Hiwassee and McKnight Members that it would be difficult to place them stratigraphically if the beds occurred within a highly faulted zone where the frame of reference was lost.

A large karst feature is located near the southwest end of Calhoun exposures. Dips in the vicinity of the sinkhole are oriented toward the axis of the syncline; many large, relatively unweathered, blocks of Calhoun lithologies exhibit highly variable dip-strike orientation from block to block. These blocks, however, show a general dip toward the deepest part of the sinkhole. The greater resistance of the Calhoun Member compared to the McKnight Member

with regard to solutional activity is best observed where the units are vertical to near vertical and weathering effects have penetrated to great depth. In such instances, the Calhoun Member continues to persist as a coherent mass, supporting the higher ridges in the area while the McKnight occupies a lower position mostly covered by deep residuum. The thicker, more quartzose beds of the Calhoun Member commonly stand in ribbed relief on heavily weathered slopes oriented perpendicular to the strike of the beds.

II. SURFICIAL DEPOSITS

The surficial deposits in this study area include, in addition to the colluvial and residual materials, highly ferruginous and manganiferous, fluvial sands and gravels at different elevations. These deposits are not necessarily terrace deposits as they seem to drape over hilltops in some areas. The deposits occur on some of the highest ridges, where cobbles and boulders are mixed with a silt to coarse sand matrix, and downward through various elevations to the upper floodplain of the present day Hiwassee River. Some deposits are well-sorted but quartzite boulders up to two feet by fourteen inches were observed in a fine to coarse sand matrix at elevations more than 200 feet above the present drainage.

Composition of fragments includes, in addition to the quartzite debris, blue, milky and smoky quartz, chert, sandstone, and sandy fossiliferous iron and manganese nodules and concretionary masses. Occassionally, large, very-angular blocks of Knox-type chert are

found "floating" in these surficial deposits, suggesting the possibility that the blocks were more or less drowned by the influx of the fluvial debris while the Knox was being let down instead of the Knox chert being transported.

Most of the manganese and iron masses are concentrated in the soils and finer quartz-sand deposits which lie directly upon the Chapman Ridge Formation or the very sandy carbonate members of the Ottosee Formation, especially the Calhoun Member. The metals occur in significant concentrations in some areas and have been sporadically prospected since the late 1800's (Stose and Schrader, 1923; Reichert, 1942). A surface pit near Swafford Knob adjacent to the Pine Knot Road was reported to have been worked some fifty to sixty years ago (early 1920's) when five railroad cars of ore were said to have been shipped to Chicago. Another concentration of iron and manganese nodules is well-exposed along the Louisville and Nashville railroad tracks. The association of these nodules and the overlying fluvial materials is well-displayed at this location, Figure 27. The rock unit underlying the fluvial materials is in this case a nearly vertical shale unit in the Ottosee Formation. Quartzite boulders up to eight inches in maximum diameter were found in the sandy debris and a channeling effect was observed a short distance north of the railroad exposures.

Southeast of Henegar Bluff along the road to Benton, thick deposits of dark, red, ferruginous, fluvial sands and gravels occur mixed with much angular chert debris from the Knox. An occasional

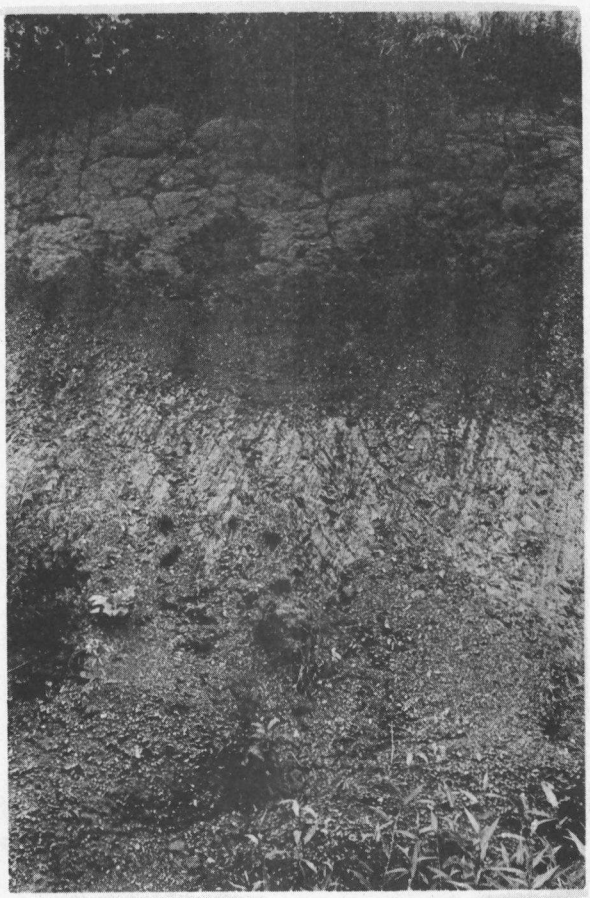


Figure 27. Iron-manganese nodule zone overlying nearly vertical Ottosee Shale at Section WB-2 east of Calhoun, Tennessee.

Note cleavage in the shale. Soil polygons are approximately one to two feet in diameter.

isolated outcrop of Knox cherty dolomite nearly buried in the fluvial material and the angularity of the chert debris in the sands and gravels indicates that the Knox debris was not transported very far. These sand and gravel deposits effectively mask the boundaries of a klippe which contains beds of cherty Knox.

III. STRUCTURE

General Discussion

The area encompassed by this study lies wholly within the Valley and Ridge structural province of East Tennessee (Figure 1, page 2), a province dominated by broad synclinal folds and low-angle thrust faulting. Anticlinal folds are less numerous and less prominent than the synclines and are commonly interrupted by the thrust faults. Strikes of the folds and faults, on a regional scale, are more or less parallel. Contrary to the regional situation where synclines occur much more commonly on the footwall of the thrust faults and the anticlines most commonly on the hanging wall, the Luskville anticline (new this report) occurs on the footwall, immediately beneath the hanging wall, of the Chestuee fault (Plate II, Structure Sections A-A', B-B', and C-C', in map pocket). The Athens syncline lies to the northwest of the Luskville anticline and they share a common limb to form a fold-pair. Several of the major structures in the study area are persistent for tens of miles along strike. Structures such as the Athens syncline, Knoxville fault, and Chestuee fault extend completely across the study area and beyond, Figure 1, page 2.

Major folds in the Calhoun area exhibit a variable plunge and are, for the most part, slightly asymmetrical with the axial plane locally overturned to the northwest (Plate II, Structure Section C-C', in map pocket). Individual beds in the steeper-dipping, southeast limb are also locally overturned to the northwest as near Blackburn Hollow, Swafford Knob, and Clear Springs Cemetery where the Lenoir, Athens, and Chapman Ridge, respectively, are near vertical to overturned. Beds in the Lenoir, Athens, Holston and Chapman Ridge Formations and the shale members of the Ottosee Formation are most commonly overturned in folds while beds in the Knox Group and the various carbonate members of the Ottosee Formation exhibit least overturning. It is suggested that the Knox, except in klippen, is least deformed because it is essentially a massive carbonate and the most competent rock involved in the folding. The Knox served as the "ram" that distorted the Chickamauga units. Of the Ottosee units, the carbonates are probably least deformed and overturned because they are monolithic, competent masses within the less competent, more highly distorted shale members. Beds of Knox occurring in the several klippen associated with the Chestuee fault are often highly distorted and commonly overturned to the northwest.

The structural attitude of the rocks in the five klippen in the area show a general conformity to the regional strike pattern, even when overturned, and are, structurally and stratigraphically, quite similar to each other.

Lithologic distribution and character of Chickamauga sediments suggests that some of the structural features in this general region were active after Knox and before late Ottosee time. Several Middle Ordovician episodes of uplift, perhaps far to the southeast, are indicated by multiple horizons of pebble conglomerates in the various Ottosee members. Coarse conglomerates, perhaps in part equivalent to those in the Ottosee, have been described in other strike-belts to the southeast by Kelberg and Grant (1956) and interpreted by them as indicating periodic, post-Knox tectonism. Additionally, very limited occurrences, in the study area, of coarse to very coarse sedimentary breccias (Figure 5, page 12) above the post-Knox unconformity further indicate at least localized uplift of relatively sharp relief. These breccias along with more tenuous data such as facies changes apparently controlled in part by small cross-folds, as in the McKnight Member, are interpreted as indicating multiple episodes of very minor structural activity within the study area.

Other structural features include two slices, fractures and joints, drag folds, and locally well-developed fracture cleavage; all of which are discussed on succeeding pages.

IV. MAJOR STRUCTURAL FEATURES OF THE CALHOUN AREA

Folds

Athens syncline. The Athens syncline is a rather broad asymmetrical, unfaulted, doubly-plunging structure that extends northeast-southwest across the study area essentially parallel to regional

strike. Southward from the Calhoun area it becomes ill-defined and is finally lost in a series of small folds in the Conasauga Shale near Goodwill Church in Bradley County, southeast of Cleveland, Tennessee. Northward, the Athens syncline is identifiable as far as the town of Neubert in southeasternmost Knox County where it becomes indistinguishable in a series of smaller folds.

The southeast limb of the Athens syncline exhibits the greatest distortion and steepest dips. Beds in this limb are locally overturned to the northwest and the less competent beds (e.g., in the Athens Formation) are complexly folded and crumpled. The writer suggests that this more severely deformed, steeply dipping attitude of the less competent beds developed when they were caught between the more competent blocks of the Knox formations and the carbonate members of the Ottosee and absorbed much of the lateral movement. Abundant evidence, such as slickensides, Figure 28, and rehealed, calcite-filled fractures, Figure 29, are present in the more competent units to demonstrate how these units responded to the deforming pressures.

The Luskville anticline serves as the southeastern boundary of the Athens syncline in the area of this study.

Luskville anticline. The Luskville anticline, as named herein, extends southwestward, from the vicinity of Madisonville in Monroe County, where it is terminated on the northeast by a tear fault, to the south of Chestuee in McMinn County where it either dies out or is hidden beneath the hanging wall of the Chestuee fault. Sparse data

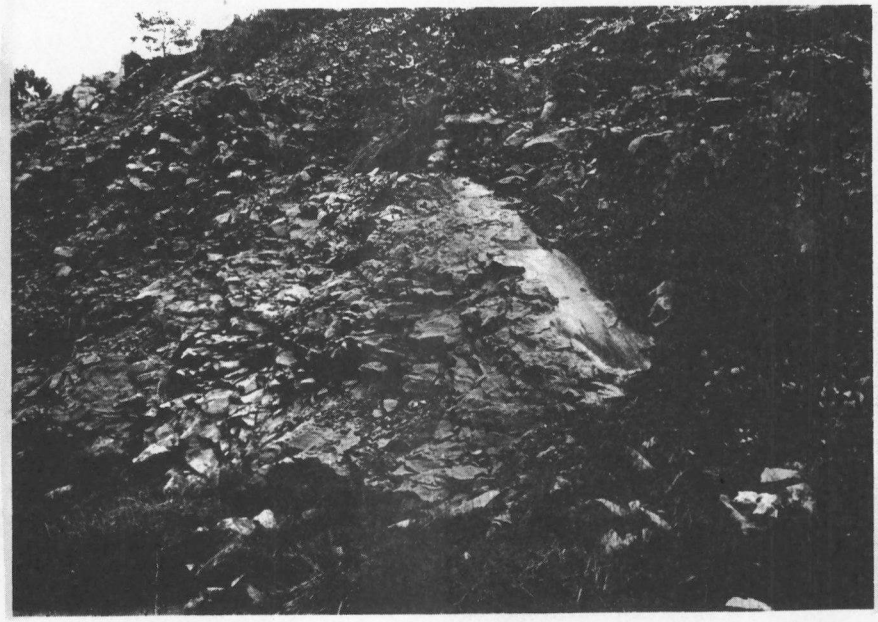


Figure 28. Slickensided surface, approximately 15 feet long, in the McKnight Member of the Ottosee Shale at Section WB-2.

The displacement is minimal.

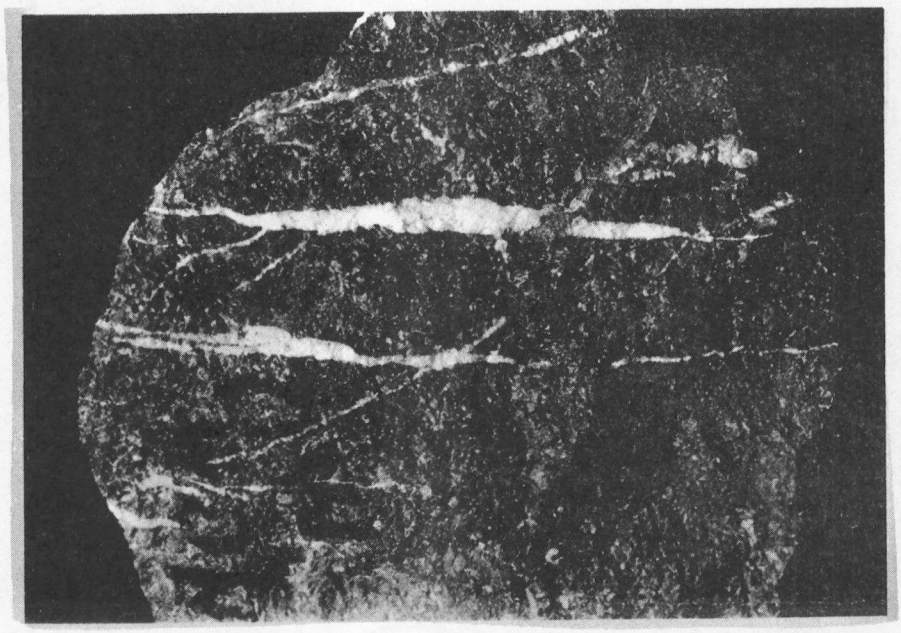


Figure 29. Calcite rehealed fractures in a thick-bedded, bioclastic limestone unit with thickest vein approximately 1/4 inch thick.

in the study area support the latter interpretation, an opinion apparently shared by Swingle (1959) whose B-B' structure section on the East Cleveland geologic quadrangle presents a similar interpretation.

The southeast limb of the anticline is overridden from the southeast by the Chestuee fault. Southwestward from the vicinity of Chestuee, the fault rides higher and higher, structurally, on the Luskville anticline and Conasauga beds are thrust upon older and older beds in the core of the anticline. East of Pinhook Bend of the Hiwassee River lower Conasauga beds of the hanging wall are thrust upon upper Conasauga beds of the footwall. There the major portion of the Luskville anticline is hidden beneath the Chestuee fault and the syncline-anticline nature of the fold-pair is not obvious (Plate I, in map pocket). Farther southward in Bradley County, the Chestuee fault, the Athens syncline and the Luskville anticline all lose definition and cannot be extended with confidence beyond Kinser Creek near Kinser Tabernacle on the Felker quadrangle of Swingle (1959).

The axis of the anticline trends northeast-southwest, essentially paralleling that of the Athens syncline. The two folds share a common limb. A small structural reversal occurs near the crest of the anticline in the Copper Ridge Formation near Luskville. The anticline and the Chestuee fault are partially offset by several small tear faults as at Luskville, Claxton, and a short distance north of Double Springs. The fold plunges gently northeastward from Double Springs to the vicinity of Piney Grove Church where a structural saddle is developed and the fold reverses plunge.

In general, the Luskville anticline and the Athens syncline are a simple fold-pair exhibiting a distorted common limb with the greatest distortion occurring in the incompetent shaly beds of the Lower Chickamauga units within that limb. The fold-pair is one of several in East Tennessee in which the syncline is located northwest of the associated anticline. These fold-pairs are related to the underlying instead of the overlying thrust fault (Rodgers, 1953). Rodgers stated that the relationship may be that of association of the folds with a refraction zone wherein the underlying fault refracts upward from a lower glide plane into the Conasauga Shale which then serves as the glide plane unit.

The writer feels that these paired folds most probably occurred as a normal consequence of compression during the early stages of deformation and that they were part of a series of folds, perhaps in part formed contemporaneous with faulting. When rupturing of one of the folds occurred it was, by chance, the west limb of the synclinal structure (east limb of the Luskville anticline) that broke to relieve the stress. The overriding block has since been removed by erosion and the remnants of the ruptured syncline associated with the Chestuee fault are no longer discernible, the hanging wall portion having been removed by erosion while the footwall portion is still hidden beneath the fault, Figure 30. Other unbroken fold-pairs should be found beneath the many thrust sheets in the Valley and Ridge, a possibility of real significance to those engaged in hydrocarbon, hydrological, or base metal exploration programs. Further, there appears to be no impelling reason to assume that the number of

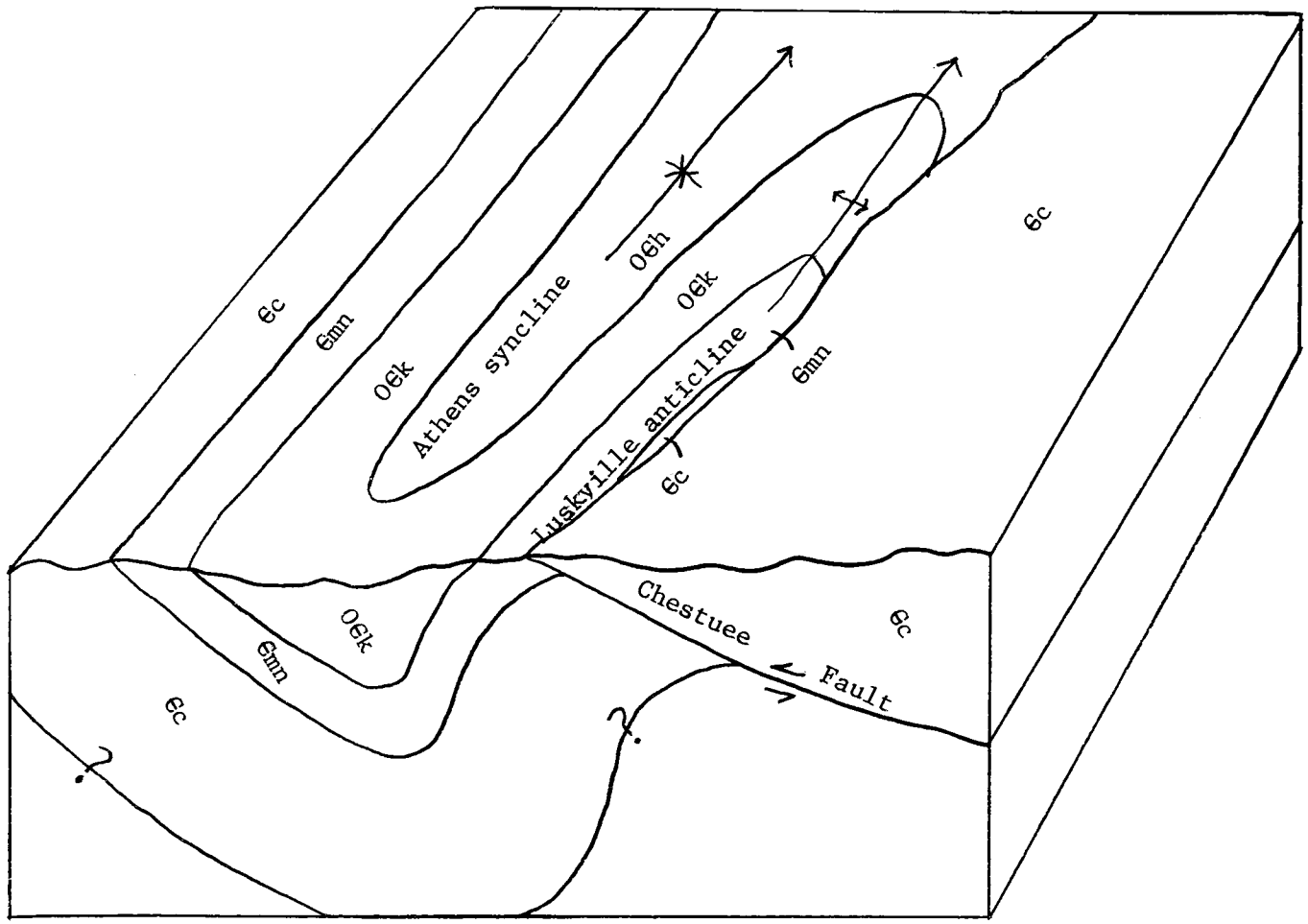


Figure 30. Sketch of a simple fold pair and thrust fault in which the major portion of the associated anticline is preserved beneath the allochthonous block; the base of the Conasauga Shale is shown as form line only as the true thickness is unknown.

fold-pairs exposed at the present day erosion surface is indicative of the relative abundance of non-exposed fold-pairs in the Valley and Ridge.

Subsidiary folds. Abundant subsidiary folds occur within the Athens syncline. Many of the smaller folds are confined to the relatively incompetent beds and are interpreted as drag folds, Figure 31. Most of the drag folds have orientations paralleling the northeasterly strike direction of the main fold. Several of the larger subsidiary folds exhibit an orientation more nearly north-south than the main syncline and therefore seemingly indicate evidence for a force couple (in the horizontal sense). Isolated exposures are occasionally associated with the synclines and the anticlines (e.g., the outcrop of the Hiwassee Member north of the Old Swafford Cemetery on Meadow Fork Road and the outcrop of the McKnight Member east of South Liberty).

Examples of subsidiary folds in the Calhoun area can be seen west of Double Springs where two anticlines and an intervening syncline trend generally across the axis of the Athens syncline. The easternmost structure, a north-plunging anticlinal fold, apparently cuts completely across the Athens syncline and is expressed as a pronounced flattening of dips on the northwest limb. A facies change occurs in the McKnight Member of the Ottosee Formation south of Carruth Hollow in close association with this cross-fold. Structural activity penecontemporaneous with deposition could account for the facies change although other valid interpretations are possible. For example, loci of post-depositional folding could have been controlled by lithologic

a.



b.

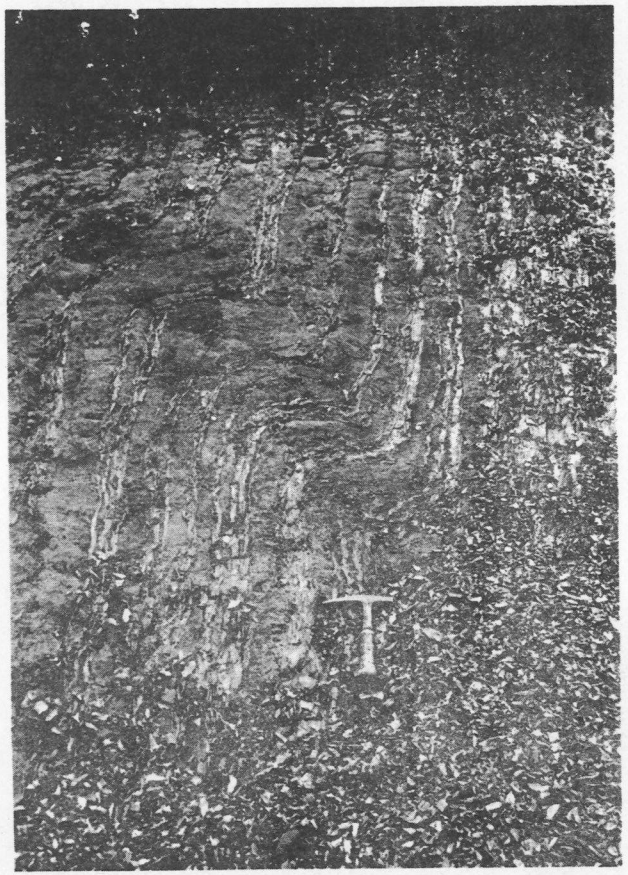


Figure 31. Dragfold in the Chapman Ridge Formation at Section WB-1 at Henegar Bluff showing thickening and thinning of beds (a) and dragfold in the Chapman Ridge Formation at Section WB-2 east of Calhoun, Tennessee.

factors but this is thought to be less likely as the facies change involves a very small proportion of the generally heterogeneous rock mass involved in the cross-fold.

Faults

Two types of faults were noted and mapped in the study area, major thrust faults and small tear or strike-slip faults. Horizontal movement along faults ranges from a few inches as intraformational breaks (Figure 32) to more than 3000 feet along the Chestuee fault. Dips on the thrust fault planes are gnerally to the southeastward. Reversals and flattening of the fault plane dip are required to explain the several erosional remnants as klippen. Fault planes were not actually seen but were mapped on stratigraphic evidence. According to Swingle (1959) and Rodgers (1953), surface dips of the major thrust faults are not necessarily indicative of fault plane dips at depth. Measurement of fault plane dips is made exceedingly difficult by low topographic relief, vegetation cover, and thick residuum.

Small tear faults associated with the Chestuee thrust fault constitute reasonable evidence that the allochthonous block of the Chestuee fault did not move smoothly on an undirectional front, perhaps indicating some form of a force couple. Extending the force couple concept regionally, Rodgers (1950) ascribed "the consistent asymmetry of Valley and Ridge deformation" to a force couple in a vertical sense, "over from the southeast, under from the northwest."

All tear faults were mapped on changes in residuum, offsets of contacts, and offsets of topographic trends associated with specific

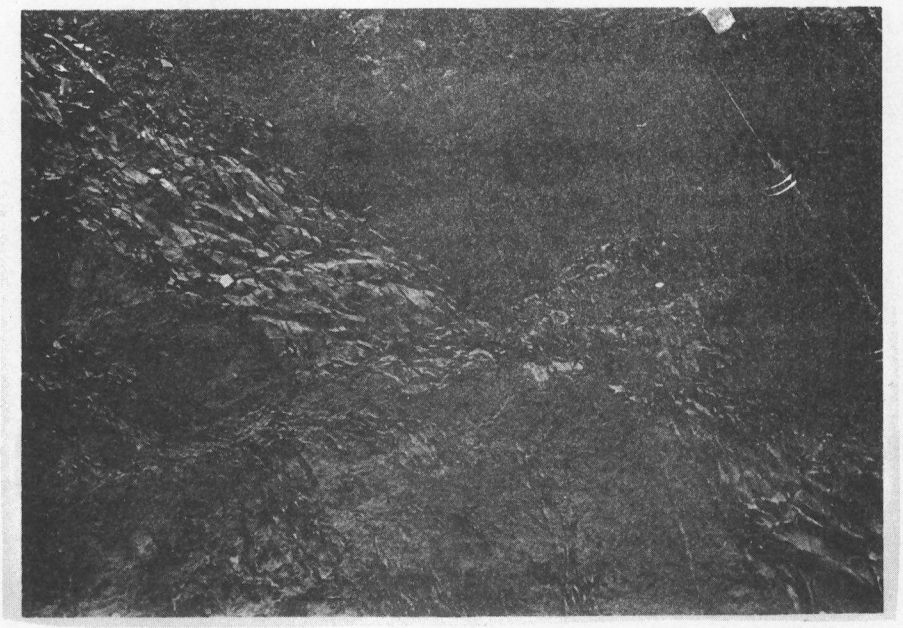


Figure 32. Small-displacement intraformational fault in a deeply weathered outcrop of the Chapman Ridge Formation in a small creek approximately one mile north of Hanks Cemetery.

Note the effects of cleavage in the less weathered beds.

lithologic units. No exposures of tear faults were seen in the area.

Chestuee fault. The Chestuee fault was first recognized and named by Rodgers (1952) in his geologic report on the Athens quadrangle in which he stated "The Chestuee fault has not been previously recognized and is probably not as extensive as the Knoxville or Saltville faults. . . ." Swingle (1959) mapped the Chestuee fault in the Cleveland area as far south as Kinser Creek in the northeast corner of the Felker geologic quadrangle where it appears to die out in a series of small folds. Northeastward, the Chestuee fault is traceable to the vicinity of Neubert, southeast of Knoxville near the Blount-Knox County line. Here the fault dies out in a complex series of small faults and folds (Hardeman, et al., 1966).

The hanging wall of the Chestuee fault is composed of Conasauga units except for that portion from Madisonville northward where Knox units occur between it and the Dumplin Valley fault to the southeast. Footwall rocks in that portion north of Madisonville are principally formations of the Knox Group although Lower Chicamauga units and the Conasauga Shale are locally preserved.

Near the southern edge of the map area the Chestuee fault is mapped only with difficulty as the surface trace of the fault occurs within the Conasauga Shale (Plate I, in map pocket). The position of the fault in this portion was placed in an ill-defined zone between relatively undistorted, steeply inclined, northwest dipping beds of Knox, Maynardville and Conasauga units on the northwest and very highly distorted, deeply weathered, poorly exposed, generally southeast

dipping Conasauga beds on the southeast. Those beds southeast of the fault zone are typical of the shale-siltstone lithologies usually seen in the lower section of the Conasauga while those northwest of the fault are of a clay shale-limestone lithologic sequence more typical of the upper portions of the Conasauga unit (Swingle, 1959).

Several previously mentioned, small tear faults offset the surface trace of the Chestuee fault in the map area. The relatively straight surface trace and unit displacement of these tear faults suggest that they are probably nearly vertical, left-lateral, strike-slip faults although some movement in the vertical sense must have occurred.

If the assumption is made that the klippen, to be described later, are derived from the thrust sheet of the Chestuee fault and that they represent the former southeast limb of the Athens syncline, or the Luskville anticline, then horizontal displacement on the Chestuee fault is estimated at a minimum of 3000 feet, using relative displacement of units involved in the klippen. The Knox lithologies in the klippen could represent units displaced great distances northwestward along a very low angle fault and thus bear no relationship to the Athens syncline. The horizontal displacement of the faulted units would then be much greater than the estimate given here, a situation thought to be unlikely by the writer and others (Roeder, personal communication, 1976). Although actual displacement and the exact location of the fault are difficult to pinpoint, excellent evidence, in addition to that presented above, of the fault's existence is the presence of the several klippen along the southeast limb of the Athens

syncline approximately one to two miles west of the fault trace. The surface trace of the fault is not expressed topographically except perhaps by small stream valleys which seem coincident, for short distances, with the fault zones. These small valleys have straighter courses than other similar streams in the immediate vicinity. Excellent examples of these apparently fault controlled stream courses can be seen near Double Springs and Piney Grove.

The dip of the Chestuee fault plane could not be accurately determined because of lack of exposures. The relatively straight-line nature of the surface trace and data gleaned from rather tenuous three-point calculations suggest a near-surface dip angle of approximately 40 degrees. The straight-line factor may, in part, be influenced by the necessity for plotting an approximate map position for the fault. However, in the writer's experience it is usually possible to place the fault position with an accuracy sufficient to detect any significant deviation of fault plane strike indicating low dip angle. Data presented here are in keeping with fault plane dips as shown by Rodgers (1953) and Swingle (1959) for this fault. Advocates of the "thick-skinned" versus "thin-skinned" (or basement-no basement theories) would most probably hold that this fault plane angle of approximately 40 degrees persists to basement while the "thin-skinned" theorists would insist on a general lessening of the angle with depth. In either case, the writer can only observe that the Chestuee fault displaces Conasauga Shale upon units as young as the Mascot Dolomite without evidence of complex pre-fault folding.

Knoxville fault. The Knoxville fault crosses the northwestern corner of the map area where Copper Ridge Dolomite beds are thrust upon the Kingsport Formation. Northeastward, in the Athens quadrangle, Rodgers (1952) mapped rocks as old as pre-Maynardville Conasauga in the hanging wall, thrust upon Mascot and Lenoir in the footwall. To the southwest, Swingle (1959) mapped Conasauga units thrust on either Copper Ridge Dolomite or Chepultepec Dolomite. In the study area the Knoxville fault is relatively simple but southward toward Cleveland the fault splits and becomes more complex (Swingle, 1959). The structural situation created by the Knoxville fault between Lenoir City and Sweetwater, that of syncline thrust on a syncline, appears to be one in which the northwest limb of the Athens syncline or its northeastern extension is duplicated in the footwall of the Knoxville fault. The description of Chickamauga units northwest of the Knoxville fault (Swingle, 1959 and Rodgers, 1953) is very similar to that of units in the northwest limb of the Athens syncline which lends considerable support to the above suggested correlation.

Klippen

In the course of this study, the writer mapped and named four previously unmapped structures, herein classed as klippen, and the northeast portion of a klippe which was mapped in part and named by Swingle (1959). These structures have been named to facilitate identification and discussion of individual characteristics. Analysis of the origin and structural characteristics of the klippen is made difficult by a paucity of outcrops, colluvial mixing of the residuum, and heavy vegetative cover.

An origin by which these structures are explained as erosional remnants of the allochothonous block of the Chestuee fault is tentatively accepted by the writer and is probably the most simple solution. It is suggested on the basis of data presented later that these are vestigial "slices" from which the overlying fault and encompassing rocks have been eroded, Figure 33.

Projection of the main Chestuee fault, from its present day surface trace, beneath these structures so that they occur on the hanging wall of the thrust fault, where they would be classed as klippen, requires a reversal of the fault plane dip and a northwestward downfolding of the fault plane. It is possible that post-fault folding warped the fault plane after the initial deformation but no data are in evidence to suggest that the footwall rocks have been refolded.

The Knox units in these "slices" are interpreted as having originated on the southeast limb of the Athens syncline. The stratigraphic sequence of oldest to the southeast, youngest to the northwest and their right side up attitude preclude these beds having come from the southeast limb of the Luskville anticline. The beds in the "slices" all have strikes very closely approximating that of the unfaulted beds upon which they lie, a situation thought very unlikely if derived from a different strike-belt or if transported great distances. The writer suggests that these "slices" broke from the footwall of the main thrust sheet during thrusting and folding, moved a short distance, broke from the overthrust block when the fault "locked up" and were overridden as renewed movement continued along

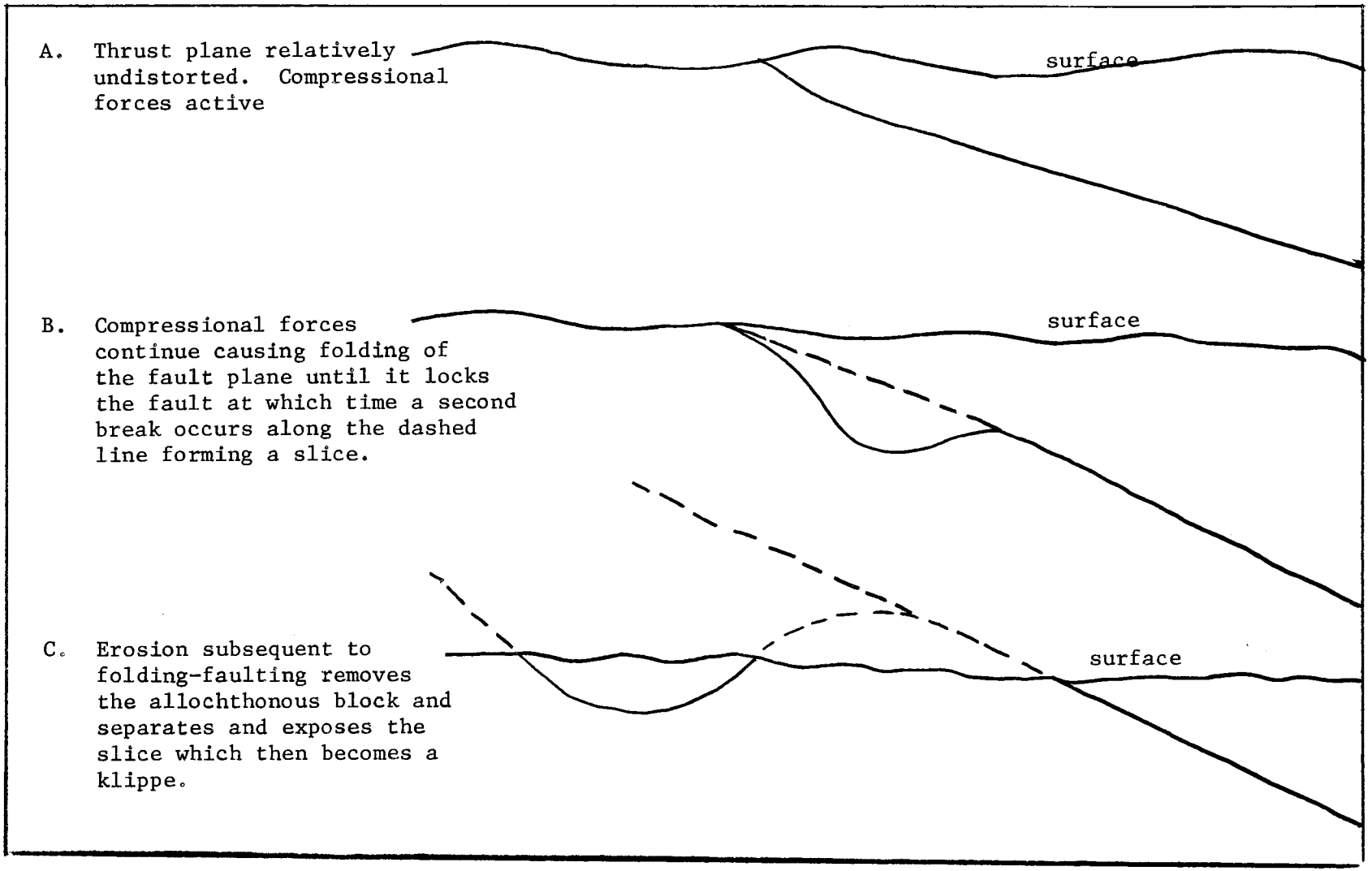


Figure 33. Sketch showing the possible development of klippen from slices.

the main Chestuee fault. Erosion has since isolated the remnants as they are seen today. It should be noted that all slices, so isolated, must be classed as klippen since they were a part of the original allochthonous block; they are also slices. A slice-origin interpretation for these structures is supported indirectly by the presence of large angular Knox chert blocks (up to two feet, maximum diameter) found scattered over much younger units farther northwest within the Athens syncline. These chert blocks are interpreted by the writer as having been let down from a higher position, in this case, the thrust sheet of the Chestuee fault. This interpretation requires two stages of sufficient fault movement so that some of the Knox units must have been thrust northwestward over the main portion of the Athens syncline while the data from the "slices" seems to require much less movement, a situation most simply explained if these isolated structures described above are slices and not klippen.

The writer suggests that a splintering of the Chestuee fault and an overriding of the resulting slice during an episode of contemporaneous folding and faulting most simply explains the relationship between the relatively steep angle of dip of the present day, near surface portion of the main Chestuee fault and the relatively flat attitude of the fault plane beneath the "slices." Rodgers (1949) has suggested that steep fault plane dips are due to a supposed upward refraction from a lower position as evidenced by the steep near surface dip of the present fault trace (see Rodgers, 1949, for a discussion of possible fault behavior with depth).

A straightforward klippen interpretation, for the origin of the structures described above, is considered as a secondary explanation for the following reasons. No hard evidence now exists to support the concept that the Knox chert debris scattered over the Athens syncline outcrop area came from the thrust sheet of the Chestuee fault instead of some higher thrust sheet. Further, valid structural mechanics do not actually prohibit the reversal and downfolding of the fault plane as described above, and finally, slices are usually wedge-shaped in form and highly shattered and complex in structure (Helton, personal communication, 1975), a description that does not closely fit that of the present day Knox remnants (see the following description of character and behavior of rock units in these structures).

These five klippen may be parts of a megaklippe that erosion has separated into parts, as well as separating the total unit from the parent thrust sheet. A very few scattered Knox chert blocks between the klippen may indicate previous continuity. A megaklippe is further suggested by the uniformity and similarity of units involved, the continuity of structural attitude, and the fact that all lie astride the outcrop area of the Lenoir Limestone, suggesting equal movement. As discussed above, these structures may, instead, also be parts of a megaslice. The klippen are described in order of occurrence from south to north.

Chatata Creek klippe. The Chatata Creek klippe is approximately 2-1/2 miles long and 1/2 mile wide. It extends from near Richey Springs on the East Cleveland quadrangle to the Union Grove Church

vicinity on the Benton quadrangle. The Chatata Creek klippe was named by Swingle (1959) who mapped the southwest portion of it on the East Cleveland geologic quadrangle and noted that it extended farther to the northeast for some undisclosed distance into the Benton quadrangle. Units involved in the klippe include parts of all units in the Knox Group and the Lenoir Limestone of the Chickamauga Group although the Copper Ridge Formation of the Knox Group and the Lenoir Limestone are not exposed in that portion of the klippe in the map area of this study.

The structural attitude of the beds is very difficult to determine. Data from scattered exposures on the Benton and East Cleveland quadrangles indicate steep northwest dips with some outcrops overturned to the northwest.

An outcrop of typical post-Knox sedimentary breccia was observed adjacent to the northwestern portion of the klippe. Here the breccia is composed, essentially, of light to medium gray limestone and dolomite fragments (see Figure 5, page 12) up to 12 inches in diameter, enclosed in a red and green mottled dolomitic mudstone matrix. The extent of the breccia could not be determined because of the limited nature and poor exposure of the outcrops. The size and angularity of the breccia fragments suggest considerable relief on the erosion surface at the time of deposition of the carbonate fragments. Carbonate fragments within the breccia are typical of the several lithologies normally occurring in the Mascot Formation. Relief on the erosion surface in this area was probably less than the thickness of the Mascot Formation as other Knox lithologies do not occur in the breccia. The

breccia is, for mapping purposes, included in the lowermost portion of the Lenoir Limestone as it cannot be mapped separately at the map scale used in this study. The incomplete section of Mascot with only the lower part of the formation preserved in the klippe and the very jumbled appearance of the breccia blocks suggest that the breccias rode, snowplow fashion, on the front or bottom of the thrust block after having been dislodged from the normal position at the base of the Lenoir. These breccias are very similar to those occurring immediately above the post-Knox unconformity in other areas of East Tennessee and probably were not generated by the thrust faulting.

Coon Denton Island klippe. The Coon Denton Island klippe contains the same units as that portion of the Chatata Creek klippe shown on the map. Beds within the klippe dip steeply to the northwest except where locally overturned. Outcrops are scarce, poorly exposed, and confined to the major tributary drainages near the Hiwassee River.

The klippe is located astride the Upper River Road southeast of the Council Church and encompasses most of Coon Denton Island in the Hiwassee River. The structure is approximately 1-1/4 miles long and 1/2 mile wide. A partial section of the rock units involved is exposed along the Upper River Road. Here a small segment of Lenoir Limestone is preserved on the northwesternmost edge of the klippe. Beds of Lenoir in the klippe and those of the Athens Formation in the footwall are highly distorted and shattered. Mascot outcrops in this area are relatively undistorted and exhibit low dips. It is suggested that the Mascot moved as part of a solid, competent block near the northwest

edge of the klippe and that the small section of Lenoir Limestone was caught up from the footwall on the front or bottom of the klippe in snowplow fashion as the breccia in the Chatata Creek klippe described previously; in essence the Lenoir Limestone occurs here as a small slice.

Horse Branch klippe. Horse Branch klippe is much smaller than those described above, less than 3/4 miles long and 1/4 mile wide, and seems to involve only the Mascot Formation. The structure lies astride the Hiwassee River on the west side of Horse Branch where it enters the Hiwassee River at Davis Bend. Exposures are very poor except at the northeast side of the Hiwassee River where exposures in the bluff over the river exhibit Mascot beds steeply overturned to the northwest. This klippe is interpreted, on the basis of the river bluff exposures and widely scattered outcrops, to be similar in structural attitude to the previously described klippen.

The area of the klippe southwest of the river is poorly defined as contacts are based on angular Mascot float in the alluvial debris of the Hiwassee River flood plain. North of the river the klippe boundary is somewhat better defined by Mascot float in the thin soils typical of the underlying Athens Formation and by occasional, poorly exposed, Mascot outcrops. Intervening outcrops of footwall rocks preclude connecting this klippe with the Coon Denton Island klippe to the southwest although, as previously mentioned, scattered fragments of Knox chert between the structures suggest that they may previously have been connected.

Swafford Knob klippe. The Swafford Knob klippe is located south of Swafford Knob and the Bowater Road. The structure is very similar to the Chatata Creek and Coon Denton Island klippen. Near the north end of this structure the Knox units of the main part of the klippe are separated by a splinter fault from Mascot, Lenoir, and Athens lithologies involved in a smaller, poorly exposed portion of the klippe which has apparently broken off and been overridden by the larger block. The maximum length of this klippe, including the smaller broken segment, is approximately 1-1/4 miles long and slightly over 1/4 mile wide.

Exposures are very sparse in the Swafford Knob klippe and the attitude in areas of no outcrop can only be estimated as steeply dipping based on known thicknesses and the width of the zone of residuum characteristic of each unit. Overturning of beds is indicated locally by the attitude of the few bedrock occurrences. Interpretations based on these data are tenuous at best as tops and bottoms could not always be readily determined. The southeast dips may, in reality, indicate structural reversal of regional dips on small folds instead of overturning.

Blackburn Hollow klippe. The Blackburn Hollow klippe extends from the tear fault across the Etowah Road approximately one mile north of Double Springs, northwestward across Blackburn Hollow to the vicinity of the Piney Grove Church. Most of the chert debris covering the outcrop area of the klippe is apparently derived from the Longview Dolomite. Small areas containing chert residuum and soils characteristic of the Chepultepec Dolomite and the Kingsport Formation were mapped

within the klippe. The boundaries of these small areas as well as the main klippe boundary is approximated in areas of no outcrop. Large blocks of chert characteristic of the Longview Dolomite are abundant in the residuum along the highest portions of the topographic ridge formed by the klippe. Longview chert debris can be seen along the gravel roads and dirt trails crossing the structure. All dips observed within the klippe were to the southeast. Evidence to indicate that the beds had been overturned could not be found, thus the beds are shown on the map in normal position. This interpretation requires that the beds either originated on the southeast limb of the Luskville anticline or have had the dip reversed during movement. Of course, the beds may have originated farther to the southeast beneath the thrust sheet and may not be in any manner related to the Luskville anticline.

The klippe is terminated on the southwest by one of the previously mentioned tear faults which also terminates the northeast end of the Lenoir outcrop in the same area and offsets the Chestuee fault (see Plate I, in map pocket). The northeastern continuance of the Lenoir unit is apparently covered by the klippe. The northwestern boundary of the klippe lies on the Athens Formation except for one small area approximately 1/2 mile west of Piney Grove Church where a very small, poorly exposed outcrop of Lenoir Limestone is adjacent to Longview chert debris within the klippe. The Lenoir in this case is interpreted as part of the autochthonous block as it does not appear to have been faulted and it occurs in normal position with regard to the Athens.

Slices

Two slices were mapped in the study area, the Piney Grove slice near the northeast corner of the area and the Claxton slice south of Bowater Road between Claxton and Luskville. These structures, defined as large blocks caught along a thrust fault, are usually wedge-shaped, highly shattered and deformed, and contain rock units intermediate in age between that of the footwall and that of the hanging wall (Helton, personal communication, 1975). Outcrops are poor to non-existent in the slices but Rodgers (1952) showed a dip symbol indicating flat beds in that portion of the Piney Grove slice on the Athens geologic quadrangle. The normal attitude of the beds adjacent to the slice supports a right-side-up attitude for the slice but this cannot be established with certainty.

Piney Grove slice. The Piney Grove slice crosses the Piney Grove Road in the vicinity of the Piney Grove Church and extends northeastward into the southern portion of the Athens geologic quadrangle, a distance of some 2-1/2 to three miles. Maximum width is less than 1/10 the length. This slice was mapped, in part, by Rodgers (1952) on the Athens geologic quadrangle although he did not name it. Rodgers did indicate the general southwestward extent of the slice and showed it, in toto, on the geologic map of East Tennessee (Rodgers, 1953). Rodgers (1952) described the structure as a "fairly large horse" around which the Chestuee fault split.

The Copper Ridge Dolomite is the only unit present in the slice. The footwall unit is the Mascot Formation and the hanging wall unit

is the Conasauga Shale. As is the case with almost all slices in East Tennessee, the rock unit involved is intermediate in age between that of rocks in the hanging wall and that of rocks in the footwall.

Outcrops of the Copper Ridge are non-existent in this slice in the map area and the boundary of the slice was drawn based on float, a not too unreliable criterion in view of the dissimilarity of Mascot, Copper Ridge and Conasauga residuum.

The rocks in the slice are thought to come from the footwall of the fault, in this case, probably from the southeast limb of the Luskville anticline beneath the Chestuee fault.

Claxton slice. The Claxton slice is located south of Claxton near the junction of the Bowater Road with the Benton Road. The slice is much smaller than the Piney Grove slice as it measures less than 1/2 mile long and approximately 1/10 mile wide at the broad end of its wedge-shaped outcrop area.

The Maynardville Member of the Conasauga Shale is the only unit occurring in the slice. Bedrock exposures are non-existent and the slice boundary is mapped on carbonate float, soils, and chert residuum. The typical "ribbony limestones" of the Maynardville occur as shattered blocks with only minor in-mixing of Copper Ridge chert residuum. Surrounding the slice, neither the Conasauga nor the Copper Ridge residuum contains any of the Maynardville-type carbonate. The rocks in the slice are so closely related in age to those above and below, it is thought that they were probably derived from Maynardville sub-crops

on the north-plunging nose of the overridden Luskville anticline, an interpretation requiring only a small lateral displacement from the southeast.

Minor Structures

Cleavage. Fracture cleavage was observed in most of the highly distorted outcrops of the study area. Occasional outcrops of the Athens Formation exhibit intersecting sets of cleavage and as a result the rock breaks into polygonal blocks or fragments on weathering. The cleavage is associated with minor tight folds and generally is parallel to the axial plane of the fold. Some outcrops, as in the Athens Formation at the road cut exposure near Council Church, exhibit cleavage so well developed and beds are so distorted as to nearly obscure the original bedding, Figure 34.

Drag folds. Drag folds occur most commonly in the more shaly units such as the Athens and the Ottosee Formations. They are, however, common in the Chapman Ridge Formation and the Calhoun Member of the Ottosee, both of which are very sandy limestones grading to very calcareous sandstones and, in the main, considered relatively competent (see Figure 31, page 77). The fold axes are essentially parallel to the axis of the Athens syncline.

Fractures and joints. Fractures and joints are common features in both competent and incompetent beds. Almost every outcrop, including some deeply weathered exposures, (Figure 35) has some evidence of these features. They are most often rehealed with calcite (see



Figure 34. Highly contorted outcrop of the Athens Formation near Council Church east of Section WB-1.

Note the cleavage and calcite filled fractures.

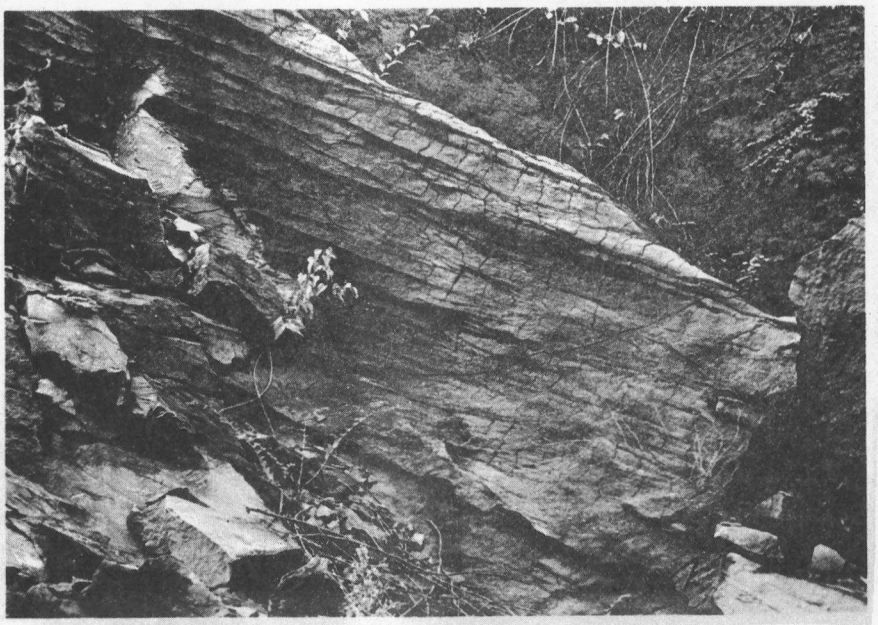


Figure 35. Rehealed fracturing and jointing in a bioclastic limestone unit exposed in hollow approximately 1/4 mile southwest of Meadow Fork Church.

Note the "brickwork" effect. Dark bands are 1/4 to 1/2 inch thick.

Figure 29, page 72) although occasional veinlets of milky quartz can be seen, especially in joints in the shales.

Joint and fracture patterns were not studied in detail because the complexity of the problem was considered beyond the scope of this paper. However, casual observations in the course of the field work indicate a joint spacing that is closer in the incompetent layers but more apparent in the more competent carbonate units where the joints have been enlarged by solutional activity. Further, joints and fractures were observed in a wide range of attitudes related to bedding planes. Many of the fracture surfaces exhibit well-developed slickenslides of apparently random orientation (see Figure 28, page 71). This is especially true in the more massively bedded carbonate members of the Ottosee Shale within the Athens syncline.

Primary structural features. Primary features are well-developed in several of the mapped rock units. Included are crossbedding, sole marks, ripple marks, mud cracks, slump structures, and crude imbrications of fossil fragments and pebbles in the pebble conglomerate beds. Some of these features are suitable for and were used to determine either top and bottom of beds or current direction. Mud cracks in the Knox units and the Maynardville Member of the Conasauga Shale were especially useful in determining top from bottom of overturned beds.

CHAPTER III

ENVIRONMENTS OF DEPOSITION

I. INTRODUCTION

Modern shelf carbonates usually reflect environmental factors in both faunal and depositional patterns. The great similarity in carbonate assemblages in widely separated shelf areas suggests that similar environmental conditions must characterize many shelves. Paleoshelf environments exhibit this similarity of assemblages which apparently was controlled by environmental factors closely related to those operative on modern shelves (Shelley, 1970). Environments of deposition for each of the Chickamauga units involved in this study are described briefly in the following paragraphs. A summary of environmental inter-relationships for the various units is also included.

Lenoir Limestone

The essentially biomicrite, sponge-algal lithologies occurring within the Lenoir Limestone represent deposition in a subtidal, back-reef, lagoonal environment that was apparently co-extensive with a deeper water, more argillaceous, essentially non-fossiliferous Athens. Exposures along the southeast side of the study area suggest a facies relationship in which the Athens thickens at the expense of a thinning Lenoir. Sporadic occurrences of dense micrites and

dismicrites of "Mosheim" type limestones beneath and perhaps within the lowermost portion of the Lenoir argues for a subtidal Lenoir environment immediately adjacent to the "Mosheim" environment of low intertidal to supratidal mudflats (Shinn, Lloyd, and Ginsburg, 1969). The occurrence of oncolites, sponges, and small corals also supports a subtidal interpretation for the Lenoir environment. Thin discontinuous, non-fossiliferous shaly lenses indicate occasional, short-term encroachment of the Athens environment into that of the Lenoir. Reefs or banks, represented by the Holston Formation, restricted circulation to the southeast and exposed Knox units formed a very low coastline to the northwest, Figure 36.

Outcrops in the southeast limb of the Athens syncline near the northwest corner of the Etowah topographic quadrangle, in which the Lenoir lithology has thinned to less than 15 feet and contains red, green, and maroon mottled, sandy to silty limestones and calcareous sandstones, may represent an early outpouring of terrigenous clastics into the carbonate environments. These variegated sediments are similar, in some respects, to other previously described units lying immediately above the post-Knox unconformity and so may represent a pulse of terrigenous clastics from the northwest into the Lenoir environment.

Athens Formation

The Athens Formation accumulated as a continuation of this terrigenous clastic outpouring and represents deposition in an environment probably quieter, deeper, and more turbid than that of the

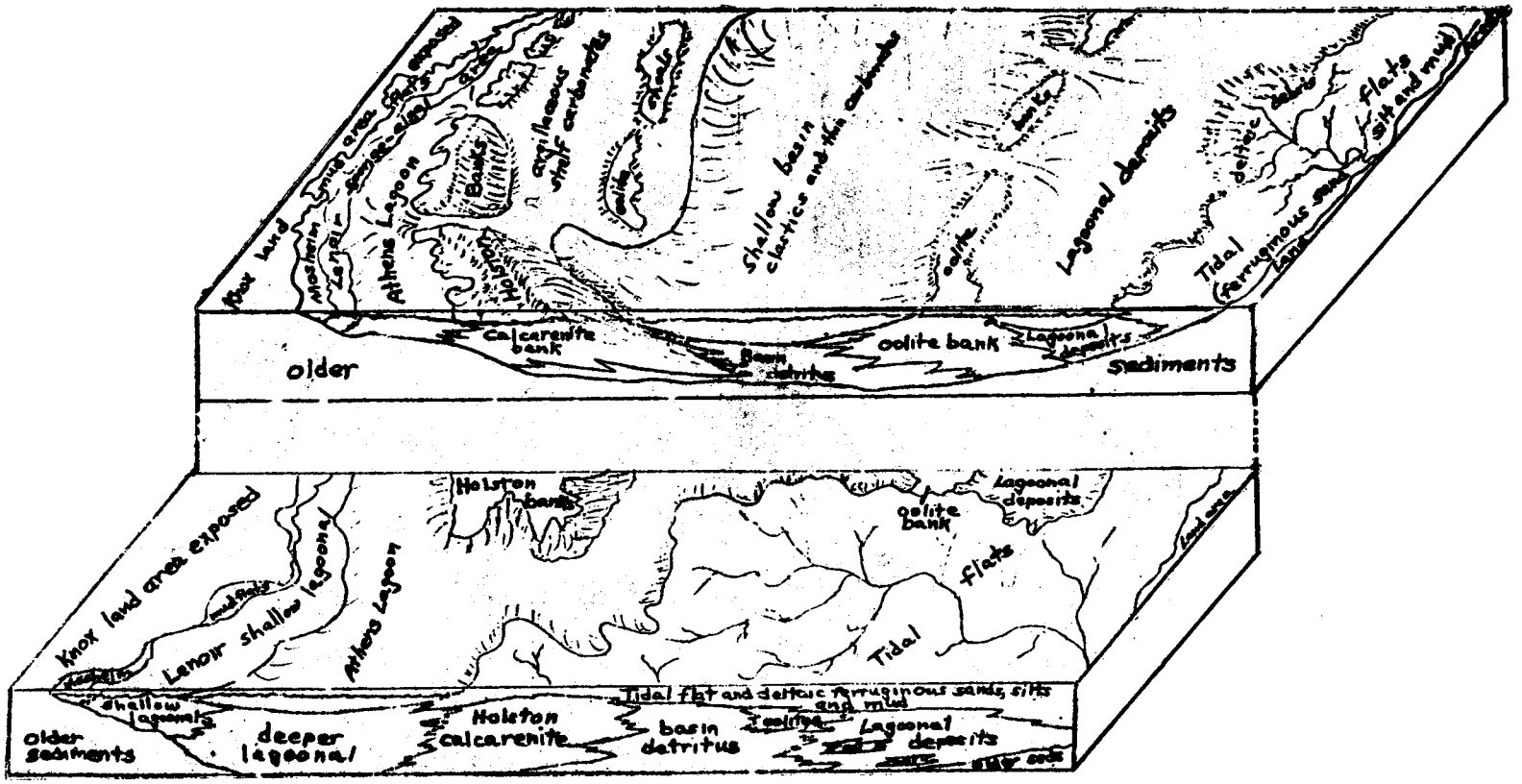


Figure 36. Regional model of depositional environments at Time "X."

Sketch is "opened" to permit sectional view near the center of the model.

Lenoir. The fauna of the Athens is that considered typical of deeper waters by other authors and the complete absence of algae (though they are very abundant in the contemporaneous Lenoir to the northeast) indicates deposition in deeper, darker water. A model depicting environmental conditions during Athens deposition (Figure 37) requires deepening of the sediment sink between the carbonate producing region to the northwest and the terrigenous clastic source to the southeast. As progressively greater quantities of terrigenous debris accumulated in this sediment sink, a variable relationship between rate of filling and rate of subsidence caused a shifting of the location of the carbonate-clastic mix interface. Thin interbeds of slightly argillaceous, fossiliferous limestone indicate shallow, relatively clear water while intercalated deposits of darker, very argillaceous to shaly limestones and calcareous shales indicate deeper, quieter conditions.

Dark shales in the Athens Formation of the study area were observed only east of South Liberty in the northwest corner of the Etowah quadrangle in a situation of very limited outcrops. However, in the next strike-belt to the southeast, Neuman (1955) noted abundant dark shales in the Blockhouse Shale which he considered to be in part equivalent to the Athens of this report. He also reported the presence of ". . .beds of calcarenite intercalated with dark shale" and concluded that they represented redistribution of offshore carbonate detritus in a marine basin exhibiting some aspects of poor ventilation and restricted circulation (Neuman, 1955, p. 169). Analysis of graptolite faunas by Decker (1952) and others indicated at least periodic free

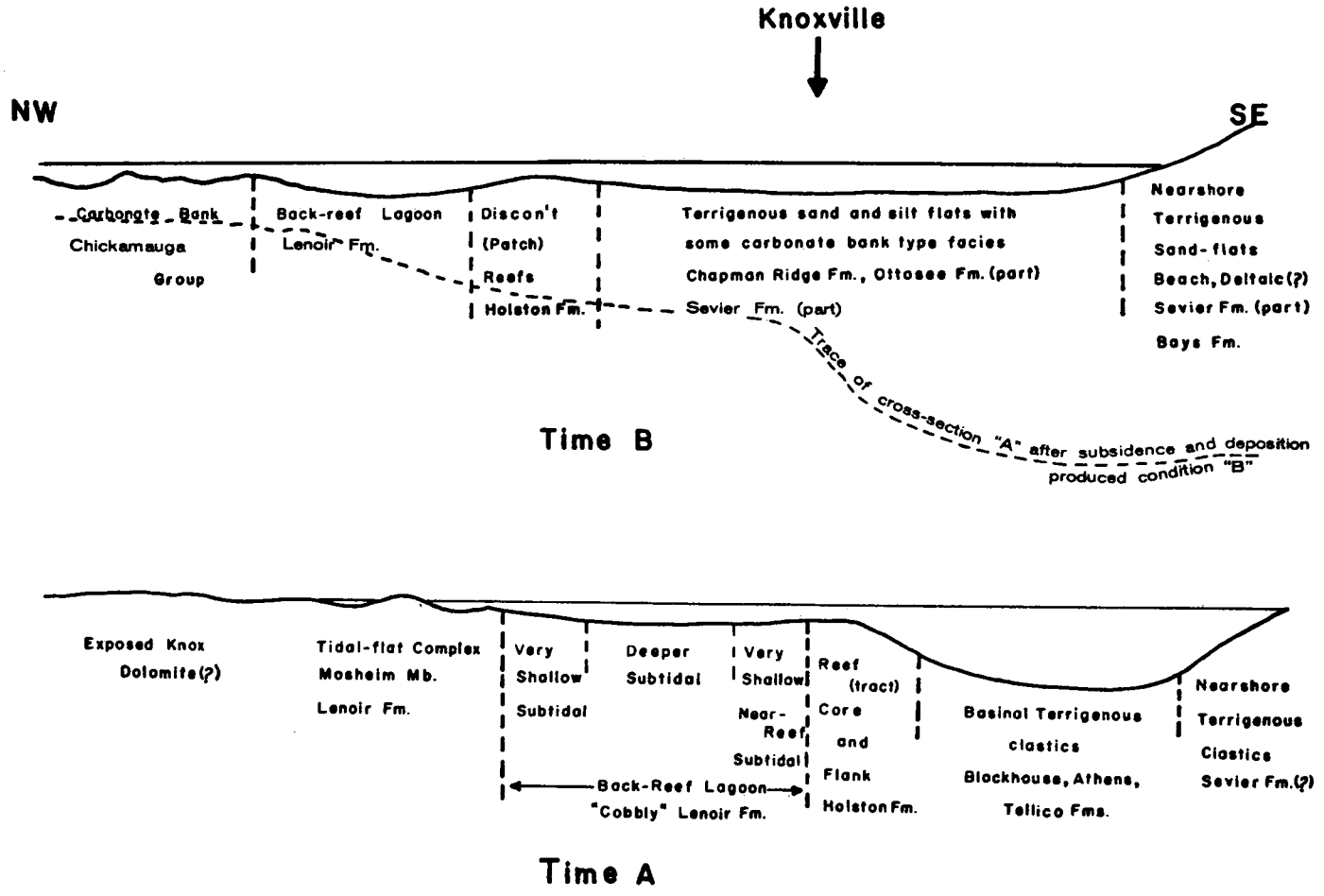


Figure 37. Regional environmental model of Middle Ordovician rocks of eastern Tennessee (from Walker and Ferrigno, 1973, p. 136).

circulation from the Athens environment into the open ocean. Fine to coarse grained sandstones, locally hundreds of feet thick, occur in the Athens Formation or its equivalents in areas south and east of the study area (see description of the Toqua sandstone member of the Blockhouse Shale of Neuman, 1955 and the "Athens Sandstone" of Hayes, 1895). In the study area the Athens Formation is sandy only near the top where a few thin beds of calcareous sandstone, which grade upward through sandy limestone of the uppermost Athens into the lowermost portion of the Holston, indicate a coarsening upward regressive pulse of terrigenous debris that preceded the deposition of the main part of the essentially quartz-free Holston Formation.

Holston Formation

The Holston Formation represents a reef or bank deposit in subtidal turbulent waters where sorting and winnowing of fines was efficiently accomplished. Bathurst (1971) described this winnowing and sorting in recent Florida carbonate environments. The coarse calcarenites of the Holston in the Calhoun area are essentially quartz-free except for the previously described minor amounts of quartz sand occurring as sandy carbonates at the base and a few "smear" sand grain films on some bedding plane surfaces. Walker and Ferrigno (1975a, p. 135) have published a synoptic Holston environmental summary for Knox County in which the Holston is described as a composite of reef-core and reef-flank facies. The reef-flank facies is described at the Deane Quarry as being 75 to 80% skeletal debris

where the ratio of pelmatozoan/bryozoan debris is generally greater than 3/2. This description of the Holston debris is in accord with the field data for the Holston in the Calhoun area. However, the corefacies described by these authors (Walker and Ferrigno, 1973a, p. 131) was not seen in the Calhoun area. The writer suggests that the Holston carbonate sands were transported short distances by wave action and bottom, perhaps tidal, currents in a manner consistent with offshore bar deposition. Near the southern border of the map area, the Holston and Athens lithologies at one small outcrop are interbedded through a vertical interval of perhaps five feet, suggesting a contemporaneity of Holston-Athens environments at least for a short time. Concurrent with Holston-Athens lithologic interbedding, the Holston lithologic unit thins markedly in the same area, perhaps as a result of rapid facies changes near the edge of the Holston calcarenite bank. Occasional thin lenses of Athens-type shaly material within the Holston support this facies interpretation and suggest periodic shifts of the Holston-Athens interface and incursions of clay-sized sediment into the normally winnowed environment. The relationship of the Holston-Athens may be that of the deeper lagoonal Athens representing the back-reef facies for a Holston reef or bank that restricted circulation into the lagoon (Silver and Todd, 1969, p. 2227). Northward in the Knoxville-Friendsville area Ferrigno (1973) suggested a similar relationship for the Holston-Lenoir units and stated that the upper three-fourths of the Lenoir may be temporally equivalent to the Holston Formation.

Chapman Ridge Formation

The mixed carbonates-terrigenous clastics of the Chapman Ridge Formation, which overwhelmed the generally quartz-free environment of the Holston, were preceeded by deposition of silty shales and very fine sandy debris, herein termed the orthocone zone (see Figure 8, page 25) containing numerous large, broken and whole, gastropod shells and profuse, large (up to four inches in diameter) orthocones, Figure 38. The gastropods and orthocones appear to have been transported because of the random orientation and "log jam" occurrence of the orthocones and the slightly abraded, broken nature of the gastropods. The material probably was not transported very far in view of the angularity of much fossil debris.

The orthocone zone oncolites are both single and compound (Figure 39) and locally make up as much as 50% of the mass. They appear on weathered surfaces as irregular, elongate ovoids or as bisquit shaped lumps, Figure 40. The compound oncolites contain much clay-size debris and commonly disintegrate when removed from the matrix.

This orthocone zone at the base of the Chapman Ridge Formation is interpreted as the initial phase of a prograding shoreline in which the lagoonal phases containing orthocone, oncolite, and gastropod debris migrated over the Holston carbonate environment, later to be overridden itself by the terrigenous quartz sand environment of the Chapman Ridge Formation. The sharp upper and lower contacts of the orthocone zone suggest relatively rapid shifting of environments, perhaps initiated by local uplift. This terrigenous clastic

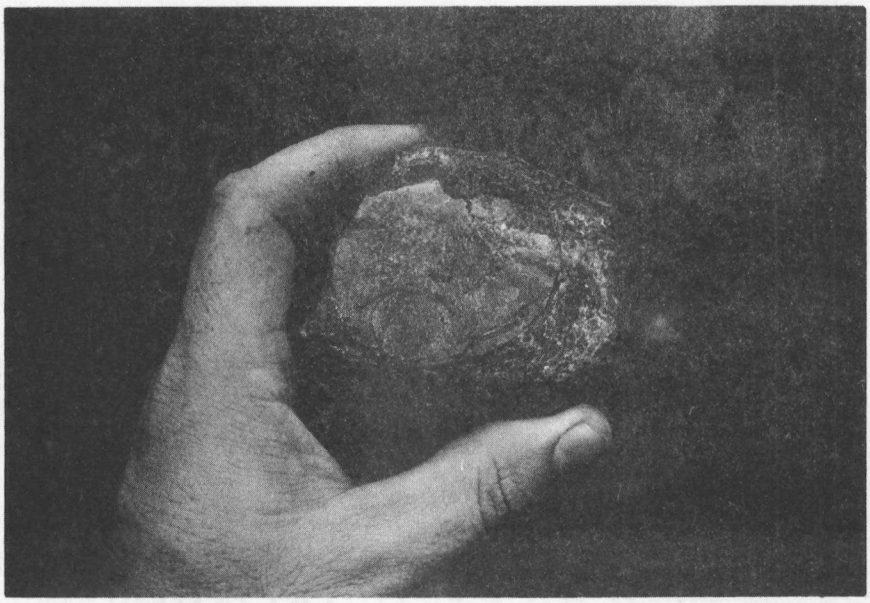
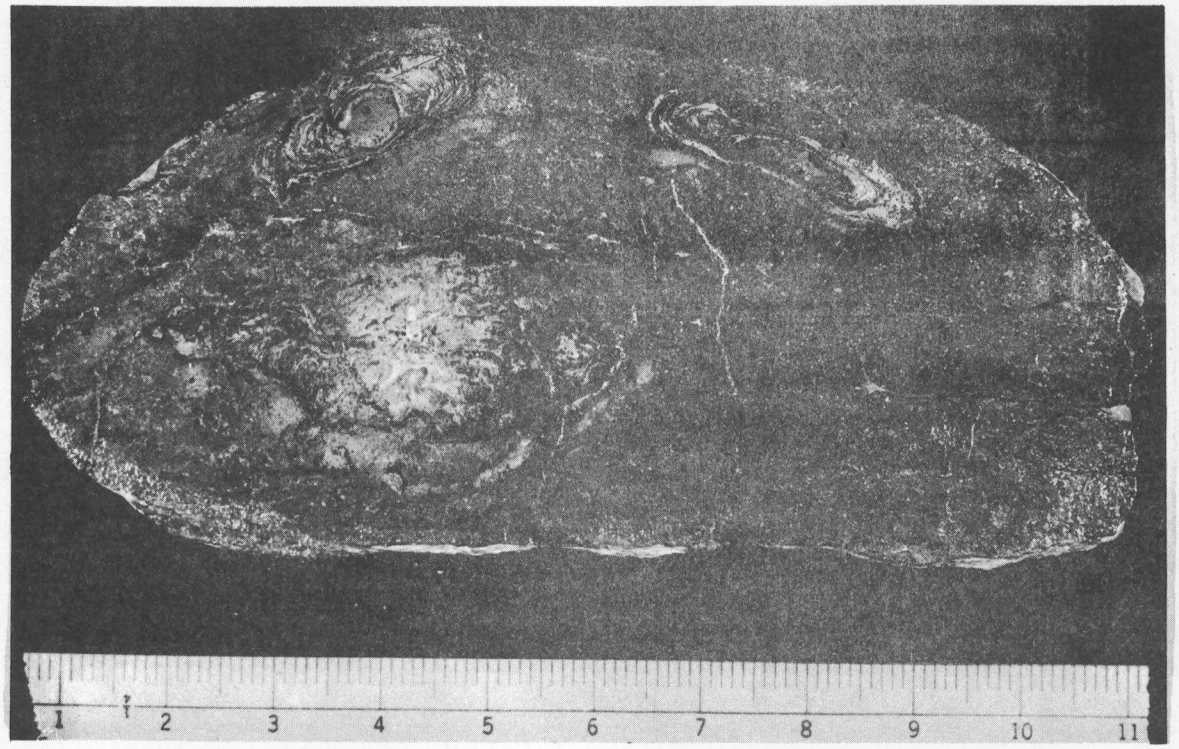


Figure 38. Sectional view of an average size orthocone from the orthocone zone at Section WB-2 east of Calhoun, Tennessee.

a.



b.

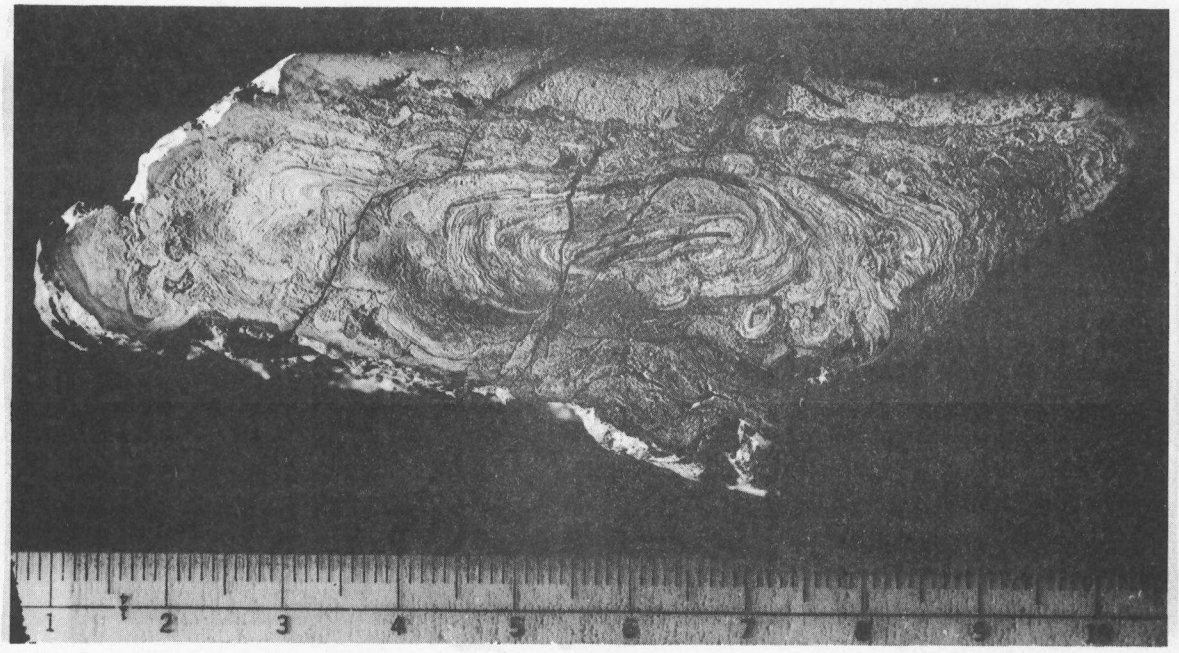


Figure 39. Algal biscuits showing both single and compound oncolites.

Scale is in inches. Note effect of slight etching of sawed section in (b).



Figure 40. Oncolite algal biscuits in situ in the oncolite zone at Section WB-2 east of Calhoun, Tennessee.

to carbonate facies interval apparently persisted for miles along depositional strike although Rodgers (1953) and Walker and Ferrigno (1973b, p. 300) have described local sections northeast of the Calhoun area in which the orthocone zone is absent and the Chapman Ridge clastics lie directly on, and to a certain extent intermix with, the Holston calcarenites. This situation was not observed in the Calhoun area. The Chapman Ridge clastics do contain much carbonate debris similar to that in the Holston but the debris is more abraded and finer grained.

This admixture of terrigenous clastic and carbonate clastic debris along with abundant ripple marks in the Chapman Ridge Formation suggest a shallow water shelf environment in which there is intimate contact between terrigenous source and the carbonate bank. Most earlier workers including Walker and Ferrigno (1973, p. 322) have put the terrigenous source of the Chapman Ridge quartz debris to the southeast. The writer, however, has observed field data requiring a southwest-northeast sediment transport direction, a requirement that could be met by longshore currents working or reworking alluviated, deltaic debris northward into a high energy carbonate environment (see Figure 36, page 101). LeRoux (1974) has described a similar situation requiring a southwest to northeast direction of sediment transport and Kashfi (1971) has described a northerly prograding deltaic environment southeast of this study area. Farther southwest in Alabama Drahovzal and Neathery (1971) have postulated a time equivalent, northwestward prograding deltaic

sequence for the Middle Ordovician of Alabama. Further, this sequence apparently mixed with and finally covered carbonate bank areas to the northwest in central Alabama.

Ottosee Shale

The Ottosee Shale requires a depositional environment very similar to the Athens Formation with the addition of scattered oolite and calcarenite banks and occasional relatively rapid influxes of coarser terrigenous debris. Times of clearer water are suggested by the more numerous thin beds of fine to medium grained, fossiliferous, non-sandy, limestone which are apparently not intimately related stratigraphically to the oolite-calcarenite facies (Baars, 1963).

Each successive carbonate unit in the Ottosee is more quartzose than the preceding member; i. e., the McKnight Member contains more quartz grains that the Hiwassee Member and the overlying Calhoun Member is by far the most quartzose member of the Ottosee. This sand probably represents spill over or escape of sand across a shallow depositional basin seaward into the carbonate bank environment. Pebble zones in the Hiwassee and McKnight Members represent episodic uplift in the pebble source area while the Calhoun represents a more powerful, continuous pulse of terrigenous debris that finally overwhelmed the calcarenite environment in essentially the same manner as the Chapman Ridge-Holston relationship described earlier. Kashfi (1971) suggested a prograding deltaic environment for both the Chapman Ridge and Neuman's Chota.

Lithology of rock fragments in the pebble zones suggest cannibalization of rock units as young as the Mascot Formation of the Knox Group, or perhaps even lowermost Chickamauga units, which must have been exposed nearby.

Red ooids in a sparry matrix in close association with red calcareous and quartzose sandstones accumulated in agitated, oxidized waters where winnowing of the clay fraction was relatively efficient. Scattered poorly preserved mud cracks were the only evidence seen suggesting periodic subaerial depositional conditions.

Ottosee shales are generally less calcareous than the Athens Formation and probably indicate more turbid water conditions which inhibited considerably the deposition of carbonate in the shale depositional environment.

II. SUMMARY OF DEPOSITIONAL ENVIRONMENTS

The rock units of the Middle Ordovician Chickamauga Group in the vicinity of Calhoun, Tennessee represent deposits in a relatively stable shelf environment although a shifting of depositional conditions was both common and sometimes abrupt. Changes in clastic volume, character, and perhaps direction of transport indicate tectonic influences. The overall pattern of terrigenous sediments, lagoonal deposits, reef or bank facies, deeper water sediments was however maintained for a considerable portion of Middle Ordovician time. This stratigraphic pattern apparently persists to the northeast through the Red Hills area to the vicinity of Knoxville

(Hathaway, 1957; Cooper, 1956). Neither of these workers make any kind of environmental interpretation. Recent workers including LeRoux (1974) and Ratliff (1974) have shown a similar pattern in portions of the next strike-belts to the southeast and northwest, respectively.

In the Calhoun area the Chickamauga rocks are interpreted, more specifically, as having been deposited in the mixed carbonate-terrigenous clastic shoreline portion of a stable shelf setting, perhaps very similar to the setting on the Florida west coast near Tampa Bay (see Ball, 1967 and Milliman, Figure 12, 1971). Walker (1974) has summarized, at least briefly, on a regional scale, many of these environmental relationships. Shoreline settings of this type have been defined as "... those in which carbonate deposition occurs so close to land that it contributes, not just to the open sea facies, but also the shoreline deposits" (Shelley, 1970, p. 117). Oolite members of the Chickamauga Formation such as the Hiwassee and McKnight further suggest shelf conditions with warm, agitated waters generally less than two meters in depth (Newell, et al., 1960; Illing, 1954; Purdy, 1961; Rusnak, 1960; and Pilkey, et al., 1966).

Fundamental to the formation of a carbonate dominated regime is an area where carbonate-producing organisms can proliferate (Blatt, et al., 1970). Any significant influx of terrigenous sediment tends to muddy the water and reduce carbonate accumulation by inhibiting the growth of organisms. Although terrigenous sediments usually are more important near shore in the mixed carbonate-terrigenous clastic

setting, some terrigenous sands do escape into the carbonate bank or reef environment (see description and figures of pebble conglomerates in the Ottosee Formation) or even into deeper water environments beyond.

In the carbonate-dominated regimes, low input of terrigenous debris may be accounted for by either low runoff, a topographically low source area, or the shoreline itself may have a gentle, seaward gradient and a broad, flat tidal zone, the last being the conditions postulated for the Calhoun area environment. The situation here is even more complex with a sediment trap between the carbonate depositional area and terrigenous sediment source. Facies belts tend to develop parallel to the shoreline in cases of low terrigenous input and extensive, elongate zones of mixed carbonate-terrigenous clastic deposition occur (Shelley, 1970 and Fabricius, et al., 1970). Holston-type bars of carbonate sand develop offshore, sometimes opposite river mouths, and extensive mixing of carbonate-terrigenous debris can occur during floods which carry the terrigenous sands into and sometimes across the carbonate environment or when large oceanic storm waves or long shore currents transport the carbonate debris into the terrigenous sand environments. In either case, units similar to the Chapman Ridge are deposited. Some mixing of the two sediment types does routinely occur at the environmental boundary as seen at the Athens-Holston transitional interface. Subsidence and deposition go hand-in-hand and currents work essentially parallel to depositional shoreline which was in this area during deposition apparently parallel

to present structural strike. Depositional features such as cross-bedding and sole marks strongly suggest a southwest to northeast transport direction for the quartz sand.

Occasionally, strong influxes of terrigenous materials, associated with either prograding deltas or shorelines, exceedingly large floods, or orogenic activity, overwhelm the carbonate bars in a specific area (LeRoux, 1974, p. 36 and p. 37), thus ending a cycle and generating a new configuration for the environmental pattern. Walker (personal communication) thinks that these influxes of sediment may only mark times when deposition exceeded subsidence in the catchment basin allowing sediments to cross the basin and reach the carbonate shelf. These influxes of terrigenous materials probably began with deposition of the pebble conglomerates seen in the McKnight unit.

Reconstruction of the specific environment of deposition for each of the Chickamauga units in the Calhoun area is made difficult by limited exposures and the relatively rapid vertical and lateral lithologic changes occurring within the units. However, as previously stated, the Chickamauga formations fit readily into a generalized regional pattern established in areas to the north and northeast in this strike-belt. Previous workers, including Wilson (1962, p. 492), Milici and Smith (1969, p. 8 and p. 12), Walker and Ferrigno (1970), Stephenson (1973), Stephenson, et al. (1973), Walker and Ferrigno (1973), LeRoux (1974), and Ratliff (1974), have recognized and commented upon or described the lagoonal-shelf-deep water facies

patterns of the Valley and Ridge Chickamauga units of East Tennessee (see Figure 36, page 101).

Deeper water toward the southeast from the carbonate banks and bars and contemporaneous subsidence is indicated by the increase in volumne of sediments, by the total absence of algae and presence of only pelagic faunal types including graptolites and obolellid inarticulate brachiopods, and the shift towards a more terrigenous clastic character in that direction. Neuman (1955, p. 167) has noted in the next strike-belt to the southeast that "... 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." Basin deepening and filling rate must surely have alternated in the dominant role with the result that shallow water carbonates including banks and bars of calcarenites similar to those in the Calhoun area, and terrigenous clastics are found interspersed with shales and in places the clastics swept across the basin from the southeast to overwhelm the clastic carbonate environments of the Holston, Hiwassee, and McKnight units in the Calhoun area. Tectonism contemporaneous with the early stages of Middle Ordovician deposition has been described by Rodgers (1971) and termed the Douglas Lake phase of the Taconic orogeny. Pebble conglomerates and pebbly sandstones in the several mapped calcarenite members of the Ottosee Formation indicate regional episodic uplift continuing through Chickamauga time.

The source of the clastic debris in the Chickamauga is generally taken, by most earlier workers, as a land area of considerable relief somewhere to the southeast of the Valley and Ridge of today. Further, the lateral equivalency of shales and sands on the southeast with carbonates on the northwest suggests a sediment source to the southeast as does the occurrences of very coarse conglomerates in certain Chickamauga formations in the next belt to the southeast. Jones and Dennison (1970) evaluated graptolite stipe orientation in a paleocurrent study and established an east to west transport direction during deposition of the Athens Formation in the southern Appalachians. However, limited data gathered during field mapping in the Calhoun area indicate a southwest to northeast transport direction for the clastics in the Chapman Ridge Formation and the Calhoun Member of the Ottosee Formation. Burk McWilliams (personal communication, 1974) reached the same conclusion during his work on the Chapman Ridge Formation in this strike-belt in the vicinity of Knoxville. Obviously, additional work needs to be done to establish the overall pattern of sediment transport in this part of the Valley and Ridge during the Ordovician.

Interpretations and conclusions of the author relative to the depositional environments, as presented herein, are preliminary, based on limited field data, and subject to refinement. Further, the writer has drawn freely upon the work of others in order to integrate data from a limited study area into a regional scheme presently evolving from research being done at The University of Tennessee and elsewhere.

CHAPTER IV

CONCLUSIONS

The following conclusions are presented from the study of the lithostratigraphy and structure of the Middle Ordovician Chickamauga Group in the vicinity of Calhoun, Tennessee:

1. The Middle Ordovician Chickamauga lithologies in the Calhoun area are similar to those now developing in modern mixed carbonate-terrigenous clastic depositional environments.
2. The Chickamauga depositional environments represented include carbonate intertidal and perhaps supratidal, subtidal bank and oolite bars, terrigenous and carbonate deposits of the basinal type and mixed quartzose and calcarenite debris representing complex shoreline and barrier bar environments.
3. Limited interbedding and intertonguing of the various Chickamauga units indicate lateral facies changes.
4. The Athens Formation in the Calhoun area is an argillaceous, slightly silty, cobbly limestone. For this reason the writer suggests calling it the Athens Formation rather than Athens Shale.
5. The Ottosee Shale in the study area contains three previously undescribed, mappable carbonate members, two of which are oolitic limestones and the third and upper one a very quartzose calcarenite.

6. The Athens Formation and the Ottosee Shale contain similar lithologies, in part, but are generally distinguishable on criteria other than stratigraphic position, such as the Athens is more silty, contains more abundant and larger cobbles and fewer clean limestone lenses.
7. The Holston and Chapman Ridge Formations are mappable and should be retained as formal units.
8. Recognition of the Calhoun Member as an upper red-weathering unit of the Ottosee Shale and unrelated to the stratigraphically lower Chapman Ridge Formation requires a re-evaluation of previous correlations with strike-belts to the northwest and southeast.
9. Several periods of post-Knox tectonic activity are supported by field data in the study area.
10. Several klippen, apparently closely associated with the Chestuee fault, are so similar, structurally and stratigraphically, to each other and the autochthonous rocks as to indicate relatively simple movement and short transport. Field data suggest these structures may have originated as slices.
11. The stratigraphic and structural interpretation shown on the state geologic map (Hardeman et al., 1966), Figure 1, page 2, is in error with regard to the Chickamauga units in the central portion of the Athens syncline near Calhoun, Tennessee.

12. Preliminary studies of field data indicate a southwest to northeast sediment transport direction for Chickamauga clastics in the Calhoun area.
13. Apparently episodic folding penecontemporaneous with deposition controlled facies patterns to some degree during Chickamauga time.

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APPENDIX

APPENDIX

MEASUREMENT CONVENTIONS

The bed thickness (Ingram, 1954) and grain-size measurements (Wentworth, 1922) followed by the writer in the physical description of the outcrops in the study area are as follows:

Bed thickness conventions

Description	Thickness
Very thick bedded	approximately three feet or greater
Thick bedded	approximately one foot to three feet
Medium bedded	approximately four inches to one foot
Thin bedded	approximately one inch to four inches
Very thin bedded	approximately 1/4 inch to one inch
Laminated	approximately 1/10 inch to 1/4 inch
Thin laminated	less than 1/10 inch approximately

Grain-size conventions

Description	Grain-size
Coarse grained	grains readily identifiable by unaided eye (approximately 1 mm and greater)

Medium grained	grains visible but not identifiable with unaided eye (approximately 1/4 to 1 mm)
Fine grained	grains not visible to unaided eye but visible with hand lens (approximately 1/10 to 1/4 mm)
Very fine grained	grains not clearly visible even with hand lens (approximately 1/10 mm or less)

I. MEASURED GEOLOGIC SECTION WB-1

This section was measured along the south side of the Hiwassee River in road cuts at Henegar Bluff near the southwest corner of the Calhoun Quadrangle, Bradley County, Tennessee (Figure 11, page 31). Thickness is given in feet.

TABLE II

MEASURED GEOLOGIC SECTION WB-1

Unit Number	Unit Thickness	Cumulative Thickness	Description
			CHICKAMAUGA GROUP
1.			Ottosee Shale, not measured at this section
2.	67	67	Chapman Ridge Formation, limestone blue-gray, red-weathering, sandy to very sandy and fossiliferous in beds; interval mostly covered; lithologies projected into section line from nearby exposures
3.	8	75	Limestone, blue-gray, red-weathering, quartzose, beds to two feet thick, crossbedded, with one to two inch shale interbeds common; thinner units tend to be the most crossbedded.
4.	38	113	Limestone, blue-gray, red-weathering, highly ferruginous, sandy, to very sandy; locally a very calcareous, quartzose sandstone, fossiliferous, fractured and locally slickensided; weathers to brown, sandy, low density, punky blocks; scattered clumps of shale intraclasts and shale stringers; some beds ripple-marked and crossbedded; incipient calcite rehealed fractures common
5.	38	151	Limestone, blue-gray to gray, fine to medium crystalline, red-weathering, iron stained and ferruginous; ripple-marked; locally crossbedded; dense, hard, fossiliferous; beds two to 12 inches thick.

TABLE II (continued)

Unit Number	Unit Thickness	Cumulative Thickness	Description
6.	8	159	Limestone, light to medium gray, red-weathering, quartzose, thin-bedded with sporadic 1/2 to one inch shale partings; unit fossiliferous in part Total thickness of the Chapman Ridge Formation, 159 feet
7.	10	169	Orthocone zone, silty shale, very calcareous, limestone; abundant orthocones and single and compound oncolites, orthocones up to four inches in diameter and oncolites up to eight inches maximum dimension; unit grades upward into more sandy beds; unit mapped with the overlying Chapman Ridge Formation Total thickness of the Orthocone zone, 10 feet
8.	58	227	Holston Formation, limestone, light cream to tan, reddish-pink and pinkish-gray, medium to coarse grained, fossil fragmental with much pelmatozoan debris as dominant fragment type; occasional bedding plane surface contains scattered, medium to coarse quartz sand grains; unit bedding slightly distorted.
9.	9	236	Limestone, blue-gray, fine to medium grained calcarenite, fossil fragmental including pelmatozoan, brachiopod and corraline debris; beds one to six inches near base become thicker to 12 inches maximum near top; unit becomes a more buff to cream and brownish-red color upward

TABLE II (continued)

Unit Number	Unit Thickness	Cumulative Thickness	Description
			Total thickness of the Holston Formation, 67 feet
10.	3	239	Athens Formation, limestone, blue-gray, fine to medium crystalline, very sandy with interbedded shale and thin lenses of light cream to tan fossil fragmental calcarenite
11.	13	252	Limestone, light to medium gray, argillaceous to shaly, becoming blue-gray, fine to medium crystalline and fossiliferous upward; scattered lenses and thin beds are very sandy; most beds contain only scattered fine sand grains; unit contains small limestone cobbles which continue upward to within one foot of the top of this unit
12.	168	420	Mostly covered interval, lithologies pieced together from scattered exposures to the side of the section line. Unit is limestone, light to medium gray, slightly fossiliferous, argillaceous, cobbly with a few cobbles fossiliferous; fossils of unit include gastropod, cephalopod, brachiopod and trilobite fragments with scattered crinoid stem segments
13.	38	458	Limestone, light to medium gray and grayish tan with light tan to brown and gray-brown streaks; cobbly with maximum cobble dimensions four by 12 inches near the base decreasing to one by six inches near the top; abundant calcite rehealed fractures

TABLE II (Continued)

Unit Number	Unit Thickness	Cumulative Thickness	Description
14.	21	479	Limestone, light to medium gray, slightly fossiliferous, argillaceous to shaly; cobble beds up to six inches apart with cobbles one to two inches thick and up to eight inches long
15.	55	534	Limestone, light to medium gray, cobbly; cobbles one to four inches maximum diameter, only roughly in beds; unit fossiliferous with fragments of trilobites, cephalopods, brachiopods; few thin sandy to very sandy beds, many silty; bedding laminations distorted around some cobbles
16.	2	536	Shale, light to medium gray, moderately calcareous; very highly sheared and shattered, perhaps indicative of small fault movement along the bedding plane
17.	54	590	Limestone, medium-gray, argillaceous to shaly, cobbles small; beds have peculiar crinkled appearance; occasional small fault offsets crinkles and dies out upward and downward; abundant calcite rehealed fractures; joints exhibit a near vertical subdued sine curve character
18.	35	625	Cobble beds medium gray, non-cobbly beds light gray, limestone, light to medium-gray, argillaceous to shaly; cobble beds up to eight inches thick, fine upward to approximately one inch

TABLE II (Continued)

Unit Number	Unit Thickness	Cumulative Thickness	Description
19.	40	665	Limestone, light to medium gray, argillaceous to shaly, in beds up to eight inches thick; unit appears crowded with cobbles which are mostly non-fossiliferous as is this whole unit except for thin discontinuous limey lenses; cobble dimensions four by 12 inches maximum; rehealed fractures common
20.	27	692	Limestone, light to medium gray, appears massive but weathers to beds one to six inches thick; joints well developed, some joints offset, apparently by post-roadcut movement due to pressure release. Few beds with hackly fracture; in some beds cobbles weather to light ocher and becomes more closely packed upward; some vertical fluting where weathering follows incipient fracturing.
21.	22	714	Limestone, gray to tannish-gray, silty to argillaceous, cobbly; locally knotty bedded; very sparse, scattered fossil fragments include gastropod, brachiopod, and trilobite debris; cobbles contain fossil fragments; beds up to eight inches thick; many calcite rehealed fractures, especially in the more limey beds.
22.	11	725	Limestone, light to medium gray, argillaceous to shaly; occasional silty to sandy bed; few thin cobbly bed with cobbles one to three inches thick.

TABLE II (Continued)

Unit Number	Unit Thickness	Cumulative Thickness	Description
23.	15	740	Limestone, light gray, argillaceous, trace silty; beds massive but weather into progressively thinner and thinner units to an end point of very thin laminations; highly mineralized joints, mostly calcite; some beds with hackly fracture; no cobbles seen.
24.	4	744	Limestone, light to medium gray, argillaceous to slightly shaly; beds one to six inches with thin laminations appearing on weathering.
25.	20	764	Limestone, light to medium gray, slightly argillaceous with occasional shaly beds; rock breaks with slight conchoidal fracture; beds two to three feet thick, some of which decompose to thinly laminated slivers on advanced weathering; no cobbles observed.
26.	13	777	Limestone, very shaly to argillaceous, very few cobbles in discontinuous beds, one to two feet apart
27.	26	803	Limestone,light to medium gray, argillaceous to shaly, cobbly; cobbles fine upward
28.	2	805	Limestone, light gray, very strongly laminated, very argillaceous to shaly; scattered single cobbles.
29.	10	815	Limestone, light to medium gray, yellow-weathering argillaceous with occasional thin lenses of fossiliferous, fine-crystalline, blue-gray limestone; cobble bed spacing decreases upward as does size of cobbles.

TABLE II (Continued)

Unit Number	Unit Thickness	Cumulative Thickness	Description
30.	3	818	Limestone, light to medium gray, very argillaceous to very calcareous shale; thin bedded to very thinly laminated; highly fractured and cleaved with laminations distorted around the cobbles
31.	15	833	Limestone, light to medium gray, argillaceous to shaly interbedded with one to three inch dark gray beds; cobbly; cobbles weather free giving a dimpled appearance to the rock face
32.	6	839	Limestone, light to medium gray, cobble beds progressively closer together upwards; laminations in matrix distorted around cobbles.
33.	33	872	Limestone, light to medium gray; fresh exposures have beds up to four inches thick but weather into laminations and chips less than 1/4 inch thick. Cobble zones occur as continuous layers and occasional single cobbles; bedded style predominates; fragments and cobbles weather with yellow to tan-orange border; cobbles decompose into thin laminated fragments on advanced weathering; unit contains an occasional small, unidentified inarticulate brachiopod as only fossil seen.
34.	26	898	Limestone, light to medium gray, argillaceous to shaly in part; locally cobbly; cobbles very dense, medium gray limestone which is fossiliferous in some cobbles

TABLE II (Continued)

Unit Number	Unit Thickness	Cumulative Thickness	Description
35.	70	968	Limestone, light to medium gray, weathers light gray, thin bedded, very argillaceous to shaly; massive on fresh surface, weathers to chippy splintery fragments mostly less than 1/8 inch thick; contains streaks and stringers of dense, medium gray limestone with abundant fossil fragments; occasional weathered bed with dimpled indentations to three inches maximum diameter. Total thickness of Athens Formation, 732 feet
36.	40	1008	Lenoir Formation, limestone, light to medium blue-gray, streaks very light tannish-gray, argillaceous, nodular-weathering; fossiliferous including brachiopods, bryozoa, corals, crinoids, oconlites, and fragments of gastropods and trilobites; unit is poorly exposed as is contact with overlying Athens Formation.
37.	5	1013	Limestone, light to medium gray with traces brownish-gray; some thin beds silty to slightly sandy carbonate debris with intermingled clay-silt clastics; thin beds have a marbled appearance due to intermixing
38.	12	1025	Limestone, medium gray to bluish-gray; weathers light gray; very fine to fine crystalline; argillaceous to shaly; fossiliferous; few scattered dolomite lithoclasts and occasional shaly dolomite and

TABLE II (continued)

Unit Number	Unit Thickness	Cumulative Thickness	Description
			shale lenses occur in the lower ten feet; unit weathers rubbly with one to two inch ovate nodular clasts on the surface of the ground.
			Total Lenoir Limestone thickness, 57 feet
			KNOX GROUP
39.	Not measured		Mascot Dolomite, dolomite, fine to very fine crystalline, buff to light cream; weathers light gray; non-fossiliferous; thick bedded; not well exposed, contact placed below lowest, blue-gray argillaceous, fossiliferous limestone.

II. MEASURED GEOLOGIC SECTION WB-2

This section was measured along the north side Louisville and Nashville railroad tracks, beginning approximately one mile east of Calhoun, Tennessee, where the railroad crosses, by overpass, Sky Light Road (Figure 11, page 31). The Lenoir Limestone and the Athens Formation are poorly exposed except for the uppermost part of the Athens and the following generalized descriptions, Table III, are pieced together from scattered outcrops and lithologic characteristics projected short distances into the line of section. All thicknesses are given in feet.

TABLE III

MEASURED GEOLOGIC SECTION WB-2

Unit Number	Unit Thickness	Cumulative Thickness	Description
			CHICKAMAUGA GROUP
			Ottosee Formation
1.	9	9	Calhoun Member, top eroded, poorly exposed, scattered outcrops indicate limestone, blue-gray, hard, dense, sandy to very sandy, fossiliferous
2.	94	103	Limestone, medium blue-gray, fossil fragmental hard, dense, sandy to very sandy, grading both laterally and vertically to very calcareous, quartzose sandstone; highly ferruginous; weathers to bright red and red-brown, punky porous, sandstone remnants in a deep, dark red, blocky textured, sandy soil; bioclastic debris evenly comingled with quartz grains although some thin beds are essentially quartz free; few thin shale interbeds; ripple marks common on some surfaces of the sandy units.
3.	85	188	Limestone, light to medium blue-gray; fossil fragmental grading to very calcareous quartzose sandstone; highly ferruginous; interbeds of fine to coarse fossil fragmental and crystalline limestone without sand more abundant near base; ripple marks common on some bedding surfaces, few poorly preserved mudcracks; calcite rehealed fractures common; small kink bands and drag folds common in some beds

TABLE III (Continued)

Unit Number	Unit Thickness	Cumulative Thickness	Description
			Total thickness of Calhoun Member preserved, 188 feet
			Ottosee Formation continued
4.	64	252	McKnight Member, limestone, light to medium gray, fossil fragmental, sandy to very sandy in beds; crossbedded; contains numerous dark bands that weather in relief stylolitic, sometimes parallel to crossbedding; unit weathers into large light gray, fluted, rounded masses; occasional interbeds of fine to medium grained quartz sandstone with sparry calcite matrix associated with lenses of fossil fragmental sandy limestone
5.	3	255	Limestone, light to medium gray and gray-brown, fossil fragmental, conglomeratic, with pebbles of chert, quartzite, sandstone, and quartz up to 1 1/4 inch maximum diameter
6.	8	263	Limestone, grayish-red to light gray, very sandy, crossbedded; interbedded with light gray, oolitic limestone and fine grained very calcareous sandstone; abundant dark bands weather in positive relief as do some fossil fragments; unit weathers, overall, to large gray fluted masses in deep red soil
7.	5	268	Limestone and pebble conglomerate, red to gray and ocher, argillaceous to shaly in the more limey portions; fossiliferous; non-oolitic; pebbles up to one inch, composed of chert, quartz, rock fragments, such as

TABLE III (Continued)

Unit Number	Unit Thickness	Cumulative Thickness	Description
			quartzite and a very occasional unidentified peculiar dark green pebble of unknown origin
8.	4	272	Limestone, red to gray and ocher, argillaceous to shaly, fossiliferous with bryozoans, brachiopods and pelmatozoan holdfasts in growth position common; some limestone beds mottled red and green
9.	24	296	Limestone, light to medium gray, oolitic, sandy; estimate 10 to 15% fine to medium, quartz sand grains; crossbedded, stylolitic; sand grains and fossil fragments form ooid nuclei with sand predominant in some beds
10.	7	303	Limestone, light to medium gray, coarse to very coarse, calcarenite, fossil fragmental, trace sandy; few sandy beds; locally crossbedded and stylolitic
11.	17	320	Limestone, reddish, yellow-green, pinkish-gray and ocher, argillaceous to shaly, typical of transition zones of oolite to shale seen elsewhere; interbedded with thin, mottled shales and red to pink, coarse fossil fragmental, crossbedded limestone containing bryozoan, pelmatozoan and brachipod debris and occasional whole fossils; also contains an occasional discontinuous thin lense of red oosparite.

TABLE III (Continued)

Unit Number	Unit Thickness	Cumulative Thickness	Description
12.	121	441	Covered interval, sparse and discontinuous exposures to north of section line indicate lithologic continuity with unit number 13 below
13.	16	457	Limestone, medium gray with slight reddish tinge, weathers light gray-brown to light tan; fossil fragmental, oolites uncommon; contains many interbeds of coarse pelmatozoan debris; abundant dark bands 1/4 to 3/4 inches thick, weather in relief, contain 45 to 55% fine to medium sand grains and much dark gray to black clay-size debris that may be organic in origin; unit contains a pebble zone near the middle with pebbles up to 3/4 inch maximum diameter with quartz, chert, and rounded rock fragments common
14.	7	464	Covered interval, nearby discontinuous outcrops to north of section line indicate continuity of lithologies with unit number 18 below
15.	5	469	Limestone, light to medium gray, oolitic with occasional fossil fragmental lense; some beds 1 to 2% fine quartz sand both as nuclei of ooids and as free grains

TABLE III (Continued)

Unit Number	Unit Thickness	Cumulative Thickness	Description
16.	4	473	Limestone, medium red to reddish-gray, much red to pink pelmatozoan debris; oolitic and in part fossil fragmental; fossil fragments include brachiopods and bryozoans, some of which are also red
17.	32	505	Limestone, light gray to light tan, oolitic; weathers to lighter grays and tans; ooids weather free, leaving pitted surfaces; stylolitic, crossbedded; occasional fossil fragmental lense; some oolitic beds weather with a white rind up to 3/4 inch thick; sharp boundary occurs between the rind and the unweathered rock
18.	102	607	Covered interval, scattered outcrops in wooded area to north of section line indicate lithologic continuity with unit number 19 below
19.	50	657	Limestone, light to medium gray, oolitic, with occasional interbeds of tan oolitic limestone with fine quartz sand nuclei predominant; other beds contain only rare quartz sand nuclei
20.	16	673	Limestone, light to medium gray, oolitic, crossbedded, stylolitic; some fossil fragmental; percentage of quartz sand nuclei estimated at approximately 15%; large slickensided surfaces common

TABLE III (Continued)

Unit Number	Unit Thickness	Cumulative Thickness	Description
21.	70	743	Limestone, light to medium gray, oolitic, locally fossil fragmental; ooids fine to medium; in some beds ooid nuclei approximately 50% fine quartz sand grains; crossbedded with occasional three to six inch interbed of coarse, fossil fragmental, oolitic limestone
22.	11	754	Limestone, light to medium gray, oolitic with a few scattered fossil fragments; crossbedded; beds 1/4 to two inches; occasional thin bed of slightly argillaceous limestone
23.	17	771	Limestone, light to medium gray, weathers light gray, slightly arenaceous, oolitic; crossbedded, stylolitic; few small cut and fill channels in the oolitic
24.	10	781	Limestone, light to medium gray with traces of red and ocher mottled; argillaceous to shaly; oolitic in part; many pelmatozoan holdfasts in growth position; unit distorted and slickensided; trace fine quartz sand grains
25.	21	802	Limestone, light to medium gray, fossil fragmental and oolitic; crossbedded and stylolitic; weathers light gray in fluted surfaces; beds to five feet thick; some intra-unit channeling of oolites; beds locally distorted with slickensides on some surfaces

TABLE III (Continued)

Unit Number	Unit Thickness	Cumulative Thickness	Description
26.	6	808	Limestone, light to medium gray, oolitic, with interbeds of coarse fossil fragmental, mostly pelmatozoan, debris; crossbedded; stylolitic with stylolites commonly parallel to crossbeds
27.	19	827	Limestone, light to medium gray, weathers very light gray; oolitic; ooids weather in positive relief; nuclei of ooids is both fine quartz sand grains and fine fossil fragments
28.	3	830	Shale, calcareous, pale red to ocher and pale green, mottled in part; thin interbeds of argillaceous to shaly limestone of same colors; fine to medium crystalline; some pelmatozoan holdfasts in growth position
29.	3	833	Shale, calcareous, pale red to reddish-gray and ocher, traces yellowish-green mottled; fossiliferous, weathers to pale yellow clayey soil
30.	12	845	Limestone, light gray to buff to pink; coarsely crystalline to fossil fragmental; thick-bedded; weathers medium gray to light gray-brown with traces of pink and pale red; unit non-oolitic and similar to Holston calcarenites
31.	8	853	Limestone, light to medium gray oolite with approximately 30% fossil fragments; thick-bedded

TABLE III (Continued)

Unit Number	Unit Thickness	Cumulative Thickness	Description
32.	37	890	Limestone, light to medium gray, very oolitic; dense; massive except for stylolites; non-fossiliferous near base with few brachiopods and bryozoans appearing upward; few thin beds fine to medium crystalline fossiliferous limestone in top 10 feet Total thickness McKnight Member, 702 feet
			Ottosee Shale
33.	109	999	Middle Unnamed Shale Member, shale medium gray, weathers light grey, few beds very calcareous and fossiliferous; few cobbly beds with cobbles usually less than one inch maximum diameter; locally silty to slightly sandy; few beds fissile
34.	7	1006	Limestone, medium to medium-dark, blue-gray with traces of pink; fine to medium crystalline with abundant pelmatozoan, bryozoan and brachiopod fragments, and an occasional coral; beds two to eight inches thick with an occasional thin shale interbed
35.	5	1011	Covered interval; weathered float fragments suggest some oolitic limestone and argillaceous to shaly limestone; perhaps inter-bedded

TABLE III (Continued)

Unit Number	Unit Thickness	Cumulative Thickness	Description
36.	14	1025	Shale, medium gray, weathers light gray, grades locally to very argillaceous to shaly, fossiliferous and fossil fragmental limestone, especially near the base; shale is calcareous, fossiliferous in part, and highly distorted; abundant calcite rehealed fractures; few small cobbles; fossils in limestone beds sillicified in part; weather in positive relief
			Total Middle Unnamed Shale Member, 135 feet
			Ottosee Shale continued
37.	15	1040	Hiwassee Member, limestone, light to medium gray, oolitic, slightly argillaceous, grading upward through one foot zone to calcareous shale of overlying unit; occasional bryozoan fragment and pelmatozoan holdfast in growth position
38.	7	1047	Limestone, light to medium gray, weathers very light gray, fine to medium oolitic; ooid boundaries slightly blurred, perhaps by recrystallization; crossbedding apparent on weathered surfaces; weathers fluted with some fluting parallel to bedding
39.	5	1052	Limestone, light to medium gray, oolitic, stylolitic, slightly crossbedded; few scattered fossil fragments; weathers light gray in rounded masses

TABLE III (Continued)

Unit Number	Unit Thickness	Cumulative Thickness	Description
40.	63	1115	Covered interval, no exposure immediately adjacent to railroad tracks but discontinuous exposures a few yards to north of tracks in a wooded area are oolitic limestone with a few interbeds of ocher colored shaly fossiliferous limestone
41.	5	1120	Limestone, light to medium gray, oolitic; massive except for stylolites; few scattered fossil fragments; some fine quartz sand grain nuclei for ooids but mostly fossil fragments
42.	8	1128	Limestone, light to medium gray, massive; oolitic with scattered fossil fragments; mostly pelmatozoan, bryozoan and brachiopod debris; faint planar bedding; ooids medium to coarse; unit well-exposed in small diameter, steep-sided sinkhole immediately adjacent to the railroad tracks
43.	6	1134	Limestone, light to medium gray, oolitic but with much argillaceous to shaly limestone interbedded with red and green mottled calcareous shale
44.	100	1234	Limestone, light to medium gray with streaks and mottlings of green, red and ocher; argillaceous to shaly, in part bioclastic with fragments of pelmatozoan bryozoan, and brachiopod debris; some beds fine to medium crystalline; few oolitic lenses; more shaly limestone lenses have pelmatozoan

TABLE III (continued)

Unit Number	Unit Thickness	Cumulative Thickness	Description
			holdfasts in growth position; few thin interbeds of red, green, and ocher mottled shale occur sporadically; outcrops appear to "float" in deeply weathered residuum; unit poorly exposed Total thickness Hiwassee Member 209 feet
			Ottosee Shale continued
45.	131	1365	Lower Unnamed Shale Member, shale, light to medium gray, traces red and ocher, thinly to very thinly laminated in part; occasional thin, blue-gray colored, brown to tan-weathering, fine to medium crystalline limestone bed grading laterally to shaly limestone; unit poorly exposed; yellow, clayey soils contain abundant thin, yellow shale chips; soil contains pale red streaks where more limey Total thickness Lower Unnamed Shale Member, 131 feet
46.	62	1427	Chapman Ridge Formation, limestone, medium blue-gray, red-weathering, sandy to very sandy; fossil fragmental; shaly lenses common, especially near top; unit poorly exposed; description based on outcrops not in line of section; contact covered at this point

TABLE III (continued)

Unit Number	Unit Thickness	Cumulative Thickness	Description
47.	70	1497	Limestone, medium blue-gray, red-weathering, sandy to very sandy, locally shaly; grades both laterally and vertically to very calcareous sandstone; some beds very ferruginous; occasional bed of ferruginous limestone up to two feet thick weathers into positive relief on the weathered slopes; unit slightly to very fossiliferous and fossil fragmental, occasional whole brachiopod; unit partially exposed
48.	56	1553	Limestone, medium blue-gray to medium gray, ferruginous; beds sandy to very sandy grading both laterally and vertically to very calcareous sandstone; fossil fragmental in part; crossbedded, numerous thin shale interbeds; more ferruginous beds appear in ribbed relief on more weathered surfaces; decomposes to punky, porous, brown, sandy blocks on advanced weathering Total thickness Chapman Ridge Formation, 188 feet
49.	14	1567	Orthocone zone, shale, light to medium gray; very silty to sandy, calcareous, locally grading to very argillaceous to silty thin bedded fossiliferous limestone; fossils include bryozoans, an occasional coral, abundant orthocone fragments and oncolites, both compound and single, up to one foot in length. Unit mapped with the overlying Chapman Ridge Formation

TABLE III (continued)

Unit Number	Unit Thickness	Cumulative Thickness	Description
			Total thickness Orthocone Zone, 14 feet
50.	10	1577	Holston Formation, limestone, cream to reddish-brown, pinkish-gray, and tan; coarse grained, fossil fragmental; crossbedded, thick-bedded; abundant calcite rehealed fractures; trace slickensides on some fracture surfaces
51.	75	1652	Limestone, cream to tan, reddish-brown and pinkish-gray; medium to coarse grained, fossil fragmental; predominantly pelmatozoan debris but abundant bryozoan fragments; occasional thin medium gray, slightly calcareous shale bed
52.	10	1662	Limestone, gray to cream and light brownish-red; medium to coarse grained calcarenite; fossil debris includes bryozoans, brachiopods, and corals but is predominantly pelmatozoan debris; beds up to 12 inches thick, locally crossbedded; some bedding planes have a few medium to coarse, well-rounded quartz grains on surface; unit mostly quartz free except for few sandy lenses near base
			Total thickness Holston Formation, 95 feet
53.	6	1668	Athens Formation, limestone, medium blue-gray, fine to medium crystalline, with thin interbeds of sandy to very sandy, fossiliferous limestone near the top; occasional thin shale lense; trace coarse crystalline and fossil fragmental

TABLE III (continued)

Unit Number	Unit Thickness	Cumulative Thickness	Description
54.	20	1688	Limestone, light to medium gray, argillaceous to shaly with occasional thin interbeds of medium blue-gray, fine to medium crystalline limestone that increase in number upwards; some beds silty to sandy; graptolites common on some bedding planes; few thin cobbly beds near base
55.	710	2398	Limestone, light to medium gray argillaceous to very argillaceous with occasional thinly laminated calcareous shale beds; cobbly to very cobbly in beds; cobbles decrease in size upward; occasional thin beds of medium blue-gray, fine to medium crystalline limestone with abundant fossil fragments including bryozoans, brachiopods, ostracods and pelmatozoan debris. An occasional, unidentified, inarticulate brachiopod was found in float material; unit weathers to yellow, clayey soil with abundant thin shale chips and splintery shards; silty to sandy locally Total thickness Athens Formation, 736 feet
56.	86	2484	Lenoir Limestone, limestone, light to medium gray and blue-gray, fine to medium crystalline argillaceous to shaly; very fossiliferous in some beds with abundant whole fossils and fragments of gastropods, cephalopods, bryozoans, brachiopods, corals and pelmatozoans; occasional beds are fossil hash; locally

TABLE III (Continued)

Unit Number	Unit Thickness	Cumulative Thickness	Description
			highly distorted by folding; sporadic dolomite lithoclasts and red and green mottled dolomitic shale lenses near base; Mosheim type lithologies not observed in this section
			Total thickness Lenoir Limestone, 86 feet
			Total Chickamauga Group thickness preserved at Section WB-2, 2484 feet
			KNOX GROUP
57.	Not measured		Mascot Dolomite, dolomite, light gray to tan, fine to medium crystalline; some thick interbeds light to medium gray, fine to very fine crystalline, unfossiliferous, very light gray-weathering limestone that weather into large rounded masses. Poorly exposed for most part; contact placed below the lowest light gray or blue-gray, argillaceous to shaly fossiliferous limestone

VITA

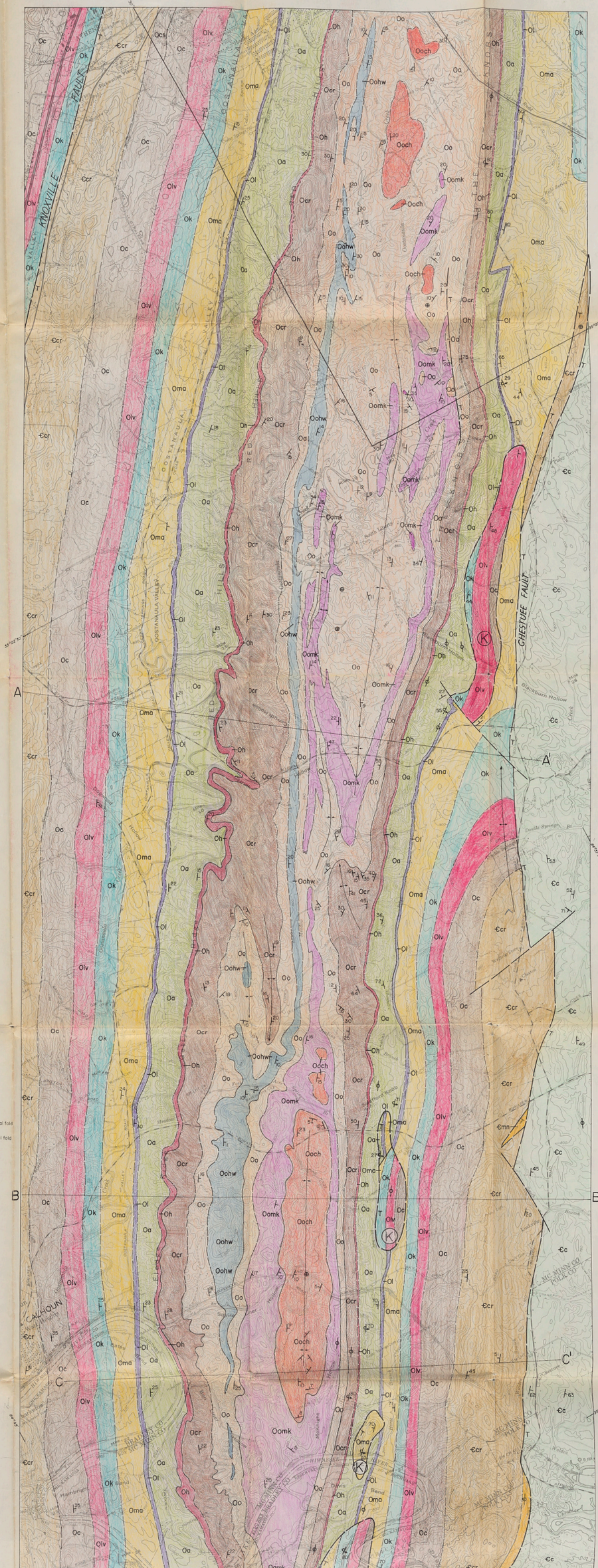
Melvin Owen Smith was born in Covington, Kentucky on October 28, 1927. He attended a one-room elementary school at Cedar Hill in Owen County, Kentucky, and graduated from Owen County High School in Owenton, Kentucky via the GED test route in 1951. He entered the University of Kentucky in the fall of 1951 and received a Bachelor of Science degree in geology in 1955. After several years in industry he received the Master of Science degree in geology from the University of Kentucky in 1964. Following another stint in industry he entered The University of Tennessee in the fall of 1967 in part-time pursuit of the Ph.D. degree while teaching full-time at Tennessee Technological University. He received his Doctor of Philosophy degree with a major in geology in June, 1976.

He is married to the former June Martin of Louisville, Kentucky. They have two sons.

PLATE 1

Geologic Map of Portions of McMinn, Bradley and Polk Counties, Tennessee

Melvin O. Smith
1976



EXPLANATION

MIDDLE ORDOVICIAN — CHICKAMAUGA GROUP

- Ooch / Oo / Oomk / Oohw / Oo — Ottosee Shale
  Ooch – Calhoun Member
  Oomk – McKnight Member
  Oohw – Hiwassee Member
  Oo – Main body of Ottosee
- Ocr — Chapman Ridge Sandstone
- Oh — Holston Formation
- Oa — Athens Formation
- Ol — Lenoir Limestone

LOWER ORDOVICIAN — KNOX GROUP

- Oma — Mascot Dolomite
- Ok — Kingsport Formation
- Olv — Longview Dolomite
- Oc — Chepultepec Dolomite

UPPER CAMBRIAN

- €cr — Copper Ridge Dolomite
- €mn / €c — Conasauga Shale
  €mn – Maynardville Limestone

CONTACT
dashed where approximate

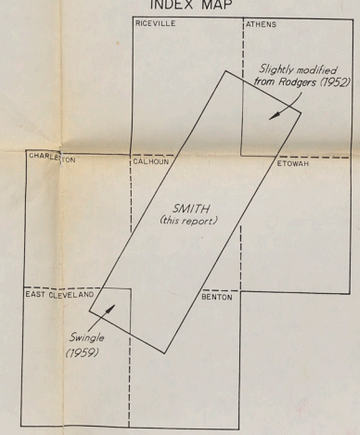
FAULT
approximate location
T on upper plate of thrust fault
(K) Klippe

STRIKE and DIP of BEDS
- 35 Normal
- 70 Overturned
- Vertical
- Horizontal
- Generalized where no numerical value is given

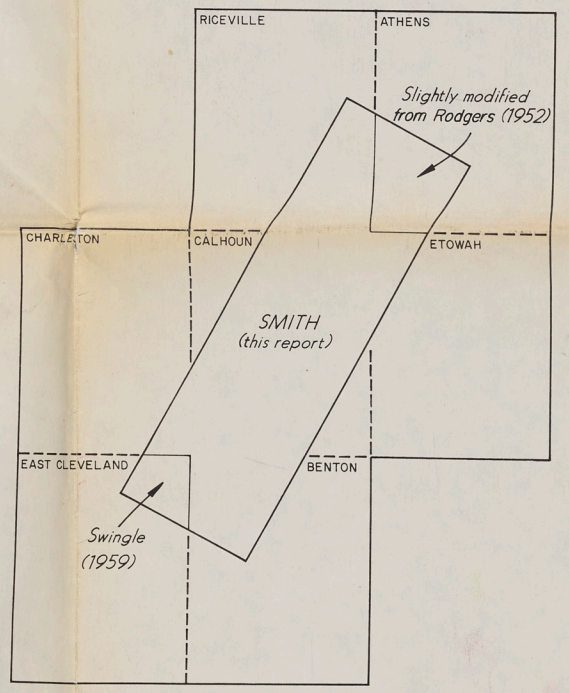
A ——— A' CROSS-SECTION LINE

FOLDS
- Approximate axis of anticlinal fold
- Approximate axis of synclinal fold

INDEX MAP



INDEX MAP



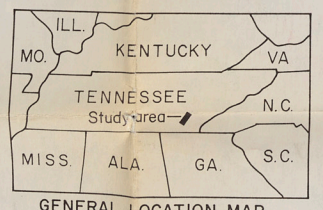
SCALE 1:24 000

1 MILE

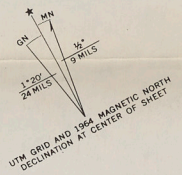
7000 FEET

1 KILOMETER

CONTOUR INTERVAL 20 FEET
DASHED LINES REPRESENT HALF-INTERVAL CONTOURS
DATUM IS MEAN SEA LEVEL



GENERAL LOCATION MAP



UTM GRID AND 1964 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

PLATE 2

Geologic Cross Sections to Accompany Plate 1

EXPLANATION

MIDDLE ORDOVICIAN — CHICKAMAUGA GROUP

- Ooch, Oo, Oomk, Oohw, Oo — Ottosee Shale
  - Ooch – Calhoun Member
  - Oomk – McKnight Member
  - Oohw – Hiwassee Member
  - Oo – Main body of Ottosee
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- Oh — Holston Formation
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LOWER ORDOVICIAN — KNOX GROUP

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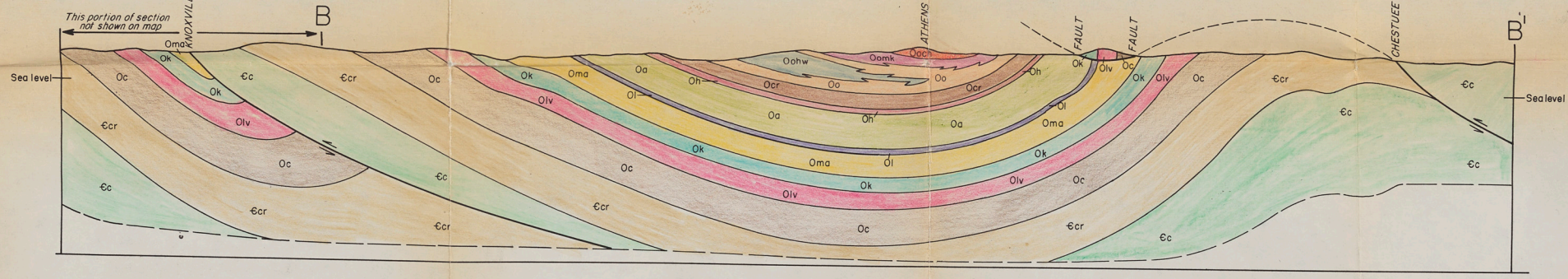
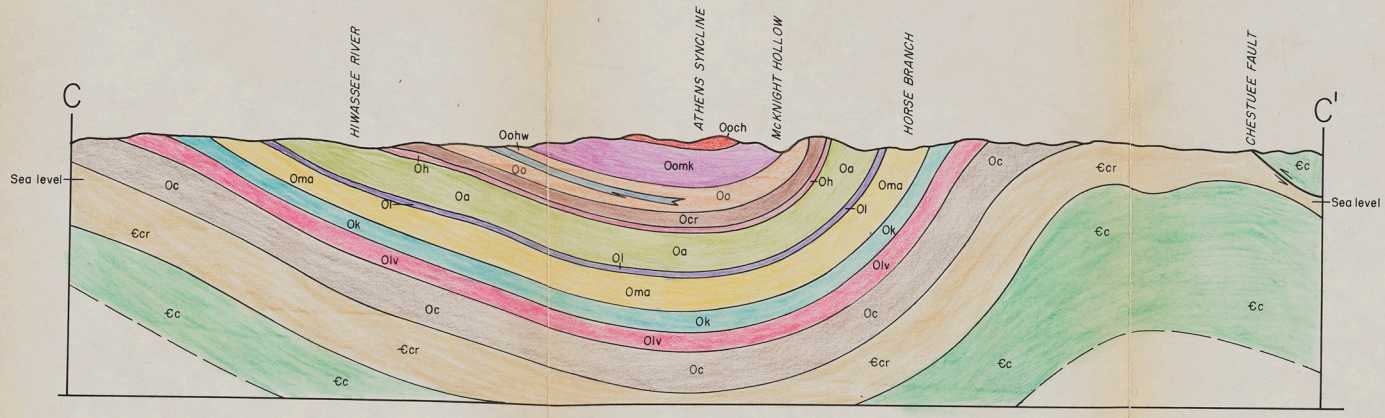
- €cr — Copper Ridge Dolomite
- €mn, €c — Conasauga Shale
  - €mn – Maynardville Limestone







VERTICAL SCALE 1"=2000'
HORIZONTAL SCALE 1"=2000'