

## CONSTRAINTS ON THE POSITION OF THE PRECAMBRIAN-CAMBRIAN BOUNDARY IN THE SOUTHERN APPALACHIANS

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**ABSTRACT.** The Chilhowee Group is a terrigenous clastic succession that records the stabilization of the eastern North American continental margin following Late Proterozoic rifting. An integration of first occurrences of *both body and trace fossils* allows for the following stage assignments: (1) upper part of Ocoee Supergroup (Wilhite and overlying Sandsuck Formation) Vendian, based on occurrences of Vendian acritarchs in the Shields and Wilhite Formations<sup>1</sup>; (2) lower part of Chilhowee Group (Cochran-Unicoi, Nichols-Hampton, and Nebo Formations) upper Vendian to lower "Tommotian-equivalent," based on first occurrences of the trace fossils *Palaeophycus*, *Planolites*, and *Skolithos*; and (3) upper part of Chilhowee Group (uppermost Nebo, overlying Murray, Hesse, and Helenmode Formations) upper "Tommotian-equivalent" to lower "Atdabanian-equivalent," based on the first occurrences of the trace fossils *Diplocraterion*, *Rusophycus*, and *Cruziana*, as well as reported occurrences of trilobites, ostracodes, hyolithids, inarticulate brachiopods, and acritarchs. The Precambrian-Cambrian boundary probably occurs within the middle or upper part of the basal Cochran-Unicoi Formation. Because the Cochran-Unicoi is predominantly a coarse-grained, feldspathic terrestrial (braided fluvial/alluvial) sequence, the precise position of the Precambrian-Cambrian boundary may never be determined in the southern Appalachian re-

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<sup>1</sup> Recent paleontological data presented by Unrug and Unrug (1990) provide evidence for a possible Silurian age for the upper part of the Walden Creek Group. Body fossils were obtained from disaggregated-shale and argillite lithologies which have been interpreted by Unrug and Unrug (1990) as enclosing matrix surrounding limestone olistoliths. The body fossils included microcrinoids, fenestrate bryozoans, ostracodes, trilobites, and agglutinated foraminifera. As these rocks are separated from the Chilhowee Group and underlying Sandsuck Formation in the area of Chilhowee Mountain by the Miller Cove fault, these authors have suggested that the shale overlying the Wilhite Formation in this area has been incorrectly mapped as the Sandsuck formation, and that this shale, as well as the remainder of the Walden Creek Group which underlies it, is of Silurian or younger age.

Mapping and paleontologic work, however, conducted to the northeast in the area between the Pigeon and French Broad Rivers (Keller, 1980) and in the Del Rio district of Cocke County (Ferguson and Jewell, 1951), indicate that the Walden Creek Group is in stratigraphic contact with the Chilhowee Group and is Vendian in age (Knoll and Keller, 1979). This apparent discrepancy calls into question several widely held structural and stratigraphic concepts about the Ocoee Supergroup. We, the authors, feel that it is beyond the scope of this study to address the relative merits of these arguments or comment as to the validity of these studies. In the absence of independent confirmation of the controversial paleontologic discoveries presented by Unrug and Unrug (1990), we maintain that the Sandsuck, Wilhite, and Shields Formations of the Walden Creek Group are Vendian in age and form a continuous stratigraphic sequence with the overlying Chilhowee Group. Whereas confirmation of these paleontologic discoveries would necessitate a reexamination of this interpretation, it would not directly affect the age assignments presented here for the Chilhowee Group.

**gion. Furthermore, the complete absence of marine carbonate lithologies (limestone, dolostone) probably precludes the preservation of a pre-trilobite, Tommotian-aspect shelly microfauna.**

#### INTRODUCTION

Much recent research has focused on establishing the position of the Precambrian-Cambrian boundary at various localities worldwide. An excellent summary of the problems involved in the determination of this major boundary is provided by Sepkoski and Knoll (1983), Cowie and Johnson (1985), and Conway Morris (1987). Twenty years ago the boundary was placed at the base of stratigraphic units containing the first trilobite body fossils. Trace fossils (arthropod and others) were later discovered stratigraphically beneath the lowest occurrence of trilobites (Alpert, 1975, 1977; Crimes and others, 1977; see Crimes, 1987, for a complete summary). Most recent has been the discovery, first in the Soviet Union and then elsewhere, of a pre-trilobite shelly fossil assemblage which commonly occurs stratigraphically beneath the zone of arthropod trace fossils and trilobite body fossils (Raaben, 1969, p. 7; Bengtson and Fletcher, 1983; Mount, Gevirtzman, and Signor, 1983, p. 225; McMenamin and others, 1983, p. 227; Gevirtzman and Mount, 1986, p. 412; Signor, Mount, and Onken, 1987, p. 426; Culver, Pojeta, and Repetski, 1988; Landing, 1988). This sub-trilobite fossil assemblage led to the definition of the basal Cambrian Tommotian-equivalent stage, in which the lowest occurrence of these problematic fossils defines the Precambrian-Cambrian boundary. Subsequent discovery of small shelly fossils in rocks stratigraphically below Tommotian-equivalent strata of the Avalon Platform of New England and Newfoundland has led to the definition of the Placentian Series (Landing, 1988; Landing and others, 1989). The Placentian Series (lowest Cambrian) then constitutes strata that contain sub-trilobite body fossils (Nemakit Daldyn-equivalent through Atdabanian-equivalent stages).

The Precambrian-Cambrian boundary in the southern Appalachians has been arbitrarily placed at the base of the Chilhowee Group based on perceived lithologic and stratigraphic differences, in spite of the fact that deposition in some areas has been viewed as more or less continuous across the boundary (King, 1949). Other researchers have chosen to assign the upper portion to the Early Cambrian and the lower part to the Early Cambrian (?) (Laurence and Palmer, 1963; Palmer, 1971) or as Early Cambrian and late Precambrian, respectively (Schwab, 1972; Bond, Nickelson, and Kominz, 1984, p. 336; Fichter and Diecchio, 1986).

Our purpose is to summarize the recent results of research conducted on the sedimentology and paleoenvironments of the Chilhowee Group (latest Proterozoic to Early Cambrian) in eastern Tennessee (Cudzil, ms; Cudzil and Driese, 1987; Skelly, ms; Walker and others, 1988) pertinent to the Precambrian-Cambrian boundary problem and to compare these results with data obtained from recent studies in southwest-

ern Virginia (Simpson and Sundberg, 1987; Simpson and Eriksson, 1989; 1990).

#### LITHOSTRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS

##### *General Setting*

The Chilhowee Group is exposed in a series of discontinuous strike belts along the western margin of the Blue Ridge from Alabama to Vermont (fig. 1; Rodgers, 1963; Schwab, 1972; Mack, 1980) and consequently possesses a complex stratigraphic nomenclature (table 1). The Chilhowee Group in the southern Appalachian region is a 600 to 1500 m thick sequence of interbedded feldspathic conglomerate, feldspathic and quartzose sandstone, micaceous siltstone, and shale (Waler and others, 1988). Chilhowee Group strata in this area have been interpreted as representing the transition from sedimentation within a continental rift system (Rast and Kohles, 1986, p. 611–612) to a passive-margin setting associated with the opening of the Iapetos (Proto-Atlantic) ocean (Hatcher, 1972, 1978; Rankin, 1975, 1976). The basal Chilhowee Group overlies Grenvillian basement in some regions and Upper Proterozoic metasedimentary and metavolcanic sequences elsewhere (table 1). This lower

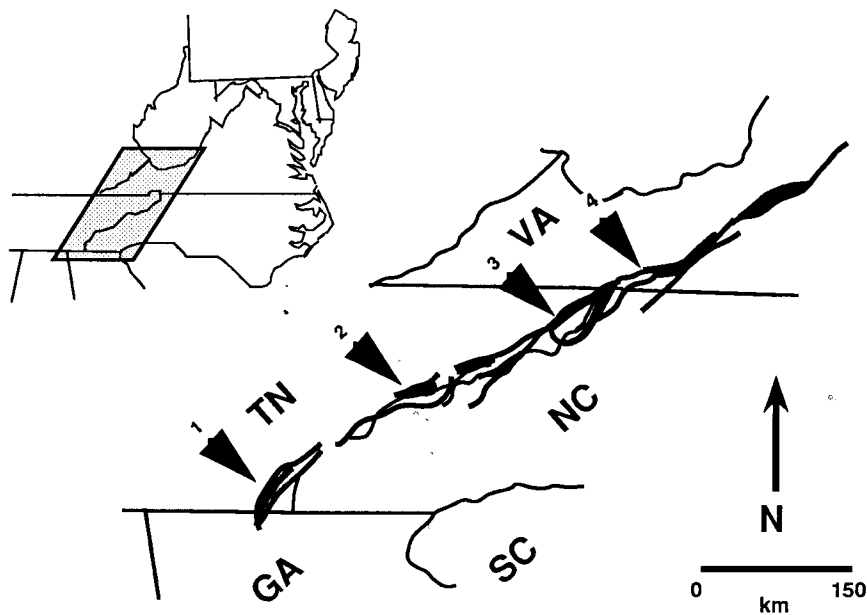


Fig. 1. Outcrop distribution (shaded black) of Chilhowee Group rocks along western margin of Blue Ridge Province. Numbers 1, 2, and 3 denote Bean Mountain, Chilhowee Mountain, and Valley Forge (Doe River Gorge loc. of Cudzil and Driese, 1987) localities, respectively, which are discussed in text. Number 4 denotes the location of section in southwestern Virginia studied by Simpson and Sundberg (1987).

TABLE 1

*Stratigraphic nomenclature for the Chilhowee Group. Modified from Schwab (1972) and Mack (1980)*

AGE	North Georgia and Alabama	Southeastern Tennessee		Northeastern Tennessee	Southwestern Virginia	Northwestern Virginia	
EARLY CAMBRIAN	Shady Dolomite	Shady Dolomite		Shady Dolomite	Shady Dolomite	Tomstown Dolomite	
	CHILHOWEE GROUP	Weisner Formation	Helenmode Formation	Erwin Formation	Helenmode Member	Erwin Formation	Antietam Quartzite
			Hesse Quartzite		Hesse Quartzite Member		
		Wilson Ridge Formation	Murray Shale		Murray Shale Member		
			Nebo Quartzite		Nebo Quartzite Member		
	Nichols Shale	Nichols Shale		Hampton Shale	Hampton Shale	Harpers Formation	
	PROTEROZOIC <sup>-?</sup>	Cochran Formation	Cochran Formation		Unicoi Formation	Unicoi Formation	Weverton Quartzite
Loudon Formation							
	base of section always faulted out	Ocoee Supergroup	Sandsuck Formation	Mount Rogers Volcanic Group or Grenville basement	Mount Rogers Volcanic Group	Catoctin Greenstone or Swift Run Fm. or injection complexes	

interval, which comprises the Cochran-Unicoi and equivalent Formations, probably represents deposition on attenuated continental crust along a tectonically inactive, thermally subsiding continental margin in southern Tennessee (Cochran Formation) and coeval sedimentation associated with active extension (synrift deposition) in northeast Tennessee and southeastern Virginia (Unicoi Formation; Simpson and Eriksson, 1989; Walker, 1990). Continental promontories and embayments inherited from Late Proterozoic rifting, which may have influenced basal Chilhowee Group sedimentation (Skelly, Driese, and Cudzil, 1987; Walker and others, 1988; Simpson and Eriksson, 1989; Walker, 1988), have been proposed by Thomas (1977, p. 1237–1240; 1983, p. 271–272). Deposition of the overlying Hampton/Erwin and equivalent formations has been interpreted to have taken place on a stabilized, thermally subsiding continental margin (Fichter and Diecchio, 1986; Walker and others, 1988; Walker, 1988). Paleocurrent data from numerous sources indicate a predominantly westward (cratonic source and that detrital sediment prograded eastward over attenuated continental crust (Schwab, 1970, 1971, 1972; Brown, 1970; Whisonant, 1970, 1974; Mack, 1980; Cudzil, ms; Skelly, ms; Cudzil and Driese, 1987; Simpson and Eriksson, 1990). Consequently, earlier workers have tentatively interpreted the basal Chilhowee deposits as fluvial or coastal alluvial deposits, whereas the

upper portion has been interpreted as representing shallow-marine (foreshore, shoreface, and shelf) deposition (Schwab, 1970, 1971, 1972; Whisonant, 1974; Mack, 1980; Cudzil and Driese, 1987; Simpson and Eriksson, 1989, 1990; Walker and others, 1988).

#### *Stratigraphic Relations in eastern Tennessee*

The Chilhowee Group has been subdivided into six formations in eastern Tennessee (table 1). The Chilhowee Group in northern outcrop belts (table 1) is extraordinarily thick and overlies Grenvillian basement (0.9-1.1 Ga) with nonconformity. The Chilhowee Group is somewhat thinner in central and southern outcrop belts (400 m as opposed to 1000 m in the northeast Tennessee, Walker and others, 1988) and overlies the Upper Proterozoic Ocoee Supergroups,<sup>2</sup> a 5 to 12 km thick synrift to thermally? subsiding basin sequence (Hadley, 1970; Knoll and Keller, 1979; Rast and Kohles, 1986, p. 602) of highly immature conglomerate, sandstone, siltstone which change upsection into texturally more mature sandstone and shale with minor conglomerate and rare carbonate units (table 2). The contact with the overlying Chilhowee Group appears conformable in southeast Tennessee, although the basal conglomerate of the Unicoi Formation in the Hot Springs window of North Carolina does contain clasts identical to lithologies of the immediately underlying Sandsuck Formation (uppermost formation of the Walden Creek Group of the Ocoee Supergroup), suggesting local disconformity. The basal contact therefore changes from conformable to slightly disconformable along depositional strike from southwest to northeast, Walker, 1990). Rocks of the Ocoee Supergroup in Tennessee display some degree of penetrative deformation, and metamorphic grade varies from subgreenschist (portions of the Ocoee Supergroup east and southeast of Tennessee are middle to upper Amphibolite grade). The occurrences of shallow-water carbonate lithofacies in the upper part of the Ocoee are particularly important (upper Yellow Breeches Member of the Wilhite Formation, Walden Creek Group; Hanselman, Conolly, and Horne, 1974) as they suggest active extension had ceased in the area before deposition of the basal Chilhowee strata. Estimates of the timing of the opening of Iapetus vary, but the most recent estimates based on dates obtained by Odom and Fullagar (1984, p. 260) from the Crossnore Plutonic Series suggest rift-related magmatism began as early as  $690 \pm 20$  Ma. Tectonism and volcanism extended into early Chilhowee time, as documented in southern Virginia and northeastern Tennessee (Simpson and Eriksson, 1989, p. 51-53; Misra and Walker, 1990). Siliciclastic marine deposition recorded by the upper portion of the Chilhowee Group along the extent of the Appalachian Orogen gave way to carbonate shelf deposition represented by the overlying Shady Dolomite and its northeastern equivalents. The position of the Precambrian-Cambrian boundary is therefore directly pertinent to the determination of an upper

<sup>2</sup>See footnote 1 on p. 258.

TABLE 2

*Stratigraphic nomenclature for the Ocoee Supergroup <sup>1</sup>west of the Greenbrier fault. Modified from King (1964), Neuman and Nelson (1965), and Hadley (1970)*

Latest Proterozoic to Early Cambrian	<b>Chilhowee Group</b>		
Late Proterozoic	<b>OCOEE SUPERGROUP</b>	Walden Creek Group	Sandsuck Formation Wilhite Formation Shields Formation Licklog Formation
		Unclassified Formation	Sandstones of Webb Mountain and Big Ridge Cades Sandstone Rich Butt Sandstone
		Snowbird Group	Metcalf Phyllite Pigeon Siltstone Roaring Fork Sandstone Longarm Quartzite Wading Branch Formation
Middle Proterozoic	Grenville Basement		

<sup>1</sup>See footnote 1 on p. 258.

limit to the age of Iapetus related continental extension because of its implications for determining the age of the youngest demonstrable rift-related activity (represented by deposits of the Unicoi Formation) in the southern Appalachians (Williams and Hiscott, 1987; Simpson and Sundberg, 1987; Walker, 1990). Hurley and others (1960) reported the only radiometric date available for the Chilhowee Group of  $552 \pm 30$  Ma based on Rb/Sr ratios determined for glauconite samples obtained from the Murray Shale at Murray Gap, Chilhowee Mountain (fig. 1). The 552 Ma date reported was calculated using a decay constant of  $1.386 \times 10^{-11} \text{ yr}^{-1}$ ; recalculation using the more widely accepted decay constant of  $1.42 \times 10^{-11} \text{ yr}^{-1}$  yields an age of  $539 \pm 30$  Ma (Cormier, personal communication, 1990). Much of the critical mapping of the Chilhowee Group was provided by King and Ferguson (1960), King (1964), and Neuman and Nelson (1965).

The basal stratigraphic unit in the Chilhowee Group includes the Cochran and Unicoi Formations and ranges from 100 to 200 m thick in the central and southern outcrop belts (Skelly, ms; Walker and others, 1988) to as much as 500 m in northeastern Tennessee and southwestern

Virginia (Simpson and Eriksson, 1989; Cudzil and Driese, 1987; table 1). Conglomerate and pebbly sandstone are abundant toward the base of the sequence and grade upward into very coarse-grained, feldspathic sandstone (Whisonant, 1974; Walker and others, 1988). Significant occurrences of clean, massive to conspicuously planar-tabular cross-stratified quartz arenite beds occur within the upper part of the Cochran-Unicoi (Cudzil and Driese, 1987; Simpson and Eriksson, 1989). Regional variations in paleocurrent flow vectors are interpreted as the result of an initial irregular morphology of the continental margin which was inherited from rifting (Walker and others, 1988, p. 45). The paleoenvironment was probably that of an coastal braid plain, which carried feldspathic detritus eastward to a high-energy marine coastline where it was locally reworked into quartz arenite sequences (Cudzil and Driese, 1987, p. 872; Walker and others, 1988, p. 48).

The Nichols-Hampton Formation conformably overlies the Cochran-Unicoi sequence and consists of about 75 to 275 m of thin-bedded clayey siltstone that is interstratified with very thin glauconitic feldspathic sandstone beds (Cudzil, ms; Cudzil and Driese, 1987; Skelly, ms, ; Walker and others, 1988; table 3). The sandstone beds display internal structures and geometries that indicate they are storm-deposited event beds (tempestites) (Skelly, ms; Walker and others, 1988, p. 44). The depositional setting was a silt- and mud-dominated marine shelf in which storms episodically transported sand eroded from the shoreface out onto the shelf. The overall sequence thickens and coarsens upward and when included together with the overlying Nebo Formation comprises a very large-scale shoaling-upward sequence (Walker and others, 1988, p. 50–52).

The Nebo Formation (termed the Nebo Member of Erwin Formation in northeast Tennessee; table 1) conformably overlies the Nichols-Hampton sequence and ranges from 20 to 120 m in thickness (Cudzil, ms; Skelly, ms; Walker and others, 1988; table 3). It is dominantly a medium-grained, submature quartz arenite to feldspathic arenite (Whisonant, 1974). The lower part is dominated by hummocky and low-angle cross-stratification, which grades upward into high-angle trough and planar-tabular cross-stratification, punctuated by densely bioturbated horizons dominated by Skolithos (Skelly, ms; Walker and others, 1988, p. 39). The paleoenvironment was probably a storm-dominated inner shelf, shoreface, and foreshore system which existed as a coeval lateral equivalent of the Nichols-Hampton outer (mud) shelf (Skelly, ms; Walker and others, 1988, p. 44).

The Murray Formation (termed the Murray Member of Erwin Formation in northeast Tennessee; table 1) conformably overlies the Nebo Formation and ranges from 70 to 105 m thick in the central and southern area (Skelly, ms; Walker and others, 1988; table 3) to about 220 m in northeastern Tennessee (Cudzil, ms; Cudzil and Driese, 1987). It consists predominantly of thin-bedded muddy siltstone (very similar to the older Nichols Formation) interstratified with thin, feldspathic glauco-

nitic sandstone beds which have tempestite structures and stratification sequences (Skelly, ms; Walker and others, 1988). Rare lingulellid brachiopods, trilobites, and ostracodes have been reported (Laurence and Palmer, 1963). The depositional environment of the Murray Formation was probably identical to that of the older Nichols Formation, namely, a low-energy mud shelf episodically affected by storms (Skelly, ms; Walker and others, 1988, p. 44).

The 40 to 100 m thick Hesse Formation (termed the Hesse Member of Erwin Formation in northeast Tennessee; table 1) conformably overlies the Murray Formation (Cudzil, ms; Cudzil and Driese, 1987; Skelly, ms; Walker and others, 1988; table 3) and consists of fine- to medium-grained, submature to mature quartz arenite which closely resembles the older Nebo Sandstone (Whisonant, 1974). Sedimentary structures are dominated by medium- to very large-scale planar-tabular cross-stratification, small- to medium-scale trough cross-stratification (some herringbone?), and locally abundant *Skolithos* (Skelly, ms; Walker and others, 1988). Paleoenvironmental interpretations for the Hesse Formation are similar to those proposed for the Nebo Formation and include inner shelf, shoreface, and foreshore environments with a mixed storm and tidal influence. Furthermore, the Murray-Hesse package comprises a second shoaling-upward sequence that followed deposition of the Nichols-Nebo package (Skelly, ms; Walker and others, 1988, p. 57).

The 15 to 60 m thick Helenmode Formation (Member) conformably overlies the Hesse Formation (King and Ferguson, 1960; King, 1964; Neuman and Nelson, 1965; table 3) and consists of very poorly exposed calcareous shale, siltstone, and glauconitic sandstone (Whisonant, 1974; Cudzil, ms). Although no exposures of this interval were examined as part of this study, earlier studies report occurrences of inarticulate brachiopods, trilobites, hyoliths, and ostracodes (Neuman and Nelson, 1965). The Helenmode is inferred to have been deposited in a shelf environment transitional between the terrigenous clastic-dominated Chilhowee shelf and the Shady Dolomite carbonate ramp (Whisonant, 1974).

#### BIOSTRATIGRAPHY

##### *Trace Fossil-Distribution*

*Valley Forge.*—The Chilhowee Group at this locality in northeastern Tennessee (fig. 1) exhibits a three-fold stratigraphy which includes the Unicoi, Hampton, and Erwin Formations (table 1) and is exposed within the Iron Mountain thrust sheet. Approximately 5 km to the southeast, the Chilhowee Group is exposed in the footwall of the Iron Mountain thrust and nonconformably overlies Grenvillian crystalline basement (Hampton Section of King and Ferguson, 1960). The stratigraphic distribution of trace fossils in the Chilhowee Group is shown in figure 2. Note that the lowest occurrence of traces is in the basal Unicoi Formation; *Palaeophycus* occurs 191 m above the base of the section in facies interpreted as representing tide-related brackish pond/lacustrine deposition

TABLE 3  
*Stratigraphy, sedimentology, and inferred depositional settings for the Chilhowee Group of the Southern Appalachians*

Formation*	Alabama/ Georgia equivalent(s)	Northeast Tennessee/ Southwest Virginia equivalent(s)	Thickness (m)**
Helenmode	uppermost Weisner	uppermost Erwin	N/A‡ (10–15)
Hesse	Weisner	upper Erwin	45 (thickens to southwest and northeast, avg 100–150)
Murray	Wilson Ridge	middle Erwin	60 (thickens to southwest and northeast, avg 70–110)
Nebo	Wilson Ridge	lower Erwin	80 (thins to southwest and northeast, avg 20–50)
Nichols	Nichols	Hampton	85 (thickens to southwest and northeast, avg 150–175)
Cochran	Cochran	Unicoi	90+ (thins to southwest and thickens to northeast, avg 100–400)

\* Stratigraphy as described at Chilhowee Group type-locality at Chilhowee Mountain, Tennessee.

\*\* Thickness listed as measured at Chilhowee Mountain followed by range over entire southern Appalachians as reported by Mack (1980), Cudzil and Driese (1987), Skelly (ms), and Simpson and Sundberg (1987).

† Lithologic description generalized for entire southern Appalachians as reported by Mack (1980), Cudzil and Driese (1987), Skelly (ms), and Simpson and Sundberg (1987).

‡ Helenmode Formation not exposed at Chilhowee Mountain. Range of thicknesses as reported by King and Ferguson (1960), King (1964), Neuman and Nelson (1965), Cudzil and Driese (1987).

TABLE 3

*(continued)*

Lithologic description†	Inferred depositional environment
Fine-grained, poorly lithified, and exposed thin-bedded sandstone and interbedded mud-siltstone	Sediment starved-STABILIZED SHELF
Large-scale, planar-tabular cross-stratified quartz arenite. Granule lags and symmetrical ripple marks locally abundant. Typically thick-bedded with an erosional base.	subtidal sand ridge-STORM DOMINATED SHELF
Variably cross-stratified, and bioturbated silt- and mudstone interbedded with varying amounts of hummocky and microhummocky feldspathic sandstone. Glauconite abundant throughout.	fairweather (mud- and siltstone) and storm (sandstone) deposition-STORM-DOMINATED SHELF
Medium-scale, planar-tabular and symmetrical ripple cross-stratified quartz arenite interbedded on various scales with hummocky and trough cross-stratified feldspathic sandstone. Rare asymmetric ripples and heavily bioturbated horizons observed at many localities.	subtidal sand ridge-STORM DOMINATED SHELF and/or various subenvironments associated with-SUBTIDAL CHANNELS AND SHOALS
Variably cross-stratified, and bioturbated silt- and mudstone interbedded with varying amounts of hummocky and microhummocky feldspathic sandstone. Glauconite abundant throughout.	fairweather (mud- and siltstone) and storm (sandstone) deposition-STORM-DOMINATED SHELF
Lithologic nature highly variably. Overall unit fines upward. Quartz/feldspar ratio increases upsection. Lower portion of unit is dominantly massive, large-scale planar-tabular, or megaripple cross-stratified, pebble-cobble conglomerate. Upper portion displays low-angle and large-scale planar-tabular cross-stratification.	transverse and longitudinal bar and associated subenvironments-BRAIDED STREAM overlain by subtidal sand ridge-STORM DOMINATED SHELF

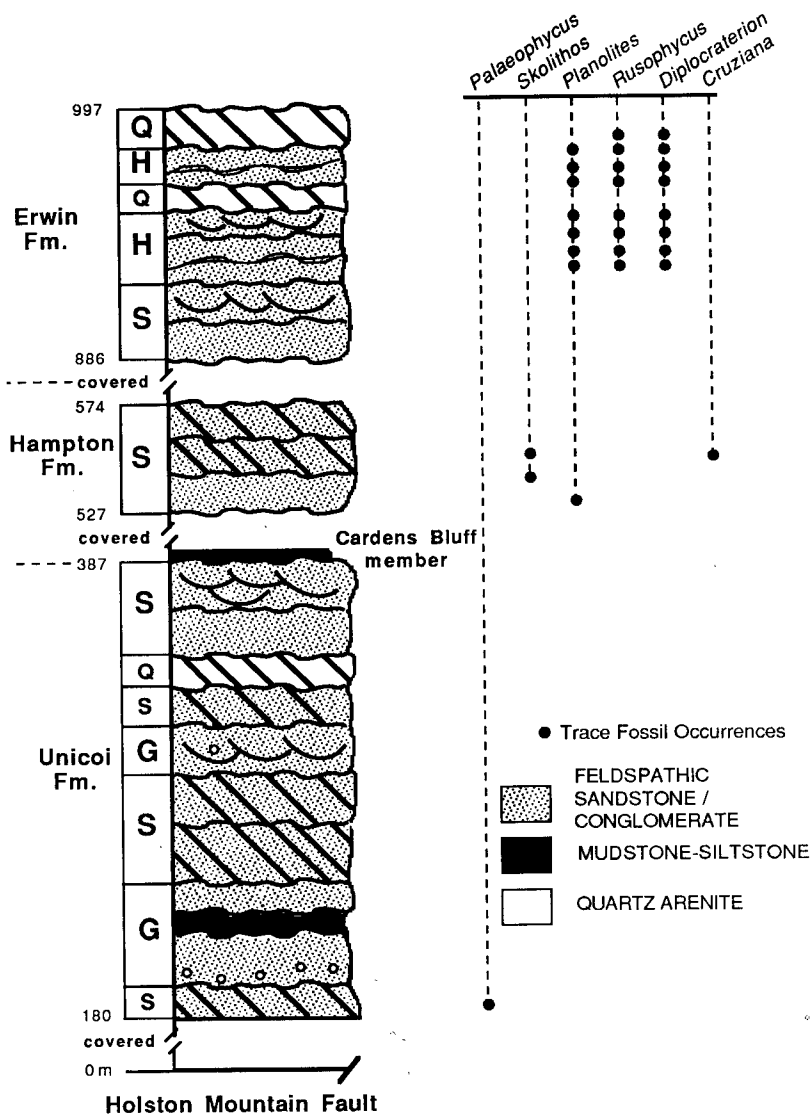


Fig. 2. Summary of trace fossil distribution in the Chilhowee Group at Valley Forge section (loc. 3 in fig. 1). Q = quartz arenite facies, H = hummocky facies, S = sandstone facies, G = conglomerate facies. Data are from Cudzil (ms).

(Cudzil, ms; Cudzil and Driese, 1987). The lowest stratigraphic occurrence of *Planolites* is in the Hampton Formation, 538 m above the base of the section (Cudzil, ms), and *Skolithos* first appears slightly higher at 555 m (fig. 2) *Rusophycus* and *Cruziana* first appear much higher in the Erwin

Formation, 936 m above the base of the section (Cudzil, ms); both traces then occur commonly throughout the Erwin (fig. 2).

*Chilhowee Mountain.*—The six-fold stratigraphy of the Cochran–Nichols–Nebo–Murray–Hesse–Helenmode Formations (table 1) is best observed at Chilhowee Mountain, the type locality of the Chilhowee Group (fig. 1; Safford, 1856). The faulted nature of the base of the best-exposed section at this locality greatly complicates the assessment of the nature of the contact between the Chilhowee Group and the underlying Upper Proterozoic Ocoee Supergroup. Examination of natural outcrop did not result in the recognition of evidence of a disconformity along the stratigraphic contact as mapped by Neuman and Nelson (1965). The stratigraphic distribution of trace fossils in the Chilhowee Group at Chilhowee Mountain is summarized in figure 3. No traces were observed in the Cochran Formation (Walker and others, 1988). The lowest stratigraphic occurrence of *Skolithos* is in a sandstone body of inner shelf origin interbedded with shale of the Nichols Formation (fig. 3). About 10 m above the first occurrence of *Skolithos* are abundant *Planolites*, which occur in association with thin-bedded tempestites and interbedded siltstone deposits in the upper Nichols Formation (Walker and others, 1988). *Skolithos* become increasingly abundant in the overlying Nebo and Hesse Formations, and *Planolites* and *Palaeophycus?* are very abundant in the Murray Formation (fig. 3). *Rusophycus* and *Cruziana*, although rare, appear first in storm shelf deposits of the uppermost Nebo and overlying Murray Formations (Walker and others, 1988). No exposures of the Helenmode were available for examination in this vicinity.

*Bean Mountain.*—The Chilhowee Group stratigraphy at this locality in southeastern Tennessee (fig. 1) closely resembles that observed at Chilhowee Mountain (table 1). The precise nature of the contact between the Chilhowee Group and the underlying Sandsuck Formation of the Walden Creek Group is poorly understood. Examination of exposures at this locality yielded no sedimentologic or petrologic evidence for the interpretation of the Sandsuck–Cochran contact as being disconformable, such as was proposed by King (1964). The lack of positive evidence of disconformity in this area results in its interpretation as conformable, in agreement with previous interpretations espoused by Neuman and Nelson (1965). No trace fossils were observed in the Cochran Formation (fig. 4). The stratigraphically lowest traces are *Planolites*, followed slightly higher in the section by *Paleophycus*. Both traces occur in the basal part of the Nichols Formation within shelf tempestite sequences (fig. 4; Skelly, ms). *Diplocraterion* appears higher in the section, within more proximal tempestite sequences of the upper Nichols Formation. *Skolithos* occurs in the overlying shoreface to inner shelf strata of the Nebo and Hesse Formations (Skelly, ms). *Rusophycus* and *Cruziana* first appear preserved on the bases of tempestite beds of the lower and middle Murray Formation (fig. 4).

*Ocoee Supergroup.*—Detailed sedimentological study of Ocoee Supergroup sequences was not conducted as part of this study. The Wilhite and

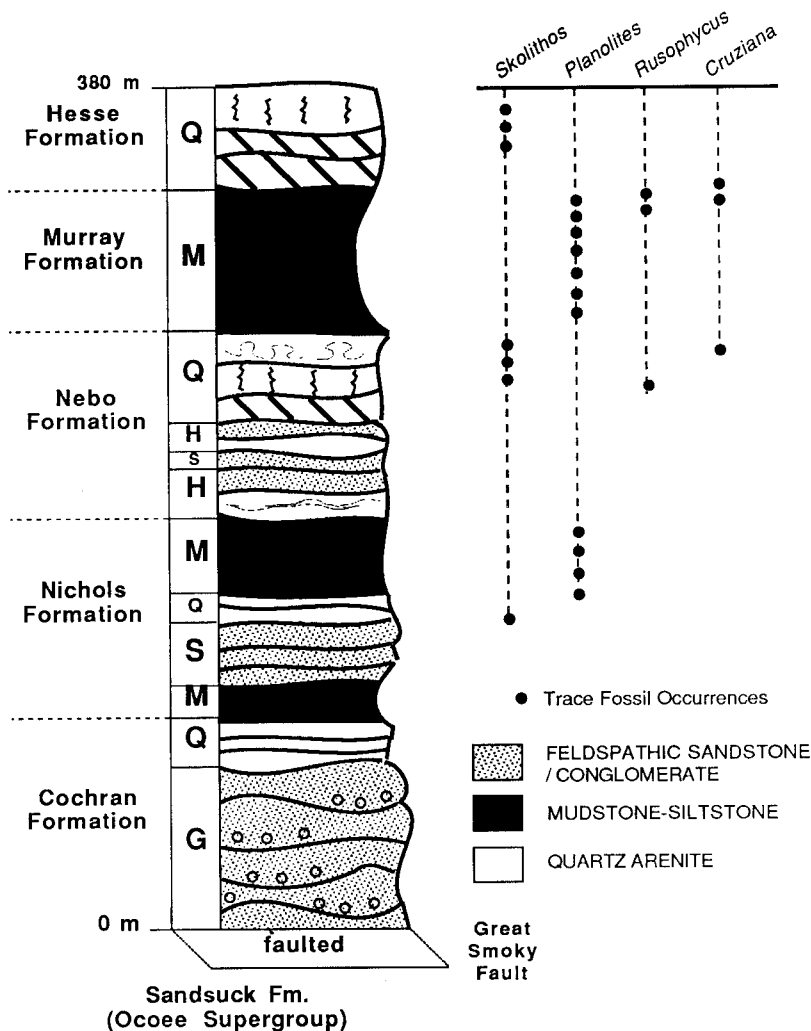


Fig. 3. Summary of trace fossil distribution in the Chilhowee Group at Chillhowee Mountain section (loc. 2 in fig. 1). Q = quartz arenite facies, H = hummocky facies, S = sandstone facies, G = conglomerate facies. See figure 2 for key to stratification symbols.

the overlying Sandsuck formations of the Walden Creek Group (table 2) were examined without success for trace fossils. No references in the published literature report occurrences of trace fossils in the Ocoee Supergroup, and these rocks are regarded herein as devoid of traces.

#### Body Fossil Distribution

*Chilhowee Group.*—Despite extensive examination of all three localities, no body fossils have been discovered within the Chilhowee Group.

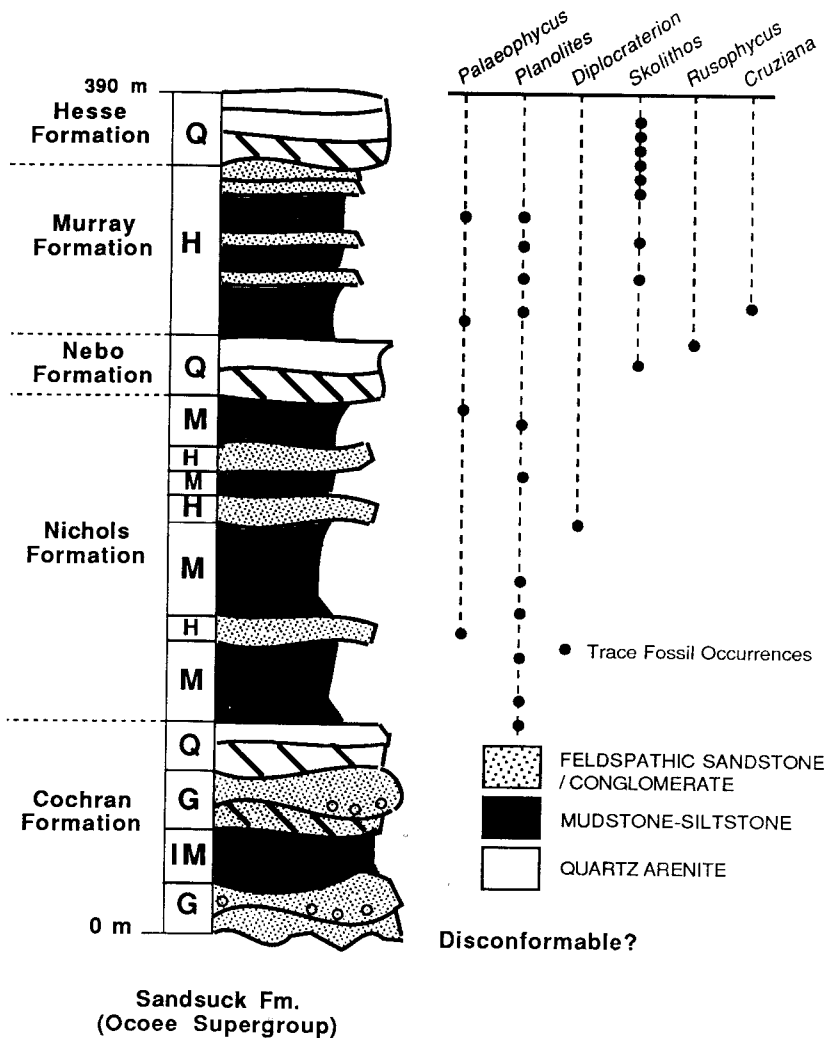


Fig. 4. Summary of trace fossil distribution in the Chilhowee Group at Bean Mountain section (loc. 1 in fig. 1). Q = quartz arenite facies, H = hummocky facies, S = sandstone facies, G = conglomerate facies. See figure 2 for key to stratification symbols. Data are from Skelly (ms).

However, body fossils (both macro- and microfauna) have been reported by previous researchers. Walcott (1890, 1891) and Keith (1895) reported the inarticulate brachiopod *Obolella* and the trilobite *Olenellus* from the Murray Shale but unfortunately did not provide locality and stratigraphic information for their collections; ostracodes and hyoliths? were also reported by the authors. Resser (1938) later described the taxonomy

of an early ostracode *Indianites tennesseensis* (= *Indiana tennesseensis*) which was apparently collected earlier by Walcott and Keith. Laurence and Palmer (1963) recollected and redescribed *Indiana tennesseensis* from the lower part of the Murray Shale at Murray Gap, Chilhowee Mountain (tables 1 and 2; fig. 3) and concluded that the Murray Shale is most certainly Lower Cambrian, whereas those stratigraphic units beneath the Murray were considered to be questionable Lower Cambrian. Acritarchs collected and described by Wood and Clendening (1982) at this same locality in the Murray Shale appear to reinforce Laurence and Palmer's (1963) earlier determination of a Lower Cambrian (Atdabanian-equivalent) stage assignment. The Chilhowee Group in much of the southern Appalachians is overlain conformably by carbonate lithologies of the Shady Formation. The Shady Formation in Alabama has yielded archaeocyathids indicative of late Placentian deposition (Bearce and McKinney, 1977, p. 469; McKinney, Tull, and Garrett, 1988, p. 279–280; Tull and others, 1988, p. 1294–1296).

*Ocoee Supergroup*.—Acritarchs collected and described by Knoll and Keller (1979) from throughout the Walden Creek Group indicate a Late Proterozoic (Vendian) age for these strata (fig. 5). Carbonate lithologies exposed within the Wilhite Formation apparently record the existence of a carbonate shelf environment within an otherwise terrigenous-dominated setting (fig. 2; Hanselman, Conolly, and Horne, 1974). No additional body fossils had been reported from any other part of the Ocoee Supergroup until the work of Unrug and Unrug (1980); see footnote 1 on page 258.

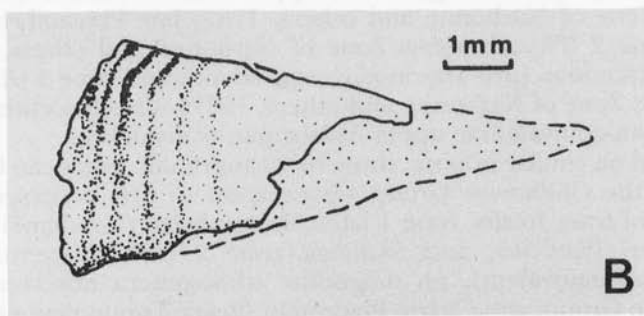
### Composite Stratigraphic Section

A composite stratigraphic section that employs all the available trace and body fossil data relevant to determination of the Precambrian-Cambrian boundary in the southern Appalachians is summarized in figure 6. Body fossils constrain the Wilhite Formation (Ocoee Supergroup) as Vendian (upper Precambrian) and the Murray Shale and higher units of the Chilhowee Group as Atdabanian-equivalent or younger (Lower Cambrian). Crimes (1987, p. 98) recently suggested that trace fossils can be used to assist in boundary assignments in cases where diagnostic body fossils are lacking. Ichnogenera with short time ranges as well as the first appearances of those with extended stratigraphic ranges are used for correlation. Crimes (1987) described three zones that occur beneath the first trilobite body fossils: zone 1 (Upper Vendian) is characterized by a low diversity assemblage characterized by simple subhorizontal burrows which include many ichnogenera that range throughout the Phanerozoic (*Planolites*, *Gordia*, *Neonereites*, *Skolithos*); zone 2 (lower Tommotian-equivalent) is characterized by a more diverse assemblage of traces which includes the first appearances of *Bergaueria*, *Phycodes*, and *Teichichnus*; and zone 3 (upper Tommotian-equivalent to lower Atdabanian-equivalent) is characterized by an assemblage that displays the greatest diversity and includes the first appearance of several ichnogenera.

era (*Astropolichnus*, *Plagiogmus*, and *Taphrhelminthopsis circularis*) and several long-ranging forms such as *Cruziana*, *Rusophycus*, and *Diplocraterion* (Crimes, 1987; Narbonne and others, 1987, p. 1280–1281). Comparison of the reported occurrences of these three assemblages with occurrences of small shelly fossil assemblages (Bengston and Fletcher, 1983; Crimes and Anderson, 1985) recognizable in strata exposed on the Burin Peninsula, Newfoundland, led Narbonne and others (1987, p. 1286) to suggest the following age re-assignments; upper half of zone 1 (*Harlaniella podolica* Zone of Narbonne and others, 1987) late Precambrian (Vendian); zone 2 (*Phycode pedum* Zone of Narbonne and others, 1987)—earliest Placentian (pre-Tommotian-equivalent); and zone 3 (*Rusophycus avalonensis* Zone of Narbonne and others, 1987)—late Placentian (lower Tommotian-equivalent to upper Atdabanian-equivalent).

Based on similar criteria, three biostratigraphic zones can be recognized in the Chilhowee Group with respect to first occurrences and diversity of trace fossils: zone 1 latest Precambrian (Vendian?) includes *Arenicolites*, *Planolites*, and *Skolithos*; zone 2 early Placentian (pre-Tommotian-equivalent), no diagnostic ichnogenera observed in the Chilhowee Group; zone 3 late Placentian (lower Tommotian-equivalent to upper Atdabanian-equivalent) includes *Cruziana*, *Diplocraterion*, and *Rusophycus*. *Palaeophycus* traces are apparently not age-diagnostic (Häntzschel, 1975). On the basis of our observations in eastern Tennessee, we would assign a late Vendian to early Placentian age to the Cochran, Nichols, and Nebo Formations and a late Placentian or younger age to the Murray, Hesse, and Helenmode Formations; fig. 6).

Simpson and Sundberg (1987, p. 123–126.) assigned a late Vendian? to late Tommotian-equivalent age to the Unicoi Formation (Cochran Formation equivalent) in Virginia (table 1). This age assignment was based on the occurrence within the Unicoi Formation of a single lobe-shaped hyporelief identified as *Rusophycus*. Field examination (by SGD) of the bedding surface from which this specimen was collected indicates that the identification of this feature as *Rusophycus*, or even as a biogenic trace, is not unequivocal (fig. 5). Furthermore, their report of a small phosphatic? conical fossil described as similar in ornamentation, size, and shape to the hyolithid *Tuojdachithes? biconvexus* (as illustrated by Brasier, 1984, fig. 3r and s) prompted them to assign a tentative age of late Tommotian or Atdabanian (= *Fallotaspis* biozone) to the overlying Hampton Formation (table 1). Simpson and Sundberg's specimen (fig. 5), however, differs substantially from that illustrated by Brasier in longitudinal profile, ornamentation, and mineral composition (phosphatic versus calcareous) precluding a reliable taxonomic assignment. If the Hampton Formation of southwestern Virginia precisely correlates with the Nichols Shale of Tennessee, then the occurrence of the hyolith? reported by Simpson and Sundberg (1987, p. 124–125) in the Hampton would require that at least some part of the Nichols (as well as all the overlying Nebo Sandstone) must be early Atdabanian-equivalent in age (as opposed to early Tommotian-equivalent as proposed herein). This apparent dis



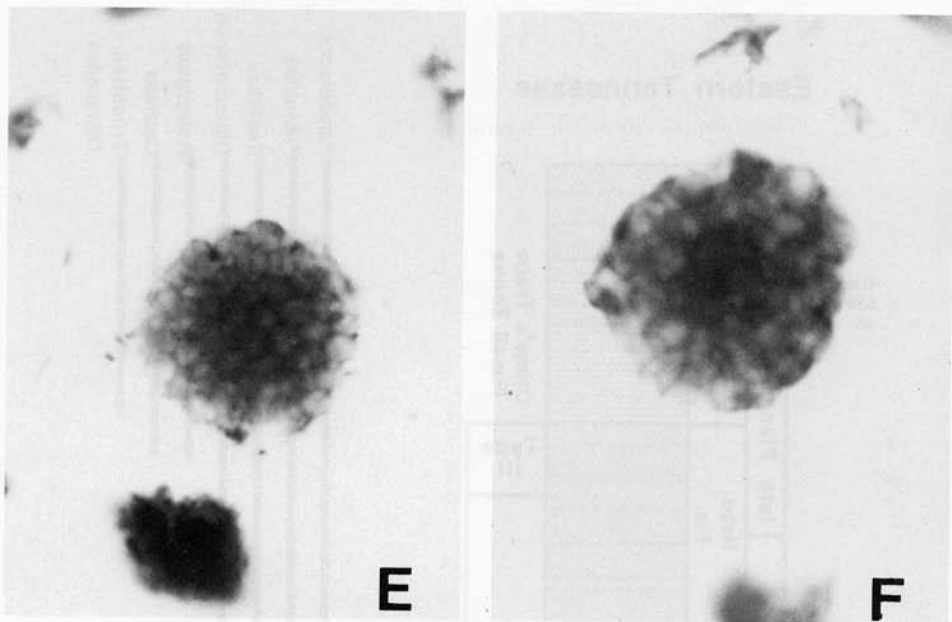


Fig. 5. Fossil discoveries pertinent to the age constraints on the Chilhowee Group in the southern Appalachians. Photographed specimens whitened with ammonium chloride sublimate. (A) and (B) are a photo and line drawing (respectively) of small phosphatic fossil tentatively identified as a hyolith? by Simpson and Sundberg (1987). (C) and (D) are photos of a lobe-shaped hyporelief identified as the arthropod trace *Rusophycus* by Simpson and Sundberg (1987). (E) and (F) are photomicrographs of Vendian acritarchs from the Shields Formation (uppermost Ocoee Supergroup) identified as *Spaerocongregus* (= *Bavlinella*) *faveolatum* by Knoll and Keller (1979). Photos provided by E. Simpson, photomicrographs provided by A. Knoll.

crepancy in the assigned ages of the coeval Cochran and Unicoi Formations as well as the overlying Nichols and Hampton Formations is difficult to resolve. In light of the inconclusive nature of the identification of these fossils and because we cannot rule out the possibility of at least some diachronism of the various Chilhowee lithologic units, a more conservative age assignment is proposed here (fig. 6).

#### *Tectono-stratigraphic effects on the nature of the Precambrian-Cambrian Boundary*

Comparison of the nature of the Precambrian-Cambrian boundary in the southern Appalachians with other well studied localities (such as the Chapel Island Formation of the Burin Peninsula, Newfoundland; Narbonne and others, 1987; fig. 7) clearly indicates that there is a strong sedimentologic and environmental control of the types of fossils (trace or body) produced and preserved in any given area. Environmental differences between these areas are dramatic; the basal Chilhowee Group of the southern Appalachians representing fluvial siliciclastic deposition, whereas the Chapel Island Formation of Newfoundland represents ma-

## Eastern Tennessee

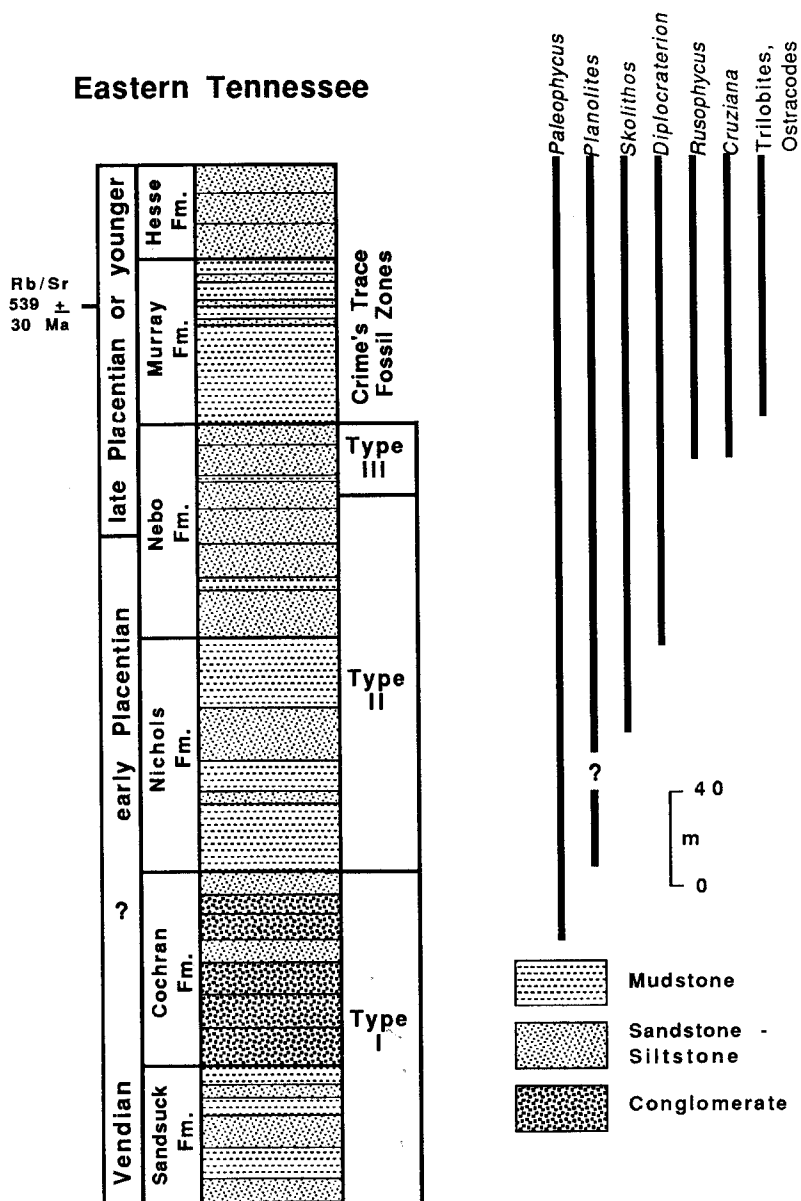


Fig. 6. Composite section showing trace and body fossil distributions plotted against a graphic log for the Chilhowee Group of East Tennessee. The Precambrian (Vendian) and Cambrian (Placentian-equivalent) age assignments based on an integrated approach (discussed in text) utilizing trace and body fossils.



rine siliciclastic and carbonate deposition. These contrasting environmental settings (of Late Proterozoic to Early Cambrian age) produced a unique suite of fossils (body and trace) which indicate that: (1) fluvial siliciclastic settings are typically devoid of trace and body fossils; (2) marine siliciclastic settings are typically dominated by trace fossils; and (3) marine carbonate settings are typically dominated by body fossils (Stanley, 1976, p. 68; Narbonne and others, 1987, p. 1279).

Because many Upper Proterozoic to Lower Cambrian sequences world-wide were apparently deposited in response to a major continental break-up (Bond, Nickelson, and Kominz, 1984, p. 341), there is a strong tectonic control on the distribution of paleoenvironments through time and space and therefore an indirect control of the nature of the Precambrian-Cambrian boundary. Study of the rift-to-passive margin transition in a number of modern and ancient examples has resulted in the recognition of a characteristic sequence of successive depositional settings as follows: (1) alluvial fan and fluvial settings, (2) incipient siliciclastic dominated marine shelf settings, and (3) stabilized, carbonate dominated (in appropriate latitudes) marine shelf settings. The nature of the Precambrian-Cambrian boundary along any continental margin may then reflect the degree to which break-up has progressed.

#### CONSTRAINTS ON THE POSITION OF THE PRECAMBRIAN-CAMBRIAN BOUNDARY IN THE SOUTHERN APPALACHIANS: OVERVIEW AND PROBLEMS

There appears to be a strong facies control on the distribution of trace and body fossils in the Chilhowee Group. In fact, these problems may ultimately prove insurmountable:

1. The basal deposits of the Chilhowee Group are largely braided fluvial/alluvial in origin (Cudzil and Driese, 1987; Skelly, ms; Walker and others, 1988; Simpson and Eriksson, 1989) and very coarse-grained. Such facies are not conducive to the recovery of either trace or body fossils. Dating the Cochran-Unicoi interval is especially critical, because it is both underlain by the Ocoee Supergroup with its Vendian acritarchs (Knoll and Keller, 1979; table 1 and fig. 5) and overlain by younger Chilhowee formations such as the Murray Shale, which contain reliable indicators of an Atdabanian-equivalent or younger age (Laurence and Palmer, 1963; Wood and Clendening, 1982). Hence, in the southern Appalachians a part of the early Placentian (pre-Tommotian-equivalent) stage may be represented by a thick sequence of fluvial or alluvial deposits.

2. The Chilhowee Group is completely devoid of any carbonate (limestone or dolostone) deposits. Therefore, the possibility of extracting shelly microfossils characteristic of the Placentian stage appears remote. Only trace fossils offer much hope of allowing for a more refined biostratigraphic zonation of the Precambrian-Cambrian boundary in the southern Appalachians, and even they have limitations (Crimes, 1987).

3. The timing of continental breakup may also prove critical. The occurrence of synrift strata of the Unicoi Formation in northeastern

Tennessee and southern Virginia (Simpson and Eriksson, 1989; Misra and Walker, 1990) suggests that the southern Appalachian margin may have been too youthful and terrigenous-clastic-dominated at the critical time intervals of approx 590 to 570 Ma to have accumulated a stratigraphic (and associated fossil) record that can be dated with a great degree of precision.

#### SUMMARY AND CONCLUSIONS

The Chilhowee Group represents a fluvial-to-marine, late synrift to early drift succession of probable late Precambrian (Vendian) to Early Cambrian (Placentian or younger) age. Age constraints are provided by: (1) the occurrence of Vendian acritarchs in the subjacent Sandsuck, Wilhite, and Shields Formations of the Ocoee Supergroup; (2) the first occurrence of *Palaeophycus* traces in the basal Cochran and Unicoi Formations; (3) the first occurrences of *Skolithos* and *Planolites* traces in the overlying Nichols and Hampton formations; (4) the abundances of well-developed arthropod (*Rusophycus*, *Cruziana*) as well as other diagnostic traces (*Diplocraterion*) in the uppermost Nebo and overlying Murray Formations; (5) the re-calculated age of  $539 \pm 30$  Ma for the Murray Formation (based on Rb-Sr ratios, as obtained from glauconite); and (6) reported occurrences (in the literature) of late Placentian or younger (Atdabanian-equivalent or younger) body fossils recovered from the Murray Shale, which include trilobites, ostracodes, inarticulate brachiopods, hyolithids, and acritarchs. Based on the recent suggestions of Crimes (1987, p. 98) that trace fossils can be used to assist in correlating the Precambrian-Cambrian boundary interval in stratigraphic sequences in which diagnostic body fossils are lacking, a late Vendian? to early Placentian (sub-Tommotian-equivalent) age is assigned to the Cochran and Unicoi Formations. An early late-Placentian (early to late Tommotian-equivalent) age is then assigned to the Nichols and Hampton Formations and the lower and middle Nebo Formation. Finally, a late Placentian or younger (Atdabanian-equivalent or younger) age is assigned to the upper Nebo, Murray, Hesse, and Helenmode Formations. The Precambrian-Cambrian boundary is probably located somewhere within the uppermost portion of Cochran-Unicoi interval. Unfortunately, this sequence is dominated by coarse-grained braided-fluvial facies, and so it may ultimately prove impossible to locate the boundary precisely because of a lack of marine facies in this critical time interval.

If the Unicoi Formation of southwestern Virginia precisely correlates (time-wise) with the Cochran and Unicoi Formations of Tennessee, then the possible occurrence of *Rusophycus* in the middle Unicoi Formation of southwestern Virginia reported by Simpson and Sundberg (1987, p. 125) suggests that the upper Cochran section in Tennessee is late Placentian (Tommotian-equivalent) age. Similarly, if the Hampton Formation of southwestern Virginia precisely correlates (time-wise) with the Nichols and Hampton Formations of Tennessee, then the occurrence of a hyolith? in the lower Hampton Formation reported by Simpson and

Sundberg (1987, p. 124–125) would indicate that the Nichols-Hampton, as well as *all* the overlying Nebo Formation, be latest Placentian (late Tommotian-equivalent to early Atdabanian-equivalent) age. More conservative stage assignments have been proposed here because of the possibility of at least some diachronism (on a regional basis) between Chilhowee formational units and the equivocal nature of the Virginia fossil discoveries. The stage assignments proposed here are therefore subject to possible revision, if and when more unequivocal body or trace fossil data become available.

#### ACKNOWLEDGMENTS

We wish to acknowledge the work of former University of Tennessee Master of Science students Mary Cudzil and Ray Skelly, whose theses provided the initial groundwork for this study. This research, over the past 6 yrs has been funded by various grants-in-aid of research from the Southeastern Section of Geological Society of America, Sigma Xi, the Discretionary Fund of the Geology Department, University of Tennessee-Knoxville, as well as unrestricted funds from the Appalachian Basin Industrial Associates consortium. Earlier versions of this manuscript were reviewed by colleagues T. W. Broadhead, K. R. Walker, and R. D. Hatcher, Jr., as well as Edward Landing (New York Geological Survey), John Rodgers (Yale), James Tull (Florida State University), P. W. Signor (University of California-Davis), and J. F. Mount (U.C.-Davis). Discussions with A. Knoll, R. F. Cormier, E. Simpson, and F. Sundberg were extremely valuable.

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