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THE TACONIC FOREDEEP AS SEDIMENT SINK AND SEDIMENT EXPORTER: IMPLICATIONS FOR THE ORIGIN OF THE WHITE QUARTZARENITE BLANKET (UPPER ORDOVICIAN-LOWER SILURIAN) OF THE CENTRAL AND SOUTHERN APPALACHIANS

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ABSTRACT. The Tuscarora and Clinch Sandstones (uppermost Ordovician to Lower Silurian) of the central and southern Appalachians are commonly considered as a widespread, homogeneous, and uniform quartzarenite blanket deposited in the foreland area of the Taconic orogen. Comparison of the stratigraphy in southwestern Virginia with that of extreme southwestern Virginia/eastern Tennessee indicates the presence of two distinct lithosomes of regional extent. The "White Sandstone Lithosome" (composed of "lower" and "upper" Tuscarora Sandstone, Poor Valley Ridge Sandstone Member of the Clinch Sandstone, and some bedsets within the Rockwood Formation) in extreme southwestern Virginia/eastern Tennessee has markedly different stratigraphic relationships to the "Heterolithic Lithosome" (composed of Rose Hill Formation, Rockwood Formation, and Hagan Shale Member of the Clinch Sandstone), when compared to the stratigraphic relationships of the two lithosomes in southwestern Virginia.

Contrary to the long-held view, the "White Sandstone Lithosome" is divisible into several distinct genetic components, each of which has its origin tied to different developmental stages of the Taconic orogen and to different eustatic sealevel events. "Lower" and "upper" Tuscarora Sandstone can be related to active compressional tectonism and foredeep subsidence, when the foredeep acted as a sediment sink for the quartz-rich detritus derived from the orogen. During a cessation of compressional tectonism, flexural isostatic uplift of the foredeep converted part of the foredeep from an active depositional site into an active erosional site. The extent of the denudation area (erosional site) is thought to be marked today by the extent of the "Tuscarora unconformity" within the central Appalachians. Quartz-rich erosional detritus was shed radially away from the denudation area and was redistributed to that part of the foredeep not affected by flexural uplift and eventually carried out of the foredeep (fill area). Redistributed detritus from the active foredeep furnished the material for the Poor Valley Ridge Sandstone of extreme southwestern Virginia/eastern Tennessee and the "Clinton" sandstone in the subsurface of Ohio. Eustatic sealevel changes might be invoked for the origin of the isolated bedsets belonging to the "White Sandstone Lithosome" within the Rockwood Formation and tentatively for the origin of the Whirlpool Sandstone in the subsurface of Ohio and West Virginia. A new location for the lithostratigraphic boundary between the Tuscarora and Clinch Sandstones within

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the Valley and Ridge is proposed, based on observations on the "White Sandstone Lithosome."

Flexural isostatic uplift of part of a foredeep provides a possible tectonic stimulus for sediment export out of a foredeep. It complements sediment export out of shallow-marine or terrestrial foredeeps through sediment bypassing, either along the axis of a foredeep or transversely across the peripheral bulge.

INTRODUCTION

The Taconic orogeny affected the eastern margin of Laurentia diachronously from the Middle Ordovician to Early Silurian (Rodgers, 1967, 1971; Williams and Hatcher, 1983). The Taconic orogeny is believed to be related to southeastward (present coordinates) subduction of Iapetan oceanic crust beneath an array of island arcs and microcontinents and to the succeeding collision of Laurentia with these terranes (Chapple, 1973; St. Julien and Hubert, 1975; Thomas, 1977; Hatcher, 1978; Hiscott, 1978; Hatcher and Odom, 1980; Rowley and Kidd, 1981; Jacobi, 1981; Williams and Hatcher, 1983; Wehr and Glover, 1985). An often cited modern analogue for this tectonic scenario is the eastern Indonesian archipelago, with the Banda Arc overriding the Sahul Shelf, the passive continental margin of Australia (Zen, 1967; Hiscott, 1978; Shanmugam and Walker, 1980; Rowley and Kidd, 1981). Concomitant with the evolution of the orogen, a system of peripheral foreland basins/foredeeps developed diachronously upon the Laurentian continental crust from present-day Alabama to Newfoundland (Hiscott, Pickering, and Beeden, 1986; Shanmugam and Lash, 1982). The foredeeps originated primarily due to loading of Laurentian lithosphere by the growing orogen, resulting in rapid downbending of the former passive continental margin of Laurentia in front of the orogen (Chapple, 1973; Jacobi, 1981; Quinlan and Beaumont, 1984). Block faulting associated with lithospheric flexure may have contributed to the rapid inception of the foredeeps (Chapple, 1973; Jacobi, 1981; Shanmugam and Walker, 1983; Bradley and Kidd, 1991). The fill of these foredeeps (clastic wedges) typically evolved from deep-marine to shallow-marine and terrestrial clastic sediments (for example, Hiscott, Pickering, and Beeden, 1986).

This paper focuses on the regionally extensive quartzarenite blanket (Tuscarora and Clinch Sandstones, fig. 1) of the central and southern Appalachians. This quartzarenite blanket is contained within the Martinsburg-Shawangunk clastic wedge (Thomas, 1977), which represents the fill of a foredeep associated with the Taconic orogeny in the central Appalachians. We attempt to show that this blanket is not homogeneous but instead is composed of genetically distinct components. We interpret each of these components to be linked to distinct stages in the evolution of the Taconic orogen and its adjacent foredeep and also to eustatic sealevel fluctuations. During the course of this coupled orogen-foredeep evolution, quartz-rich detritus was either clearly confined within the Taconic foredeep, reached the basin fringe, or even spilled over into areas adjacent to the active foredeep. Our interpretation sheds new light upon the regional stratigraphy of the area of overlap between the central and southern Appalachians and redefines the stratigraphic relationship between the Clinch and Tuscarora Sandstones. The results also contribute to the continuing discussion of the tectonics of the central Appalachians and its manifestation within the foreland area. We emphasize that "homogeneous" sandstone blankets might hide a more complex evolutionary history not only with respect to eustatic sealevel changes but also with respect to the tectonics of the orogen and the resulting behavior of the foredeep.

The data for this paper were obtained from stratigraphic and sedimentologic studies within the Valley and Ridge of southwestern Virginia to eastern Tennessee (Dorsch, ms; Driese, 1988; Driese and others, 1991; Dorsch, Bambach, and Driese, 1994). The Upper Ordovician to Lower Silurian clastic-wedge deposits studied (fig. 1) are discontinuously exposed in several Alleghanian thrust sheets (fig. 2).

GEOLOGIC SETTING

During the Late Ordovician to Early Silurian, the Martinsburg-Shawangunk clastic wedge of the central Appalachians developed from deeper water hemipelagites (basal Martinsburg Formation, McBride, 1962; Shanmugam and Lash, 1982; Drake and others, 1989), over foreland flysch ("turbiditic" Martinsburg Formation, McBride, 1962; Lash, 1988), to foreland molasse (uppermost Martinsburg Formation, Oswego Sandstone, Juniata Formation, Tuscarora Sandstone, Rose Hill Formation, to the top of Martinsburg-Shawangunk clastic wedge). The evolution of the foredeep fill mirrors the sequential development of the Taconic orogen in the central Appalachians with respect to changing plate-tectonic conditions (Dorsch, Bambach, and Driese, 1994). The locus of maximum lithospheric loading, subsidence, and thickness of the foredeep fill is situated in present-day southern Pennsylvania, Maryland, and northern Virginia (Beaumont, Quinlan, and Hamilton, 1988). In areas more distal from this locus, the Martinsburg Formation is not represented by deep-water deposits but consists of storm-dominated, shallow-marine deposits ("tempestitic" Martinsburg Formation, Reedsville Shale; Kreisa, 1981). These distal areas, including southwestern Virginia, experienced less flexural subsidence primarily due to increased distance from the main load.

A similar, but slightly older foredeep (Middle Ordovician), developed to the southwest in the southern Appalachians, with the locus of maximum subsidence and thickness of the foredeep fill centered in Tennessee (Thomas, 1977; Beaumont, Quinlan, and Hamilton, 1988). This foredeep and its fill (here referred to as the Blount foredeep and the Sevier-Bays clastic wedge, respectively) display a sequential development similar to that of the Taconic foredeep and the Martinsburg-Shawangunk clastic wedge of the central Appalachians (Rodgers, 1971; Thomas, 1977; Shanmugam and Lash, 1982; Shanmugam and Walker, 1980, 1983; Read, 1980; Drake and others, 1989). The Blount foredeep and

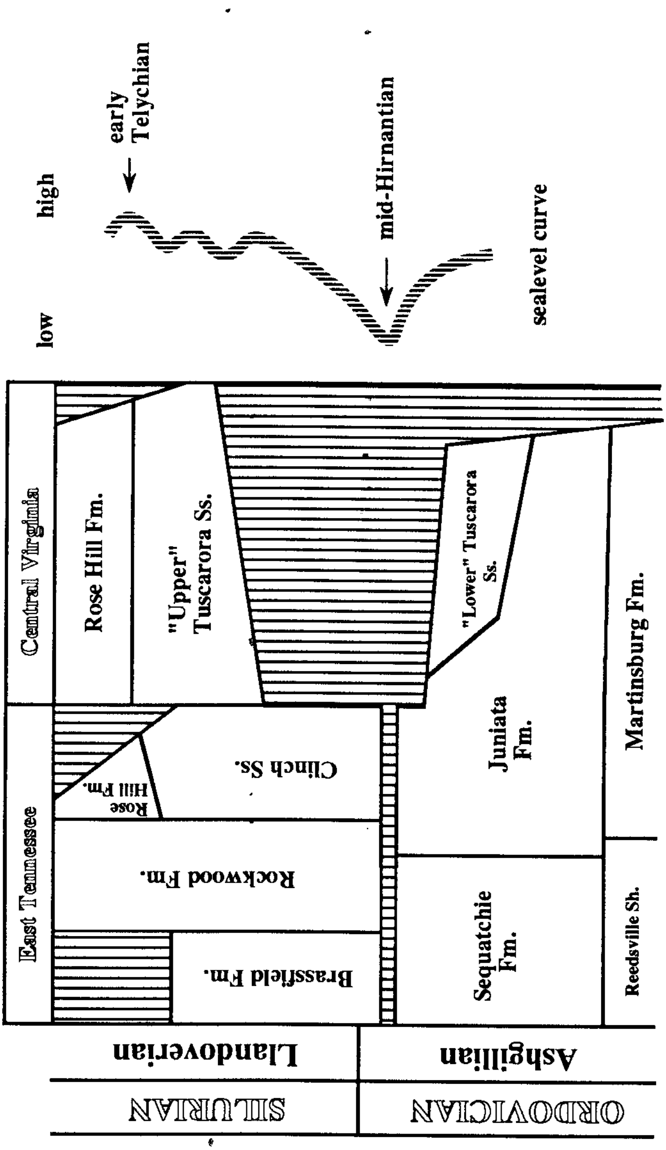

Fig. 1. Correlation chart for Upper Ordovician/Lower Silurian stratigraphic units from southwestern Virginia to eastern Tennessee. Sealevel curve is based on Johnson, Kaljo, and Rong (1991). Lacunae are indicated by vertical ruling.

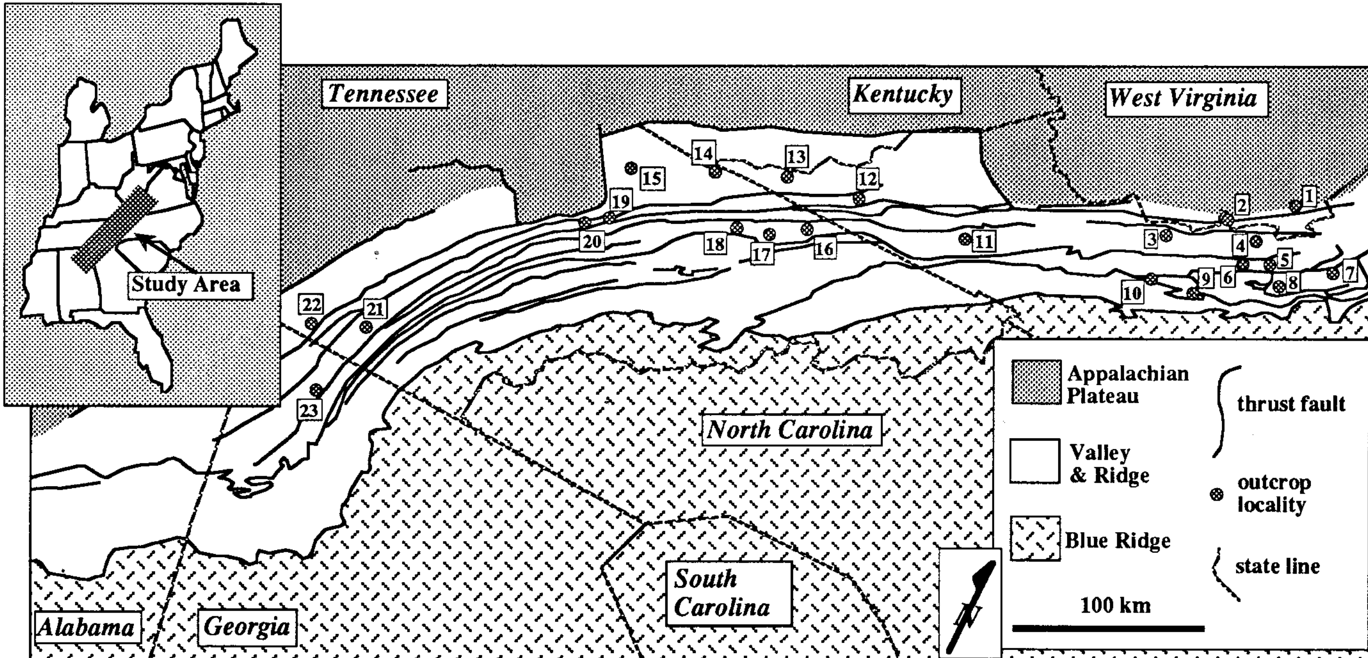

Fig. 2. Location map of the study area in the Appalachian Valley and Ridge from southwestern Virginia to southeastern Tennessee. Outcrop localities are: 1—Gap Mills, 2—Narrows, 3—South Gap, 4—Cascades, 5—Gap Mountain, 6—McCoy, 7—Catawba Mountain, 8—Fagg, 9—Draper Mountain, 10—Cove Mountain, 11—Little Moccasin Gap, 12—Stickleyville (Powell Mountain), 13—Hagan, 14—Cumberland Gap, 15—La Follette, 16—Little War Gap, 17—Flat Gap, 18—Beans Gap, 19—Lone Mountain, 20—Melton Lake, 21—Green Gap (Whiteoak Mountain), 22—Tiftonia, 23—Ringgold.

Sevier-Bays clastic wedge are related to the Blountian orogeny (Drake and others, 1989) or Blountian phase of the Taconic orogeny (Rodgers, 1953, 1971).

In central and southwestern Virginia the fringe of the Taconic foredeep overlaps the fringe of the Blount foredeep. Deposits of the Martinsburg-Shawangunk clastic wedge ("tempestitic" Martinsburg Formation, Juniata Formation, Clinch Sandstone) overlie deposits of the Sevier-Bays clastic wedge and even reach into eastern Tennessee (Thomas, 1977, see especially his fig. 4; Drake and others, 1989). The outcrops in southwestern Virginia and Tennessee visited for stratigraphic and sedimentologic studies (fig. 2) are situated in this area of overlapping clastic wedges.

REGIONAL STRATIGRAPHY AND SEDIMENTOLOGY

The following paragraphs and table 1 concisely summarize the stratigraphy and present a succinct sedimentologic interpretation of the uppermost Ordovician to Lower Silurian deposits (fig. 1) in southwestern Virginia and extreme southwestern Virginia/eastern Tennessee. More detailed process-sedimentologic interpretations of the discussed stratigraphic units are provided by Dorsch (ms) for southwestern Virginia and by Driese (Driese, 1988; Driese and others, 1991) for eastern Tennessee. Significant gaps in preserved strata are caused by the "Tuscarora unconformity" in southwestern Virginia and the Devonian Wallbridge Discontinuity in Virginia and Tennessee (fig. 1). These unconformities cut out parts of the "lower" Tuscarora Sandstone, Juniata Formation, and Martinsburg Formation ("Tuscarora unconformity") and parts of the "lower" and "upper" Tuscarora Sandstone, Clinch Sandstone, and Rose Hill Formation (Wallbridge Discontinuity).

The usage of "proximal" and "distal" refers to the present-day exposures of Taconic foredeep deposits within the Valley and Ridge. Proximal refers to outcrops close to the Blue Ridge in the southeast, whereas distal refers to outcrops close to the Cumberland Plateau in the northwest. Truly distal and proximal deposits of the Taconic foredeep are concealed beneath the Cumberland Plateau to the northwest (distal deposits) and beneath the crystalline thrust sheets, or eroded away, to the southeast (proximal deposits) of the Valley and Ridge.

Southwestern Virginia

Tuscarora Sandstone.—The Upper Ordovician to Lower Silurian clastic deposits of southwestern Virginia (fig. 1) are part of the Taconic foreland molasse. The Tuscarora Sandstone unconformably overlies the Martinsburg Formation in the southeastern (proximal) outcrop belts (fig. 2, outcrops at Fagg and Catawba Mountain) and conformably overlies the Juniata Formation in the medial and northwestern (distal) outcrop belts, except at the Gap Mills locality (fig. 2), where Tuscarora Sandstone rests unconformably upon Juniata Formation. It was discovered recently that the prominent unconformity at the base of the Tuscarora Sandstone in the proximal outcrop belt can be traced throughout the Valley and Ridge (Bambach, 1987; Dorsch, Bambach, and Driese, 1994). This unconformity, named the "Tuscarora unconformity" by Dorsch, Bambach, and Driese (1994), rests within the Tuscarora Sandstone in the medial and distal outcrop belts (except at the Gap Mills locality) and divides the Tuscarora Sandstone into the sedimentologically distinct "lower" and "upper" Tuscarora Sandstone (Bambach, 1987; Dorsch, Bambach, and Driese, 1994; fig. 3A). Table 1 provides a brief summary of the sedimentological characteristics of the "lower" and "upper" Tuscarora Sandstone.

The "lower" Tuscarora Sandstone intertongues with redbeds of the Juniata Formation and is considered a facies equivalent of the upper Juniata Formation. The present distribution of the "lower" Tuscarora Sandstone reflects original depositional geometry (decreasing thickness away from the source area in the southeast/east) and magnitude of erosional removal beneath the "upper" Tuscarora Sandstone (Dorsch, Bambach, and Driese, 1994).

The "upper" Tuscarora Sandstone overlies with a clear disconformity Martinsburg Formation, "lower" Tuscarora Sandstone, or Juniata Formation (fig. 1) and thins from distal outcrop belts in the northwest toward proximal outcrop belts in the southeast. Throughout the Valley and Ridge, a conglomeratic sandstone to sandy conglomerate marks the onset of the "upper" Tuscarora Sandstone. At Catawba Mountain, however, approx 3 m of medium-grained, white sandstone is sandwiched between the conglomerate and the Martinsburg Formation (Bambach, 1987; Dorsch, ms; Dorsch, Bambach, and Driese, 1994).

Hayes (ms) documented that the Tuscarora Sandstone in southwestern Virginia constitutes almost exclusively mature to supermature siliceous quartzarenite. The framework-grain population is dominated by monocrystalline and polycrystalline quartz, and feldspar is virtually absent; although lithic fragments occur, they do not constitute a significant portion of the framework-grain population. Gravel within the Tuscarora Sandstone is composed of vein quartz and of polycrystalline quartz with sutured subgrain boundaries (Hayes, ms). Of special importance for provenance interpretations are lithic fragments and their stratigraphic distribution, as exemplified by a suite of sandstone samples taken during construction of the tunnels through East River Mountain along I-77, along strike to the southwest of the Narrows outcrop (fig. 2; Hayes, ms). Sedimentary lithic fragments (chert, siltstone, indurated mudstone) occur in the "lower" Tuscarora Sandstone and are absent in the "upper" Tuscarora Sandstone. Polycrystalline quartz with prominent sutured subgrain boundaries, interpreted as metamorphic lithic fragments, occurs throughout the Tuscarora Sandstone but increases in abundance upsection (Hayes, ms). Schistose lithic fragments (stretched polycrystalline quartz with either muscovite or biotite) occur in the upper half of the "upper" Tuscarora Sandstone at the tunnel sections.

TABLE 1

Sedimentologic characteristics of formal and informal lithostratigraphic units covered in this report

Lithology	Bedding	Sedimentary Structures	Trace Fossils	Other
"lower" Tuscarora Sandstone (informal)				
predom. medium- to coarse-grained, partly pebbly, yellowish-white quartzarenite; some interbedded greenish-gray mudstone and siltstone	predom. medium- to thick-bedded	trough cross stratification, one example of HCS; paleoflow toward the W to N	v. abundant; *Monocraterion, Skolithos, Rusophycus; Cruziana, Planolites*; rare *Arthrophycus*; bioturbation up to 100%	
"upper" Tuscarora Sandstone (informal)				
clean, white, (pebbly) coarse- to medium-grained (some fine-grained) quartzarenite; rare gray mudstone, grayish black siltstone	predom. medium- to thick-bedded, some thin-bedded	trough cross stratification, paleoflow toward W to N; some amalgamated HCS	v. abundant; *Arthrophycus, Skolithos*; some *Monocraterion, Arenicolites, Chondrites*; rare *Rusophycus, Phycodes* (?); some pipe-rock	some acritarchs; v. rare brachiopods (*Ancillotoechia* sp.)
Rose Hill Formation				
predom. olive-brown to maroon-red mudstone, intercalated tobacco-brown to maroon-red sandstone and siltstone; sandstone: fine-grained or coarse-grained	thin- to v. thinly-bedded (fine-grained sandstone) or thin- to medium-bedded (coarse-grained sandstone)	HCS, wave-ripple cross stratification; some bioclastic lags, normal grading; gutter casts; trough and planar cross stratification (coarse-grained sandstone)	*Planolites, Skolithos, Monocraterion*; some *Chondrites, Teichichnus, Rusophycus, Cruziana*; bioturbation up to 100%	some hematitic sandstone beds; abundant body fossils (brachiopods, ostracodes, trilobites, crinoid ossicles, acritarchs, some graptolites, tentaculites, gastropods, cephalopods, pelecypods)
Hagan Shale Member (Clinch Sandstone)				
predom. gray-green mudstone, siltstone, shale; intercalated brownish-gray sandstone; sandstone: fine- to v. fine-grained, rarely medium-grained	predom. thin-bedded (sandstone)	horizontal stratification, HCS, wave-ripple cross stratification; v. rare trough cross stratification (medium-grained sandstone)	*Planolites, Palaeophycus, Chondrites*; some *Cruziana, Rusophycus, Skolithos, Monocraterion*; bioturbation up to 100%	rare hematitic sandstone beds

Poor Valley Ridge Sandstone Member (Clinch Sandstone)				
light-gray, medium- to v. coarse-grained quartz-arenite; some interbedded siltstone and mudstone; rare gravel lags	predom. medium- to thick-bedded	trough cross stratification, some ripple cross stratification, horizontal stratification; paleoflow toward NW and W; rare mudstone drapes	abundant; *Skolithos, Diplocraterion, Planolites, Palaeophycus, Rusophycus*; *Arthrophycus*; bioturbation up to 100%	v. rare brachiopods (Miller and Fuller, 1954); bioturbated reddish sandstone with desiccation cracks (Stickleyville locality)
Rockwood Formation				
gray-green shale and mudstone; intercalated sandstone, siltstone, calcarenite; sandstone: predom. dark-brown, fine- to v. fine-grained; some light colored medium- to coarse-grained	thin- to medium-bedded, amalgamated intervals thick-bedded (finer grained sandstone); thick-bedded (coarser grained sandstone)	HCS (partly amalgamated), wave-ripple cross stratification; bioclastic lags, normal grading; gutter casts; trough cross stratification; paleoflow toward NW and W (coarser grained sandstone)	*Planolites, Chondrites, Palaeophycus*	some hematitic sandstone beds; abundant body fossils (brachiopods, pelmatozoans, bryozoans, trilobites, acritarchs)
"basal transgressive sandstone" (informal)				
dark-brown sandstone; v. fine- to fine-grained; locally sand- and pebble-sized phosphate and chert grains, Juniata and Sequatchie lithiclasts, fossil fragments, and some glauconite		high-angle cross stratification, wave-ripple cross stratification	bioturbation up to 100%	

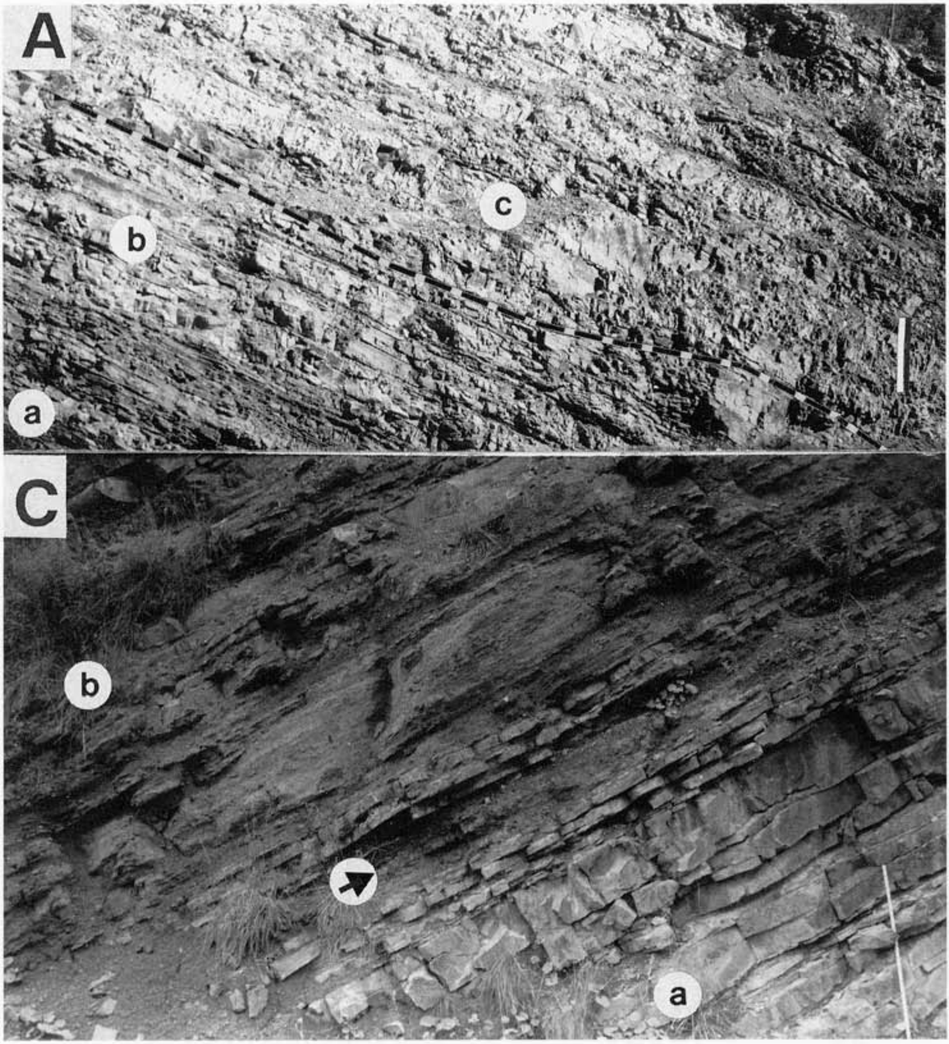

Fig. 3. Field appearance of the stratigraphic units and the two lithosomes. (A) Juniata Formation (a), "lower" Tuscarora Sandstone (b), and "upper" Tuscarora Sandstone (c) at South Gap, southwestern Virginia; stippled line indicates location of the "Tuscarora unconformity;" scale bar is approx 4 m. (B) Rose Hill Formation at South Gap, southwestern Virginia; sandstone beds encased in mudstone represent tempestites; staff is approx 1.30 m.

The "lower" Tuscarora Sandstone of southwestern Virginia constitutes the upper segment of a coarsening-upward succession, which started within the Martinsburg Formation. This can be best appreciated at the Cove Mountain locality, where the thickest section of "lower" Tuscarora Sandstone is preserved. The "lower" Tuscarora Sandstone, in

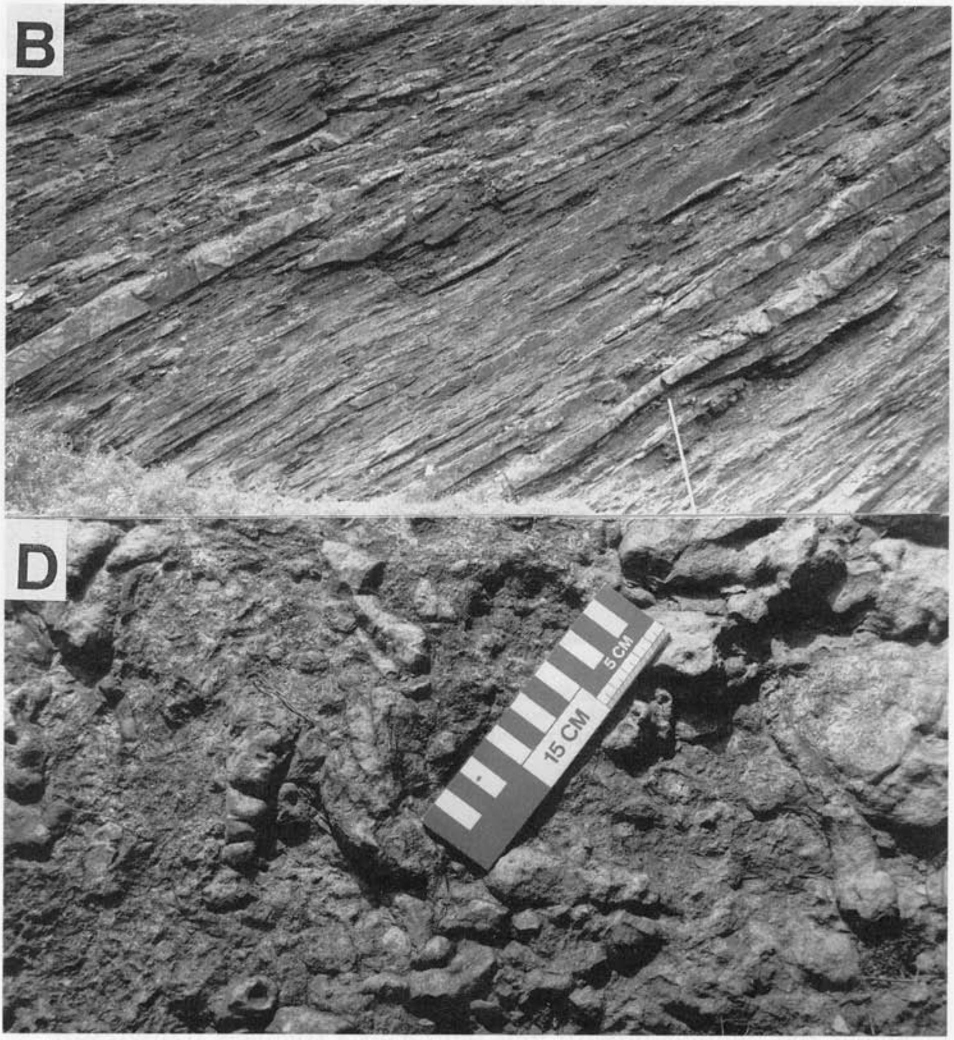

Fig. 3(C) Marine flooding-surface (at arrow) separating "upper" Tuscarora Sandstone (a) from overlying Rose Hill Formation (b) at South Gap, southwestern Virginia; arrow indicates coarse-grained interval (very coarse quartz grains, phosphatic pebbles, complete bioturbation) immediately above the flooding surface; staff is 1.50 m. (D) Bedding-plane view of top of "upper" Tuscarora Sandstone at McCoy, southwestern Virginia; overlying mudstone and shale of the Rose Hill Formation is weathered away, exposing the bedding surface covered by large (unidentified) burrows; the contact between the two stratigraphic units corresponds to the marine flooding-surface.

general, also displays a coarsening trend toward the southeast/east, the inferred location of the source area (see for example, Butts, 1940; Amsden, 1955; Pettijohn, 1970; Dennison, 1970; Hayes, ms; Whisonant, 1977). Based on stratification types and trace fossils, the "lower" Tusca-

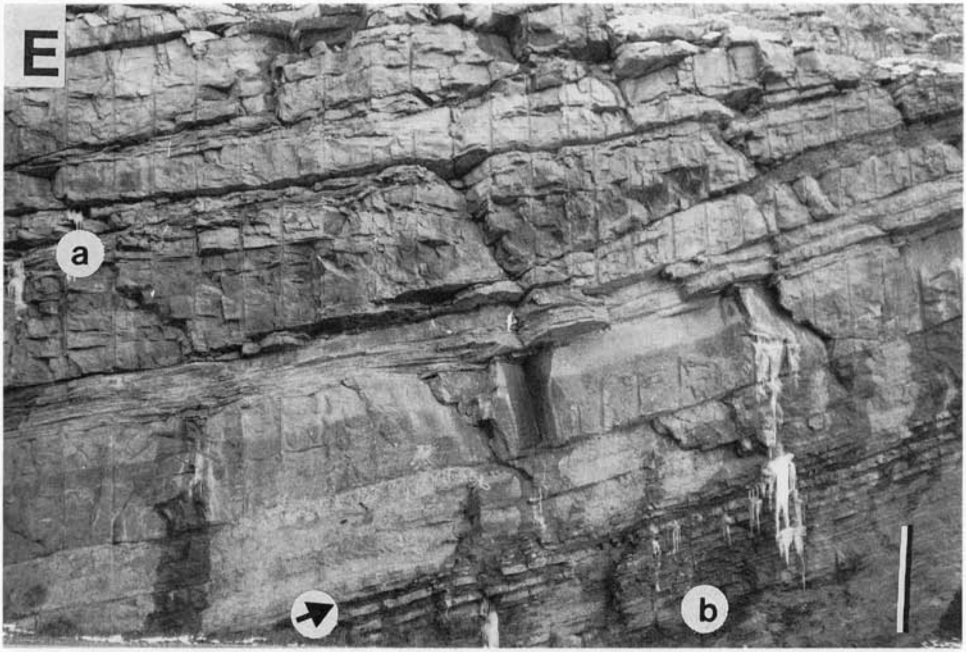

Fig. 3(E) Clinch Sandstone at Stickleyville (Powell Mountain), extreme southwestern Virginia; the contact between the Poor Valley Ridge Sandstone Member (a) and the subjacent Hagan Shale Member (b) is indicated by the arrow; scale bar is approx 2.0 m.

rora Sandstone is interpreted as storm-dominated shallow marine deposits seaward of the shoreface. The coarsening-upward succession might have shallowed to subaerial conditions, but potential sedimentological evidence for subaerial exposure is not preserved due to erosional removal beneath the "upper" Tuscarora Sandstone (Dorsch, ms).

The "upper" Tuscarora Sandstone in southwestern Virginia is interpreted as storm-dominated upper to lower shoreface deposits. This fining- and thinning-upward unit represents a complete transgressive sequence (transgressive systems tract, retrogradational parasequence) onlapping onto a subaerial erosion surface. The sequence boundary ("Tuscarora unconformity") at the base of the "upper" Tuscarora Sandstone and the transgressive surface are amalgamated, and no deposits of a lowstand systems tract are preserved (Dorsch, ms).

Rose Hill Formation.—The Rose Hill Formation conformably overlies the "upper" Tuscarora Sandstone along a marked and distinct contact. This Formation is distinct and sedimentologically different from the underlying Tuscarora Sandstone (table 1). A survey of the abundantly occurring body fossils is provided by Lampiris (ms).

The Rose Hill Formation is composed of shallow-marine deposits formed in water deeper than the "upper" Tuscarora Sandstone. The

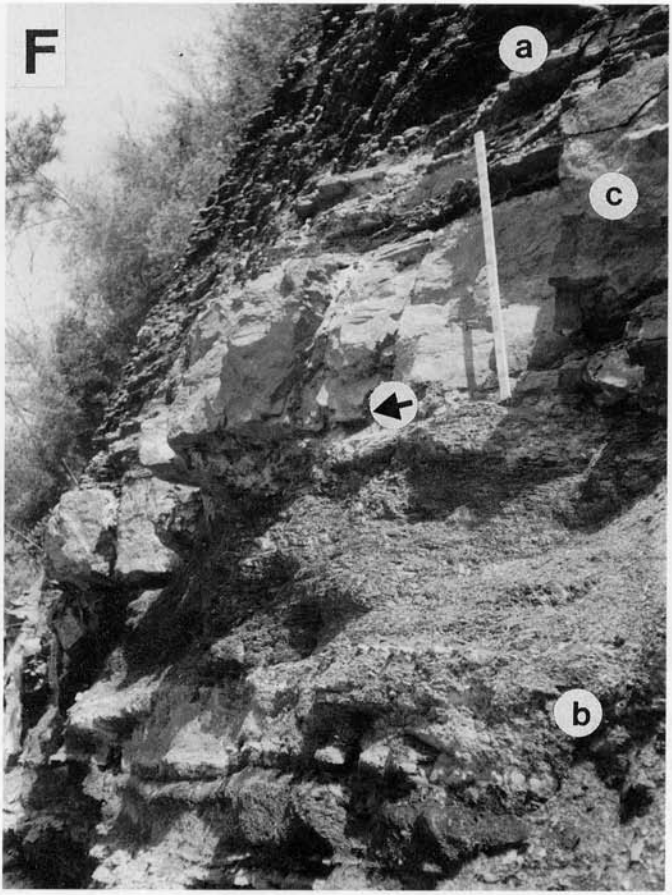

Fig. 3(F) Contact between Hagan Shale (a) and Sequatchie Formation (b) at Lone Mountain, eastern Tennessee; the distinct contact is indicated by the arrow and corresponds to a glacio-eustatic sequence boundary; the "basal transgressive sandstone" (c) forms the base of the Hagan Shale; the top portion of the Sequatchie Formation is composed of bioturbated greenish and maroon mudstone with intercalated calcarenite beds; paleosols are developed at this stratigraphic position in more proximal outcrop belts to the southeast; staff is 1.20 m.

fine-grained hummocky cross-stratified sandstone beds represent tempestites of varying distality from the source area, whereas the coarser grained, high-angle cross-stratified sandstone beds probably represent storm-dominated deposits more proximal to the shoreline. All the sandstone beds are contained within mudstone and shale, which constitute the fairweather deposits between storm events (fig. 3B). The distinct contact between the Rose Hill Formation and thė Tuscarora Sandstone throughout the study area is interpreted as a marine flooding-surface (Dorsch, ms; fig. 3C, D).

Fig. 3(G) Middle part of the Rockwood Formation at Melton Lake, eastern Tennessee; a thick unit of Poor Valley Ridge Sandstone-type bedset (between the arrows) is inserted into the mudstone-dominated heterolithic Rockwood Formation; the upper 50 cm of this bedset is formed by oolitic ironstone associated with a marine-flooding surface; the upper arrow marks three-dimensional small dunes developed and preserved on top of the ironstone bed; staff is 1.60 m.

Chronostratigraphic framework.—Biostratigraphic data for the Tuscarora Sandstone are absent because of the scarcity of body fossils. The "lower" Tuscarora Sandstone interfingers with the Juniata Formation which succeeds the *Orthorhynchula* zone at the top of the Martinsburg Formation. The Juniata Formation is customarily placed into the Ashgillian (fig. 1; Butts, 1940; Twenhofel and others, 1954; Diecchio, 1985; Springer and Bambach, 1985; Dennison and others, 1992). Evidence for the Hirnantian (latest Ashgillian, fig. 1) glacio-eustatic sealevel events, which are so prominently developed in eastern Tennessee (see below), cannot be detected in the preserved strata of the Juniata Formation and "lower" Tuscarora Sandstone of southwestern Virginia. Sedimentological evidence for these events probably was developed in southwestern Virginia but was eroded away during development of the subaerial exposure surface, which later became the "Tuscarora unconformity" upon deposition of the "upper" Tuscarora Sandstone (Dorsch, Bambach, and Driese, 1994). Deposition of the preserved "lower" Tuscarora Sandstone, therefore, had to have started before the early Hirnantian, providing a minimum lower age limit for the Tuscarora Sandstone (fig. 1).

The magnitude of the lacuna associated with the "Tuscarora unconformity" can only be estimated (Dennison and others, 1992; Bambach personal communication, 1992), because dateable fossils are not present. The marine flooding-surface marking the contact between the Tuscarora Sandstone and the Rose Hill Formation (fig. 3C) is tentatively placed into the early Telychian (Late Llandoverian, fig. 1; Lampiris, ms; Bambach personal communication, 1992). Rapid transgression and development of the marine flooding-surface at the base of the Rose Hill Formation in southwestern Virginia, therefore, can be related to the documented eustatic sealevel rise in the earliest Telychian (fig. 1; Johnson, Kaljo, and Rong, 1991).

Eastern Tennessee and Extreme Southwestern Virginia

The Silurian stratigraphy of extreme southwestern Virginia and northeastern Tennessee was summarized most recently by Miller (1976). The Clinch Sandstone of extreme southwestern Virginia is differentiated into a lower Hagan Shale Member and an upper Poor Valley Ridge Sandstone Member (Miller and Fuller, 1954; fig. 3E). To the southeast, in the outcrop belt closest to the Blue Ridge, Miller (1976) used Clinch Sandstone (undifferentiated) without its bipartite division developed in outcrops to the northwest. The lithostratigraphic term Rockwood Formation was applied in outcrop belts to the west and southwest of the Clinch Sandstone (differentiated and undifferentiated; Miller, 1976). In contrast to Miller (1976), Driese (1987, 1988) applied the bipartite nomenclature of the Clinch Sandstone also in the southeasternmost Silurian outcrop belt in Tennessee (fig. 2, outcrops at Beans Gap, Flat Gap, Little War Gap). He further extended the Rockwood Formation into outcrop belts, which Silurian strata were previously referred to by Miller (1976) as Hagan Shale and Poor Valley Ridge Sandstone.

The following synopsis of the stratigraphy and sedimentology of the Clinch Sandstone, the Rose Hill Formation, and the Rockwood Formation in eastern Tennessee and extreme southwestern Virginia is taken from Driese (1987, 1988) and Driese and others (1991) unless indicated otherwise.

Clinch Sandstone.—The Clinch Sandstone, with its lower and upper members, occurs in extreme southwestern Virginia (fig. 2, outcrops Little Moccasin Gap, Stickleyville, Hagan) and in the southeastern outcrop belts in eastern Tennessee (fig. 2, outcrops Little War Gap, Beans Gap, Flat Gap). The Clinch Sandstone grades laterally into the Rockwood Formation toward the west and southwest (Rodgers, 1953; Dennison and Boucot, 1974; Miller, 1976; Driese, 1988). The Poor Valley Ridge Sandstone Member is markedly different sedimentologically from the underlying Hagan Shale Member (table 1; fig. 3E, F). The Hagan Shale Member of the Clinch Sandstone unconformably overlies the Juniata Formation (figs. 1, 3F) and is conformably succeeded by the overlying Poor Valley Ridge Sandstone Member of the Clinch Sandstone.

The sandstones of the Hagan Shale Member and the Poor Valley Ridge Sandstone Member can also be differentiated petrographically (fig. 4, based on Schoner, ms; Marks, ms; and Fischer, ms). The framework-grain population of medium-, fine-, and very fine-grained sandstone samples of the Poor Valley Ridge Sandstone Member is exclusively quartz (predominantly monocrystalline quartz) for 95 percent of the analyzed samples, and feldspar is virtually absent. The sandstone samples of the Hagan Shale Member, in comparison, display higher amounts of feldspar, albeit the modal percentage never exceeds 9 percent. Gravel horizons, found only in the Poor Valley Ridge Sandstone, are made up exclusively of vein quartz. Schoner (ms) furthermore observed an upward increase in both textural (degree of roundness, grain-size sorting) and compositional (modal percentage of monocrystalline quartz) maturity within the Clinch Sandstone at Beans Gap.

The Hagan Shale Member represents offshore storm-sandstone beds (tempestites) dispersed within fairweather mudstone. The depositional environment was similar to that of the Rose Hill Formation of southwestern Virginia (see above), the Rose Hill Formation of extreme southwestern Virginia, and the Rockwood Formation of eastern Tennessee (see below). The Poor Valley Ridge Sandstone Member is interpreted to represent northwest-migrating, marine, subaqueous dunes. Episodic storm currents were responsible for offshore-directed bedform migration away from the shoreface. Water depth for the dunes of the Poor

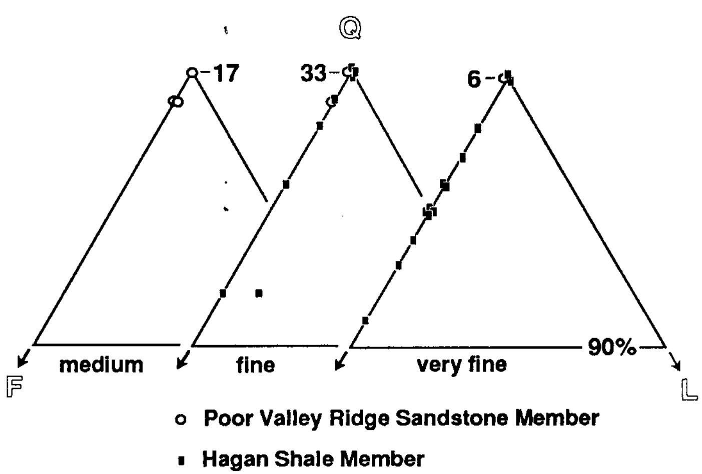

Fig. 4. QFL-diagrams for medium-, fine-, and very fine-grained sandstone samples from the Poor Valley Ridge Sandstone Member and Hagan Shale Member of the Clinch Sandstone. Modal percentages of framework grains for sandstone samples were obtained by point counting (300 points per thin section). Only the >90 percent-quartz area of the QFL-diagrams is shown. Numbers at the Q-apex indicate multiple sample plots. Samples of medium-grained sandstone cannot be compared, because sandstone of this grain size is absent within the Hagan Shale Member. Based on Schoner (ms), Marks (ms), and Fischer (ms).

Valley Ridge Sandstone Member was shallower than for the storm and fairweather deposits of the Hagan Shale Member. Preserved desiccation cracks at the top of the Poor Valley Ridge Sandstone Member at Stickleyville indicate filling of the available accommodation space and intermittent subaerial emergence on coastal sandflats (Marks, ms). Shallower water might also be indicated by mudstone-draped foresets in some beds at Beans Gap, indicating probable tidal influence (Driese, 1987).

Rose Hill Formation.—The Rose Hill Formation conformably succeeds the Poor Valley Ridge Sandstone Member of the Clinch Sandstone. In most outcrops, however, the Rose Hill Formation is missing due to erosional removal beneath the Devonian Wallbridge Discontinuity or due to erosion associated with the present-day land surface. Where remnant deposits of the Rose Hill Formation are present, such as at the Little Moccasin Gap, Hagan, or Stickleyville outcrop localities (fig. 2), the Formation is very similar in character to the Rose Hill Formation of southwestern Virginia (Miller, 1976; Miller and Fuller, 1954).

Rockwood Formation.—The Rockwood Formation is the lateral (to the west and southwest) lithostratigraphic equivalent of the Clinch Sandstone and the Rose Hill Formation (Rodgers, 1953; Dennison and Boucot, 1974). The lithostratigraphic term is applied in areas where the sandstone succession of the Poor Valley Ridge Sandstone Member of the Clinch Sandstone is not identifiable as a separate and mappable lithostratigraphic unit. In these areas (fig. 2, outcrops at Cumberland Gap, Green Gap, Melton Lake, and Lone Mountain) the Hagan Shale Member of the Clinch Sandstone and the Rose Hill Formation join due to pinch-out of the Poor Valley Ridge Sandstone Member of the Clinch Sandstone and form the Rockwood Formation (Miller, 1976). A summary of the sedimentological characteristics of the Rockwood Formation in eastern Tennessee is provided in table 1.

Of special interest are coarser grained and high-angle cross-stratified sandstone beds within the middle part of most Rockwood stratigraphic sections (fig. 3G). The bedsets rest with sharp-erosive contact on mudstone interspersed with thin sandstone beds and are commonly capped by a hematitic sandstone bed. The bedsets are overlain in turn by interbedded mudstone and thin sandstone beds. At Green Gap, most of the sandstone beds are stained red (Easthouse and Driese, 1988). These sandstone beds are reminiscent of the sandstone facies, which constitutes the bulk of the Poor Valley Ridge Sandstone Member of the Clinch Sandstone.

The Rockwood Formation is interpreted as storm-dominated, shallow-marine deposits. Offshore mud deposition within the Early Silurian epicontinental seaway was episodically interrupted by storms, producing the heterolithic succession of fairweather mudstone and shale punctuated by sandy tempestites. The bedsets of Poor Valley Ridge-like sandstone most likely represent shallow-marine shoreface deposits.

"Basal Transgressive Sandstone."—The base of the Hagan Shale Member of the Clinch Sandstone and the base of the Rockwood Formation are

marked by a distinctive, thin (≤ 3 m), dark-brown sandstone, informally termed the "basal transgressive sandstone" (fig. 3F, Gogola, ms; Driese and others, 1991). This unit is regionally extensive and can be traced from extreme southwestern Virginia, through eastern Tennessee, into northern Georgia and Alabama, where it resides at the base of the heterolithic Red Mountain Formation (Gogola, ms; Bolton, ms). The "basal transgressive sandstone" is overlain by shale with interbedded thin tempestites of the Hagan Shale (fig. 3F) or Rockwood Formation in eastern Tennessee and extreme southwestern Virginia. The "basal transgressive sandstone" overlies the Juniata or Sequatchie Formations, which display evidence of subaerial emergence and erosion. Vertisol-like claystone paleosols are developed in the top part of estuarine to tidal-flat deposits of the Juniata Formation at Beans Gap and Stickleyville (fig. 2; Driese and Foreman, 1992). The "basal transgressive sandstone" truncates the paleosols, and marine burrows reach down from the overlying transgressive sandstone sheet into the upper part of the decapitated paleosols (Driese and Foreman, 1991).

The "basal transgressive sandstone" represents a regionally extensive, transgressive sandstone sheet, which is interpreted as having developed during erosional shoreface retreat (Gogola, ms). The sandstone sheet is considered to constitute an amalgam of shoreface to proximal inner offshore deposits (Gogola, ms). Complete bioturbation and authigenic glauconite and phosphate point to a low sedimentation rate. The coarser grains and most of the finer sediment represent eroded and reworked material from the underlying redbeds of the Juniata and Sequatchie Formations. The sandstone sheet can be termed a condensed transgressive lag. The overlying deposits of the Hagan Shale Member or the Rockwood Formation represent more distal offshore environments, in marked contrast to the shallow-marine environments represented by the "basal transgressive sandstone" (Gogola, ms).

Chronostratigraphic framework.—The Juniata Formation and the Sequatchie Formation are regarded as middle and late Ashgillian in age (Rodgers, 1953; Twenhofel and others, 1954; Miller and Fuller, 1954; Milici and Wedow, 1977), whereas the Clinch Sandstone (with its two members) and the Rockwood Formation are placed into the Llandoverian (Butts, 1940; Rodgers, 1953; Berry and Boucot, 1970). The "basal transgressive sandstone" and the underlying exposure surface are probably related to the glacio-eustatic sealevel events in the Ashgillian (fig. 1; Gogola, ms; Driese and others, 1991). Scarce biostratigraphic data from outcrops close to the Appalachian Plateau seem to indicate that strata underlying the "basal transgressive sandstone" reach into the upper Ashgillian, whereas strata directly above the "basal transgressive sandstone" can be placed into the lowermost Llandoverian (Gogola, ms; Driese and others, 1991). The development of paleosols and subaerial exposure surfaces in the top part of the Juniata and Sequatchie Formations, therefore, can be correlated with the end-Ordovician eustatic sealevel fall linked to glaciation centered in present-day northern Africa (for example, Sougy and Lécorché, 1963; Bennacef and others, 1971). The "basal transgressive sandstone," then, is regarded as evidence for the swiftly ensuing eustatic sealevel rise due to ablation of the Saharan glaciers. These glacio-eustatic sealevel events occurred from the beginning of the Hirnantian to the mid-Hirnantian (fig. 1; Brenchley, 1989). The "basal transgressive sandstone," if interpreted as a condensed transgressive lag, must be diachronous. The degree of diachroneity, however, can be regarded as small, because the glacio-eustatic sealevel rise in the mid-Hirnantian is believed to have been rapid (Brenchley, 1989; Brenchley and others, 1994). The "basal transgressive sandstone," therefore, might be useful as a *practical* chronostratigraphic marker, similar to some condensed shell deposits in the Miocene of Maryland (Kidwell, 1989). In addition, the "basal transgressive sandstone" constitutes a convenient lithostratigraphic marker for the (approximate) placement of the Ordovician-Silurian systemic boundary throughout the southern Appalachians (Gogola, ms; Driese and others, 1991). The chronostratigraphic placement of this systemic boundary, however, has to be sought in the lowermost part of the Rockwood Formation, Hagan Shale Member, and Red Mountain Formation. The exact temporal extent of the lacuna associated with the regional disconformity between Ashgillian redbeds and the "basal transgressive sandstone" cannot be ascertained, due to the paucity of adequate biostratigraphic data. The close temporal proximity of glacio-eustatic sealevel fall and rise within the Ashgillian (Brenchley, 1989; Brenchley and Storch, 1989; Brenchley and others, 1994) and the limited biostratigraphic data from outcrops close to the Appalachian Plateau (Gogola, ms), however, make it highly probable that the duration of time not recorded by rock is rather small.

Biostratigraphic data indicate that the Rockwood Formation spans most of the Llandoverian (Easthouse and Driese, 1988). The original temporal upper limit of the Rockwood Formation remains unknown, because it is truncated by a pre-Devonian erosion surface. Lack of biostratigraphic information renders it impossible to assign an age to the transition from Hagan Shale Member to Poor Valley Ridge Sandstone Member of the Clinch Sandstone. The Rose Hill Formation in extreme southwestern Virginia and eastern Tennessee seems to commence earlier than the Rose Hill Formation in southwestern Virginia. Occurrences of *Eocoelia hemisphaerica* within the lowermost Rose Hill Formation at Little Moccasin Gap (Miller 1976) and Hagan (Miller and Fuller, 1954, Bambach unpublished data, personal communication, 1992) indicate that deposition of Rose Hill Formation started before the Telychian (and before the earliest Telychian eustatic sealevel event), probably in the late to middle? Aeronian (based on the range of E. *hemisphaerica* as given by Bassett, 1989).

DEFINITION AND EXTENT OF REGIONAL LITHOSOMES

The stratigraphic units overlying the Upper Ordovician redbed succession throughout the central and southern Appalachians can be grouped into a "White Sandstone Lithosome" and a "Heterolithic Lithosome." Both lithosomes are distinct in their characteristics (table 2) and are of regional extent.

In southwestern Virginia, the Upper Ordovician redbed succession is overlain by and grades into the "White Sandstone Lithosome," which is split into two parts by the "Tuscarora unconformity" (fig. 5). The "White Sandstone Lithosome" is succeeded by the "Heterolithic Lithosome" along a distinct and sharp contact. Farther to the southwest, in extreme southwestern Virginia and eastern Tennessee, a lower "Heterolithic Lithosome" occurs between the Upper Ordovician redbed succession and the onset of the "White Sandstone Lithosome." The "Heterolithic Lithosome" commences with the "basal transgressive sandstone" throughout the area (fig. 5). The "White Sandstone Lithosome" in extreme southwestern Virginia and eastern Tennessee is completely encased within the "Heterolithic Lithosome," which overall is the dominant lithosome in these areas. The contact between the two lithosomes is conformable (distinct to gradational) vertically and intertonguing and pinching-out laterally. The regional distribution of the two lithosomes is depicted, furthermore, in three stratigraphic cross sections constructed perpendicular to structural strike (fig. 6). The thickness of the "White Sandstone Lithosome" in southwestern Virginia (fig. 6, sec. A-A′) is severely influenced by erosional removal of strata prior to deposition of the upper part of the lithosome. The "White Sandstone Lithosome" in northeastern Tennessee (fig. 6, sec. B-B′) does not contain the "Tuscarora unconformity" and thins markedly toward the northwest, where it pinches out into the "Heterolithic Lithosome." The present-day erosion surface and the Devonian Wallbridge Discontinuity render it impossible to depict the remaining parts of the Silurian stratigraphic interval. It is reasonable to assume, however, that the "Heterolithic Lithosome" once extended to the southeast, eventually covering the "White Sandstone Lithosome." The cross section in southeastern Tennessee (fig. 6, sec. C-C′) reveals that the "White Sandstone Lithosome" thins markedly from

TABLE 2

Salient distinguishing characteristics of the 'White Sandstone Lithosome' and the 'Heterolithic Lithosome.' See text for discussion

'White Sandstone Lithosome'	'Heterolithic Lithosome'
sandstone-dominated (>90%)	mudstone-dominated, with interbedded sandstone, siltstone (<35%)
coarser grained	finer grained
white quartzarenite	darker colored
high-angle cross stratification	wave-ripple cross stratification, HCS, planar stratification
"lower" and "upper" Tuscarora Sandstone	Hagan Shale Member
Poor Valley Ridge Sandstone Member	Rockwood Formation
beds/bedsets within Rockwood Formation	Rose Hill Formation

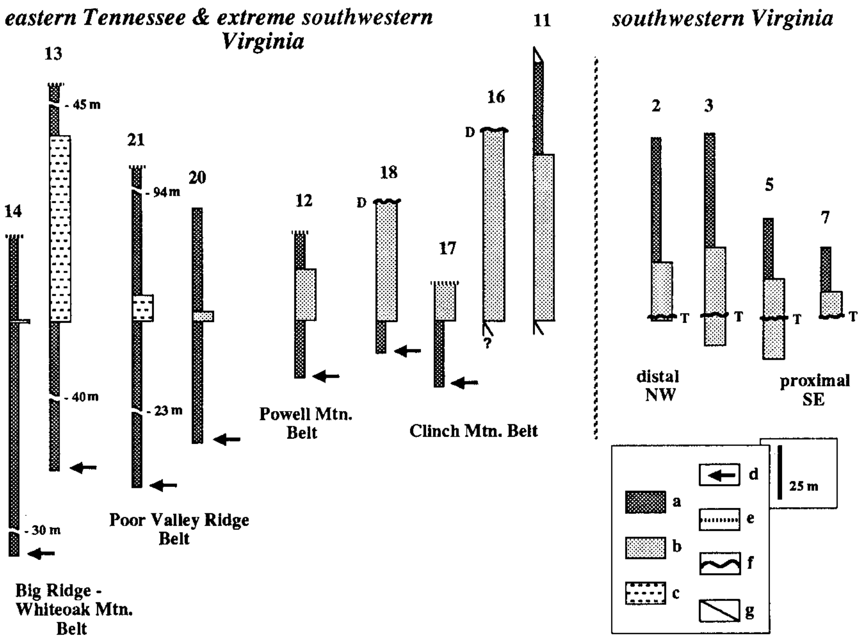

Fig. 5. Representative measured sections of the stratigraphic interval overlying the Upper Ordovician redbed succession from southwestern Virginia to eastern Tennessee. The sections portray the distribution of the "Heterolithic Lithosome" and "White Sandstone Lithosome." For location of sections please see numbered outcrops in figure 2. Legend: a—"Heterolithic Lithosome;" b—"White Sandstone Lithosome;" c—interfingering of "Heterolithic Lithosome" with "White Sandstone Lithosome;" d—location of "basal transgressive sandstone;" e—present-day erosion surface; f—unconformity, T = "Tuscarora unconformity," D = Wallbridge Discontinuity; g—covered interval. Some measured sections have section omitted (in m) for ease of illustration.

the northeast to the southwest and continues to thin toward the northwest/west.

The stratigraphic cross sections clearly show that the "White Sandstone Lithosome" in Tennessee and extreme southwestern Virginia occurs as an oddity within the "Heterolithic Lithosome," which otherwise dominates the exposed Lower Silurian stratigraphic interval. The cross sections also portray the markedly different stratigraphic relationships of the two lithosomes to each other and to the underlying redbed succession, when the areas of southwestern Virginia (and to the northeast) and extreme southwestern Virginia/eastern Tennessee are compared.

ISOSTATIC BASIN REBOUND AND ITS INFLUENCE ON THE ORIGIN OF THE "WHITE SANDSTONE LITHOSOME"

The Taconic foredeep in the central Appalachians and its foredeep fill, the Martinsburg-Shawangunk clastic wedge, evolved sequentially, closely tied to the evolution of the Taconic orogen. This coupled orogen-

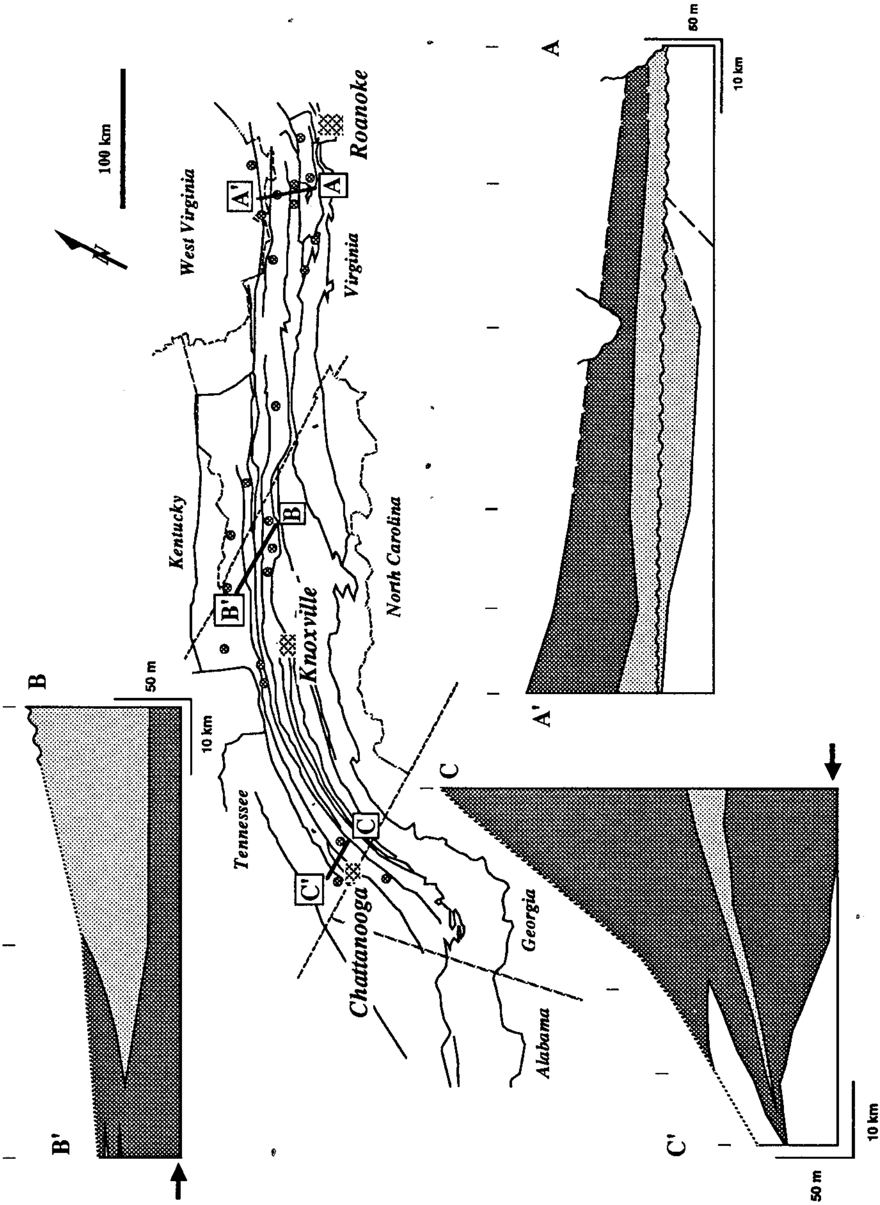
100 km
N
West Virginia
Virginia
Roanoke
A'
A
Kentucky
North Carolina
Knoxville
B
B'
Tennessee
C
C'
Chattanooga
Georgia
Alabama
A
A'
50 m
10 km
B
B'
50 m
10 km
C
C'
50 m
10 km

Figure 6

foredeep evolution is the expression of the prevailing plate tectonic regime during the Late Ordovician to Early Silurian along the eastern (present coordinates) Laurentian continental margin (Dorsch, Bambach, and Driese, 1994). The Taconic foredeep evolved from a deep-marine underfilled stage to a shallow-marine/terrestrial underfilled or overfilled stage. This scenario is typical for peripheral foredeeps which develop on thinned continental crust of former passive continental margins loaded by a growing orogen (Dickinson, 1974). Figure 7 schematically illustrates part of this sequential development, as expressed in the evolution of the Martinsburg-Shawangunk clastic wedge from foreland flysch to foreland molasse (*sensu* Ricci Lucchi and Ori, 1984).

Of particular interest for our discussion is a phase of flexural isostatic rebound of the foredeep, which is believed to be manifest prominently in the "Tuscarora unconformity." The "Tuscarora unconformity" is interpreted here to represent a rebound unconformity which developed following the completed accretion of (an) outboard terrane(s) to Laurentia (Dorsch, Bambach, and Driese, 1994). Completed accretion led to cessation of convergence and thrusting, which halted load-induced foredeep subsidence. During the ensuing phase of rearrangement of the plate-tectonic regime, erosion and extensional tectonism thinned the orogen, resulting in flexural uplift of the orogen and its adjacent foredeep as an isostatic response to the negative load (fig. 7D; Dorsch, Bambach, and Driese, 1994). Within the foredeep, relative magnitude of flexural uplift decreased radially away from the locus of maximum loading (Beaumont, Quinlan, and Hamilton, 1988). At present, we are not able to quantify the relative proportions of erosion and extensional tectonism for thinning of the orogen. The magnitude and distribution of flexural uplift within the foredeep, however, were probably not affected by a change in the relative proportions of these two factors (Jamieson and Beaumont, 1988). The erosional surface within the foredeep, created during isostatic rebound, was covered during resumption of deposition of Tuscarora Sandstone ("upper" Tuscarora Sandstone), giving rise to the "Tuscarora unconformity" (fig. 7E). This renewed phase of foredeep sedimentation was primarily related to resumed load-induced foredeep subsidence, caused by accretion of another terrane(s) to the ocean-facing side of the orogen (Dorsch, Bambach, and Driese, 1994), in concert with eustatic sealevel rise during the Early Silurian (Johnson, Kaljo, and Rong, 1991).

Fig. 6. Stratigraphic cross sections (on palinspastic base) displaying the stratigraphic relationship and distribution of the "Heterolithic Lithosome" and "White Sandstone Lithosome." Locations of cross sections are indicated on the base map. For identification of outcrop localities please see figure 2. Dense stipple pattern depicts the "Heterolithic Lithosome," the lighter stipple pattern depicts the "White Sandstone Lithosome." The arrow at the base of cross sections B-B′ and C-C′ indicates the location of the "basal transgressive sandstone." Areas of cross sections left unpatterned correspond to redbed succession or carbonate rocks. Palinspastic base for section A-A′ based predominantly on balanced cross sections by B. A. Couzens and W. M. Dunne (unpublished data), palinspastic base for sections B-B′ and C-C′ provided by Roeder and Witherspoon (1978).

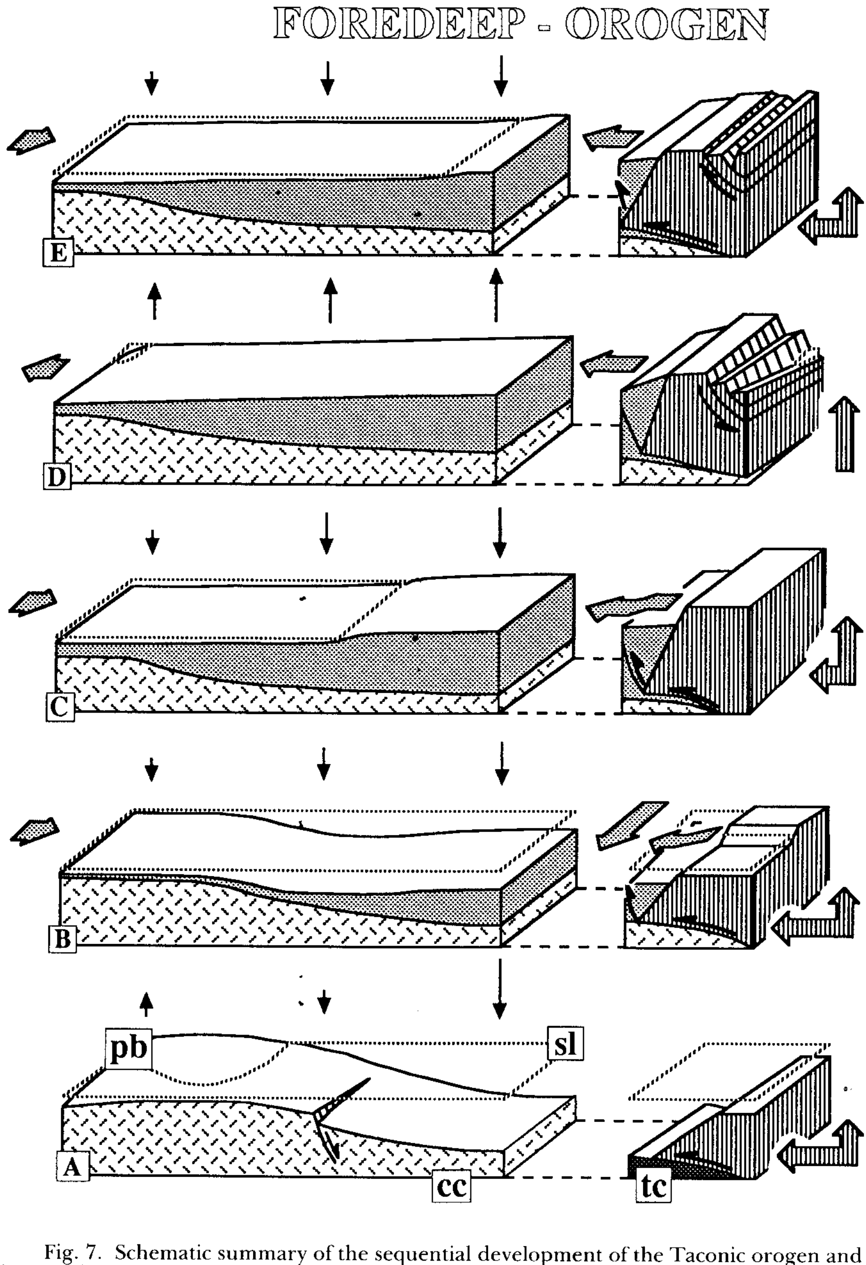

Fig. 7. Schematic summary of the sequential development of the Taconic orogen and its associated foredeep during the Taconic orogeny in the central Appalachians (from Dorsch, Bambach, and Driese, 1994). The foredeep fill (clastic wedge) evolved from pre-foreland flysch (basal Martinsburg Formation (A); over foreland flysch (Martinsburg Formation, Reedsville Shale (B); to foreland molasse (uppermost Martinsburg Formation, Oswego Sandstone, Juniata Formation, "lower" Tuscarora Sandstone (C); panel D depicts the phase of isostatic basin rebound (flexural uplift), that interrupted deposition of the foreland molasse; foreland molasse deposition resumed with the "upper" Tuscarora Sandstone. Vertically ruled arrows indicate relative magnitude of lateral translation of the orogen versus topographic uplift; stippled arrows indicate dominant dispersal system and sediment derivation; thin vertical arrows indicate relative magnitude of foreland subsidence and uplift. Abbreviations: cc—continental crust; tc—transitional crust; sl—sealevel; pb—peripheral bulge.

Flexural uplift of part of the foredeep as an isostatic response to erosional thinning (Beaumont, 1981; Stockmal, Beaumont, and Boutilier, 1986) or to both erosional and extensional thinning of the orogen (Jamieson and Beaumont, 1988; Beaumont, Quinlan, and Hamilton, 1988) can be viewed as an integral part in the evolution of an orogen-foredeep couplet following cessation of compressional tectonism. Several authors have pointed out that this phase is expressed as a regional unconformity developed within the foredeep fill/clastic wedge (Heller and others, 1988; Jamieson and Beaumont, 1988; Cant and Stockmal, 1989).

Exposed more proximal parts of the Taconic foredeep reveal that erosion associated with isostatic basin rebound cut down into the Martinsburg Formation (Bambach, 1987; Diecchio, 1985; Dennison and Head, 1975). Erosion provided detritus for deposition away from the erosional sites. Erosional detritus was mainly derived from the "lower" Tuscarora Sandstone and also from the Juniata Formation. The detritus, therefore, is expected to be rich in quartz. Based on the recognition of the "Tuscarora unconformity" and its geodynamic interpretation, we propose that erosional detritus produced during flexural uplift of part of the Taconic foredeep constituted the material deposited as the more "distal" parts of the "White Sandstone Lithosome" in extreme southwestern Virginia and eastern Tennessee.

The model of flexural isostatic rebound of part of the Taconic foredeep and cannibalization and redistribution of foredeep deposits during a lull in compressional tectonism correspond to a general model of foredeep behavior outlined previously by Heller and others (1988). These authors attributed the spreading of coarse-grained sediment to flexural isostatic rebound of the orogen and the adjacent proximal foredeep, during what they termed the post-orogenic phase. Proximal foredeep deposits were eroded and redistributed toward the distal part of the foredeep and beyond, while an erosional surface was cut in the more proximal foredeep (Heller and others, 1988).

Figure 8 outlines the conceptual model of sediment derivation for the "White Sandstone Lithosome" in extreme southwestern Virginia and eastern Tennessee. Flexural isostatic rebound of part of the Taconic foredeep established an erosional surface (fig. 8, denudation area) which sloped radially away from the locus of maximum uplift situated in present-day southern Pennsylvania, Maryland, and northern Virginia (Beaumont, Quinlan, and Hamilton, 1988). In southwestern Virginia, this denudation surface was inclined toward the southwest and west. Flexural uplift of part of the foredeep terminated deposition of Tuscarora Sandstone ("lower" Tuscarora Sandstone) and led to erosion of predominantly "lower" Tuscarora Sandstone but also of Juniata Formation, Oswego Sandstone, and Martinsburg Formation. The part of the foredeep designated as the "denudation area" was converted from an active depositional site (=sediment sink) to an active erosional site (=sediment exporter). Erosional detritus was shed along the paleoslope

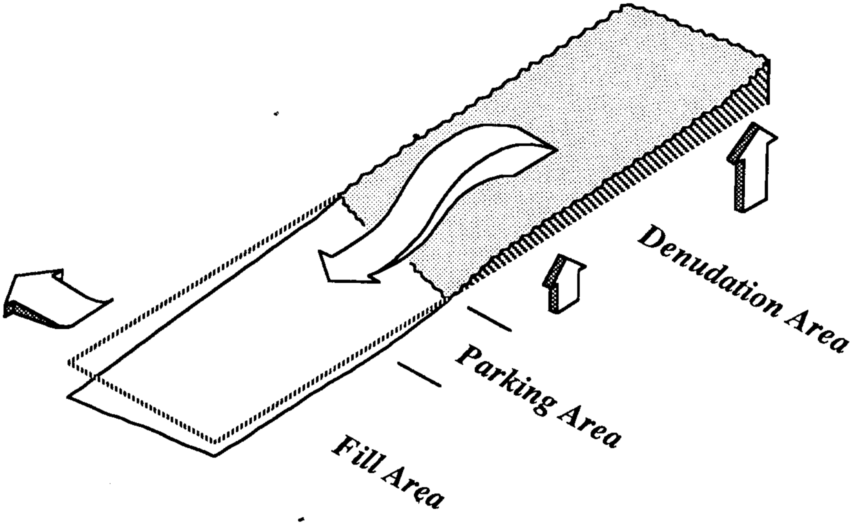

Fig. 8. Conceptual model of sediment derivation for the "White Sandstone Lithosome" in extreme southwestern Virginia and eastern Tennessee. Vertical arrows indicate relative magnitude of isostatic basin rebound (flexural uplift); wavy line and stipple pattern outline area of active erosion (denudation area); broken line depicts sealevel and frames area of active sedimentation (parking area, fill area); large horizontal arrow indicates route of detritus supply from area of uplift and erosion into area of available accommodation space; small horizontal arrow indicates movement direction of subaqueous bedforms within the accommodation space due to ambient storm conditions. Model was inspired by Ricci Lucchi's model (1987) for derivation of Apenninic megaturbidites but, naturally, is strongly modified.

from the denudation area into a "parking area" and a "fill area" in the more distal parts of the Taconic foredeep not affected by flexural uplift, at the fringe of the foredeep, and beyond. The detritus was remolded into northwest-migrating subaqueous two-dimensional and three-dimensional dunes by the ambient storm system (Driese and others, 1991) and was redistributed into and within the fill area. The accommodation space of fill and parking area is thought to have been created by the overall eustatic sealevel rise commencing in the mid-Hirnantian and lasting through the Early Silurian (Brenchley, 1989; Johnson, Kaljo, and Rong, 1991). This accommodation space was not destroyed by tectonism, because it was beyond the reach of flexural isostatic rebound.

The present-day distribution of the denudation area is outlined by the occurrence of the "Tuscarora unconformity," whereas the parking area is a rather narrow belt marginal to the area covered by the "Tuscarora unconformity." The fill area is represented by the area beyond the occurrence of the "Tuscarora unconformity," where the "White Sandstone Lithosome" occurs sandwiched within the "Heterolithic Lithosome" (figs. 5, 6). In this area distant from the sites of the active Taconic orogeny, the "Heterolithic Lithosome" represents the "normal" sedimentation, which was abruptly interrupted by the incursion of sediments of the "White Sandstone Lithosome."

Detritus was likely not only shed toward the southwest into present-day Tennessee but also along the paleoslope toward the west, northwest, and north, radially away from the area of maximum flexural isostatic uplift. A "White Sandstone Lithosome" with similar stratigraphic relationships to the surrounding deposits, as described from the outcrops of extreme southwestern Virginia and eastern Tennessee, is expected to appear in a north/northwest direction.

Figure 9 (from Lukasik, ms) is a lithostratigraphic cross section depicting the Lower Silurian stratigraphic relationships in the subsurface of southern Ohio, which correspond to the ones in eastern Tennessee and can be traced into western West Virginia (Lukasik, ms; Coogan, 1991). The "White Sandstone Lithosome" encompasses the "Clinton" sandstone, a drillers' term for sandstones in the subsurface of Ohio, which is equivalent to the Tuscarora Sandstone farther to the east in West Virginia (Lukasik, ms). In southern Ohio, the "Heterolithic Lithosome" consists of the Cabot Head Shale and Lulbegrud Shale and displays an intimate interfingering relationship with the "White Sandstone Lithosome" (Lukasik, ms). The "White Sandstone Lithosome" thins toward the west/northwest, away from the source area (denudation area) developed within part of the Taconic foredeep farther to the southeast/east.

A small unit of "White Sandstone Lithosome" occurs in the cross section below the main part of the "White Sandstone Lithosome" and the

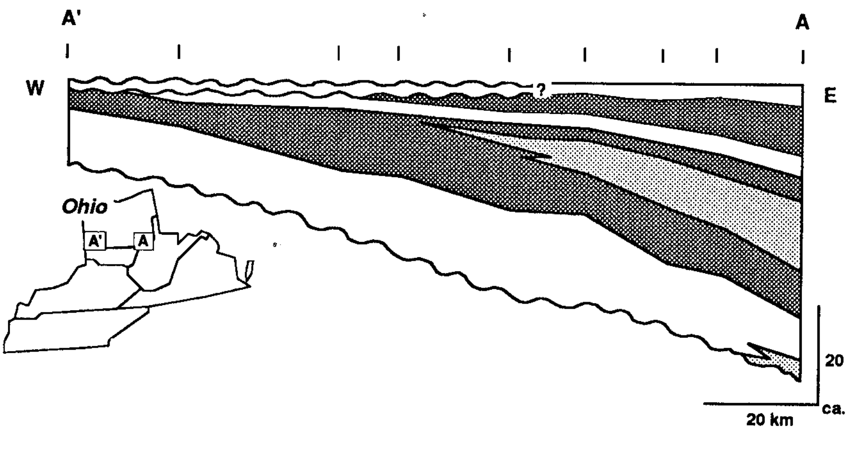

Fig. 9. Stratigraphic cross section showing the distribution of the "Heterolithic Lithosome" and "White Sandstone Lithosome" in the subsurface of southern Ohio. Compare to stratigraphic cross sections in figure 6. Dense stipple pattern depicts the "Heterolithic Lithosome," the lighter stipple pattern depicts the "White Sandstone Lithosome." The unpatterned areas within the cross section correspond to carbonate deposits and indicate the interfingering of the distal portion of the Martinsburg-Shawangunk clastic wedge with non-clastic-wedge deposits (modified from Lukasik, 1988, his fig. 10).

"Heterolithic Lithosome" (fig. 9). This is the distal end of the Whirlpool Sandstone, which overlies the Upper Ordovician redbed succession (here Queenston Shale) along a regional disconformity and interfingers with the Brassfield Formation (Lukasik, ms). The occurrence of the Whirlpool Sandstone along a disconformity above redbeds corresponds to the location of the "basal transgressive sandstone" in extreme southwestern Virginia and eastern Tennessee.

Sealevel drop is considered to be responsible for creation of the subaerial exposure surface on top of the redbed succession (fig. 10A, B). It also made quartzarenite beds of the "lower" Tuscarora Sandstone within the more proximal foredeep available to erosion. During sealevel fall, quartz-rich detritus prograded toward the northwest, closely following the retreating shoreline. Beyond the depositional limit of the "lower" Tuscarora Sandstone, the quartz-rich detritus came to rest on top of the redbed succession (fig. 10B). During subsequent sealevel rise, the quartz-rich deposits were (partially) reworked and covered by fine-grained clastic or non-clastic deposits. Within the more proximal foredeep, deposition of the "lower" Tuscarora Sandstone resumed (fig. 10C). Outcrop studies in New York and Ontario revealed that the lower part of the Whirlpool Sandstone represents deposits of braided streams, whereas the upper part represents shallow-marine deposits (Middleton, Rutka, and Salas, 1987). Applied to the subsurface occurrence of the Whirlpool Sandstone in southern Ohio, the lower part of the Whirlpool Sandstone might represent the progradational phase of spreading of erosional detritus of the "lower" Tuscarora Sandstone during sealevel fall, whereas the upper marine portion might correspond to the subsequent sealevel rise. The disconformity beneath the Whirlpool Sandstone corresponds to a sequence boundary overlain by lowstand (braided stream) deposits (Brett, Goodman, and LoDuca, 1990). The fluvial deposits, in turn, are overlain by marine deposits along a transgressive surface (Brett, Goodman, and LoDuca, 1990). It is possible, however, that the intervening fluvial deposits were completely removed during sealevel rise, and that the sequence boundary and transgressive surface are amalgamated.

The sealevel changes invoked for the origin of the Whirlpool Sandstone in the subsurface of southern Ohio might be related to Hirnantian glacio-eustasy (see also Brett, Goodman, and LoDuca, 1990). The Whirlpool Sandstone in this part of the basin, therefore, might have the same cause as the "basal transgressive sandstone" in eastern Tennessee and extreme southwestern Virginia, which occupies a corresponding stratigraphic position. It has to be emphasized, however, that Middleton, Rutka, and Salas (1987), Middleton (1990), and Cheel and Middleton (1993) argue for tectonic tilting as the primary influence on the origin of the Whirlpool Sandstone in New York and Ontario.

The "basal transgressive sandstone" of eastern Tennessee and extreme southwestern Virginia is not a white quartzarenite sheet, simply because "lower" Tuscarora Sandstone was not available as a detritus source in this area. The "lower" Tuscarora Sandstone of the Taconic

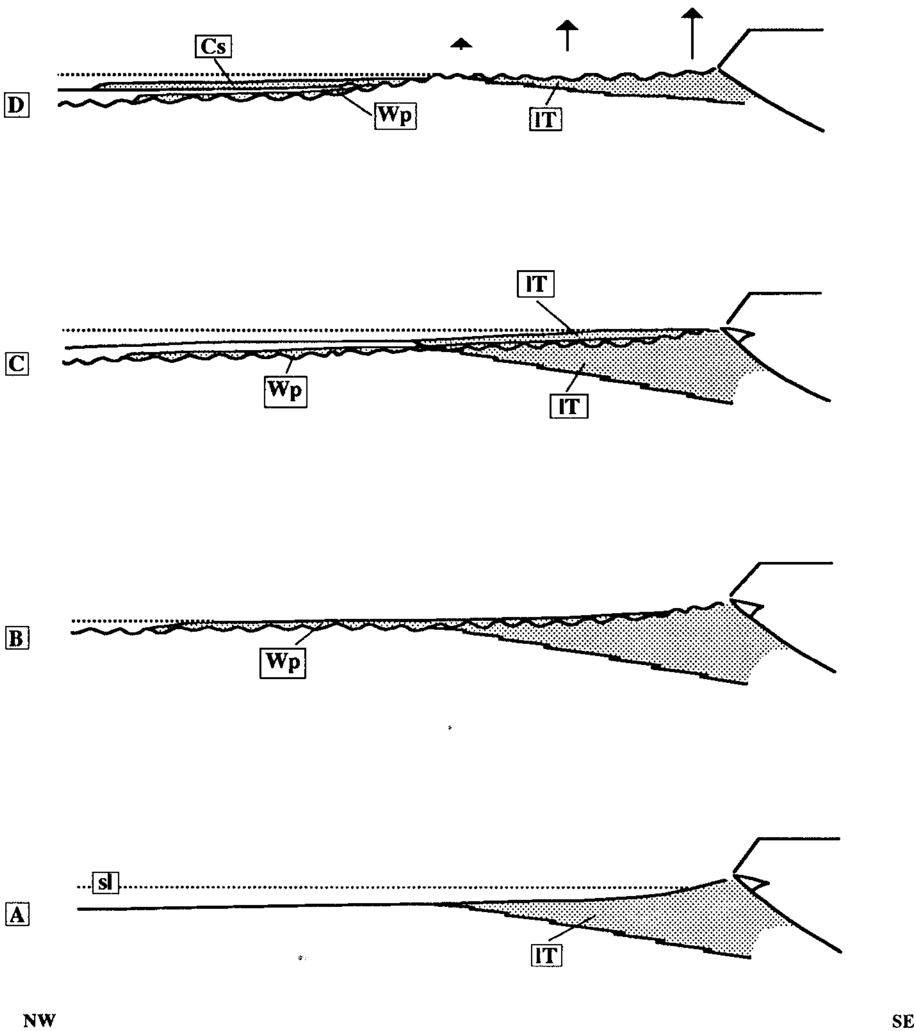

Fig. 10. Highly schematized diagram showing the development and distribution of the Whirlpool Sandstone along a southeast to northwest transect (approximately from southwestern Virginia to Ohio). Abbreviations: sl—sealevel, lT—"lower" Tuscarora Sandstone, Wp—Whirlpool Sandstone, Cs—"Clinton" sandstone; stippled area: components of the "White Sandstone Lithosome;" arrows indicate relative magnitude of isostatic basin rebound (flexural uplift). A—foredeep sedimentation: "lower" Tuscarora Sandstone interfingers with redbed succession of the Juniata Formation; B—sealevel fall (Hirnantian glacio-eustasy?); C—sealevel rise (Hirnantian glacio-eustasy?); D—flexural isostatic rebound of the foredeep. See text for discussion.

foredeep terminated by interfingering with redbeds of the Juniata Formation somewhere to the southwest in the vicinity of present-day Wytheville, Virginia. The Whirlpool Sandstone, furthermore, was cut from the more proximal parts of the Taconic foredeep during isostatic basin rebound and is preserved today only in the more distal parts of the foredeep which were beyond the effects of isostatic rebound (fig. 10D).

The "White Sandstone Lithosome" along a southeast-northwest transect in the central Appalachians consists, therefore, of the "lower" and "upper" Tuscarora Sandstone in the main part of the foredeep and of the two northwestward excursions of the Whirlpool Sandstone and the "Clinton" sandstone/Tuscarora Sandstone. The latter is encased within the "Heterolithic Lithosome" and can be considered as the stratigraphic equivalent of the Poor Valley Ridge Sandstone Member of the Clinch Sandstone and of the white, coarser grained quartzarenite beds within the Rockwood Formation of extreme southwestern Virginia and eastern Tennessee. Like its brethren in eastern Tennessee and extreme southwestern Virginia, this stratigraphic unit is interpreted to represent redeposited erosional detritus produced during a phase of flexural isostatic rebound (fig. 8).

DISCUSSION

Recognition of the "Tuscarora unconformity" in southwestern Virginia and its interpretation as an isostatic rebound unconformity (Dorsch, Bambach, and Driese, 1994) provided the impetus for a new look at the regional stratigraphic relationships above the Upper Ordovician redbed succession in the central and southern Appalachians. Flexural uplift of foredeep deposits, erosion, and redistribution of the detritus, as outlined in the model above and by Heller and others (1988), can account for the occurrence of the "White Sandstone Lithosome" within the "Heterolithic Lithosome" in eastern Tennessee, extreme southwestern Virginia, and in the subsurface of Ohio. This stratigraphic relationship is in marked contrast to the distribution of the same two lithosomes throughout the rest of Virginia.

Derivation of the quartz-rich detritus for the Poor Valley Ridge Sandstone Member of the Clinch Sandstone and for similar but thinner sandstone tongues within the Rockwood Formation in eastern Tennessee and extreme southwestern Virginia can be linked to the phase of flexural isostatic uplift within southwestern Virginia (and to the northeast). Based predominantly on paleocurrent information, the source for the quartz-rich detritus in eastern Tennessee and extreme southwestern Virginia was commonly sought to the southeast of the present-day outcrop belt (for example, Amsden, 1955; Dennison, 1970; Whisonant, 1977). The lithologic similarity of the Tuscarora and Clinch sandstones, nevertheless, led some authors to suspect a common source area, located to the northeast in Virginia (present-day Massanutten synclinorium; Driese and others, 1991).

Paleocurrents

A major difficulty with the notion of a northeastern source area for the quartzarenite in eastern Tennessee was the absence of any southwest-directed paleocurrent indicators within the Tuscarora Sandstone (Whisonant, 1977). Our model, however, indicates that the Tuscarora Sandstone is not homogeneous but split into two distinct parts by the "Tuscarora unconformity." In this model, the subaerial surface indicated by the "Tuscarora unconformity" (denudation area, fig. 8) was the site of the dispersal system, probably braided rivers. Deposits of the dispersal system were reworked during transgression of the sea onto the denudation area, completely obliterating any evidence of the former dispersal system and its paleocurrent indicators. The amalgamation of transgressive surface with the "Tuscarora unconformity" was pointed out earlier (see above and Dorsch, ms). The detritus shed into the parking and fill area (fig. 8) was overprinted by the ambient storm system and was reworked completely into northwest-migrating subaqueous bedforms. This caused the destruction of any paleocurrent indicators within the quartz-rich deposits of eastern Tennessee and extreme southwestern Virginia bearing witness for a northeastern source area. The storm system, as reconstructed by Driese and others (1991), was the dominant influencing force on the sedimentation pattern during the Early Silurian in the southern and central Appalachians. It is responsible for the consistent west-to-north-directed paleocurrent indicators found in the "lower" and "upper" Tuscarora sandstones (Dorsch, ms; Whisonant, 1977) and in the Poor Valley Ridge Sandstone (Driese, 1988; Driese and others, 1991). The storm system clearly favored the preservation of exceptional high-magnitude storm deposits over day-to-day fairweather deposits.

Coarse Sandstone Tongues of the Rockwood Formation and Red Mountain Formation

The extension of the "White Sandstone Lithosome" as discrete tongues into the Rockwood Formation is attributed to regression (Driese and others, 1991). Sharp-based bedsets of shoreface sandstone rest within deeper marine, offshore mudstone intercalated with tempestites and are commonly capped by a hematitic sandstone bed (fig. 3G; Driese, 1988; Driese and others, 1991). The emplacement of these shoreface bedsets can be related either to ample sediment supply exceeding the available accommodation space during relative sealevel rise or stillstand (normal regression, *sensu* Posamentier and others, 1992) or to relative sealevel fall and concurrent loss of accommodation space (forced regression, *sensu* Posamentier and others, 1992). The hematitic beds topping the shoreface-sandstone bedsets mark rapid marine flooding and the return to an offshore depositional setting.

Based on sedimentology, ichnology, and scant biostratigraphic information, Easthouse and Driese (1988) explained the sudden occurrence of a coarser grained sandstone tongue within the Rockwood Formation at

Green Gap (fig. 2, Whiteoak Mountain) by relative sealevel fall and tentatively linked this event to the eustatic sealevel fall in the Llandovery C_{2-3}. It is likely that the "Heterolithic Lithosome" in eastern Tennessee (predominantly the Rockwood Formation) was strongly influenced by eustatic sealevel changes as recorded for the Llandoverian from different continents by Johnson, Kaljo, and Rong (1991). The wide areal spread of these thin and coarse grained quartz sands away from the Poor Valley Ridge Sandstone and the denudation area in Virginia might reflect the influence of Llandoverian eustatic sealevel falls.

A more detailed discussion of the importance of normal versus forced regressions in the emplacement of the shoreface-sandstone bedsets within the Rockwood Formation is hampered at the moment by the lack of biostratigraphic data and the resulting inability to correlate the sandstone tongues across the multitude of thrust sheets with certainty. The present-day erosion surface and the Devonian Wallbridge Discontinuity, furthermore, are responsible for the fragmentary record of the "Heterolithic Lithosome" within eastern Tennessee. Eastern Tennessee and extreme southwestern Virginia, nevertheless, promise to be a fertile ground for testing and investigating the concept and the stratigraphic implications of forced regressions. Efforts to address these questions are currently under way.

Lighter colored, coarser grained, and typically high-angle cross-stratified sandstone tongues can be found encased within heterolithic deposits of the Llandoverian Red Mountain Formation of northwestern Georgia and northeastern Alabama (Chowns and McKinney, 1980; Bolton, ms). These sandstone tongues are reminiscent of the Poor Valley Ridge-like sandstone tongues resting within the Rockwood Formation of eastern Tennessee. The "basal transgressive sandstone" is present in most of the outcrops in northwestern Georgia and northeastern Alabama and marks the base of the heterolithic Red Mountain Formation (Gogola, ms; Bolton, ms). The increased thickness of the coarser grained sandstone tongues within the Red Mountain Formation and their distance from the rebound area in southwestern Virginia make it highly unlikely that the quartz-rich detritus was funnelled down to Georgia and Alabama. We believe, instead, that a second input center (a point source?) was present in this part of the southern Appalachians. The spread of the coarser grained sandstone tongues might be related to eustatic sealevel drops during the Llandoverian. Mixing of detritus supplied from the rebound area in Virginia with detritus supplied from the source area in present-day Alabama and Georgia is likely. The spread of detritus supplied by the two sources and the area of detritus mixing is currently not possible to estimate.

Provenance Relationships of the "White Sandstone Lithosome"

Based on the presented stratigraphic relationships and their interpretation and the available petrographic data (Hayes, ms; Schoner, ms; Marks, ms; Fischer, ms), the provenance relationships within the "White

Sandstone Lithosome" from southwestern Virginia to eastern Tennessee can be elucidated. The "lower" Tuscarora Sandstone was derived from the Taconic orogen (fig. 11; for example Folk, 1960; Pettijohn, 1970; Hayes, ms; Whisonant, 1977) and is interpreted as a northwestward tapering wedge of light-colored, quartz-rich sandstone, interfingering with and overlying the redbed succession of the Juniata Formation in southwestern Virginia (fig. 10A; Dorsch, ms). The source terrain probably included quartz-rich sedimentary deposits (Chilhowee Group) and various low-rank metamorphic units (Hayes, ms; Whisonant, 1977; Folk, 1960) of the Taconic externides (fold-thrust belt) and internides. It is also possible that deposits of the "lower" Tuscarora Sandstone closest to the orogen were cannibalized, as the externides of the Taconic orogen grew cratonward and incorporated foredeep deposits. Reworking of "lower" Tuscarora Sandstone during sealevel lowering (Hirnantian glacio-eustasy?) provided the detritus for the Whirlpool Sandstone (fig. 11). Flexural uplift of part of the Taconic foredeep made the "lower" Tuscarora Sandstone available as the principal detritus source for a second (or third) time. This time, detritus of the "lower" Tuscarora Sandstone was shed radially away from the locus of uplift into areas to the southwest, west, and northwest not affected by flexural uplift (fig. 10D), giving rise to such units as the Poor Valley Ridge Sandstone Member of the Clinch Sandstone in eastern Tennessee and extreme southwestern Virginia and the "Clinton" sandstone in the subsurface of Ohio (fig. 11). The absence of polycrystalline quartz with sutured subgrain boundaries in the gravel

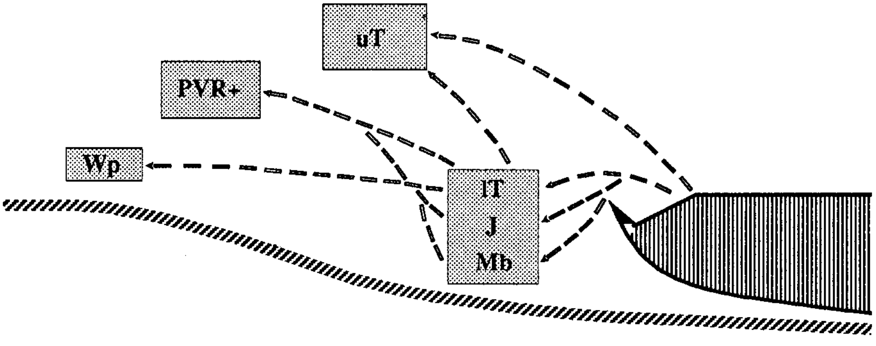

Fig. 11. "Provenance web" portraying the inferred provenance relationships for the "White Sandstone Lithosome" from southwestern Virginia to eastern Tennessee. The "lower" Tuscarora Sandstone (lT) is derived from the Taconic orogen, as are the Juniata Formation (J) and Martinsburg Formation (Mb). The "lower" Tuscarora Sandstone provided the detritus for the Whirlpool Sandstone (Wp) during (glacio-eustatic?) sealevel fall; for the Poor Valley Ridge Sandstone Member of the Clinch Sandstone and the "Clinton" sandstone (PVR+), together with contributions from the Juniata and Martinsburg formations, during flexural isostatic uplift of part of the Taconic foredeep; and for the "upper" Tuscarora Sandstone (uT) during thrust-load induced transgression. The "upper" Tuscarora Sandstone, however, received most of its detritus from the Taconic orogen during renewed thrusting.

and sand population of the Poor Valley Ridge Sandstone (Schoner, ms) is in marked contrast to the "lower" Tuscarora Sandstone (Hayes, ms) and can be attributed to destruction of these grains during transport from the erosional site in southwestern Virginia to the depositional site in eastern Tennessee. The occurrence of some red-colored sandstone and siltstone beds in the upper part of the Poor Valley Ridge Sandstone at Stickleyville (Marks, ms; Driese, 1988; Driese and others, 1991) might indicate the influx and rare preservation of red-colored Juniata detritus, made available in southwestern Virginia as erosion breached through the "lower" Tuscarora Sandstone. Preservation and identification of detritus of the Martinsburg Formation (predominantly mudstone and coquinite limestone, Kreisa, 1981) also made available to erosion during isostatic flexural uplift is highly unlikely. The "upper" Tuscarora Sandstone is believed to be composed of detritus of "lower" Tuscarora Sandstone, which was reworked during marine transgression onto the subaerial exposure surface created during flexural uplift (Dorsch, ms), and of new material supplied from the orogen during a renewed phase of thrusting (fig. 11). The influx of schistose lithic fragments (Hayes, ms) might attest to this input of new material. Hayes (ms) interpreted his petrographic data from the Tuscarora Sandstone of southwestern Virginia to indicate an evolution from a predominantly sedimentary/low-rank metamorphic source to a predominantly crystalline (metamorphic and plutonic?) source. Quartzarenite grains (as discrete lithic fragments) are conspicuously absent from the gravel and sand population of the Poor Valley Ridge Sandstone and related sandstone tongues within the Rockwood Formation of extreme southwestern Virginia and eastern Tennessee (Schoner, ms; Marks, ms; Fischer, ms). A possible explanation for this observation might be that the "lower" Tuscarora Sandstone was not lithified substantially at the time of erosion to provide quartzarenite detritus.

A Lithostratigraphic Boundary for the Tuscarora and Clinch Sandstones

This new look at the regional stratigraphic relationships allows, furthermore, a more precise definition of the geographic position for the lithostratigraphic boundary between the Clinch and the Tuscarora sandstones. Currently, the boundary between the two formations is not clearly fixed and changes according to the respective worker (Butts, 1940; Whisonant, 1977). The most common usage is the one proposed by Dennison (1970) in which Clinch Sandstone is used to the southwest and Tuscarora Sandstone is used to the northeast of the New River in southwestern Virginia. We would like to propose the usage of Tuscarora Sandstone within the area covered by the "Tuscarora unconformity" (fig. 8, the denudation area) and where the "lower" Tuscarora Sandstone interfingers with the redbed succession of the Juniata Formation (if not eroded away). Clinch Sandstone is used in the area where the "Tuscarora unconformity" is absent and where a part of the "Heterolithic Lithosome" (Hagan Shale Member with "basal transgressive sandstone") can be found beneath rocks of the "White Sandstone Lithosome" (fig. 8, the fill area). As already mentioned above, the Clinch Sandstone has its lithostratigraphic equivalent in the subsurface of Ohio in the "Clinton" sandstone and the underlying Cabot Head Shale. In the Valley and Ridge of Virginia and Tennessee, the boundary between the Clinch and Tuscarora sandstones falls between the outcrops at Cove Mountain (fig. 2, Tuscarora Sandstone, outcrop loc. 10) and Little Moccasin Gap (fig. 2, Clinch Sandstone, outcrop loc. 11).

Tectono-stratigraphy of the Uppermost Ordovician to Lower Silurian Taconic Molasse

Figure 12 illustrates our view of the chronostratigraphic relationship between the "White Sandstone Lithosome" and the "Heterolithic Lithosome" from southwestern Virginia to eastern Tennessee. It relates different parts of the lithosomes to distinct events in the evolution of the Taconic orogen.

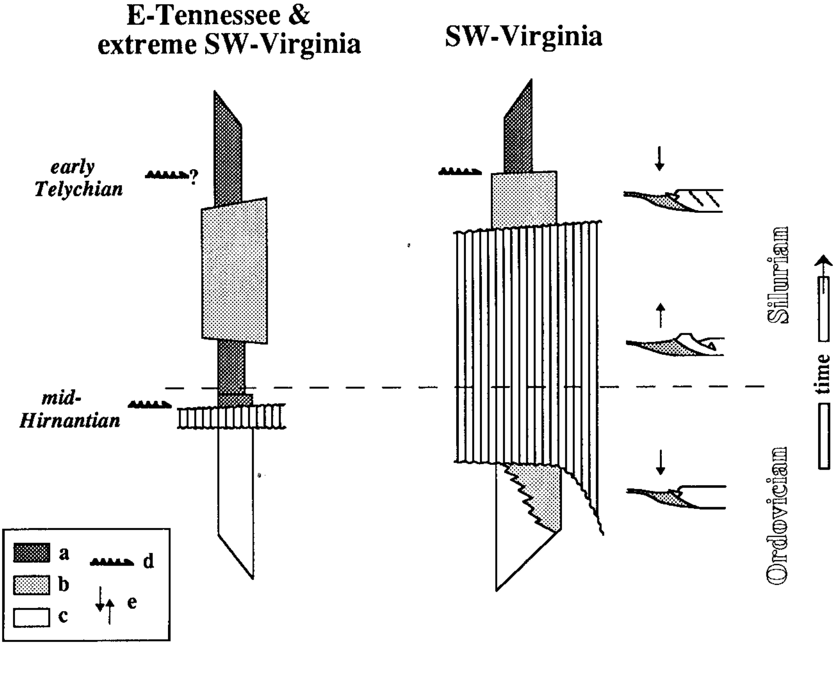

Fig. 12. Schematic chronostratigraphic diagram detailing the relationships between the two regional lithosomes above the Upper Ordovician redbed succession. Abbreviations: a—"Heterolithic Lithosome," b—"White Sandstone Lithosome," c—Ordovician redbed succession, d—marine flooding-surface (as discussed in detail in the text; note diachroneity of marine flooding events indicated by the slightly sloping onlap surfaces), e—arrows indicating foredeep behavior (flexural subsidence or flexural isostatic uplift). Because firm biostratigraphic data are lacking for most of the studied stratigraphic interval, this chronostratigraphic framework has to be considered as provisional.

Two regional lithostratigraphic marker beds/surfaces of inferred chronostratigraphic significance are developed in extreme southwestern Virginia/eastern Tennessee ("basal transgressive sandstone") and southwestern Virginia (top "upper" Tuscarora Sandstone), respectively. Both markers are thought to be related to rapid marine flooding. Biostratigraphic data, albeit limited, make a reasonable placement of the markers within the chronostratigraphic framework possible. They allow, furthermore, linkage of the regional flooding events to documented and well established eustatic sealevel curves of the Upper Ordovician and Lower Silurian (for example Brenchley, 1989; Johnson, Kaljo, and Rong, 1991). Neither lithostratigraphic marker bed/surface is precisely isochronous. Diachroneity, however, is considered to be minimal, even on the regional scale of observation, because marine flooding is inferred to have been rapid. In eastern Tennessee and extreme southwestern Virginia, the "basal transgressive sandstone" overlies a subaerial exposure surface and is considered to reflect glacio-eustatic sealevel rise associated with ablation of Saharan glaciers in the mid-Hirnantian (Gogola, ms; Driese and others, 1991). In southwestern Virginia, the marine flooding-surface developed on top of the "upper" Tuscarora Sandstone is interpreted to reflect the early Telychian eustatic sealevel rise (Dorsch, ms), as documented by Johnson, Kaljo, and Rong (1991). Unequivocal identification of this latter flooding event within the Rockwood Formation and the remnants of the Rose Hill Formation of eastern Tennessee and extreme southwestern Virginia is not possible, because adequate biostratigraphic data in concert with sedimentologic data are lacking at present. Due to paucity or lack of datable fossils, placement of the Ordovician-Silurian boundary and temporal extent of the lacunae (fig. 12) have to be considered as approximate.

Despite these limitations imposed by the paucity of biostratigraphic information, several inferences concerning the regional lithosomes and their relationship to the Taconic orogeny can be made. The "White Sandstone Lithosome" is partitioned into three parts, with each part having its distinct tie to different developmental stages of the Taconic orogen (fig. 12). In southwestern Virginia, the "White Sandstone Lithosome" (Tuscarora Sandstone) is bisected by the "Tuscarora unconformity." The "lower" Tuscarora Sandstone is thought to be related to active thrusting within the orogen and active foredeep subsidence due to thrust-loading. Sediment of the "lower" Tuscarora Sandstone was confined within the Taconic foredeep which acted as a sediment sink. Conversion of part of the Taconic foredeep from a sediment sink to a sediment exporter took place during flexural uplift of part of the foredeep. Flexural uplift caused erosion of previously deposited sediment and redistribution of that detritus into parts of the foredeep not affected by flexural isostatic rebound and beyond the confines of the foredeep. This phase in the evolution of the Taconic orogen is thought to be documented by the "Tuscarora unconformity" in southwestern Virginia and by the redistributed erosional detritus (fig. 12), which constitutes the

"White Sandstone Lithosome" in extreme southwestern Virginia and eastern Tennessee (fig. 6, Poor Valley Ridge Sandstone, coarser grained sandstone tongues within Rockwood Formation) and southern Ohio (fig. 9, "Clinton" sandstone). The whole foredeep was reestablished as a sediment sink following resumption of thrusting and thrust-load induced subsidence (fig. 12). Supply of quartz-rich detritus toward the distal foredeep and beyond was gradually shut off, and the detritus was confined within the more medial and proximal foredeep comprising the "upper" Tuscarora Sandstone.

The "White Sandstone Lithosome" in eastern Tennessee and extreme southwestern Virginia probably owes its origin to tectonism within the Taconic foredeep of the central Appalachians, which in turn reflects the tectonic evolution of the Taconic orogen. This lithosome interrupts, for a period, the complacent, mud-dominated, "normal" sedimentation ("Heterolithic Lithosome") in this area (fig. 6). The "White Sandstone Lithosome" is interpreted to correspond, for a large measure, to a lacuna within the outcrop sections of southwestern Virginia (fig. 12), a stratigraphic relationship already postulated by Heller and others (1988) as expected in foredeeps. The "Heterolithic Lithosome" represents tectonically calm conditions during the latest Ordovician and Early Silurian in an area remote from active Taconic tectonism at the same time. Eastern Tennessee was the primary area affected by tectonism and active foredeep sedimentation (foreland flysch to foreland molasse; for example, Keller and Walker, 1980; Read, 1980; Shanmugam and Lash, 1982; Drake and others, 1989) during the earlier Blount orogeny (or Blount phase of the Taconic orogeny; Rodgers, 1953, 1971; Shanmugam and Lash, 1982; Drake and others, 1989). The "Heterolithic Lithosome" in southwestern Virginia commenced later with the Rose Hill Formation and might indicate similar and quiescent tectonic conditions (see also Folk, 1960).

The unconformity indicated by the paleosols in the Juniata Formation and by the overlying "basal transgressive sandstone" represents a sequence boundary related to glacio-eustasy within the Ashgillian. This unconformity was cut out in southwestern Virginia and superseded by the "Tuscarora unconformity." The "Tuscarora unconformity" represents a sequence boundary, which owes its origin to tectonism and is developed only in the area affected by flexural isostatic rebound (Dorsch, ms).

Flexural uplift of part of the foredeep resulted in destruction of accommodation space and erosion at more proximal locations within the foredeep. This led to redistribution of sediment into more distal parts of the foredeep and even to export of sediment. This tectonic stimulus for sediment export complements sedimentary export through sediment bypassing. The latter occurs when rate of sediment delivery to the foredeep is greater than subsidence rate of the foredeep and when the foredeep is filled above or near sealevel. Sediment bypassing and export, both laterally along the basin axis and/or transversely across the peripheral bulge, is accomplished either by pronounced currents within shallow-marine foredeeps (for example Taiwan straits, Covey, 1986) or by fluvial systems within non-marine foredeeps (for example Himalayan foredeep, Covey, 1986; Burbank and Beck, 1991; Late Cretaceous Idaho-Wyoming-Utah foredeep, Flemings and Jordan, 1989).

CONCLUSIONS

1. The uppermost Ordovician to Lower Silurian stratigraphic units above the Upper Ordovician redbed succession in the central and southern Appalachian Valley and Ridge can be subdivided into the distinctly different "White Sandstone Lithosome" (Tuscarora Sandstone, Poor Valley Ridge Sandstone Member of the Clinch Sandstone, and some beds/bedsets within the Rockwood Formation) and "Heterolithic Lithosome" (Rose Hill Formation, Rockwood Formation, and Hagan Shale Member of the Clinch Sandstone). In southwestern Virginia, the "White Sandstone Lithosome" dominates, which is divided by the "Tuscarora unconformity" into the "lower" and "upper" Tuscarora Sandstone and is succeeded by the "Heterolithic Lithosome." In extreme southwestern Virginia and eastern Tennessee, the "Heterolithic Lithosome" dominates, which commences with the "basal transgressive sandstone" and encapsulates the more exotic "White Sandstone Lithosome."

2. The lithostratigraphic term Tuscarora Sandstone should be used within the area covered by the "Tuscarora unconformity" and/or where the "lower" Tuscarora Sandstone interfingers with the Juniata Formation. Clinch Sandstone, on the other hand, should be used within the area marked by the absence of the "Tuscarora unconformity" and by the presence of the "White Sandstone Lithosome" contained within the "Heterolithic Lithosome."

3. In contrast to the commonly held view, the "White Sandstone Lithosome" does not form a simple, homogeneous, and uniform quartzarenite blanket throughout the central and southern Appalachians but hides a more complex history. This lithosome is divisible into separate components, with each component having its distinct ties to different developmental stages of the Taconic orogen in the central Appalachians and to eustatic sealevel changes.

4. The detritus for the "lower" Tuscarora Sandstone was shed from the growing Taconic orogen and deposited within the foredeep during thrust-load induced foredeep subsidence. The glacio-eustatic sealevel events during the Hirnantian (latest Ordovician) might tentatively be reflected in the Whirlpool Sandstone (subsurface of southern Ohio and parts of West Virginia), whose stratigraphic position and probable origin correspond to that of the "basal transgressive sandstone" (extreme southwestern Virginia to northern Alabama/Georgia). Detritus for the Whirlpool Sandstone was derived from erosion of "lower" Tuscarora Sandstone during sealevel drop.

5. The "Tuscarora unconformity" (interpreted as an isostatic rebound unconformity) developed following a cessation in Taconic compres-

sional tectonism. Flexural isostatic uplift/rebound converted part of the Taconic foredeep from an active depositional site and sediment sink to an active erosional site and sediment exporter. In the area of uplift (denudation area), evidence for the Hirnantian glacio-eustatic sealevel events was cut out, and the erosional detritus produced was redistributed radially away from the denudation area into parts of the foredeep not affected by rebound and into areas at the fringe of the foredeep and beyond (parking area and fill area). The "White Sandstone Lithosome" in extreme southwestern Virginia and eastern Tennessee (Poor Valley Ridge Sandstone and bedsets within the Rockwood Formation) is interpreted to be part of this redistributed material, which interrupted the normal, mud-dominated sedimentation in that area. The "Clinton" sandstone in the subsurface of southern Ohio is regarded as a lithostratigraphic equivalent. The quartz-rich detritus was overprinted and distributed within the fill area by the ambient storm system. The isolated bedsets of the "White Sandstone Lithosome" within the Rockwood Formation, demarcating the farthest spread of this lithosome, might represent forced regressions. Sediment export caused by tectonism (flexural isostatic uplift) complements sediment export through sediment bypassing, which is described from various shallow-marine and terrestrial foredeeps.

6. The "upper" Tuscarora Sandstone is interpreted to be related to a new phase of compressional tectonism and active foredeep subsidence, in concert with eustatic sealevel rise in the Llandoverian. The transgression reworked erosional detritus which covered the denudation area and thereby destroyed evidence of the distributive system. Most of the material for the "upper" Tuscarora Sandstone, however, is believed to have come from the Taconic orogen during this new phase of thrusting.

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