PALEOGEOGRAPHIC INFLUENCES ON SANDSTONE COMPOSITION ALONG AN EVOLVING PASSIVE MARGIN: AN EXAMPLE FROM THE BASAL CHILHOWEE GROUP (UPPERMOST PROTEROZOIC TO LOWER CAMBRIAN) OF THE SOUTH-CENTRAL APPALACHIANS

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ABSTRACT: **This study demonstrates the utility of combining numerical analysis and detailed facies analysis to examine the effects of provenance and depositional setting on the composition of ancient sandstone suites from transitional tectonic settings such as those associated with an evolving rifted continental margin. By using factor analysis the relative effects of provenance and depositional setting on sandstone composition can be examined semiquantitatively. This study examines sandstone compositional variation in the lower Chilhowee Group, which records the rift-to-drift transition of the Laurentian-Iapetus margin.**

Cross plots for each data subset were constructed to reflect stratigraphic position with respect to the fluvial-marine transition, as independently identified from sedimentological criteria, as well as paleogeographic position. The composition of medium-grained sandstones of the basal Chilhowee Group of Tennessee, North Carolina and Virginia mainly reflects the degree of modification of sediment composition by sedimentary processes during transportation. Comparison of petrologic and sedimentologic data from the Tennessee embayment and the Virginia promontory allow inferences on paleogeography. Low-energy, distal fluvial environments dominated in the Tennessee embayment, suggesting an area characterized by low relief. Higher-energy, distal, alluvial-fan environments are limited to the Virginia promontory, indicating that this area was a higher-relief terrain than the Tennessee embayment. Source-rock type was apparently similar along the entire margin, although the relative abundance of each lithology was variable. Sandstone composition across the region reflects mainly the effectiveness of fluvial processes in reducing the labile fraction. The boundary between the Tennessee embayment and the Virginia promontory records a fundamental tectonic boundary such that each segment of the margin experienced a unique stratigraphic evolution.

INTRODUCTION

Although the relationship between tectonic setting and sandstone composition has long been recognized (Dickinson 1971, 1985; Dickinson and Suczek 1979; Pettijohn et al. 1987), sandstone provenance in transitional tectonic settings is often more difficult to interpret (Mack 1984; Johnsson and Stallard 1989). For example, paleogeographic variation along an evolving passive continental margin results in concomitant erosion in drainage basins of differing relief and source-rock composition as well as sedimentation in variable depositional settings. Consequently, sandstone composition may vary between two lithostratigraphically and chronostratigraphically equivalent units. Significant trends in suites of petrographic data from such successions are not always easily identified from visual inspections of commonly used ternary diagrams, unless fundamental changes in source rock and variation in the degree of modification by physical processes are considered.

In an attempt to clarify interpretations of various sandstone suites, Ingersoll (1990) proposed a threefold hierarchy for actualistic petrologic models: (1) First-order models, considered for individual outcrops or individual mountains, (2) Second-order models, appropriate for data sets obtained from entire mountain ranges or basins, and (3) Third-order models, useful for continental-scale studies (where each point may represent the mean value for a related suite). Compositional variation results directly from variation in source rock in first-order models, and indirectly (via tectonic setting) in second-order and third-order models (Ingersoll 1990).

PURPOSE

Our study represents a systematic examination of the variation in sandstone composition along an exhumed, southern Appalachian segment of the Laurentian-Iapetus passive margin, which developed during latest Proterozoic to earliest Cambrian time (Fig. 1; Rankin 1975, 1976; Thomas 1977, 1983, 1991; Hatcher 1978, 1987, 1989; Wehr and Glover 1985; Fichter and Diecchio 1986; Walker et al. 1988, 1989; Simpson and Eriksson 1989, 1990). Chilhowee Group strata, representing the rift-to-passive-margin transition, blanketed the entire evolving margin from Alabama to Vermont (Thomas 1977; Hatcher 1987, 1989; Walker et al. 1988, 1989; Simpson and Eriksson 1989). The uppermost Proterozoic to Lower Cambrian basal Chilhowee Group (Fig. 2) contains distal-alluvial-fan, proximal- and medial-braid-plain, upper-shoreface, and lower-shoreface to inner-shelf deposits preserved in the allochthonous western Blue Ridge (Cudzil and Driese 1987; Simpson and Sundberg 1987; Walker et al. 1988; Simpson and Eriksson 1989; Walker and Driese 1991). Present in the Chilhowee Group is an identifiable fluvial-to-marine transition that recorded the change from a rift to passive-margin tectonic setting (Cudzil and Driese 1987; Walker et al. 1988, 1989; Simpson and Eriksson 1989). The framework composition of basal Chilhowee Group sandstones provides information on the relative effect of changes in depositional setting and provenance along the evolving margin. The interaction of these factors resulted in complex compositional variation. Consequently, numerical analysis of data from known depositional and tectonic affinities can be used to quantify variability within populations (e.g., sandstone samples from the Chilhowee Group) and reduce the ambiguity inherent in studies of "transitional" sandstone suites (Ingersoll 1990).

STRATIGRAPHIC AND PALEOGEOGRAPHIC FRAMEWORK

Previous studies of the Chilhowee Group have provided data to construct the stratigraphic and paleogeographic framework in which sandstone composition can be used to elucidate tectonic history. These studies include examinations of the regional stratigraphic patterns (Schwab 1972; Thomas 1977; Mack 1980; Wehr and Glover 1985; Fichter and Diecchio 1986), the sediment dispersal system and gross sandstone petrology (Whisonant 1970, 1974; Schwab 1972), and most recently, the evolving depositional systems via facies analysis (Cudzil and Driese 1987; Walker et al. 1988; Simpson and Eriksson 1989, 1990).

The regional distribution of Grenvillian basement and variation in sediment thickness, as well as later Paleozoic deformational patterns, led Rankin (1975, 1976) and Thomas (1977, 1983) to propose that extension resulted in an irregular continental margin with associated isolated microcontinents (e.g., internal massifs of the Pine Mountain block and the Sauratown Mountain window; Thomas 1977; Hatcher 1987; Walker et al. 1989). Using the terminology of Thomas (1983), the present-day recesses and salients recognizable in the map pattern of the Appalachian orogen coincide with promontories and embayments, respectively, in the early Paleozoic Laurentian margin. This paper deals with paleogeographic

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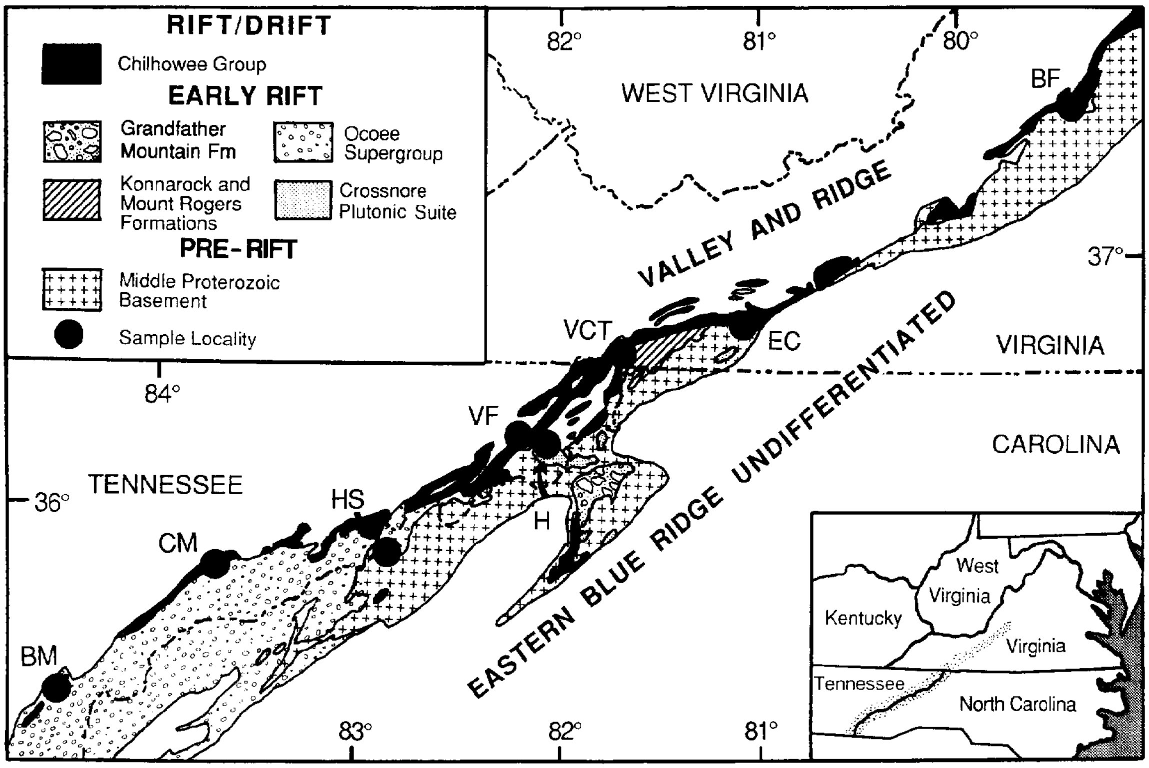

FIG. 1.—Exposures of the Chilhowee Group along the frontal Blue Ridge of Tennessee, North Carolina and Virginia: BM = Bean Mountain, Tennessee; CM = Chilhowee Mountain, Tennessee; HS = Hot Springs window, North Carolina; VF = Valley Forge, Tennessee; H = Hampton, Tennessee; VCT = Virginia Creeper Trail, Virginia; EC = Elk Creek, Virginia; and BF = Balcony Falls, Virginia. Geologic map modified from Rankin et al. (1989).

aspects of the Laurentian-Iapetus margin; therefore, the terms "promontory" (an angle or curve of the rifted margin concave cratonward) and "embayment" (an angle or curve of the rifted margin concave oceanward) will be used (see Thomas 1977, 1983 for further explanation). The dominant paleogeographic elements in the study area include the Tennessee embayment and the Virginia promontory (Fig. 2). These tectonic elements mirror the southeastern limit of undeformed Grenvillian basement and are defined by the distribution of Upper Proterozoic rift-related strata of the Ocoee Supergroup and Mount Rogers Formation.

Pre-Chilhowee Group Stratigraphy

The Ocoee Supergroup is lithologically diverse and composed of dominantly marine and subordinate nonmarine units that may be more than 12 km thick (Hadley 1970; Rast and Kohles 1986). This sequence of upper Proterozoic strata represents the fill of a rift basin that in part defines the Tennessee embayment (Fig. 2; Thomas 1977, 1983; Rast and Kohles 1986). Amphibolites, interpreted as possible metamorphosed mafic volcanic flows, are present in the lower part of the Ocoee (Abrams 1987; Misra and Lawson 1988; Rankin et al. 1989). Geochemical analyses of samples of these amphibolite bodies indicate the presence of trace-element signatures similar to mid-ocean-ridge basalts (Misra and Lawson 1988). Such geochemical signatures may indicate that significant crustal attenuation occurred, despite the low volumetric abundance of volcanic rocks in the Ocoee as defined by King et al. (1958).

The southwestern boundary of the Virginia promontory is defined by the northern limit of Upper Proterozoic volcanic and siliciclastic strata of the Mount Rogers and Konnarock formations (Figs. 1, 2) and siliciclastics of the Grandfather Mountain Formation (Fig. 1; Rankin 1975, 1976, 1993; Thomas 1977). The Mount Rogers and Konnarock formations have a combined thickness greater than 3 km. The Konnarock Formation is composed dominantly of glaciolacustrine siliciclastic strata (Schwab 1976, 1981; Rankin 1993; Miller in press). Volcanic strata of the Mount Rogers Formation represent an active part of the Late Proterozoic rift system termed the Pine Mountain rift zone of the Blue Ridge rift by Thomas (1991).

Chilhowee Group Stratigraphy

The basal Chilhowee Group in the southern Appalachians comprises two coevally deposited and regionally distinct stratigraphic units, termed the Cochran and Unicoi formations (Fig. 2). In southeastern Tennessee, the Cochran Formation overlies the Sandsuck Formation of the Walden Creek Group (uppermost unit in the Ocoee Supergroup, Figs. 1–3). The Sandsuck and basal Cochran at Bean Mountain appear to be in depositional contact (Walker et al. 1988; Walker and Driese 1991), although the contact is erosional to the northeast where the basal conglomerates contain shale clasts identical to rocks in the underlying Sandsuck Formation. The Cochran Formation is 100–200 m thick and composed of feldspathic pebbly sandstone and conglomerate with minor interbedded quartzose sandstone.

In the study area, the Unicoi Formation (1) disconformably overlies the Sandsuck Formation (Hot Springs window, North Carolina; Oriel 1950); (2) nonconformably overlies Grenvillian basement (northeasternmost Tennessee and southwestern Virginia; King and Ferguson 1960), and (3) disconformably overlies the Upper Proterozoic Konnarock Formation near Mt. Rogers, Virginia (Rankin 1967, 1993; Thomas 1977; Simpson and Eriksson 1989). In northeast Tennessee and adjacent Virginia, the

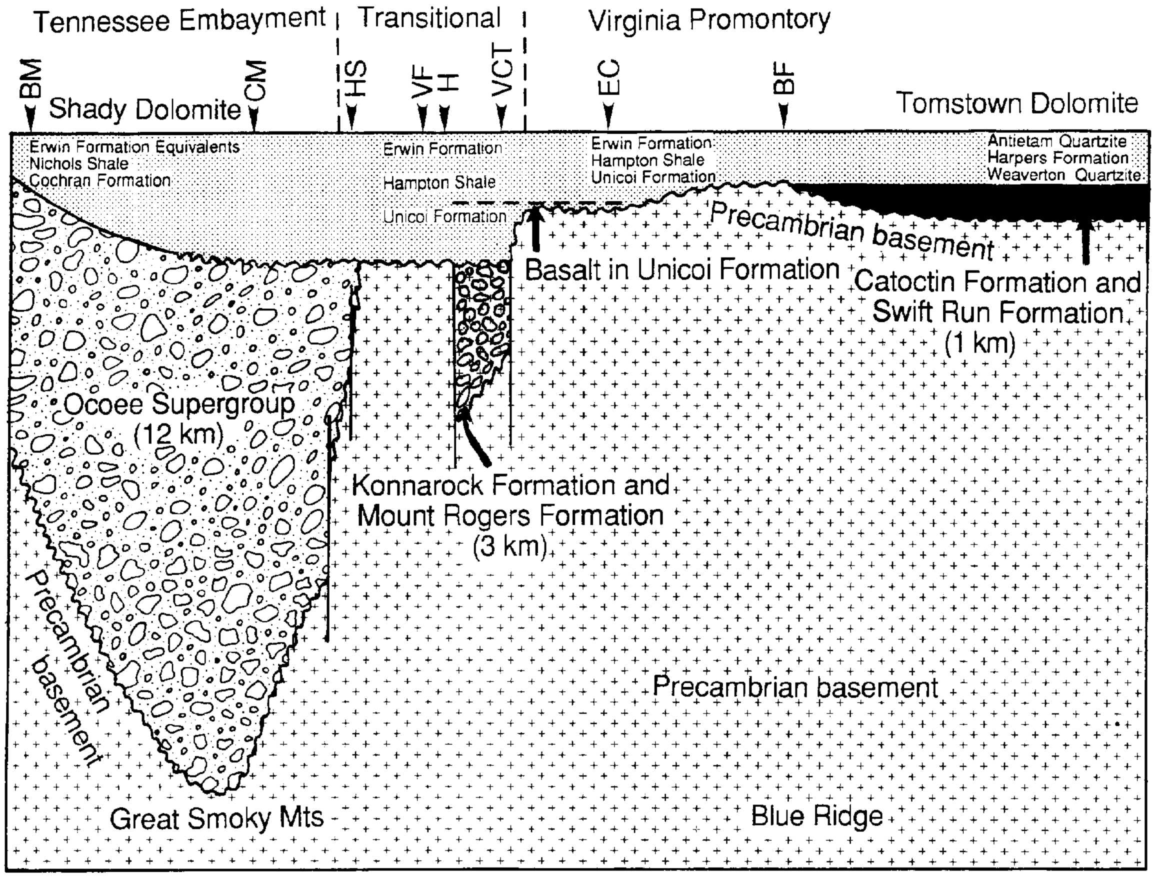

FIG. 2.—Stratigraphic strike section along the Laurentian-Iapetus margin in Tennessee, North Carolina, and Virginia showing the Chilhowee Group and underlying stratigraphic units (modified from Thomas 1991). BM = Bean Mountain, Tennessee; CM = Chilhowee Mountain, Tennessee; HS = Hot Springs window, North Carolina; VF = Valley Forge, Tennessee; H = Hampton, Tennessee; VCT = Virginia Creeper Trail, Virginia; EC = Elk Creek, Virginia; and BF = Balcony Falls, Virginia.

Unicoi Formation is a sequence 400–500 m thick that ranges from lithic and feldspathic conglomerate to pebbly sandstone with interbedded quartzose lithologies. In many parts of the study area the lower Unicoi (unlike the Cochran to the south) contains one to three basalt flows that range in thickness from less than 1 m to 10 m (King and Ferguson 1960; Rankin 1967; Simpson and Eriksson 1989).

DEPOSITIONAL SETTING

We chose eight locations exposing the lower Chilhowee Group along the frontal Blue Ridge in southern Virginia and Tennessee (Figs. 1, 3) that (1) maximized continuous stratigraphic exposure, (2) provided greatest sedimentological information, and (3) crossed the Virginia promontory and Tennessee embayment (Fig. 2). The sections were measured to document grain size, bedding thickness, scale and type of cross-stratification, presence or absence of trace fossils and body fossils, and vertical and lateral facies transitions (Fig. 3; see Cudzil and Driese 1987; Walker et al. 1988; Simpson and Eriksson 1989). Facies were defined and interpreted on the basis of hydrodynamic criteria and compared to modern and ancient analogues to provide constraints on the depositional setting (Walker et al. 1988, Walker and Driese 1991, Simpson and Eriksson 1989).

Vertical and lateral variations in the depositional facies in the Cochran and Unicoi formations allow identification of the fluvial-to-marine transition (Fig. 3; Cudzil and Driese 1987; Walker et al. 1988; Simpson and Eriksson 1989). The lower part of the Cochran and Unicoi formations probably represents a distal alluvial-fan system that graded distally into a complex system of braided streams associated with a coastal braid plain (Walker et al. 1988; Simpson and Eriksson 1989). At each of the various localities, one of three types of fluvial-to-marine transition was identified: (1) a single contact, in which marine strata abruptly overlie fluvial deposits, (2) a meter-scale intertonguing transition, and (3) an intertonguing transition over tens of meters, with two or more thick fluvial-to-marine transition sequences.

Paleocurrent data indicate that this vast fluvial system drained areas located cratonward and prograded from the craton toward the present-day east (Schwab 1972; Whisonant 1974; Cudzil and Driese 1987; Walker et al. 1988; Simpson and Eriksson 1989). Distal alluvial-fan deposits in the Unicoi Formation of northeastern Tennessee and southwestern Virginia indicate that the Virginia promontory had localized tectonic relief in the latest Proterozoic (Fig. 3; Cudzil and Driese 1987, Simpson and Eriksson 1989). Absence of similar alluvial-fan deposits in equivalent strata in southeastern Tennessee (Fig. 3; Walker et al. 1988; Walker and Driese 1991) indicates that relief in the Tennessee embayment was comparatively small. Primary sedimentary features and trace fossils in the upper part of the Cochran–Unicoi interval indicate that deposition occurred in marine environments ranging from upper shoreface to inner shelf in a wave- and tide-dominated shoreline system (Cudzil and Driese 1987; Walker et al. 1988; Simpson and Eriksson 1989). On the bases of gross stratigraphy (including nature of underlying strata or basement), facies architecture, and type of fluvial-marine transition, each stratigraphic

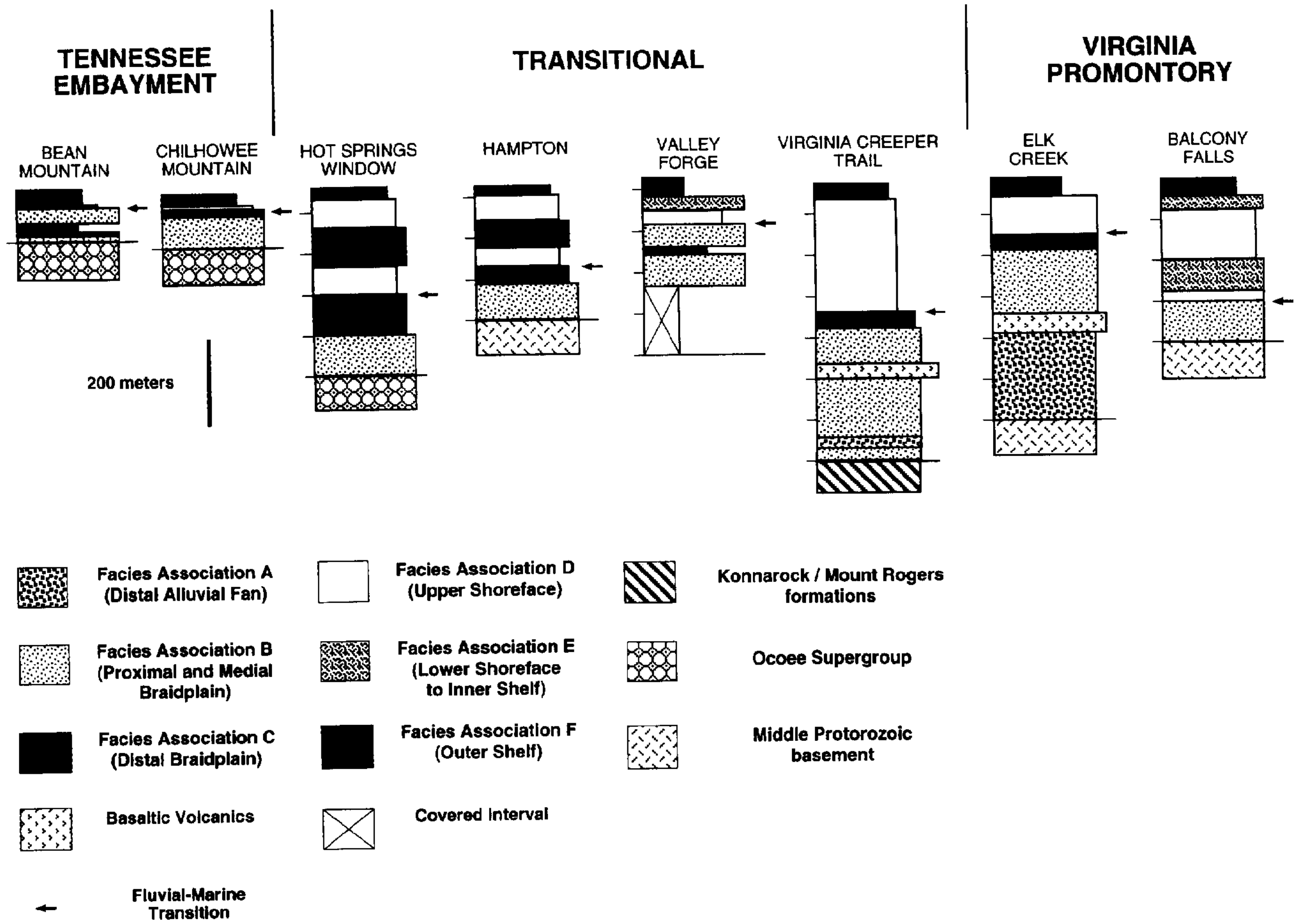

FIG. 3.—Stratigraphic sections measured at each locality. Note relative abundance of various facies assemblages and position of fluvial-to-marine transition and basement type.

section was assigned to a paleogeographic element, as follows: (1) Balcony Falls and Elk Creek—Virginia promontory; (2) Virginia Creeper Trail, Valley Forge, Hampton and Hot Springs Window—transitional zone; and (3) Chilhowee Mountain and Bean Mountain—Tennessee embayment (Fig. 3).

PETROGRAPHIC ANALYSIS

Samples were systematically collected for petrographic analysis at roughly ten-meter intervals in each measured section. Each sandstone sample can therefore be categorized with respect to paleogeographic elements and its position with respect to the fluvial-to-marine transition. A thin section from each sample was prepared and stained with sodium cobaltonitrate for feldspar identification. A variety of framework grains were identified thin sections (Table 1).

In each thin section, an average of 300 grains were point-counted using the Gazzi-Dickinson method (Ingersoll et al. 1984, 1985; Suttner and Basu 1985), and additional counts for polymineralic grain types were tallied separately. The relative abundance expressed as a percent of framework grains was calculated for visual comparison (Fig. 5). Numerical analysis used a log ratio of counts to avoid spurious correlations that may result from the unit-sum constraint (Butler 1979; Aitchison 1986; Woronow 1990; Woronow and Love 1990; Heins in press). Problems may arise in some data sets, however, because a significant subset may have to be dropped because categories with zero observations cannot be transformed into a log ratio (i.e., the quotient is undefined). To avoid this latter problem, a small value (i.e., 1×10^{-3}) was added to the number of observations in all categories.

Factor analysis was done using Statview SE+ statistical software. The software was used to calculate parameters related to sampling adequacy (chi-square), eigenvalues and variance proportionality, eigenvectors, and factor score weights for orthogonal transformation solutions. Factor score weights were then multiplied by the original raw count for each category of framework grains. The resulting products were then summed for each

TABLE 1.—*Framework grain types observed in samples taken from the Cochran and Unicoi formations of the basal Chilhowee Group*

Monocrystalline quartz	Qm
Polycrystalline quartz (3–7 subgrains)	Qp (3–7)
Polycrystalline quartz (> 7 subgrains)	Qp (> 7)
Plagioclase feldspar	P
Potassium feldspar	K
Lithic volcanic	Lv
Lithic sedimentary	Ls
Lithic metamorphic	Lm
Clay	Clay
Accessory opaques	Other

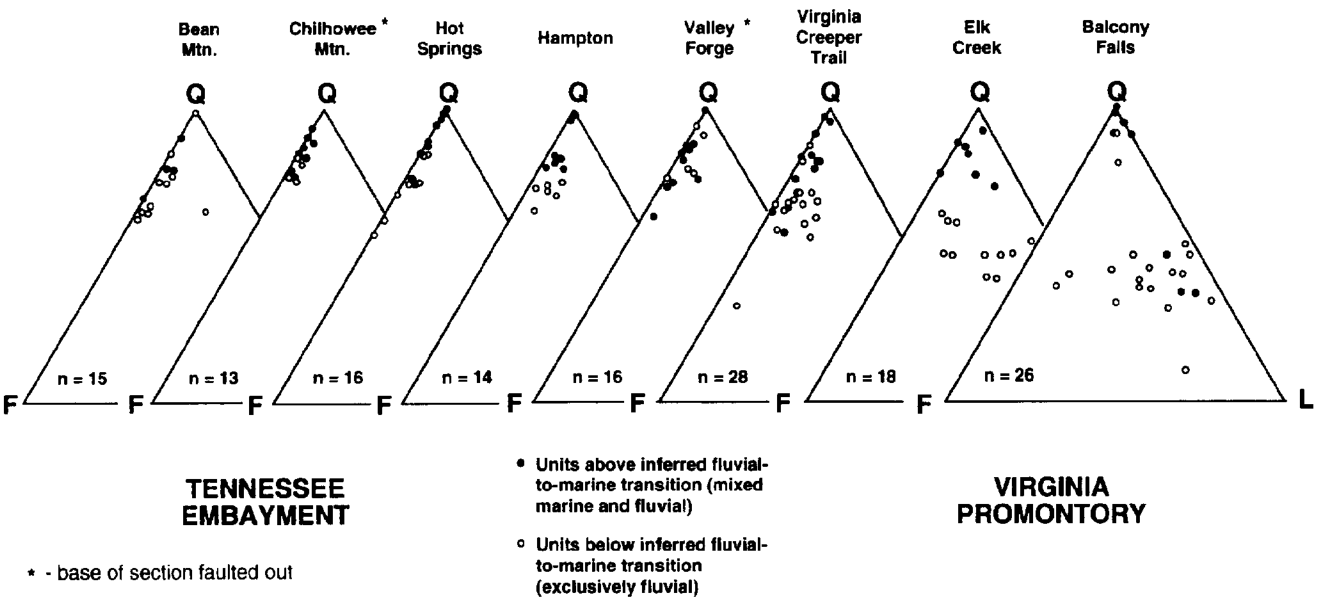

Fig. 4.—QFL plots for sandstone suites at each locality. Note systematic decrease in frequency of labile rock fragments from north to south.

sample, resulting in a total factor score for each sample for factor 1 and factor 2. Cross plots (Fig. 5A–D) were then constructed plotting SUM F1 on the x-axis and SUM F2 on the y-axis (for greater discussion of factor analysis, see Davis 1986 and discussion below). Multiple plots for each data subset were made, reflecting paleogeographic and stratigraphic position (i.e., Tennessee embayment vs. Virginia promontory and above vs. below the fluvial-to-marine transition).

Table 2.—*Results of factor analysis WR.61 (all samples)**

Eigenvalues	Magnitude	Variance Proportion	
Value 1	2.105	.234	
Value 2	1.540	.171	
Value 3	1.178	.131	
Value 4	1.027	.114	
Value 5	0.904	.100	
Eigenvectors	**Vector 1**	**Vector 2**	**Vector 3**
LR Qp (3–7)	−.110	−.030	−.525
LR Qp (> 7)	−.106	.113	.675
LR P	.560	.159	−.122
LR K	.162	.578	−.198
LR Lv	.504	.248	−.065
LR Ls	.025	.277	.377
LR Lm	−.418	.468	−.049
LR Clay	.274	.221	.164
LR Other	−.364	.470	.197
Factor Score Weights for Orthogonal Transformation Solution	**Factor 1**	**Factor 2**	**Factor 3**
LR Qp (3–7)	.061	−.059	.145
LR Qp (> 7)	−.030	−.006	.824
LR P	.405	−.139	.020
LR K	.472	.361	.009
LR Lv	.449	−.024	−.099
LR Ls	−.022	.069	−.136
LR Lm	−.016	.462	.139
LR Clay	−.011	−.080	.442
LR Other	.011	.475	−.138

* Components: Log ratio Qp (3–7), Qp (> 7), P, K, Lv, Ls, Lm, Clay, Other, n = 150; Chi Square: 190.314. Log Ratio X = LOG($(X + 1 \times 10^{-3})/Qm$), where X = number of framework grains counted in approximately 300 observations (see text for more detailed discussion).

RESULTS

The plots show variations in the sample populations that can be attributed to several factors, including either change in depositional setting or variation in paleotectonic setting. Trends identified on QFL plots for each locality suggest systematic decrease in the frequency of labile rock fragments from north to south (Fig. 4). This decrease may reflect a systematic reduction in the abundance of volcanic and metamorphic rocks in the drainage basins contributing sediment to the depositional settings of the margin. Alternatively, this decrease may reflect systematic removal of the labile fraction by fluvial processes. Basal Chilhowee Group sequences of the Tennessee embayment contain a greater proportion of distal fluvial facies than do correlative sequences to the northeast in the vicinity of the Virginia promontory (Fig. 3). This distribution of data indicates that variation in the gross depositional systems along the rifted margin exerted a significant control on sandstone composition. We also examined, quantitatively, whether or not Chilhowee Group sandstone samples from different paleogeographic settings and depositional environments (previously defined on other criteria) could be separated on the basis of unique petrographic characteristics. A multivariate data set such as ours, which consists of 150 thin-section samples for which 9 petrographic variables were measured, is more easily analyzed quantitatively using multivariate numerical techniques.

We chose factor analysis because it is a numerical technique useful for either interpreting relationships between variables (R-mode) or between samples (Q-mode) in a set of multivariate data (Davis 1986). We used R-mode factor analysis in our study. Although originally developed for use in psychology and intelligence testing (e.g., IQ is a "factor" that is extracted from test scores), factor analysis is now common in the physical and biological sciences. In simplest terms, "factors" are created from linear combinations of the original variables, using eigenvalues and eigenvectors from the correlation matrix for the variables measured on the samples. A factor analysis is considered successful if it explains a large proportion of the sample variance with a minimum number of factors. The "loadings" on the factors give some sense of measure of the relative importance of the respective variables in defining the factors. Factor loadings are somewhat analogous to correlation coefficients between variables, in which large

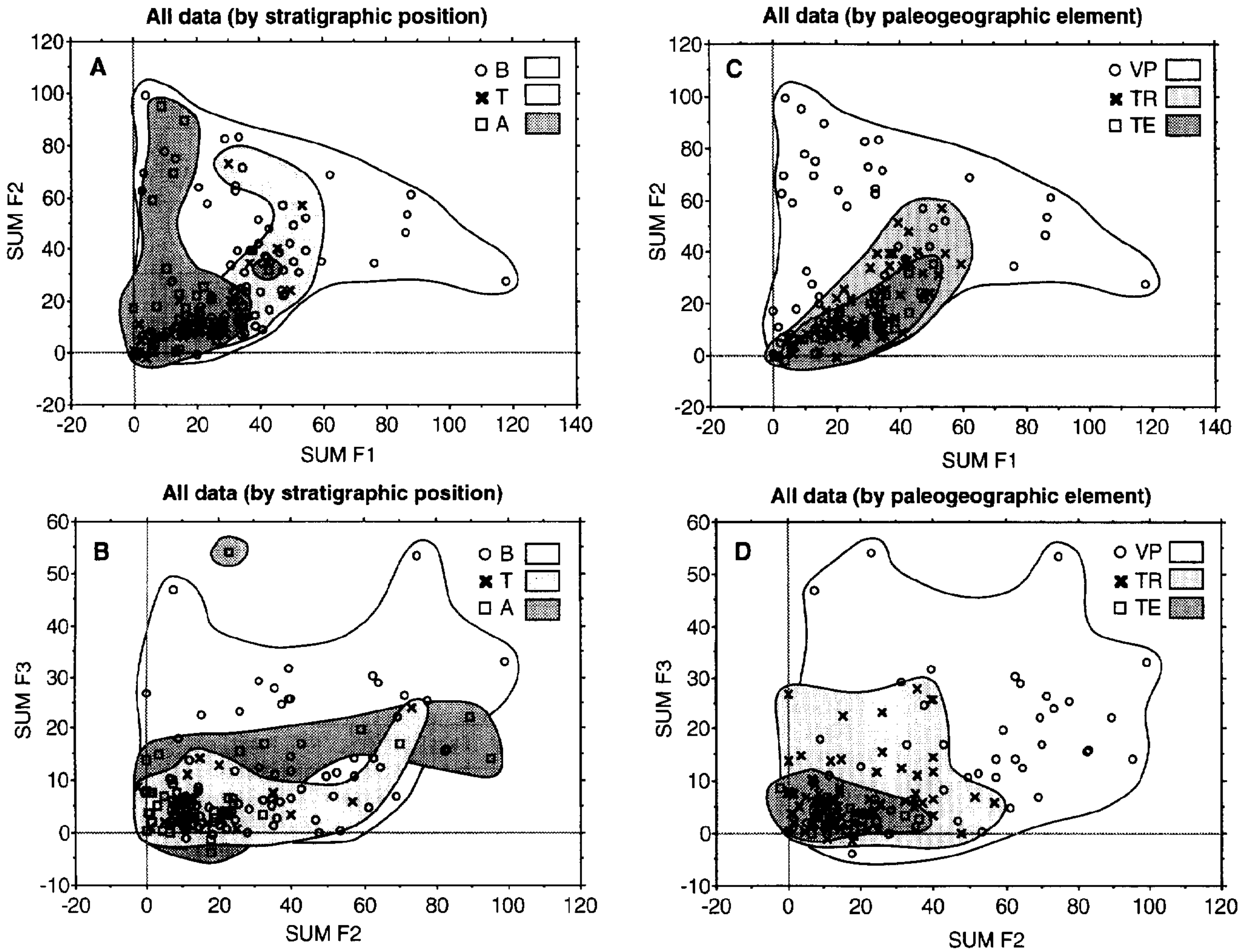

FIG. 5.—Cross plots of factor scores. A) Cross plot of factor scores for F1 vs. F2. Data from all localities are included. Data points are categorized by position with respect to fluvial-to-marine transition: A = above, B = below, and T = transition. Note imperfect separation of dominantly marine field and dominantly fluvial field. B) Cross plot of factor scores for F2 vs. F3. Data points are categorized by position with respect to fluvial-to-marine transition: A = above, B = below, and T = transition. Note imperfect separation of dominantly marine field and dominantly fluvial field. C) Cross plots of factor scores F1 vs. F2. Data from all localities are included. Data points are coded by paleogeographic position, VP = Virginia promontory, T = transition (include rift basin margins), and TE = Tennessee embayment. Note improved separation relative to Figure 5A, suggesting that the degree of reworking as a function of paleogeographic setting is a prime factor in controlling sandstone composition. D) Cross plot of factor scores for F2 vs. F3. Data from all localities are included. Data points are coded by paleogeographic position, VP = Virginia promontory, T = transition (include rift-basin margins), and TE = Tennessee embayment. Note improved separation relative to Figure 5A, suggesting that the degree of reworking as a function of paleogeographic setting is a prime factor in controlling sandstone composition.

negative or positive values are interpreted as significant. Factor "scores" represent a rescaling of each sample in the multivariate data set in terms of the loadings on the factors. Factor scores are typically depicted as plots of points on axes, and can be scrutinized to see if patterns exist, particularly whether or not distinct subsets of the sample population can be separated using factors.

Table 2 summarizes the results of the factor analysis of the entire data set (normalized to avoid some computational problems, as described previously). Five factors were initially extracted. The first three account for 53.6% of the total sample variance. Factor 1 has high positive loadings on P and Lv, and large negative loadings on Lm and accessory minerals. It is therefore characterized by the presence of feldspars (especially plagioclase) and volcanic lithic fragments. Factor 2 has high positive loadings on K, Lm, and accessory minerals, and therefore is characterized by the presence of K-feldspars, metamorphic lithic fragments, and accessory minerals. Factor 3 has high positive loadings on Qp (> 7) and Ls, and a high negative loading on Qp (3–7) and appears to be characterized by the presence of polycrystalline quartz with a large number of subgrains and by sedimentary lithic fragments (chiefly chert). The score weights for the three factors (Table 2) were then computed for each sample to produce factor-score cross plots (Fig. 5).

Source Rock and Tectonic Setting

Distinct sample fields were separated better (although not perfectly) on the factor-score plots using paleogeographic setting (Fig. 5C, D) than on plots based on paleoenvironmental setting (Fig. 5A, B). Sediment deposited in and restricted to the Tennessee embayment (represented by the Cochran Formation) shows less petrographic variability than sediment deposited on and adjacent to the Virginia promontory (represented by the

Unicoi Formation). The Tennessee embayment samples thus tend to be quartzo-feldspathic in composition, whereas the Virginia promontory samples tend to contain more lithic fragments and polycrystalline quartz regardless of their depositional setting.

Depositional Processes and Settings

Despite many attempts to use all possible variable combinations and reductions in factor analyses, there is a persistent and significant overlap in the factor-score plots between the fluvial and marine fields (Fig. 5A). Fluvial samples generally plot in a distinctly larger field, reflecting their greater compositional heterogeneity. Marine samples, in general, occupy a smaller field. Some fluvial samples (generally from the Cochran Formation) plot in the marine field, whereas some marine samples (generally from the Unicoi Formation) plot in the fluvial field (Fig. 5B). This lack of separation of fields may be interpreted as resulting from at least one of the following: (1) marine processes were less effective than expected in "cleaning up" heterogeneous, compositionally immature fluvial sand, (2) the marine environments adjacent to the Virginia promontory were "overwhelmed" by large amounts of immature sand derived from the local uplands, or (3) mixing of fluvial and marine sands resulted in a transitional field, as can be seen in Figures 5A and 5B; samples identified as being from the transitional interval plot in both the fluvial and marine fields, as well as between those fields, indicating mixed characteristics. The most proximal depositional settings were identified within the Unicoi Formation of Virginia, indicating the area of that the Virginia promontory can be characterized as a higher-relief terrain with a higher proportion of granitic-gneissic and volcanic source rocks. The Tennessee embayment, on the other hand, can be characterized as a low-relief terrain composed predominantly of sedimentary source rocks. The Unicoi Formation, deposited adjacent to the Virginia promontory, has a more variable composition, probably reflecting first-order (*sensu* Ingersoll 1990) variation in source regions (Figs. 4, 5C, D).

CONCLUSIONS

Analysis of the petrology of basal Chilhowee Group sandstones in Tennessee, North Carolina, and Virginia shows that paleogeographic setting (Tennessee embayment vs. Virginia promontory) is a better predictor of sandstone composition than depositional setting alone. Variation in the composition of medium-grained sandstone of the basal Chilhowee Group (Figs. 4, 5) appears to reflect the degree to which mechanical abrasion in the fluvial system removed labile rock fragments prior to final deposition and lithification. The low percentage of labile grains in samples from the Tennessee embayment is interpreted to reflect destruction of labile grains during protracted fluvial transport prior to deposition in more distal settings of the system (i.e., longer transport distances resulted in greater reduction in labile grains). Comparison of the composition of samples from above and below the fluvial-to-marine transition suggests that fluvial reworking modified the primary composition of the sand before it reached the shoreline (Figs. 4, 5A, B). Sedimentologic and petrologic data from the Tennessee embayment and the Virginia promontory therefore support the following conclusions on paleogeographic variation across the area: (1) low-energy, distal fluvial environments dominated in the Tennessee embayment, suggesting low-relief terrain; (2) proximal, alluvial-fan environments were restricted to the Virginia promontory, indicating higher-relief terrain; (3) types of source rock were apparently uniform along the margin, although the relative abundance of each type may have varied; (4) sediment composition across the region mainly reflects the effectiveness of fluvial reworking to reduce the labile fraction; and (5) the boundary between the Tennessee embayment and the Virginia promontory represents a fundamental boundary such that each segment of the evolving margin underwent a unique stratigraphic evolution. Although this study was not intended to test any particular tectonic model, this final conclusion is compatible with previous work (Thomas 1977, 1983, 1991, 1993) in which the boundary between the Tennessee embayment and the Virginia promontory was interpreted as a transform segment within the evolving Laurentian-Iapetus margin. The gross variations in Chilhowee Group stratigraphy, thickness, facies architecture, and sandstone petrology across this possible transform could be the result of variation in tectonically established relief during the rift phase and differences in subsidence rates during the subsequent passive-margin phase.

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