Newly Discovered Mesozoic Basins in the Virginia Blue Ridge: Sedimentology, Provenace, Structure, and Tectonics

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Newly Discovered Mesozoic Rift Basins in the Virginia Blue Ridge: Sedimentology, Provenance, Structure, and Tectonics

A thesis submitted in Partial Fulfillment of the Requirement for the Degree of Bachelor of Science (Honors) in Geology, The College of William and Mary in Virginia

by

Ari Hartmann

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Abstract

Deposits of iron-oxide cemented conglomerate and coarse sandstone were recently discovered in northern Albemarle County and southern Madison County, in the eastern Blue Ridge Province of north central Virginia. These deposits are interpreted to represent remnant Mesozoic rift basins on the basis of deformational age constraints, sedimentary provenance, and lithologic similarity and proximity to other Mesozoic sedimentary rocks. Mesozoic rift basins occur along eastern North America and were formed by tensile stresses from the breakup of Pangea and the birth of the Atlantic Ocean in the mid to late-Triassic and early Jurassic. The Beautiful Run Basin (new name) in Madison County is comprised of two erosionally separated ~100-200 m wide iron-oxide cemented conglomerate and sandstone deposits bounded by a normal fault trending 040 on their NW side. The Burnley Basin (Nelson, 1962) in Albemarle County is comprised of two erosionally separated ~50-100 m wide iron-oxide cemented conglomerate and sandstone deposits. In contrast to the Beautiful Run Basin, the Burnley Basin displays structural complexity, and may occur along a right stepping segment of the same normal fault. Both the Beautiful Run and Burnley basins abut a 10-400 m belt of graphite schist, called the Johnson Mill Member (Allen, 1963) of the Lynchburg Group, acted as a detachment surface during Mesozoic extension and controlled basin formation. Clast assemblage analyses on the Burnley Basin and Beautiful Run Basin reveal a local provenance. Similar analyses of conglomerates of the Culpeper and Barboursville Basins depict a larger westerly source area. Restoration of the Burnley and Beautiful Run basins assuming a conservative 1.5 km of erosion shows those two basins merging with the Barboursville/Culpeper Basin in an imbricated fault block geometry.
Introduction

In the Fall of 2004, Professor Chuck Bailey and his research student Margaret Kroehler were doing fieldwork in southern Madison County, Virginia, when they found a pile of boulders and several small "nubs" of iron-oxide cemented conglomerate topping a farm hill (herein called the Beautiful Run study area). These rocks occurred in what had been previously mapped as the Neoproterozoic metasedimentary Lynchburg Group (Allen, 1963; Virginia Division of Mineral Resources, 1993). Conglomeratic layers do occur in the Lynchburg, but Lynchburg conglomerates are metamorphosed to greenschist facies, and non porous with little to no iron content. In contrast, the conglomerates found by Bailey and Kroehler were unmetamorphosed, highly porous, and brownish-red in color due to iron-oxide abundance in the matrix. It was immediately clear to Bailey and Kroehler that these red conglomerates were unrelated to the Lynchburg Group rocks in which they had been mapped (Bailey, personal correspondence). Pursuing the implications of this realization lay beyond the scope of their regional structural and geophysical study.

Beginning in the summer of 2007, I undertook this research project under professor Chuck Bailey with an aim to elucidate the origin, nature, and larger geologic implications of these "unusual" red conglomerates in southern Madison County. The study was later expanded to include a second field site in northern Albemarle County after a small (<500 m²), Mesozoic conglomerate deposit named the Burnley Basin was noted to have been mapped west of the Barboursville Mesozoic Basin by Nelson (1962). Beyond its initial discovery, the Burnley Basin has not been studied until this project.
Background and Previous Work

Mesozoic Rift Basins

Numerous exposed, northeast-southwest trending Mesozoic rift basins in occur eastern North America (Figure 1). They occur as far north as Nova Scotia and as far south as North Carolina, and have analogs in Europe and Africa. Through a variety of methods, including paleontology, biostratigraphy, and radioisotope dating of basalt flows, their ages have been constrained to the middle Triassic through lower Jurassic periods (e.g. Cornet, 1977; Dunning and Hodych, 1990; Lucas and Huber, 2003; others). During this time, the supercontinent Pangea was rifting apart and a proto-Atlantic Ocean was developing between what are now the North American and African continents. Tensile stresses associated with this event reactivated Paleozoic structures and created axial rift valleys ranging up to several hundred kilometers on either side of the central rift axis, from ~225 Ma to ~195 Ma (Ratcliffe and Burton, 1985; Schlische, 1993). Continental sediments ranging in thickness up to 7 km were deposited in the basins over a period of some 30 million years (Weems and Olsen, 1997; Faill, 2005). Most of the basins are half-grabens bounded on the west by a large normal fault, though some are faulted on the east or are full grabens (Schlische, 1993).

In Virginia, larger Mesozoic rift basins include the Taylorsville, Richmond, Farmville, Culpeper and Barboursville basins. The latter two basins, along with the Gettysburg Basin in Maryland and Pennsylvania and the Newark Basin in New Jersey and New York, represent the geologic western-most belt of Mesozoic rift basins in North America. It is likely that these four basins were originally connected and since separated by folding and erosion (Faill, 1973). The Culpeper and Barboursville Basins straddle the
eastern limb of the Blue Ridge anticlinorium, and occur 3-5 km east of both the Beautiful Run and Burnley study areas (Figure 1).

Four major rock types characterize Mesozoic rift basins deposits: basalts, shales, arkosic sandstones, and conglomerates (Lorenz, 1988). Each rock type has a distinct spatial and temporal occurrence. Basalts were primarily extruded in the early Jurassic, and were extruded over laterally extensive areas (Weems and Olsen, 1997). Shales were deposited in lakes and occur near the middle of the basins - areas of lowest topography to which water was preferentially drained. Shales are also associated with humid periods when standing bodies of water were supported by frequent precipitation. Arkoses were deposited fluvially throughout the basins. Conglomerates tend to occur along basin margins, where high relief associated with the fault scarp produced coarse, poorly sorted alluvial fan deposits (Bull, 1972; Lindholm et al., 1979; Lorenz, 1988). Coarse-grained conglomerates that occur along the faulted basin borders may also record periods of fault movement (Lindholm et al., 1979; Arguden and Rodolfo, 1986).

**Rift Basin Conglomerates**

Paleomagnetic data have shown the North American continent straddled the equator during late Triassic and early Jurassic rift basin formation (Witte and Kent, 1991). This, along with sedimentological data including caliche nodules, mudcracks, and playa lake deposits, indicate a generally hot and arid climate in Mesozoic North America. The immense size of the Pangaean supercontinent insulated its interior (including paleo-Virginia) from the moderating effect of the ocean. Strong seasonality, including swings in precipitation frequency and intensity, may have resulted. Such climatic characteristics, in
Figure 1. Map of Eastern North America showing exposed Mesozoic rift basins, in black (not all labeled). The two new basins discussed in this study are highlighted in red. Adapted from Olsen (1990).
tandem with tectonic extension, are conducive to the formation of alluvial fans. A similar geography can be seen in the modern American west.

Past studies have interpreted Mesozoic rift basin border conglomerates as alluvial fan deposits (e.g. Lindholm et al., 1979; Arguden and Rodolfo, 1986; others). Within an alluvial fan, multiple facies can occur. Poorly sorted, debris flow deposited conglomerates are common in the proximal fan (closest to the scarp), and fine with distance (Lorenz, 1988). Past studies have identified debris flows using characteristics including matrix-supported conglomerates (Lindholm et al., 1979), mica grains oriented parallel to flow (Lindholm et al., 1979), and normal grading (Stevens and Hubert, 1980). Sieve deposits occur when sediment rich water flows onto a porous, alluvial surface, allowing the water to infiltrate and deposit its load as a clast supported conglomerate (Lorenz, 1988). In the more distal reaches of the fan, fine-grained, sandy fluvial deposits dominate, commonly terminating in well-sorted clay and silt-rich sediments interbedded with clayey floodplain or playa lake deposits.

While much research has been devoted to the fossiliferous shales and arkoses and radiometrically datable basalts of the North American Mesozoic rift basins, far fewer studies have focused on the border conglomerates. This is unfortunate, as conglomerates provide a compelling record of syndepositional regional geography. Lindholm et al. (1979) examined clast type and provenance of Culpeper Basin border conglomerates. Faill (2003) completed a similar provenance study in the Barboursville, Culpeper, Gettysburg, and Newark Basins. Both studies found that clast assemblages displayed exclusively western provenance, and paleo-flow markers indicated generally eastward flow. Provenance varied laterally along the length of the basin, and given this lateral
variation both Lindholm et al. and Faill attempted to delineate the paleogeography during deposition in the Mesozoic. A similar effort is made in this study.

**Regional Geology**

*Overview*

In north-central Virginia, the Blue Ridge Province forms an approximately 30 km wide, north-northeastward plunging anticlinorium with Neoproterozoic to Cambrian sedimentary (Chilhowee Group), meta-sedimentary (Lynchburg Group), and meta-volcanic (Robertson River Suite) rocks on either limb and a Mesoproterozoic granitoid basement core (Fig. 2). The Burnley and Beautiful Run study areas are located in the eastern limb of the anticlinorium, ~5 km from the Piedmont Province border. Mesozoic rocks in both study areas are faulted into the Neoproterozoic meta-sedimentary rocks of the Lynchburg Group (detailed below), and are also located several kilometers west of the Culpeper and Barboursville Mesozoic basins (Fig. 3).

**Lynchburg Group Lithology and Stratigraphy**

The Lynchburg Group is a ~12 km thick sequence of metasedimentary rocks in the eastern limb of the Blue Ridge Anticlinorium (Wehr, 1985). Due to Paleozoic folding and tilting the Lynchburg Group dips approximately 40-60° to the SE in the study areas. Lynchburg Group rocks surrounding the Burnley and Beautiful Run basins display several distinct lithologies. Feldspar and quartz rich rocks with clastic texture and minor to abundant amounts of mica and pyrite represent the dominant Lynchburg Group lithology in both study areas. These rocks have been metamorphosed to upper greenschist
Figure 2. Geologic map of the Blue Ridge Province in North-Central, Virginia. Location of study areas marked by 'x'. From Bailey et al. (2003).
Figure 3. Geologic map portraying study areas (Burnley and Beautiful Run) in relation to regional geology. Gray (Y) represents Mesoproterozoic Blue Ridge basement granitoids, Orange (Zgr) represents the Neoproterozoic metavolcanic Robertson River Suite, Brown (Zs) represents the Neoproterozoic metasedimentary Lynchburg Group, Green (Zc) represents the Neoproterozoic-Cambrian Catoctin metabasalt, and Violet represents Mesozoic basin sedimentary rocks. Note from the underlying DEM that Catoctin Greenstone (Zc) holds up noticeably high relief. Sample locations from Barboursville and Culpeper basins marked by 'x'.
facies but original sedimentary structures, including cross-bedding and normal grading, are commonly visible (Wehr, 1983). The protolith for clastic, feldspar-rich Lynchburg Group rocks are poorly sorted arkosic sandstones and greywackes (Wehr, 1985; Conley, 1988). Small (1 cm - ~1 m) interbeds of phyllites, slates (Fig. 4a), and mica and graphite schists represent silty and muddy protoliths, and are included in the meta-arkose lithology for mapping purposes. Both study areas include the Ball Mountain and Charlottesville formations as mapped by Wehr (1983). Because those two formations are nearly lithologically identical in the study areas, this study makes no distinction between them.

A mappable, southwest to northeast trending 10-400 meter belt of graphite schist (Fig. 4b) occurs in both the Burnley and Beautiful Run study areas. Nelson (1962) first described this band of graphitic schist, calling it the Johnson Mill member of the Lynchburg Formation. In his PhD thesis on the geology of the Lynchburg Group in the Culpeper and Rockfish River areas, Wehr (1983) includes it as the upper section of the largely meta-arkosic Ball Mountain Formation. For the purpose of this study, the original Johnson Mill Member nomenclature is resurrected.

Meta-igneous bodies in the Lynchburg Group have been interpreted as mafic and ultramafic sills intruded into the Lynchburg Group sometime in the late-Neoproterozoic (Allen, 1963; Wehr, 1983; Weiss, 2000). These rocks range from coarse, hornblende and plagioclase amphibolites to chlorite schists.

As a stratigraphic sequence, the Lynchburg Group has been interpreted as a submarine alluvial deposit, with the Johnson Mill Member representing a period of anoxic sediment starvation (Wehr, 1983).
Figure 4a. Hand sample of a Lynchburg Group meta-arkose capped by a thin lens of slate.

Figure 4b. Hand sample of the Johnson Mill Member graphitic schist of the Lynchburg Group.
Methods

The two primary methods used in the project were detailed (1:6,000 and 1:12,000) geologic field mapping, and clast assemblage analyses undertaken in the laboratory.

Geologic field-mapping took place sporadically, beginning in the summer of 2007 and ending in March of 2008. Low relief meant few large outcrops, and necessitated the occasional use of coarse and abundant float as a proxy for bedrock. 103 rock type data points were taken in the two study areas, with an associated 58 structural measurements made. These field data were used to construct two geologic maps, one for both the Beautiful Run and Burnley study areas, and to make structural and sedimentological interpretations concerning the geology of both areas.

Clast assemblage analyses were made using rock slabs cut from field samples. Each slab was overlain with a 1-centimeter transparency grid and data concerning the clast was taken at each crosshatch. Data fields included clast rock-type, roundness, degree of weathering, length of long and short axes, and long axis orientation within each sample. Roundness was measured on a 0 to 3 scale, 0 being angular and 3 being round. Weathering was qualitatively measured on a 0 to 2 scale, 0 being no weathering and 2 being heavy weathering. When a crosshatch occurred over pore-space visible in hand sample, or matrix, defined by grains less than 2 mm in size, it was noted. 1,673 data points and 573 unique clast data points were taken and entered into Microsoft Excel. Analyses were made on both conglomerates from the Burnley and Beautiful Run study areas, as well as conglomerates from one site in both the Culpeper and Barboursville basins (Cedar Mountain and Haudricks Mountain members of the Bull Run Formation,
respectively). A total of 14 slabs were counted in this manner. Thin sections were made to better identify rock types represented by the clasts.

Secondary methods include lineament analyses made using shaded relief maps produced from Digital Elevation Models (DEM). Underlying geologic structures commonly manifest themselves through linear topographic features. Thus, characterizing lineament orientations in a study area can partially illuminate otherwise hidden underlying structural geology. DEMs of the Burnley Basin and Beautiful Run Basin study areas were generated using the 3 arc second SRTM data available on the USGS’ Seamless Server. Linear features greater than 200 meters in length were traced on four versions of both maps, lit from the northeast, southeast, southwest, and northwest respectively. Each differently lit map version highlighted a slightly different set of lineaments. These different sets were overlain on a common map, and where two or more lineaments overlapped, a “master lineament” was traced. Orientation and length of each of the master lineaments were measured. Each master lineament was weighted to its length and the weighted orientations were plotted as a rose diagram using the software program Stereonet v. 6.3.3. A larger, regional DEM map was also inspected in a more qualitative manner.

Additional secondary methods include a paleo-flow analysis using a field-oriented cross-bedded sandstone sample. Two flat faces were cut on the field-oriented sample using a slab-saw. The rakes of two sets of beds on both faces were found in reference to the strike of each face. The strike and dip of each of these faces were found using a Brunton compass. Strike and dips of the two faces were plotted as great circles using the software program Stereonet v. 6.3.3. Rakes associated with the two bedding sets were
then plotted as points on the great circles, and a third and fourth great circle were found that connected two points (associated with bedding set rakes) on each of the two great circles (associated with the two cut faces). The strike and dip of the two resulting great circles represented the strike and dip of the two bedding sets. Based on crosscutting relationships, one set was interpreted as originally horizontal and another as cross-beds. Thus, the dip direction of the cross-beds provided a tentative paleoflow direction.

Cross section restoration (projecting geologic contacts into the above-surface) was an important theoretical exercise. It elucidated structural and geometric relationships between the Burnley and Beautiful Run basins and the Culpeper and Barboursville basins, as well as the paleogeography of the Blue Ridge anticlinorium.

Paleomagnetic analyses for absolute dating purposes are planned for the summer of 2008. Field-oriented samples will be drilled from at least two bedrock outcrops in the Burnley Basin. The samples will be sent to Scott Georgis at SUNY-Geneseo to measure the remnant magnetism preserved in the iron-oxide cement. From that, the samples' paleo-latitude in modern day coordinates will be calculated and correlated with known regional paleo-latitudes through Earth history. The results of this analysis will likely represent an age of diagenesis (precipitation of iron-oxide cement) and not of deposition, but will provide a lower bound to further constrain the age of deposition.
Results

Lithology of Mesozoic Deposits:

Deposits of sedimentary rocks in both the Burnley and Beautiful Run study areas are iron-cemented, with volumetric iron-oxide content ranging from 10-30% as determined by percent opaques in thin section. Their iron-richness lends them colors ranging from brown to maroon to purple-red. Mesozoic deposits in both study areas are a mix of matrix- and clast-supported conglomerates with pebbles, cobbles, and boulders ranging from centimeters to over 0.5 meters in a sandy quartz matrix (Fig. 5a). A second, less extensive, often cross-bedded coarse-quartz sandstone facies occurs in both study areas as well (Fig. 5b). High porosity is pervasive in both sandstone and conglomerate, ranging from 15-30% as determined by thin-section analysis (see page 60 for discussion of porosity and iron content).

Conglomerate samples were taken at one site from both the Barboursville and Culpeper basins. In the Barboursville Basin, samples were taken on Haudrick Mountain (alternatively known as Hardwick Mountain), a 278 meter topographic high underlain by iron-cemented conglomerates of the Haudrick Mountain Member of the Bull Run Formation (Lee and Froelich, 1989; Weems and Olsen, 1997). In the Culpeper Basin, samples were taken on Rt. 721 on the east bank of the Robinson River from the Cedar Mountain Member of the Bull Run Formation (Lindholm et al., 1979; Weems and Olsen, 1997). Past studies of the Cedar Mountain Member - alternately known as the Mountain Run Member (Lee and Froelich, 1989) - describe it as a greenstone conglomerate (Lindholm et al., 1979; Weems and Olsen, 1997). Both the Cedar Mountain and Haudrick Mountain members are of Norian (latest Triassic) age (Weems and Olsen, 1997).
Figure 5a. Conglomerate boulder in the Beautiful Run study area.

Figure 5b. Moderately well-sorted maroon sandstone in the Burnley study area. Cross-bedding not present.
Rocks of the Burnley and Beautiful Run basins show some lithological resemblance to the Mountain Run and Haudrick Mountain members of the Culpeper and Barboursville basin deposits. Those members are predominantly matrix-supported conglomerates intertongued with sandstones, deposited in debris-flow dominated alluvial fans at the base of Mesozoic-aged normal fault scarps (Lee and Froelich, 1980; Weems and Olsen, 1997).

**Thin Section Petrology:**

2-4 thin sections were made of rocks from each the Culpeper, Barboursville, Beautiful Run, and Burnley basins.

**Culpeper Basin**

Three thin sections were made from the conglomeratic Cedar Mountain Member of the Bull Run Formation. On average, the matrix is composed of 30-60% angular to sub-rounded quartz grains 0.01 to 1 mm in size, 35-50% opaque minerals (likely iron-oxides), and ~5% sheet silicates (likely chlorite), with ancillary amounts of apatite, plagioclase, and zircon. A large ( > 2 cm) clast of coarse sandstone (Fig. 6) was composed of ~75% subangular quartz grains 0.5 to 2 mm in size, ~20% feldspar (of which 50% is plagioclase, 25% is K-feldspar, and 25% is perthite or anti-perthite), another coarse sandstone clast is 80% quartz, 10% feldspar (mostly plagioclase), 5% sericite, and 5% opaque minerals. On the basis of feldspar abundance and greenschist facies metamorphic minerals (notably chlorite), these clast types are interpreted as meta-arkosic sandstones of the Lynchburg Group.
Figure 6. Clast of coarse arkosic sandstone of likely Lynchburg Group provenance bordering a fine-grained, felty greenstone. Poorly sorted, angular quartz grains in a fine-grained silica and iron-oxide cement, visible in the bottom right, characterize the matrix.
A second clast type displays felty texture with ~50% plagioclase and ~50% fine grained minerals with moderate relief and high birefringence, interpreted to be actinolite, epidote, and chlorite (Fig. 7). Opaque minerals (likely magnetite) are also present. The mineralogy and texture of this clast are those of greenstone. Catoctin Formation greenstone occurs on both the western and eastern limb of the Blue Ridge anticlinorium. Other clasts with identical mineralogy but varying mineral modes and textures are common, composing more than 80% of the clast assemblage.

Regrettably, a less common third and fourth clast type was not captured in either of the two thin sections. In hand sample, one is tan to grey-green to dark grey in color, with fine, indistinguishable grains (likely clay minerals), and common crenulations. In several of these clasts, the fine-grained lithology described above is seen in contact with a grey-blue, medium to coarse-grained sandstone, which also forms its own clast at times (Fig. 8). A complete lack of schistosity in hand sample for the fine-grained portion of these clasts likely means that they do not represent phyllites and schists of the Lynchburg Group, but rather mildly deformed mudstones and quartz sandstones of the Chilhowee Group, likely the Harpers Formation.

**Barboursville Basin:**

Two thin sections were made from the conglomeratic Haudricks Mountain Member of the Bull Run Formation in the Barboursville Basin. In both samples, the matrix is composed of 40-60% fine grained lithic fragments and 30-50% poorly sorted, angular to subrounded quartz and sericite grains in an iron-oxide cement (Fig. 9).
Figure 7. Plane polarized (top) and cross-polarized (bottom) photomicrograph of three greenstone clasts in Culpeper Basin conglomerate. Top left clast, characterized by fine grained, high relief grains, is epidosite. Top right clast is abundant in magnetite.
Figure 8. Siltstone in contact with a normally graded (?) immature sandstone in Culpeper Basin conglomerate (Cedar Mountain Formation).
Figure 9. Photomicrograph of Barboursville Basin conglomerate. Note the prevalence of meta-arkose clasts, likely from the Lynchburg Group, and fine-grained clasts, likely from the Chilhowee Group.
Lithic clasts are mostly coarse-grained, sericitized sandstone and fine-grained sheet-silicate rocks. The latter clast type is largely unfoliated and likely represents fine-grained, mildly deformed siltstones and mudstones of the basal Chilhowee Group. Felsic metavolcanics, red and tan in hand sample, are easily identifiable in thin section by their elongate blebs of opaque minerals (Fig. 10). Greenstone, identifiable by felty texture, fine pale-green epidote and actinolite grains, and opaques, was also noted in one of the thin sections.

**Burnley Basin:**

Four thin sections were made from Burnley Basin conglomerate and sandstone. The sandstone facies is ~20% pore space and ranges from 20%-40% iron-oxide cement (Fig. 11). Angular quartz grains 0.05 to 2 mm compose 90% of all grains. Mica and micaceous lithic fragments less than 0.2 mm compose the remaining 10%.

Conglomerates of the Burnley Basin have matrixes similar in composition to the coarse-grained sandstone facies, with slightly poorer sorting (.01 to 3 mm quartz grains in the matrix). Lithic fragments are dominantly graphite schist, with high (>60%) percent opaque minerals, and a ductilely deformed fabric.

**Beautiful Run Basin:**

Four thin sections were made from Beautiful Run Basin conglomerates. The samples have a sandy matrix of subrounded to angular quartz grains cemented by iron-oxide (Fig. 12). Percent iron-oxide ranges from 15%-30% by area. Lithic clasts are
Figure 10. Plane polarized (top) and cross-polarized (bottom) photomicrograph showing felsic metavolcanic clast bordering a meta-siltstone of likely Chilhowee Group provenance.
Figure 11. Iron-oxide rich sandstone from the Burnley Basin in plane-polarized light. Iron oxide content estimated to be ~35%.
Figure 12. Plane polarized (top) and cross polarized (bottom) photomicrograph showing texture and composition of the Beautiful Run conglomerate. Note mica in lower right corner, and the abundance of pore space (after feldspar?).
dominantly quartz and sericite rich phyllites and meta-arkoses (with sheet-silicates having replaced feldspar). Pore space composes between 15% and 30% of the thin sections by area. 1-2 mm rounded grains of zircon and apatite are rare (Fig. 13).

*Johnson Mill Graphite Schist:*

One thin section was made of the Johnson Mill graphite schist. The sample displays a ductilely deformed sericite and opaque mineral matrix with small, stretched and shattered veins and blebs of quartz (Fig. 14a). While the exact graphite content of the schist is unknown, it is estimated to be above 30% by this study, based on qualitative characteristics, such as its ability to mark paper, and the abundance of opaque minerals in thin section (Figs. 14b).

*Clast Assemblages:*

Results from clast assemblage analyses performed on rocks of the Burnley and Beautiful Run Basins reveal a highly local provenance derived exclusively from the Lynchburg Group. Local provenance particularly characterizes rocks of the Burnley Basin, where the dominant clast type graphite schist occurs in a 400 meter band surrounding the basin. Graphite schist constitutes 80% of clasts in Burnley Basin conglomerate, with the remaining 20% composed of vein quartz, phyllite, and meta-arkose (Figs. 15 and 16). In the Beautiful Run Basin, vein quartz and meta-arkose dominate (55% and 25%, respectively) with ancillary amounts of graphitic schist and phyllite (Fig. 17).
Figure 13. Plane-polarized photomicrograph of quartz sand and iron-oxide matrix from Burnley Basin conglomerate. High relief, detrital apatite grain is visible in center of view.
Figure 14a. Graphite schist from the Burnley Basin area in cross-polarized light. Highly birefringent mineral are white mica. A "shattered" quartz vein is present in the center of view. Opaque (black) minerals are a combination of graphite, pyrite, and iron-oxide.

Figure 14b. Larger photomicrograph displaying microfolding and high opacity of the graphite schist. Sample from the Burnley area.
Figure 15. Bar graph depicting the average clast assemblage across three slabs of Burnley Basin conglomerate. Numbers capping bars represent percent of assemblage. Error bars depict minimum and maximum percents of assemblage across the three slabs.
Figure 16. This clast supported sample of Burnley Basin conglomerate displays an almost exclusive graphite schist assemblage. Different colors are a result of differing levels of oxidation and vein quartz.
Figure 17. A bar graph depicting the average clast assemblage across six slabs of Beautiful Run Basin conglomerate. Numbers capping bars represent percent of assemblage. Error bars depict minimum and maximum percents of assemblage from the three slabs.
Clast assemblage results from the Barboursville and Culpeper basins are more complex. In both of those basins, at least five distinct clast types are present: greenstone, metamorphosed felsic-volcanics, arkoses and meta-arkose, quartz sandstones, fine-grained sedimentary and meta-sedimentary rocks (mudstones and phyllites), and vein quartz (Figs. 18-21). Greenstone dominates Culpeper Basin conglomerate, representing 73% of all clasts, while meta-arkose and quartz sandstone comprise the majority (82%) of the Barboursville Basin conglomerate.

Based on mineralogical, color, and textural similarities to various bodies of rock in the Blue Ridge province, clast types were assigned to specific formations to elucidate likely provenance. Greenstones were attributed to the Catoctin Formation, likely derived from the eastern limb of the Blue Ridge. Metamorphosed felsic volcanic rocks, characterized by fine-grained orange and tan clasts with elongate blebs of opaque minerals visible in thin section (Fig. 9), were attributed to the Robertson River meta-volcanic suite. Arkoses and meta-arkoses, differentiated by the occurrence of abundant detrital feldspar or abundant sericite after detrital feldspar, respectively, were attributed to the Lynchburg Group. Quartz sandstones were attributed to the mildly deformed, siliciclastic Chilhowee Group, specifically the Weverton Formation. Fine grained clasts are likely representative of more than one formation, and were difficult to differentiate in thin section. Clasts preserving the contact between sandstones of likely Chilhowee Group provenance and gray to black fine grained rocks (Fig. 8) allowed for identification of the latter clast type as Chilhowee Group even when similar contacts were not preserved (which was mostly the case). These types of fine-grained clasts are generally massive or display crenulated lamination. Fine grained, foliated clasts were interpreted as Lynchburg
Figure 18. Photograph displaying some clast lithologies seen in the conglomeratic Cedar Mountain Member of the Culpeper Basin.
Figure 19. A bar graph depicting the average clast assemblage from two slabs of Culpeper Basin conglomerate. Numbers capping bars represent percent of assemblage. Error bars depict minimum and maximum percents of assemblage across the three slabs.
Figure 20. Photograph depicting some clast lithologies occurring in the conglomeratic Haudricks Mountain Member of the Barboursville Basin.
Figure 21. Bar graph depicting the average clast assemblage across two slabs of Barboursville Basin conglomerate. Numbers capping bars represent percent of assemblage. Error bars depict minimum and maximum percents of assemblage from the two slabs.
Group phyllite. A graph of clast provenance for conglomerates of the Culpeper and Barboursville basins illustrates those basins' heterogeneous provenance and far-reaching, western source area (Figs. 22 and 23).

**Mapping:**

Geologic maps of the Burnley and Beautiful Run basins and associated cross-sections are portrayed in Figures 24 and 25. Both study areas are dominated by meta-arkose and phyllite. One occurrence of Lynchburg Group conglomerate was found in the meta-arkosic Lynchburg unit in the Beautiful Run study area. The Lynchburg conglomerate occurs as a single layer of rounded granitic cobbles (<0.2 m) in a well-cemented, iron-oxide deficient, sandy quartz and feldspar grain matrix. The graphite schist Johnson Mill Member forms a NE striking belt through both study areas. Mesozoic deposits (orange) unconformably overlie Lynchburg Group rocks. A normal fault was mapped on the SE side of the Johnson Mill graphite schist belt in the Beautiful Run study area. Structure in the Burnley study area is more complex as suggested by stratigraphic thickness variations and linear features oblique to the Johnson Mill graphite schist belt (discussed further on page 66).

**Bedding:**

A field oriented sample of cross-bedded sandstone from the Burnley Basin was analyzed in the laboratory (Figs. 26a and 26b). One set of beds were interpreted to be cross-beds on the basis of their truncation by an overlying bedding set. The rakes of suspected cross-beds on both faces were found in reference to the strike of each face. A
Suspected Provenance for Culpeper Basin Conglomerate

Figure 22. Normalized bar graph of suspected provenance for clasts in Culpeper Basin conglomerate (Cedar Mt Fm).
Figure 23. Normalized bar graph of suspected provenance for clasts in Barboursville Basin conglomerate (Haudricks Mt Fm).
Figure 24a. A geologic map of the Beautiful Run study area. Bold line on southeast side of the graphite schist belt represents a normal fault. Fault ticks point to the downfaulted hanging wall. Triangle symbols represent bedrock foliation measurements, while hatchmark symbols represent bedding measurements.
**Fig 24b.** Geologic cross-section of the Beautiful Run Basin study area. 4.8x vertical exaggeration.
Figure 25a. Geologic map of the Burnley study area. Symbols are used as in Figure 24a, with the addition of a fold line (oblique to normal fault) with arrows indicating anticlinal geometry.
Fig 25b. Geologic cross-section of the Burnley Basin study area. 2.4x vertical exaggeration.
Figure 26a. Bedrock outcrop from which the field-oriented, cross-bedded sandstone was taken. Burnley Basin study area.
Figure 26b. Photograph showing two near-perpendicular cut faces of a field-oriented, cross-bedded sandstone of the Burnley Basin. Based on cross-cutting relationships seen on face A, bedding set b3 and b4 were interpreted as cross-beds.
third great circle was plotted to connect the dots representing rakes of suspected cross-beds (Fig. 26c). This great circle representing the cross-bed set had a strike of 085° and a dip of 16° to the south. Dip direction of cross-beds is commonly interpreted to represent paleoflow direction, thus paleoflow in the Burnley Basin was roughly in the direction towards the SSE.
Figure 26c. Stereogram depicting great circles representing two cut faces on a field oriented, cross-bedded sandstone sample (in black) and the strike and dip of the cross-bedset (in pink). Rakes between the cross-beds and a field oriented strike line were measured and plotted on the great circles representing the cut faces on which the measurements were made. A great circle, representing the cross-bed set, was picked to connect the two rake points. Strike and dip of cross-bed set was found to be 085° 16 to the South, which is the inferred paleoflow direction.
Discussion

**Age Constraints:**

The conclusions of this research project are based on the deposits of interest being Mesozoic in age. Thus, it is important to address why this inference of Mesozoic age has been made. Strictly speaking, the only definite age constraint for the iron-cemented conglomerates and sandstones of the Burnley and Beautiful Run areas is a maximum age provided by the Alleghanian Orogeny approximately 300 Ma. This must be a maximum age because it represents the last orogenic deformation event in eastern North America, and the rocks in question are undeformed.

Evidence strongly suggests that the iron-cemented conglomerates and sandstones in the Burnley and Beautiful Run areas are rift-related rocks Mesozoic in age:

1) The Burnley and Beautiful Run areas are close (3-5 km) to the Barboursville and Culpeper Mesozoic rift basins. This proximity suggests they may be erosional remnants of those basins.

2) The lithologic similarities between rocks of the Burnley and Beautiful Run areas of the Barboursville and Culpeper Mesozoic rift basins, and other rift-related border conglomerates (coarse, poorly sorted conglomerates and cross-bedded sandstones, high iron content), suggest that these deposits likely formed via similar mechanisms (scarp generation, debris flows, oxidation, etc.). As the deposits occur in the same area as the Culpeper and Barboursville Basin, similar formation mechanisms imply similar formation time.
3) The highly local provenance of deposits, especially in the Burnley Basin, imply a
tectonic event. Without some sudden, brittle deformation of the crust (scarp and basin
formation), it is difficult to imagine a manner in which gravelly sediments mostly
composed of angular, coarse clasts of a very unresistant rock (graphite schist) could have
accrued.

4) The deposits both abut a suspected fault. Evidence for this fault is discussed on page
81.

Other possible assumptions concerning the basins’ ages seem less likely. For
example, the Burnley and Beautiful Run deposits could be younger than Mesozoic in age,
deposited in a paleo stream-valley and somehow preserved in the sedimentary record.

Two lithologic characteristics of the deposits refute this possibility. First, angular
grain shape and large grain-size (clasts up to 0.5 meters) imply significant topographic
relief necessary to generate such coarse and immature sedimentation, as well as to deposit
a sedimentary package to depths capable of producing diagenesis (barring precipitation of
secondary minerals by groundwater). While modern stream and stream valley sediments
are commonly coarse, clasts are typically more rounded than those of the Burnley and
Beautiful Run basins, where ~45% of clasts are either angular or subangular. It is
unlikely that adequately significant topographic relief has existed in either study area for
many tens of millions of years. The most recent, regional geologic event capable of
producing topographic relief consistent with extensive coarse sediment deposition and
diagenesis was continental rifting in the Triassic. Further, Chilhowee Group rocks do not occur in the study area’s modern drainage basin. Their presence indicates that the deposits cannot be of modern age.

Second, and more importantly, the local provenance of conglomerates in the Burnley and Beautiful Run study areas does not agree with stream valley depositional model. As high energy environments that often flow over large distances and varying lithologies, streams tend to entrain pebbles and cobbles of somewhat heterogeneous provenance and/or high durability. Clasts of the Burnley and Beautiful Run basins have neither of those traits. The small extent and weakness of the Johnson Mill graphite schist in particular seems to require some brittle tectonic event in order for its erosion and deposition in the study areas.

Thus, the two recently discovered deposits of iron-oxide cemented conglomerates and sandstones in northern Albemarle and southern Madison counties are interpreted as Mesozoic rift basins. The Burnley Basin had been discovered and named by Nelson (1962). The Mesozoic deposits in southern Madison County are newly discovered and unnamed, and will herein be known as the Beautiful Run Basin, in reference to the stream that flows by them. As previously mentioned, a paleomagnetic analysis on rocks of the Burnley areas will hopefully yield a rough absolute date, and obsolete the discussion over the validity of my project's grand assumption.

**Paleogeography:**

For the purpose of this study, "geography" is defined by the pattern of surface lithology and topographic relief. Clast assemblage analyses of rift basin conglomerates
undertaken in this study suggest that Mesozoic geography differed markedly from the modern. Most tellingly, clasts of Blue Ridge basement rocks (Mesoproterozoic granitoids currently exposed in the core of the anticlinorium) are not present in conglomerates of the western margins of the Culpeper and Barboursville basins (Lindholm et al. et al., 1979). Bailey et al. (2006) write that the absence of basement clasts in the Culpeper Basin must mean that by the middle Mesozoic, when basin deposition was occurring, the basement was not yet exposed in the core of the Blue Ridge anticlinorium. Clast assemblage analyses from this study support this inference, with the qualification that only one among several laterally homogenous conglomeratic formations was sampled from each of the Culpeper and Barboursville basins. Nevertheless, past research on those conglomeratic formations did not find basement clasts either (Lindholm et al. et al., 1979).

It is possible that the Blue Ridge basement rocks were, in fact, exposed in the basin source area, but were not transported or preserved during transport. Parker (2008) inspected cobble lithologies of quaternary terrace deposits along the James River in the western Piedmont province and did not find cobbles of granitoid composition – this despite the fact that basement rocks are the most areally extensive lithology in the Blue Ridge province (which the James River drains). In the modern climate, igneous, feldspar-rich rocks characteristic of the Blue Ridge basement are intensely weathered and do not form stream cobbles. In the Mesozoic during deposition, however, the eastern North-American climate was arid and weathering-limited (Lorenz, 1988). Thus, it seems likely that the lack of basement is a result of non-exposure and not intense weathering.
Projecting formation contacts into the above-surface shows that approximately 1 km of the basement itself has been eroded. Given that the basement was likely unexposed in the Mesozoic, one can calculate a rough, minimum erosion rate for the Blue Ridge Province over the last 200 Ma. The minimum erosion rate needed to remove 1 km material in 200 Ma is 5 m per 1 Ma, or 0.5 cm per 1 Ka.

This calculation assumes the basement was exposed almost immediately after rift basin deposition. In reality, the "cover rock" sequence of the Blue Ridge, which includes the Catoctin Formation, Swift Run Formation, and Chilhowee Group, may have thickly mantled the basement during the Mesozoic. The Chilhowee Group and Catoctin Formation cover sequence reaches 5 km of thickness in some places (Bailey, personal correspondence). If only 1 km of that sequence capped the basement during the middle Mesozoic, than the calculated erosion rate would double to 10 m per Ma, or 1 cm per Ka. Assuming 2 km of post-Mesozoic erosion, geology of Blue Ridge province was restored to illustrate likely Mesozoic geography (Fig. 27). The validity of the restoration also rests on the assumption that large-scale structure in the Blue Ridge province was set by Mesozoic time and has not changed since. The results elucidate the likely source areas for sediments found in the basins. The Mesoproterozoic basement was still mantled by Catoctin greenstone and Chilhowee Group siliciclastics. That is why no basement clasts occur in Blue Ridge Mesozoic rift basins. Catoctin and Chilhowee rocks are resistant ridge formers that hold up the modern Blue Ridge Mountains, and likely held up a more broadly elevated ridge with maximum elevation above the center of the anticlinorium. Only after the cover sequence was breached did aggressive weathering and erosion occur in the granitoid core of the anticlinorium, resulting in the trough shaped topographic
Figure 27. Geologic cross section of the Blue Ridge showing Mesozoic reconstruction assuming approximately 2 kilometers of erosion. The modern surface is represented by dashed line. Adapted from Bailey (2004).
modern profile. Chilhowee Group rocks cropped out in folded inliers east of the anticlinorium’s western limb. These inliers, and not the western limb where Chilhowee Group rocks currently crop out, were the likely source for the mudstones, low-grade phyllites, and quartz sandstones seen in the Culpeper and Barboursville Basins.

The presence of Harpers and Weverton formation clasts but not Antietam Formation clasts is unsurprising if most of the Chilhowee clasts were derived from folded inliers near the middle of the anticline. The Antietam Formation is a well-sorted quartz sandstone deposited on beaches and shallow marine waters on the western paleo-coast of the Iapetan Ocean. Grain size likely fined from sand to silt and clay towards the east in deeper Iapetan waters. Thus, we may be seeing, but not recognizing, the fine, deep-water equivalent of the Antietam sandstone in

Mesozoic conglomerates. Clasts that preserve siltstone and mudstone in contact with coarse, poorly sorted sandstone (Fig. 8) may represent deeper water Iapetan turbidite deposits no longer visible in the Blue Ridge province.

The Burnley and Beautiful Run basins display exclusively Lynchburg Group provenance. This local provenance is likely a function of where we are sampling in the stratigraphic section. Erosion has removed most of both basins, leaving only the very oldest deposits. These were deposited as coarse-grained sediments during the onset of normal faulting when sediment was being shed exclusively from the young fault scarp composed of Lynchburg Group rocks. By contrast, the modern surface transects Culpeper Basin rocks deposited later in that basin's evolution, after it had become enlarged enough to capture large, exotic clast importing drainage network. Figure 28 illustrates the likely history of sedimentary provenance in the Beautiful Run Basin through time.
Figure 28. Cross-sections of the Beautiful Run and Barboursville basins showing interpreted provenance and structure through time.
Provenance studies of Culpeper and Barboursville basin conglomerates from different stratigraphic layers and formations (as opposed to the single site for each basin sampled for this study) would yield a richer and more informed model of paleogeographic evolution during deposition in the Mesozoic, and represents a potentially fruitful area of further study.

**Depositional Environment:**

Sedimentary deposits in both the Burnley and Beautiful Run basins are dominantly coarse, poorly sorted, matrix supported conglomerates. These characteristics have been used in past studies to identify debris flow deposits (e.g., Arguden and Rodolfo, 1986). Rare, clast supported conglomerates (Fig. 16) may represent sieve deposits, or perhaps debris flow deposits whose fine-grained portion has mostly been winnowed out by stream flow. Cross-bedded sandstones record the presence of streams. These three facies characterize the proximal portion of an alluvial fan. The local provenance of conglomerates in both basins belies the likely importance of mass wasting events over that of importation by streams in the method of sedimentation. However, rounded or subrounded clasts of vein quartz, which make up 51% of vein quartz clasts in the Beautiful Run Basin and 45% of vein quartz clasts in the Beautiful Run, suggest some sediment input from a small stream or streams.

**Iron Content:**

One of the most striking characteristics of the rocks of the Burnley and Beautiful Run basins is their color, which ranges from deep maroon to brown to brick red. The
proximal source of these colors is iron-oxide cement, ubiquitous in both the Beautiful Run and Burnley basins (Figs. 11, 29). Iron-oxide content, as measured by the opacity in thin section, ranges from 15 to 30% by area.

Traditionally, atmospherically unstable, iron-bearing minerals such as hornblende and olivine have been considered the dominant source of diagenetic iron in similar “red beds” (Walker, 1968). Pyroxene and amphibole bearing rocks, however, are absent in both the Burnley and Beautiful Run conglomerate clast assemblages and the Lynchburg Group rocks into which the basins were faulted, so the iron must have some other provenance.

The Johnson Mill Member of the Lynchburg Group is a thin (10-400 meter) band of graphitic schist with numerous blebs and stringers of pyrite, and was mined for pyrite in the 20th century (Nelson, 1962). In the study area, it is common to see pyrite dissolution pores upwards of 1 cm in width (Fig. 30). Pyrite (FeS₂) from the Johnson Mill is likely the source of iron. When pyrite is exposed to the atmosphere, it reacts with water and oxygen to form ferrous iron ions and sulfuric acid:

\[
4\text{FeS}_2 (s) + 14\text{H}_2\text{O} (l) + 14\text{O}_2 (g) \rightleftharpoons 4\text{Fe}^{2+} (aq) + 8\text{SO}_4^{2-} (aq) + 8\text{H}^+ (aq)
\]

pyrite           water           oxygen           ferrous iron           sulfuric acid
Figure 29. Iron-oxide cement (fine grained red material) infilling space between angular quartz grains in a sandstone of the Burnley Basin. Deep, “blood” red color of cement and minor dichroism are diagnostic of hematite. Seen under reflected, cross-polarized light.
Figure 30. Isometric pores from pyrite dissolution in a Lynchburg Group phyllite from the Burnley Basin area.
The ferrous iron is then oxidized to ferric (3+ charged) iron and bonded to oxygen to form hematite (Fig. 29). Based on reflected light thin section analysis, hematite seems to be the dominant iron-oxide in Burnley and Beautiful Run basin rock cement. Local acidic conditions promoted by the oxidation of pyrite in the Johnson Mill Member explain why feldspar rich, but not quartz or clay rich, clasts in conglomerates of the Burnley and Beautiful Run basins are so weathered compared to feldspar rich clasts in the Culpeper and Barboursville basin conglomerates (Fig. 31). Acidified groundwater may also be responsible for the high (15%-30%) porosity of rocks in the Burnley and Beautiful Run basins (particularly if the Johnson Mill graphitic schist acted as an aquiclude). The utter lack of feldspar grains in the matrix is curious given that feldspar-bearing rocks occur abundantly in the source area. Detrital feldspar grains in the matrix may have been intensely weathered to mobile clays, leaving pore space. Thus, high porosity is Burnley and Beautiful Run basins rocks may be a secondary feature, and not a result of limited compaction.

**Structure:**

**Overview:**

Research in the last two decades has shown that structural geometry of Mesozoic rift basins in Eastern North America is far more complex than had been imagined in past models of relatively simple "horst-fault-graben" configuration. The border faults of most basins, for example, are not continuous linear features but rather are segmented and variably oriented (Schlische and Withjack, 2005). It is likely that many of these normal faults are reactivated Paleozoic thrust faults (Ratcliffe et al., 1986), though Mesozoic
Figure 31. A bar chart depicting the average amount of weathering of fine-grained sheet silicate rocks and meta-arkosic rocks in conglomerates of four rift basins. Feldspar rich clasts in the Burnley and Beautiful Run are more extensively weathered than those same types of clasts in the Culpeper and Barboursville basins. They also display a larger ratio of feldspathic clast weathering to sheet silicate clast weather (table on right). This study suggests strong feldspar weathering conditions were achieved in the Burnley and Beautiful Run study areas by the dissolution of pyrite from the Lynchburg Group.
faults cross-cutting older structures attest to dominant stress-field control (as opposed to preexisting structural control) of at least some Mesozoic normal faults. Fault orientation controlled the relative magnitude of normal vs. strike slip movement. The fault movement type controlled the amount of displacement and basin thickness, with true normal movement leading to maximum displacement and basin thickness. Furthermore, the importance of postrift deformation and associated structural features has only recently been realized. Postrift folding and subsequent erosion has likely "separated" once contiguous basins; the Barboursville and Culpeper Basins are an example (Faill, 1973). Basin inversion - or the transition from extensional to compressional stress due to outward push from an incipient mid-ocean ridge - may have controlled much of the post-rift deformation. Structural complexity is particularly significant along the normal faulted basin borders, where drag-related stresses caused complex folding and pervasive brittle deformation in the hanging wall (Schlische, 1993; Olsen, personal correspondence 2008). Given the limited nature of rock exposure in the Burnley and Beautiful Run basins, it is difficult to precisely characterize their structure.

**Burnley Basin**

In the Burnley Basin study area, the Johnson Mill schist forms a 040° trending 200 m to 400 m wide belt of structurally weak graphite schist. Significant vein quartz precipitation attests to a history of faulting along this unit. Mesozoic deposits in the Burnley Basin sit unconformably upon and were likely faulted into the Johnson Mill graphite schist. As in the Beautiful Run study area, The NE trending Johnson Mill graphite schist belt in the Burnley Basin area hosts a NE trending, Mesozoic normal fault.
Field data, however, suggest that smaller-scale faults and/or folds oblique to the principle NE trending fault may also occur in the Burnley Basin area. The Johnson Mill belt appears to be variable thick in the study area. Wehr (1983) suggests that abrupt changes in the stratigraphic thickness of Lynchburg Group members, likely reflect unmapped faults or folds.

Bedding at two outcrops in the Burnley Basin strike ~285 and dip to the NNE. Bedding dip along normally faulted borders in rift basins is often ambiguous. Dipping beds can result from either 2) the originally sedimentary dip of foreset beds on an alluvial fan, in which case the dip direction points away from the fault, 2) hanging block tilting, in which case the dip direction points towards the fault, or 3) syn- or post-rift folding, in which case the bedding dip says little about the position and geometry of the normal border fault. Given the lack of exposure, it is impractical to decide which of these three causes bedding dip in the Burnley Basin and all will be considered.

If bedding dip represents an original sedimentary feature, then a ~N-striking normal fault, away from which the surface of an alluvial fan would have dipped, exists on the SW of Mesozoic deposits. This interpretation is my least favored. If the fault truly lies to the SW of deposits in the Burnley area, than the area NW of the Johnson Mill graphite schist represents the down-dropped hanging wall. Yet the Beautiful Run Basin abuts the Johnson Mill graphite schist to the belt's SE - clear evidence that the area SE of the Johnson Mill graphite, not the area NE, was down-dropped. Bedding dip observed in Burnley Basin Mesozoic strata cannot be an original, sedimentary feature.

If bedding dip represents syndepositional, hanging block tilting, than a ~N striking normal fault exists NE of the Mesozoic deposits. Two distinct linear features
abutting (or near abutting) the extent of Mesozoic deposits in the Burnley Basin may indicate the presence of a fault or faults in this orientation. The first feature is a band of vein quartz approximately 15 m wide and trending ~340° (Fig. 32). The second feature is the shape and direction of Purdy Creek, which seems to truncate the southwestern group of Mesozoic deposits and runs straight through that area in a direction striking ~340°. There also seems to be a general elongate shape of Mesozoic rock outcrop in the ~340° orientation. NW-trending normal faults bounding the deposits on their east and west could have formed via transtension. Transtensional faulting occurs when a bend occurs in a strike-slip or dip-slip fault, causing a "pull-apart" at that bend.

I do not favor this model for several reasons. First, as illustrated by a geologic cross-section (Fig. 25b), the model requires variable topography on the basin floor of several 10's of meters to connect the two erosionally separated deposits. Second, cross-beds indicate paleoflow to the south. This paleoflow direction does not agree with a normal fault scarp bounding deposits on the east. Third, a NE-SW orientation of brittle failure is questionable; the rocks into which the Burnley Basin were faulted have a major preferred plane of failure along foliation and a minor preferred plane of failure corresponding to bedding, both of which are oriented NE-SW.

Rift related features striking ~340° are not uncommon in north-central Virginia, however. Numerous diabase dikes occur throughout the Blue Ridge province and record a σ3 stress field oriented northeast-southwest corresponding to the proposed direction of elongation for the Burnley Basin. Both local lineament data derived from DEM’s (Fig. 33) and larger regional data of dike orientation (McHone, 1988) support the notion that extensional stresses oriented NW-SE may have been of local importance. Yet, no
Figure 32. Linear zone of vein quartz pebbles and cobbles in the Burnley study area. The zone continues tens of meters into the woods. Mesozoic deposits lay to the photographer's right.
Figure 33. Rose diagram depicting the roughly bimodal orientation of linear features to the NE and NNW in the Burnley Basin study area.
NW-trending brittle deformation features that controlled basin formation (as with the western border faults of the Culpeper and Barboursville basins) have been documented in southeastern North America. Evidence is not compelling enough to interpret the Burnley as the first such NW-trending Mesozoic basin.

The third model in which deposits were affected by syn- or post-rift folding is least troubling. In the Newark and Gettysburg basins, the border fault system consists of many fault segments, some less than 1 km in length, in a generally right-stepping geometry (Schlische, 1992). There may be apparent right-stepping off-set of the Johnson Mill graphite schist belt in the Burnley Basin study area, a so-called "fault ramp". Transverse folds perpendicular to the normal border fault are commonly seen in the hanging wall adjacent to the border fault in the Newark Basin (Schlische, 1992). These folds are typically anticlinal, as normal fault displacement lessens towards the fault ramp. The presence of a small (< 100 m), open fold is congruent with limited foliation and bedding data in the Johnson Mill graphite schist and Mesozoic deposits (Fig. 25b). Folding may have not been accommodated by the more structurally competent Lynchburg Group meta-arkose. Small-scale synclines bordering the anticline may have preserved Mesozoic deposits.

Beautiful Run Basin:

Field data in the Beautiful Run study area suggests a half-graben of southwest-northeast orientation bounded on the northwest by a normal fault. This interpretation is made principally on the presence of the Johnson Mill graphite schist abutting the deposits on their northwest, as well as the elongate distribution of the Mesozoic deposits in the
SW-NE orientation. In addition, DEM lineament data from the Beautiful Run study area depict a unimodal orientation of local structure in the NNE direction (Fig. 34; discussed further on pg. 75). There is no outstanding evidence requiring an eccentric structural interpretation, as was the case in the Burnley study area; a SW-NE orientation of the basin and its normal fault is parsimonious.

As a test of the interpreted structural model for the Beautiful Run Basin, the textural immaturity of clasts in a Beautiful Run Basin conglomerate outcrop was plotted as a function of that outcrop's distance from the inferred fault (Fig. 35). Theoretically, as transport in streams and debris flows brought clasts farther from the fault scarp, breaking and rounding of the clasts would promote increased textural maturity. Thus, clasts nearest to the fault scarp should be least mature, and those farther from the scarp most mature. Textural immaturity was defined as:

\[(\text{The Ratio of Long to Short Axis, or Sphericity})^2 / (\text{Unitless Roundness Number})\]

Roundness was measured on a scale of 0 to 3; 3 being rounded, and 0 being angular. Thus, as angularity in the denominator goes up (Roundness number moves towards 0), immaturity goes up too. Likewise, a less spherical clast (that is one whose long axis is significantly larger than its short axis) will promote a higher textural immaturity number. The long to short axis ratio was squared to give it more weight, as it was a purely objective measure, in contrast to rounding number whose determination was subjective and may have significant associated error.
Figure 34. Rose diagram depicting the roughly unimodal orientation of linear features to the NNE in the Beautiful Run Basin study area.

N = 39; Size of largest petal = 18.3%
Figure 35. A graph plotting textural immaturity as a function of distance from the inferred border fault. While a strong negative correlation does exist, indicating correct inference of fault location, it is questionable whether the supposed change in textural maturity could take place over such a short distance.
The plot does indeed show a negative linear relationship between distance from the inferred fault and textural immaturity, supporting the interpretation of a normal fault on the northwest side of the deposits.

Using a circular flume to simulate transport of limestone grains, Humbert (1968) demonstrated a positive, asymptotic relationship between distance traveled and roundness. Sphericity was little changed by transport however; limestone grains began with an average sphericity (short axis / long axis) of 0.75 and did not reach 0.8 until ~130 simulated kilometers. I suggest that this "sphericity inertia" may be a function of large (0.8) original sphericity. As foliated phyllites and sheet silicates, most clasts in the paleo-Beautiful Run area started with a lower sphericity number, perhaps close to 0.5, and may have become spherical at a higher rate in that range. A study on cracked clay fragments eroded into a temporary mine gully records a sphericity change from 0.7 to 0.8 100 meters from the scarp (Faimon and Nahyba, 2004).

The fining direction of conglomerate clasts has been used to infer the position of the normal fault scarp in Mesozoic basin deposits (e.g. Arguden and Rodolfo, 1986). Grain size and distance from the suspected fault in the Beautiful Run Basin were plotted against each other and show a weak negative correlation (Fig. 36), further supporting the interpretation of a normal fault bounding the deposits on their northwest side.

Lineament Analysis:

Patterns of linear features tentatively support the field data-based structural interpretations for both the Burnley and Beautiful Run basins. In the Burnley Basin study area, the lineament data has a strong mode in the northwest-southeast orientation, close to
Figure 36. Average long axis length for three different clast types as a function of distance from the inferred normal border fault in the Beautiful Run Basin. A negative relationship between the two variables, while weak, provides some supporting evidence for the normal border fault position as inferred.
Figure 37. Simplified cross-sections of a rift basin demonstrating imbricated fault-block geometry and how erosion can change what is considered the border fault. Note also how erosion could possibly "strand" a sub-basin beyond the modern border fault.
~340°. If local, differential stresses caused folding or normal faulting in the northwest-southeast orientation, it is logical that other linear features – faults or folds – are locally present in that orientation, and that is borne-out by the large, local lineament mode in that orientation. A second, less prominent mode occurs in the “classic Appalachian” southwest-northeast trend. A third, even smaller mode trends west-northwest to east-southeast. Past studies have shown that fractures in this orientation are not uncommon in rocks of the Virginia Blue-Ridge (Hasty, 2005).

In the Beautiful Run basin study area, the lineament data has a strong mode in the northeast-southwest orientation. This trend is parallel to the two linear map features – the Johnson Mill member belt of graphitic schist, and the normal border-fault of the Beautiful Run Mesozoic deposits.

**Summary of Structural Geometry:**

Knowledge of the structural architecture of Mesozoic rift basins in eastern North America has expanded in recent years through seismic imaging and deep coring. Of particular significance to this project, the prevalence of intrabasinal faults and imbricated fault block rift geometry has been highlighted by numerous studies (e.g. Root, 1988; Schlische, 1992). In this structural geometry, discrete fault blocks are imbricated like a stack of tilted dominoes, dipping away from the border fault. Each successive fault block (moving towards the border fault) is perched higher than the last. This is because displacement along each fault equals the sum total of displacement along all the fault blocks before it. This geometry enables erosion to "strand" sub-basins beyond the border fault system, or to change which fault is considered the border fault (Fig. 37).
In this case, the term border fault is used merely to mean that normal fault which bounds rift deposits. In truth, the original (meaning syn-rift) border fault is located far beyond what is currently considered the border fault. This "true" border fault goes unrecognized simply because Mesozoic rocks no longer abut it, drawing attention to the fault's existence. Without the remnant deposits that abut it, the Johnson Mill fault would have likely gone undetected. It is possible that even more distal normal faults associated with the Culpeper Basin exist to the west of the Johnson Mill Fault. By contrast, the Burnley and Beautiful Run basins likely represent the true geologic western-most Mesozoic rift basin deposits in North-America, as any further imbricated fault blocks would have bounded even higher deposits now completely eroded away.

**Basin Restoration:**

In order to elucidate its structural geometry, the Beautiful Run Basin and its surrounding area were restored to its paleo-extent by projecting geologic contacts into the above-surface assuming ~1.5 km of erosion (Fig. 38). Malinconico (2003) used vitrinite reflectance to calculate post-Mesozoic erosion of the Taylorsville Basin in eastern Virginia. A maximum of 2.6 km of material had been eroded over a postrift antiform caused by basin inversion, while a minimum of 0.9 km had been eroded from both "tipped-out" edges. Organic paleothermometers near the modern day surface of the Newark Rift Basin record maximum depths of over 6 km over suspected antiforms. Thus, ~1.5 kilometers of erosion in the higher elevation Blue Ridge province seems reasonable, if a bit conservative.
Figure 38. Cross-sectional Block Diagram of the Barboursville and Beautiful Run Basins and Surrounding Geology, with Mesozoic Restoration. Rounded pattern abutting normal faults represent conglomerate and sandstone deposits.
The restoration shows the Beautiful Run and the Barboursville (and, by extension, the Culpeper) basins merging at approximately 1 km above the modern surface. The merge would occur at lower paleo-elevations assuming a more gentle graben onlap, and at higher paleo-elevations assuming a steeper one. Displacement across basin bounding normal faults is greatest towards the center and least (eventually reaching 0 displacement) toward the edges (Schlische, 1993).

The Johnson Mill Fault:

Wehr (1983) mapped the contact between the Johnson Mill Member and the Charlottesville Formation on its east as a fault, doing so on account of 1) recrystallization of the Johnson Mill graphite schist at some locales, and 2) “truncation”. It is unclear exactly what Wehr means by "truncation"; it seems unlikely that the contact between the Johnson Mill Member and the Charlottesville Formation could have been seen clearly in outcrop. Nevertheless, this study provided further evidence for a fault on the east side of the Johnson Mill Schist in the form of remnant rift basins, significant vein quartz and possible vein-quartz brecciation, and DEM data portraying a prominent lineament along the Johnson Mill Member.

Graphite is a low-friction material and can act as a fault lubricant (e.g. Dubey, 2004). As a planar band of low-strength material bounded on either side by higher strength material, the Johnson Mill Member graphite schist belt is a good candidate for faulting. Movement was most recently normal (Mesozoic), though it seems likely that Paleozoic and earlier contractional tectonic events caused reverse movement along the fault. Vein quartz in the Johnson Mill graphite schist appears frequently brecciated, while
the graphite schist itself displays fabrics indicative of ductile deformation. The presence of vugs in some samples of vein quartz limits the depth, and thus the age, of at least some vein quartz precipitation to the post-Paleozoic.

The Burnley and Beautiful Run basins were plotted on a local DEM (Fig. 39). This figure highlights the surprising fact that a notable lineament corresponding with the Johnson Mill graphite schist belt connects the two basins. The Johnson Mill schist is structurally weak - graphite has a Mohs hardness of 1-2 - and is a highly unlikely ridge-former on its own. Rather, significant, fault-related silicification (vein quartz precipitation) in the Johnson Mill Member is responsible for the ridge. Figure 40 shows a photograph taken on the ridge, highlighting the Beautiful Run Basin and the supposed kinematics of faulting.

**Syndepositional vs. Postdepositional Faulting:**

In his review of research on Eastern North American rift basins, Schlische (2003) lists three principle points of recent contention. New data from this study provides insight into two of these points. The first asks whether the structural geometry and orientation of North American rift basins reflect "a uniform stress field reactivating variably oriented Paleozoic structures, or to a history of changing stress regimes?" In the case of the Burnley and Beautiful Run basins, pre-existing structure - the Johnson Mill schist belt - clearly controlled basin formation.

What can be more powerfully spoken to, indeed even put to rest by this study's findings, is Schlische's second point of contention: "Are the major structures bounding and contained within the basins syndepositional or postdepositional?"
Figure 39. A modest NE-trending ridge connecting the Burnley and Beautiful Run basins appears to correspond with the Johnson Mill graphite schist belt. The ridge likely reflects faulting and significant vein quartz precipitation within the Johnson Mill belt.
Figure 40. View to the NNE in the Beautiful Run Basin study area near Uno, Virginia. Photo taken on Johnson Mill fault ridge (normal fault drawn in black) looking towards the Beautiful Run Basin (drawn in orange).
Strong evidence for syndepositional faulting from past research includes 1) coarse conglomerates along the border faults, and 2) growth beds as revealed by seismic imaging and inferred from drill cores. Some (Faill, 1973, 2003; De Boer and Clifton, 1988; Root, 1988) have disputed the interpretation of growth beds in seismic reflection profiles, and don't consider border conglomerates strong enough evidence on their own for syndepositional faulting. They contend a simpler model entails broad, crustal downwarp, followed by sediment infill and finally rift graben development, as in the onset of the Lake Baikal rift episode (Faill, 1973).

Faill (1973, 2003) has suggested that such a broadly downwarped basin once connected the Newark, Gettysburg, Culpeper, and Barboursville basins. He further postulates that the mega-basin, which he names the Birdsboro Basin after a central locale in Pennsylvania, was originally wider by many kilometers. Initially, the discovery of the Burnley and Beautiful Run Basins seemed a tentative support of Faill’s Birdsboro Basin model. If the Culpeper and Barboursville were originally kilometers wider, than undiscovered erosional remnants likely existed somewhere in the Blue Ridge province. Perhaps we had found them in the Burnley and Beautiful Run basins.

But rather than supporting Faill's controversial Birdsboro Basin Model, sedimentological and provenance data gathered during this project seem to render it untenable.

Fig. 41 shows the proposed paleo-extent of the Birdsboro Basin. In this model, the Burnley and Beautiful Run basins, shown in red, occur as part of a large (50 km wide) alluvial fan complex in the south-western corner of the Birdsboro Basin. Faill calls this
**Figure 41.** A paleogeographic map plotting the Burnley (Bu) and Beautiful Run (Be) basins in relation to various inferred lithosomes of the Birdsboro Basin. If this model were correct, similar provenance would exist throughout basins fed by the "Cedar Mountain Alluvial Fan"; this is not the case. Culpeper and Barboursville basins bolded. Adapted from Faill (2004).
fan complex the Cedar Mountain regional alluvial fan, after the border conglomerate formation in the Southern Culpeper of the same name.

Given that the Cedar Mountain fan complex is fed by a large river system, one would expect some homogeneity of sediment provenance across the fan. To the contrary, data from this study shows significant heterogeneity of sediment provenance. This likely means that 1) either the basins were originally separate, or 2) that sediment input was delivered by many small streams instead of one large one (and its deltaic off-shoots). As a diffuse rather than discrete tectonic feature, broad depression favors homogenous sedimentation into a large and “well-mixed” basin. In contrast, grabens and half-grabens sharply isolated by normal fault scarps will experience more locally derived sedimentation. The local provenance of clasts in the Burnley and Beautiful Run provide strong evidence for syndepositional faulting. This is especially true given the nature of the local rocks seen in Burnley and Beautiful Run basin conglomerates. Graphite schist, clearly, is not a natural cliff-former. A tectonically generated scarp within the Johnson Mill graphite schist belt is effectively the sole manner by which the small belt of Johnson Mill graphite schist could have been eroded in abundant coarse, angular fragments.

**Potential Problems and Inconsistencies:**

As with all field geology research projects, conclusions have been based on incomplete and imperfect data. A short discussion of potential inconsistencies is merited.

If the Burnley and Beautiful Run basins are merely erosional remnants of originally larger basins many kilometers wide, then it seems that similar erosional remnants would have likely been found in extensive mapping in the area; they have not
(Nelson, 1962; Allen, 1963; Wehr, 1983). Given the small modern extent of deposits, however, other erosional remnants would be easy to overlook. A traverse along the Johnson Mill Fault with an open mind and watchful eye might yield future discoveries.

Foliation in Lynchburg Group rocks dip to the SE. This foliation is Paleozoic and was already in place by Mesozoic time. Movement along the NE trending normal fault would have tilted rocks in the hanging wall, reducing the magnitude of SE dipping foliation. Yet there is no systematic difference in the dip of Lynchburg Group foliation in the hanging wall (SE of the Johnson Mill Fault) versus the footwall (NW of the Johnson Mill Fault). Paul Olsen (personal correspondence) claims that simultaneous and equal deformation in the footwall as well as the hanging wall during normal faulting can maintain the dip of bedding or foliation between the two blocks. Seeing this, the uniformity of foliation dips across the Johnson Mill fault may not pose a fatal problem to the proposed structural model.
Conclusions

Two recently discovered deposits of iron-cemented conglomerate and sandstone in the eastern Blue Ridge of north-central Virginia represent remnant Mesozoic rift basins. The Burnley and Beautiful Run formed as half-grabens bordered on the west by a normal fault. This fault occurred in the structurally weak Johnson Mill graphite schist belt of the Lynchburg Group. As displacement increased through time, the basins merged with the Barboursville and Culpeper basins (which were then contiguous). The faults bounding both sets of basins were likely related by an imbricated fault block geometry, allowing for erosion to strand the Burnley and Beautiful Run to the west.

The Burnley and Beautiful Run basins are, geologically speaking, the western-most Mesozoic rift basins yet discovered in Eastern North America, a fact that questions the nature of "border faults" or "border fault systems" in the western set of Mesozoic rift basins (Barboursville and Culpeper included). While a strict definition is lacking, past studies seemed to have defined the "border fault", or "border fault system", as the fault or system of faults which bound the extent of Mesozoic rocks in a rift basin. This study highlights the probability that more distant faults associated with imbricated fault blocks commonly exist. If so-called border faults have been mapped primarily on the basis of the modern extent of Mesozoic deposits, than it seems likely that previous studies have overlooked more distant faults. That is to say that many, if not most, of those Mesozoic faults currently mapped as border faults are not, in fact true border faults. Rather, they are part of a system of faults comprising an imbricated set of fault blocks, the more distal of which have had their sedimentary fill eroded. The true border faults do not, in their current configuration, bound Mesozoic deposits.
Local provenance during the onset of sedimentation, as well as the clear structural control of basin formation implied by the basins' mutual abutment on the Johnson Mill graphite schist, attest to syn-depositional rifting. This newest piece of evidence should end the recently vigorous debate over syn- vs. post-depositional faulting.

Lastly, provenance of conglomerates from the Culpeper and Barboursville basins, in tandem with geologic cross-section reconstructions, illuminate Mesozoic geography of the Blue Ridge province in north-central Virginia. During Mesozoic time, the basement was likely still mantled by the Catoctin Formation and Chilhowee Group on at least the eastern half of the anticlinorium. Resistant greenstone held up broad ridge in contrast to the current 'major ridge - trough - minor ridge configuration' west to east topographic configuration of the Blue Ridge anticlinorium. Fold-bounded Chilhowee Group inliers occurred several kilometers farther east than the Chilhowee Group's modern extent. Because of this, deeper water equivalents to the largely subaerial and near-shore Chilhowee Group units may be uniquely preserved in Mesozoic basin conglomerates.
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Lastly, I would like to thank my fellow students in the Department for their help and intellectual discourse, but mostly for their friendship. Long nights in the Chamber were really not so bad in your company. You're beautiful.
Figure 42. The author and kindly farmer Harrison Lohr standing in the Beautiful Run study area (and holding a piece of the Beautiful Run Basin).
Works Cited


Cornet, W.B., 1977, The palynostratigraphy and age of the Newark Supergroup [Ph.D. thesis]: United States (USA), Pennsylvania State University at University Park, University Park, PA, United States (USA).

De Boer, J., and Clifford, A.E., 1988, Mesozoic tectogenesis; development and deformation of "Newark" rift zones in the Appalachians (with special emphasis on the Hartford Basin, Connecticut); Triassic-Jurassic rifting; continental breakup and the origin of the Atlantic Ocean and passive margins: Developments in Geotectonics, v. 22, p. 275-3


Dunning, G.R., and Hodych, J.P., 1990, U/Pb zircon and baddeleyite ages for the Palisades and Gettysburg sills of the northeastern United States; implications for the age of the Triassic/Jurassic boundary: Geology (Boulder), v. 18, p. 795-798.


Hasty, B., 2005, Kinematic and Temporal Significance of Fractures in the Western Blue Ridge Province, North-Central Virginia [Senior Thesis]: United States (USA), College of William and Mary, Williamsburg, VA, United States (USA).


Lorenz, J.C., 1988, Triassic-Jurassic rift-basin sedimentology; history and methods: United States (USA), Van Nostrand Reinhold Co., New York, NY, United States (USA).

Lucas, S.G., and Huber, P., Nov. 9-10, 1996, Vertebrate biostratigraphy and biochronology of the nonmarine Late Triassic; The great rift valleys of Pangea in eastern North America; Volume 2, Sedimentology, stratigraphy, and paleontology, in Aspects of Triassic-Jurassic rift basin geoscience, Rock Hill, CT, United States: United States (USA), Columbia University Press, New York, NY, United States (USA).


Parker, L. 2008 Evidence for knickzone generation and landscape disequilibrium through surficial studies of the James River, Central Virginia Piedmont [Senior Thesis]: United States (USA), College of William and Mary, Williamsburg, VA, United States (USA).


Schlische, R.W., Nov. 9-10, 1996, Progress in understanding the structural geology, basin evolution, and tectonic history of the eastern North American rift system; The great rift valleys of Pangea in eastern North America; Volume 1, Tectonics, structure and volcanism, in Aspects of Triassic-Jurassic rift basin geoscience, Rock Hill, CT, United States: United States (USA), Columbia University Press, New York, NY, United States (USA).


Weiss, J. 2000, The Origin of Mafic and Ultramafic Rock Bodies in the Blue Ridge Province, Madison County, Virginia [Senior Thesis]: United States (USA), College of William and Mary, Williamsburg, VA, United States (USA).


Wehr, F.L., I.I., 1983, Geology of the Lynchburg Group in the Culpeper and Rockfish River areas, Virginia [Ph.D. thesis]: United States (USA), Virginia Polytechnic Institute and State University, Blacksburg, VA, United States (USA).

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**Appendix I. Field station and data (NAD 1927).**
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Appendix I cont.
### Appendix II. Sample Excell table showing clast assemblage data.

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