The Stratigraphic Relationship of The Catoctin, Unicoi, and Harpers Formations Within A Fault-bounded Rift Basin in Central Virginia.

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Advisor: Dr. Edgar W. Spencer

This thesis is dedicated to:

Beverly Nabers Bowring

who has supported me throughout

my entire venture as a geology

student while at Washington & Lee.

Thank you.

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ABSTRACT

Sediments deposited within a rift basin that is now situated in the Blue Ridge region of central Virginia include spilitic metabasalt, which exhibit pillow structures, alluvial slump deposits, fluvial channel sands, deltaic siltstones and shales. The basin is bounded on its northwestern flank by granulites of the Pedlar Formation and by augen gneiss of the Ductile Deformation Zone (Bartholomew,1972) to the southeast. The sedimentary package rests unconformably upon the Pedlar Formation and underlies a thrust contact below the Ductile Deformation Zone. The ten separate facies that are contained within the basin illustrate the tectonic association between active faulting, volcanism, and the deposition of shallow water sediments.

This belt of sediments is a linear collection of late Precambrian - early Cambrian rift-basin facies. Vertical and horizontal gradational transitions are evident from field mapping.The sedimentary facies model implies that the depositional environments were contained within a basin of high vertical relief.

The intertongued relationship of lenticular, discontinuous sediments causes stratigraphic problems. Lithological comparisons of the rocks within the basin are made to the Catoctin, Unicoi and Harpers Formations. However, the facies model proposed to explain the basin does not attempt to delineate formations.

The sediments are to be considered as a distinct deposition of continental alluvial clastics and volcanics contained by the crystalline basement complexes on either side.

Introduction

The paper describes the geochemical, compositional and textural character of the rocks mapped by Bloomer and Werner(1955). The area is geographically southeast of Beverlytown, around the Lynchburg Reservoir and on Brown Mountain. The sediments were collectively named Swift Run and the greenstone belt was termed the Catoctin(Bloomer and Werner,1955). The type section of the Swift Run is located near Swift Run Gap in Rockingham County, Virginia. The spilitic metabasalts that are exposed within the northern end of this basin have been called Catoctin 'greenstones' because they are similar to exposures found in Catoctin Mountain, Maryland (A. Keith, 1894).

Detailed field mapping was undertaken to determine the stratigraphic relationship that existed between the volcanics, tuffs and coarse conglomerates exposed in the northern portion of the basin to the repetitive and thick sequence of phyllitic sandstones, shales and mudrock of the southern portion of the map area.

Ten facies are described and mapped. The greenstone belts are interbedded with distinctive sedimentary rocks. Chloritic phyllites and graywackes were deposited as a cyclic series as were the shales and sandstones. The interfingered relationship that exists between these sediments led to a possible explanation for the depositional environment of the sediments.

The connection between both the lateral and vertical facies changes determined the historical stages of this rift-basin.

GEOLOGIC SETTING

In central Virginia, located in the southeastern portion of the Buena Vista quadrangle, a belt of northeasterly trending volcanics, graywackes, siltstones and shales are exposed along the northwestern flank of the Blue Ridge anticlinorium. The Blue Ridge is an anticlinorium, which is cored by 1.0 Ga (Grenville) basement complex. (Espanshade, 1970)

The belt of rocks, examined in this paper, is approximately twelve kilometers long and one kilometer wide. The outcrops are well exposed along many of the creeks and rills that run perpendicular to the general strike of the beds. The contact of the basement and sediment to the northwest appears to be a thrust fault. Relatively undeformed granoblastic rocks are down-dropped relative to intensely sheared upthrown sedimentary rocks. The schematic diagram of the structural history of the area suggests that this fault was originally formed during tensional rifting of the continental blocks. It is appropriate to make the distinction that this earlier normal fault is now the thrust fault contact for the overlying phyllites.

The rifting events associated with the normal faulting is assumed to have begun in the late Proterozoic and resulted in the opening of the Iapetus or Proto-Atlantic Ocean (Odom, 1982).

The sediment/basement contact to the southeast appears to be a thrust fault as the upthrown augen gneiss of the Ductile Deformation Zone overlies the relatively undeformed sediments of the down-dropped block. The thrusting event that is responsible for the compression of the basin and the inclusive sediments is thought to have occurred, in central Virginia, during the Taconic Orogeny.(Wehr and Glover, 1985)

Although age constraints have not been placed on individual greenstone outcrop belts of this particular area, a range of 690-570 Ma. (Eocambrian) is postulated due to the relationship of the greenstone dikes to the granitic plutons and the evidence for the fossils **skolithus** found in the upper strata in the section.

METHOD OF STUDY

The construction of the sedimentary facies model is based upon the primary sedimentary features that were recorded in the field. Cross-bedding, horizontal and convolute laminations, graded bedding and fining upward cycles were used to determine the depositional environments of the facies.(Schwab,1977) Rock exposures are excellent in the area and several complete fining-upward cycles were located. Based upon textures, compositions, geochemical and petrological analyses, many of the outcrop belts can be mapped accurately along strike for several hundreds of meters.

Lithologies, structural fracture patterns and volcanic characteristics were recorded in the field. Examples of crossbedding (trough type) are infrequent but generally the source area of flow appeared to be from either the northwest or southeast. Ripple marks are found in only a few sandstone beds.

Over 500 geochemical analyses were made by examining 35 samples that were representative of the lithologies found in the field. Twenty-five of these samples are described in the appendices of this paper. Approximately fifteen analyses were made of each sample. The data were averaged and, unless specifically designated, the oxide percents represent average rock compositions. Each sample is presented in a range from five to eight analyses. The scanning electron microscope proved to be an essential tool for tracking many of the outcrop belts. High concentrations of sodium, iron, calcium and potassium aided in the determination of the source rocks. Petrographic analysis was made of 25 samples that were prepared for thin section.

The geologic map and cross-sections were drawn using this collection of data. The confirmation of the hypotheses proposed in this paper rests heavily upon the the correlation of the data to the constructed facies model diagram.

LITHOLOGICAL DESCRIPTIONS

The sedimentary basin defined by flanking crystalline basement complexes contains ten lithofacies. Facies is used in this paper to describe "a body of rock with specified characteristics" (Reading, 1986) . Since fossils are absent in these rocks, the emphasis is placed on the physical and geochemical characteristics of the rock and the term lithofacies is used.

Facies is a term that is defined to have several different meanings. It is used to describe an observation: of the rock product, for example 'a sandstone facies'; of the products of a particular process, for example 'a turbidite facies'; of the environment in which a collection of rocks formed, for example 'a fluvial facies'; of an association with tectonics, for example 'a post-orogenic facies'. However, the meaning of facies must be clearly specified so as to avoid confusion. This paper attempts to objectively describe the separable rock bodies as ten lithofacies. Each facies is distinctive and reflects a particular process of deposition (Reading, 1986). For example, spilitic greenstones are described as a facies and, due to the characteristic pillow structures, are thought to have come into contact with an aqueous envirnment. Therefore, the facies 'associations' into which the greenstones are included is related to both processes (fluvial) and tectonics (rifting).

Each lithofacies will be collectively interpreted to propose an 'associated' depositional environment for the basin in order to better explain the lateral and vertical variations of the lithologies.

Each of the three cross-sections reflects the proportional representation of the ten lithofacies. While all of the various rocks are exposed in each of the three cross-sections, the proportional ratios of rock types varies considerably. For example, in the northern part of the map area, volcanics and conglomerates far outweigh shales and phyllites. In the central part, graywackes and phyllites dominate the section. The southern part is represented by an increase in sandstones. The facies associations represent gradual transitional changes which suggests proximal depositional environments.(Rust, 1979)

FACIES I

The laminated ash/siltstone is a banded, tuffaceous, grayish purple ash and grayish green siltstone which outcrops throughout the entire area. This facies is generally included as a lithology of the Unicoi Formation. The finer grained ash is highly fissile and composed of mostly iron rich clay minerals. The quartz grains show a low degree of sphericity and angularity but appear to be moderately sorted. Linear beds composed of an inordinate amount of opaques separate much lighter beds of potassium feldspar. The constituent minerals are rich in phosphorus, manganese, titanium, iron and magnesium. Siltstone, interbedded with the ash, is almost exclusively composed of illite and quartz grains. The bedding of this rock is often contorted and folded. The percentage of siltstone to ash varies from outcrop to outcrop. Frequently, beds composed entirely of purple ash can be located. Though not exclusively limited to a particular stratigraphic position, this facies is found most frequently in close approximity to greenstone outcrops and the Pedlar Formation. The cleavage is often slaty and cuts, at a steeper angle, across bedding planes.

FACIES II

Brown Mountain Conglomerate is a massive, coarse to pebble, poorly sorted, chloritic, conglomeratic feldspathic graywacke. The name is derived locally from exposures along the flanks and crest of Brown Mountain. This light green rock may be mistaken for the crystalline basement complex if exposures have become weathered to a light reddish-brown. However, this misidentification is often due to the high concentration of feldspar clasts derived from both the intrusive and extrusive rocks of the area. The potassium feldspar minerals from the basement rocks are frequently one to two centimeters in size and range from very angular to well rounded in shape. The sodium feldspar minerals are likely to be the result of the breakdown and decomposition of the greenstone spilites. Many fragments of greenstone can also be observed within the matrix of the rock. Quartz grains range from sub-angular to well rounded and are generally show a high degree of sphericity. The matrix is predominantly composed of chlorite and potassium feldspar clay minerals. Crossbeds are exceedingly rare but a fining upward to siltstone and shale beds can observed at numerous outcrops. Beds range in thickness from a meter to a several meters. Beds are unequal in thickness and pinch out along strike after only a dozen meters. Brown Mountain Conglomerate is strongly lithified and weathers out in a distinctive spheroidal pattern which resembles the exfoliation of the basement rocks.

Thin section analysis reveals perthite, microcline and sodic plagioclase (An 30). Detrital quartz grains show overgrowths and sutured polycrystalline boundaries. Magnetite, hematite and apatite are included in the matrix.

FACIES III

Catoctin greenstone is a spilitic metabasalt which outcrops as thin linear belts in a northeasterly direction. In this particular area of study, no fewer than two dozen distinct strips of greenstone were traced along a N10E strike direction. Albitized andesine, chlorite, epidote, calcite, augite, prehnite and actinolite are the primary constituents. Scanning electron microprobe analysis reveals the critical level (4%) of sodium content required for classification of the greenstones as spilitic in composition. Hematitic quartz and veins of epidote are noted as characteristic features of the massive greenstone.

Pillow lava structures have now been recognized in several of the outcrops in this area (Bowring and Spencer, 1987). The pillows are ellipsoidal in shape and vary in size from 5 cm. by 10 cm. up to 15 cm. by 30 cm. The rims of these pillows contain higher concentrations of iron, titanium and magnesium; while the cores are somewhat higher in silica and sodium. The discovery of pillow structures provides clear evidence that the lavas were extruded into an aqueous environment. The greenstone contains amygdules of chlorite, albite and epidote. At the northernmost tip of the greenstone exposures, an unusually thick outcrop of spilite is present. Excellent examples of pillows, flow breccia, amygdules, epidote veins and sedimentary fragments caught up in the lava flows can be observed at the Davis Mill Creek Falls locality. Portions of greenstone, from this site, were examined under the SEM and revealed an interestingly low sodium content (0.00-0.50). It is possible that, at this sight, examples of basalt that were not metasomatized by contact with water are still intact. Almost all epidote veins exhibit extensional fractures perpendicular to the longitudinal direction of flow. Cleavage planes measured at several hundred outcrops of greenstone indicates N15E 45-75SE and N10E 75-85NW to be the most common.

FACIES IV

This friable, pale red, subarkosic sandstone appears intermittantly in the northern region of the mapped area. This outcrop belt is defined by low ridges. The potassium oxide (0.78-12.67) percent varies considerably from outcrop to outcrop but the iron content remains consistantly high (29-36%) at each location. Planar tabular cross-bedding can usually be measured at the outcrops. Bedding thicknesses range from 10 mm. to 20 cm. The rocks are moderately sorted, spherical and angular to rounded. Graded bedding is frequently apparent and illustrates the transition to shale. Feldspar crystals are either microcline or perthitic in composition. Due to the friable nature of these rocks, it is difficult to predict exactly how much of the facies is composed of this lithology. As in the sandstones of the Unicoi, heavy minerals include apatite, rutile, ilmenite, tourmaline, pyrite, and zircon (Bloomer and Werner,1955). The matrix is composed of clay minerals.

FACIES V

Graywacke and phyllite have been recognized as representative of the Harpers Formation (Bloomer & Werner 1955). The repititious couplets are thinly laminated, poorly sorted, chloritic sandstones interbedded with highly fissile phyllites compose of elongated quartz grains showing undulatory extinction. The phyllite matrix is composed of predominantly potassium and calcium feldspar clay minerals. Ilmenite, rutile, magnetite, pyrite and tourmaline all appear in abundance throughout the rock. The phyllite beds are much frequently folded along a northeast fold axis while the deformation of the graywackes usually appears as boudinage-type strain. The phyllites are various shades of green and blue in an unweathered condition; however, decompositon causes the iron minerals to give the rocks a buff or pale red appearance. Bedding surfaces are gradational between the coarse and fine grain rocks. Cross-bedding is rare in the phyllites but occasionally small scale cross-stratification can be recorded. Cross-bedding is virtually non-existant in the sandstone portions but graded bedding can be observed. Beds range in thickness from a few centimeters to one or two meters but no one particular lithology dominates the sequence. The beds are discontinuous over short distances and are lenticular in structural shape. Quartz-filled extensional fractures occur in both the phyllites and the graywackes. The fracture patterns are generally aligned perpendicular to the bedding planes in a N45W 80SW direction. Rip-ups of ash and greenstone can be observed.

FACIES VI

Pebbly arkose has been described as a facies of the lower Unicoi. Polycrystalline quartz grains range in size from coarse sand to pebbles. Much of the metasedimentary quartz has developed granophyric textures. Angular fragments of perthite, microcline, magnesite (calcite?), ash, and basement are supported in matrix of angular quartz, clay, chlorite and iron oxide minerals. This very poorly sorted rock ranges in color from deep red to pale purple is distinguishable in appearance by the rounded quartz pebbles that stand out in relief. There is no evidence of graded bedding or cross-stratification. Many of the rocks contain thin laminations of ash beds that can be used for recording the orientation of the units. Beds of the pebbly arkose vary in thickness from two meters up to ten meters. Siltstone beds of 5 to 10 cm. frequently separate the massive arkoses. While these rocks are resistant to weathering and appear to hold up several of the ridges (Pond Mtn. and Piney Mt.), they are very difficult to trace along strike. Beds are evidently lenticular in shape and can be recorded to outcrop for only a few tens of meters at any one locality.

FACIES VII

Arkosic siltstone is a moderately sorted, fissile rock composed of sub-angular to sub-rounded detrital quartz and potassium feldspar grains. It is light gray to pale green in color and usually exhibits festoon-type cross stratification. Opaque minerals delineate thinly laminated beds. Occasional well rounded blue quartz grains will appear to float in the matrix of siltstone. Beds range in thickness from one meter to several meters in thickness. This unit of siltstone is differentiated from the aforementioned phyllite/siltstone couplets in that with this rock, no phyllites or shales are interbedded.

FACIES VIII

Iron banded sandstone is a well sorted, sub-rounded to rounded feldspathic arenite. The feature that distinguishes it from other sandstone members is a clear pattern of light and dark banding that appears on the weathered surface of the rock. The SEM analysis revealed high concentrations of calium plagioclase and iron oxides in the darker bands and perthitic feldspar concentrations in the lighter bands. The geochemical signature of this rock allowed a fairly confident tracing of this thin but distinctive rock along a northeasterly strike direction. The banded sandstone is interbedded with shales and phyllites that are exposed along the Pedlar River.

FACIES IX

Pyritic sandstone is also similar to the phyllites and shales of the Pedlar River region but SEM analysis reveals anomalously high concentrations of iron sulfide in the form of pyrite crstals. The rock is poorly sorted and composed of angular to sub-rounded quartz grains supported by a matrix of chlorite, sericite and illite. The finer grained portions of the rock are crenulated. Beds which contain unusually high concentrations of pyrite range in thickness from one meter to five meters. Pyrite crystals range from microscopic to 2 cm. in width.

FACIES X

Basal Conglomerate contains basement clasts that range in size from 5 cm. to 50 cm. are suspended in a matrix of graywacke. The basement clasts rounded to well rounded and are composed almost entirely of perthitic, antiperthite feldspar and quartz in a granoblastic texture. The matrix contains calcic plagioclase, microcline, perthite, apatite and iron oxide opaque minerals. The apatite concentrations are by far greater than any other rock examined from the field. This outcrop, and possibly one other further down Enchanted Creek, are the only basal conglomerates located in the mapped area. The outcrops are small and discontinuous but are significant in being representational of a particular kind of depositional environment. This lithofacies is interpreted to be an alluvial fanglomerate. The matrix that supports the basement clasts is very fine grained immediately adjacent to the cobble. The siltstone grades imperceptably outward to a coarser sized sediment and ultimately into an overlying feldspathic siltstone and ash. Although the size of the basement clasts suggests that the source area was nearby, it cannot be determined whether the outcrop is in conformable contact with the underlying basement complex. One of the most interesting structural features of the outcrop is the apparent strike and dip of the bedding planes. All beds immediately overlying the basal conglomerate for several meters strike to the northwest (40-60 degrees) and dip to the southwest at angles that vary from 40 to 55 degrees. Since the basement is situated only 150 meters to the west, these beds have been rotated to a northeasterly strike and southeasterly dip at the fault contact between the sedimentary shales and the basement. This is the only location in this map area where beds strike NW and dip SW.

STRATIGRAPHY

The lower portion of the Swift Run Formation is described by Bloomer and Werner (1955) as consisting of "a conglomeratic graywacke with clasts from about 0.50 inch to 5 feet in diameter composed of quartz, potash feldspar, and granite in an inequigranular matrix of quartz, feldspar, lithic fragments, and a paste-like aggregate of sericite and chlorite". Further description, by Bloomer and Werner, of the phyllites located near the Lynchburg Reservoir reads, "formed from subgraywacke , containing much crystalloblastic sericite, chlorite, and quartz and meager amounts of crystalloblastic oligoclase and biotite... variable thickness of the formation extends from 0 to 400 feet".

The Catoctin Formation is composed of spilitic greenstone, graywackes, arkoses, chloritic schists, phyllites, tuffs and siltstones (Bloomer and Werner,1955).

The Chilhowee Group can be subdivided into three (or four) mappable stratigraphic units: a lower unit consisting of conglomeratic sandstones, siltstones greenstone volcanics, reddish tuffs, subgraywackes and pebbly conglomerates (Unicoi); a middle unit consisting of argillites, shales, phyllites, subgraywackes, thinly laminated siltstone all of which can be interbedded with thin sandstone beds (Harpers); and an upper unit consisting primarily of quartz arenites with minor amounts of shale (Antietam).(Schwab, 1986) and (Bloomer and Werner, 1955)

Without the aid of fossils, radiometric age-dating and clear unconformities, it is difficult to differentiate between the volcanics of the Swift Run, Catoctin and Unicoi and even more so, to place in the correct formation, the phyllites and shales of the Catoctin, Unicoi and Harpers. Bloomer and Werner (1955) were apparently aware of the problem, as the following descriptions indicate, "...in the upper part of the Unicoi, there is subgraywacke so much like that in the Harpers that without pebbles the formations cannot be distinguished" and "these greenstones and the tuffs in the Swift Run are analytically indistinguishable from these rock types in the Catoctin and Unicoi...".

Therefore, the intention to stratigraphically arrange the sedimentary units into clear and concise formations may be thwarted by the confusing overlap of sediments. The interfingered relationship of the numerous facies suggests that the basin be examined as a collection of sediments that bear strong resemblance to the Swift Run, Catoctin, Unicoi and Harpers. It is possible to draw approximate formational contacts within the mapped basin but it would be misleading to lable the phyllites of the central area as Harpers without conclusive stratigraphic control. Lithological transitions can be observed from the bottom of the section to the top (from the Pedlar contact to the Ductile Deformation Zone) and from the northeastern end to the southwestern portion of the map area.

Three facies associations are recognized to coexist within the basin. The northern portion includes pillow basalts, related ash deposits and conglomerates which are thought to represent the deposition of sediments volcanics associated with the initial rifting of the basin (Wehr, 1983). As the basement complex began tensional deformation, high angle faults provided the necessary relief to generate alluvial fans composed of rounded basement clasts(Schwab, 1974) . Conglomerates consisting of large, angular feldspar clasts, spilitic basalt fragments and rip-ups of ash are disseminated along the basin floor as fluvial channels attempt to distribute the ever increasing supply of sediment. These coarser sediments are overlain by cross-bedded siltstones. Shallow marine or lacustrine deposits consisting of horizontal and convolute laminations suggest a terrestrial envirnment (Schwab, 1974). Finally, thin beds of structureless mudrock and shales are deposited as overbank fines (Schwab, 1974).

The ratio of coarse grained sediments to fine is also measured in two directions. The area northeast of the Lynchburg Dam contains approximately 70% coarse clastics and 20 % lavas and 5% shales and phyllites. In the central portion of the basin, pebbly arkoses, ash and graywackes still dominate the lower portion of the section but the lava flows and associated sodium rich sediments have all but disappeared. The phyllites and shales which appeared infrequently further to the north now dominate the upper strata of this section. These thin, alternating beds of chloritic sandstone and shale represent the second stage of basin down-warping (Van Houten, 1977).

As the the basin subsided, a repetitive series of interbedded shales and coarse angular graywackes was deposited as a thick sequence of laterally expansive sediments (Ethridge and Wescott, 1984). Detailed mapping reveals that the ratio of phyllites to sandstone favors the finer sediment by approximately 65% to 35%. Overall, in the central portion of the basin, shales, siltstones, phyllites and minor arenites almost completely dominate the section. Friable sub-arkoses, graywackes and lava flows are rarely exposed.

Highly fissile shales, horizontally laminated siltstones and matrix-supported wackes suggest a fluvial environment of deposition. The sediments are representative of deposition in ox-bow lakes and floodplain areas(Schwab, 1974) and (Wehr, II, 1983). Although greenstone lavas are still associated with the phyllites in the upper section of this area, the basalts are possibly only distal extensions of the main flows. It should be noted, though, that these phyllites adjacent to the greenstones contain high concentrations of sodium oxide percents. This is also characteristic of sediments adjacent to the greenstones in the northern map area.

The southern part of the basin includes the extensive and prolific ash beds that are so well represented throughout the basin. However, the appearance of an increasingly thicker sequences of sandstones interbedded with the already prevalent shales signals the end of the lava flows. Generally, the geochemical oxide percents narrow dramatically to include only potassium, iron, magnesium and titanium, silica and aluminum. The sandstones are thinly laminated and are generally low lying undisturbed beds of moderately sorted subrounded sub-arenites interbedded with highly fissile shales. The depositional environment for these lithologies is interpreted to be shallow water and fluvial dominated deltas (Hoffman, Dewey and Burke,1974).

The ten facies of the three geographical areas are mapped as having an interfingered relationship. The three dimensional map reveals that virtually all beds strike in a northeasterly direction and dip to the southeast. Post-depositional compression during the Taconic Orogeny caused thrust faulting, slickenlines, folding, boudinage, crenulations, tilting of the beds and fracture patterns to develop in the rocks of the basin. Folds are overturned asymmetrically to the northwest. Patterns and slickenlines found in the fine grained phyllites and shales suggest that compressional forces were from the southeast.

Boudins, observed in the interbedded subarkosic sandstones, are oriented with the long axis parallel to the direction of the fold axes: N25E. The most prevalent fracture surface is N30E 50-65SE. The ductile deformation zone to the southeast is thrust up over the sediments. The shales to the northwest are sheared extensively in an unconformable contact with the Pedlar.

CONCLUSION

The sediments of a rift basin are tectonically controlled. Distinctive sedimentary facies are created by extension, subsidence and compression. These continental rift-related sediments and pillow lavas provide a clear example of the relationship that exists between clastics, volcanics and intrusives.

The constraints of formational contacts might be better appreciated by viewing the collective package as an interfingered arrangement of several facies. The schematic diagram illustrates three significant stages in the history of the basin (Chen Changming, 1981). Contained within flanking ranges of crystalline basement rocks, the sediments gradually underwent transition from one depositional environment to the next. Tectonic compression has caused the entire sedimentary package to be structurally bound between the two igneous complexes.

The relationship of these sediments to the Unicoi and Harper's on the northwestern flank of the intervening Pedlar is suggestive at best. Similarities are recognizable at many of the isolated outcrops. However, the distinct arrangement of sediments and volcanics within this particular basin makes stratigraphic comparison uncertain. These facies are more likely to represent an isolated basin associated with the continental rifting during the Late Precambrian.

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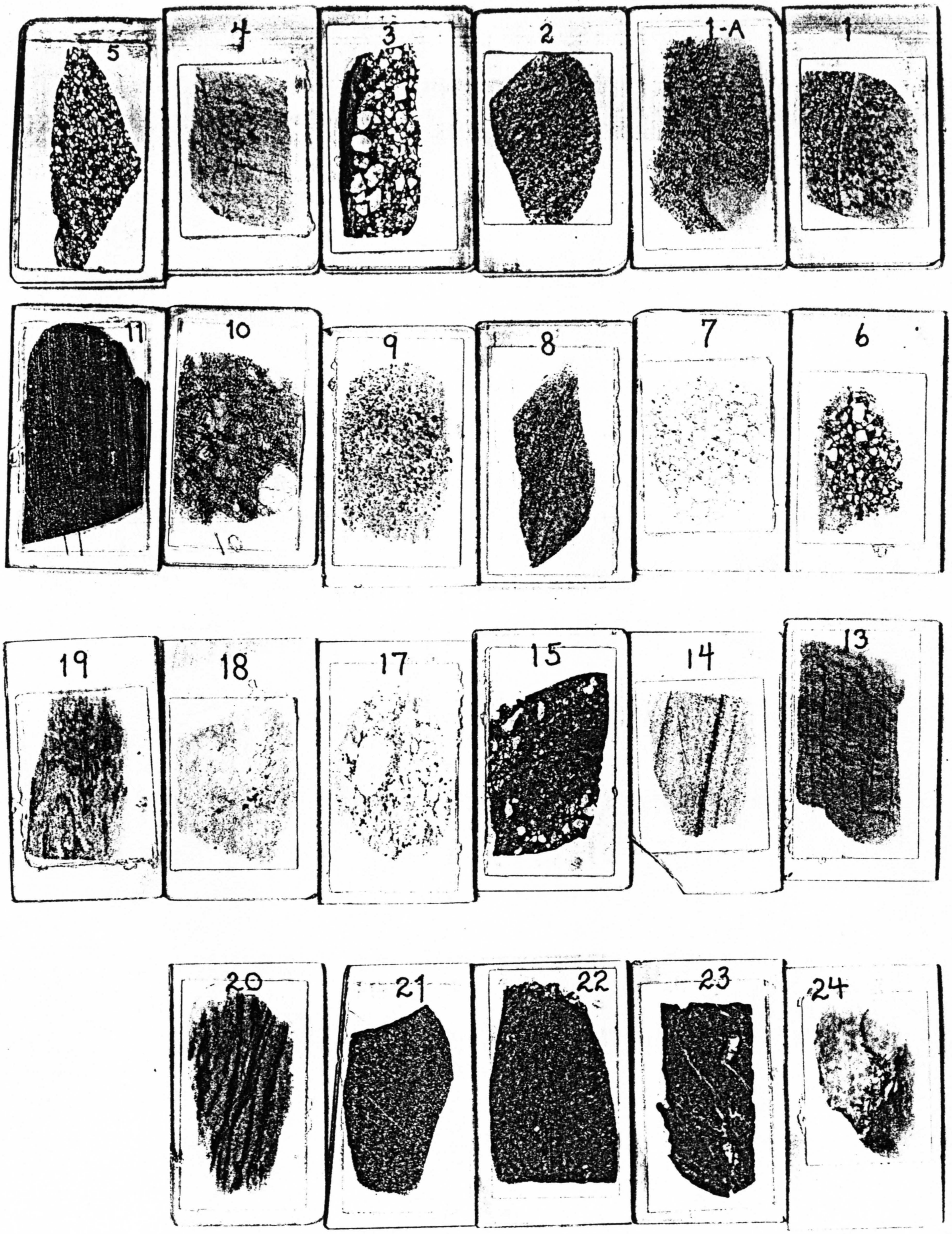
SPECIMENS PREPARED FOR SEM AND THIN SECTION ANALYSIS

Lithology	Location
1. Basal conglomerate (5048)	Enchanted Creek
1-A. Basal conglomerate (5048)	Enchanted Creek
2. Siltstone (5042)	Enchanted Creek
3. Phyllite/sandstone (5020)	Pedlar River
4. Siltstone/shale (5217)	Piney Creek
5. Arkosic sandstone (5206)	Pond Mtn., Brown's Creek
	Irish Creek, Piney Mtn.
6. Ash/siltstone (5053)	Swapping Camp Ck., Piney M.
	Brown's Ck., Buckhorn Ridge
7. Graywacke (5048)	Enchanted Creek
8. Sandstone/shale (5020)	Pedlar R., Brown's Creek
	Enchanted Ck., Beverlytown
9/10. Conglomerate (5625&5626)	Swapping Camp, Piney Mt.
	Buckhorn Ridge, Long Mt.
11. Ash (5055)	Beverlytown, Brown's Creek
	Pedlar River, Piney Mt.
13. Shale/phyllite (5218)	Pedlar River, Swapping Camp
14. Sandstone (5054)	Enchanted Ck., Pedlar River
15. Pyritic sandstone	Brown's Creek, Pedlar River
16. Phyllite (5309)	Devil's Branch, Brown's Ck.
17. Sandstone (5315)	Devil's Branch
18. Shale/ phyllite (5019)	Pedlar River, Brown's Ck.
19. Arkosic sandstone (5043)	Pond Mt., Piney Mt.,
20. Greenstone (5624) SEM only	Long Mt.,Piney Mt.,Swapping

21 through 24 Greenstone Thin-section only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Geochemical oxide percents for sediment samples collected in the area of investigation: (Location number)

Sample No. 1 (5048) Arkosic basal conglomerate; rounded clasts of crystalline basement complex; clasts range in size from cobble (30 cm.) to pebble (5 cm.). Matrix material is an immature sediment composed of angular feldspar crystals and subrounded quartz grains ranging in size from 2 cm. to .5 cm.

Basement clast specimens:

	1	2	3	4	5	6	7	8
Al_2O_3	10.98	11.02	10.75	10.50	10.88	10.67	20.69	19.88
SiO_2	83.13	81.09	82.60	83.10	82.98	83.75	65.26	66.20
K_2O	5.89	7.89	6.65	6.40	6.14	5.58	12.89	12.22
Na_2O							1.17	1.70

Matrix (average composition):

	1	2	3	4	5	6	7	8
Al_2O_3	11.16	11.99	12.14	12.45	11.76	7.91	9.13	5.93
SiO_2	55.35	54.46	47.84	46.50	52.63	58.92	57.22	64.71
MgO	0.63	1.08	1.04	1.23	0.87	0.00	0.23	0.00
P_2O_5	5.44	4.99	7.16	6.89	4.39	3.31	6.05	13.03
K_2O	5.03	5.02	5.08	5.42	5.61	3.43	4.41	2.19
CaO	7.10	6.78	8.72	8.25	7.93	5.99	5.59	14.14
TiO_2	6.92	6.12	5.67	5.78	6.28	7.46	4.19	0.00
FeO	8.37	9.56	11.37	13.48	10.53	12.98	13.18	0.00

Sample No. 2 (5052) Light grey siltstone conformably overlying basal conglomerate; predominantly fine-grained sediment with rare rounded blue quartz grains (1-2cm.) suspended in the matrix. occasional festoon type cross-bedding at the top of the unit which measures one meter thick at the outcrop:

Rock specimen 5052 (average composition):

	1	2	3	4	5
Al_2O_3	26.21	25.34	26.89	22.67	25.35
SiO_2	48.11	47.87	45.44	51.18	52.81
MgO	2.06	2.52	3.02	2.73	2.55
K_2O	10.42	11.09	11.89	12.48	10.92
TiO_2	3.05	2.17	2.01	1.48	2.68
FeO	10.15	11.00	11.78	10.36	9.67

Sample No. 3 (5020) Interbedded dusky blue green phyllite and coarse sandstone. Rock is composed of alternating pebble conglomeratic sandstone of sub-rounded (.7) subspherical (.7) quartz grains and fine grained siltstone/phyllite of (.5) sphericity and (.1) roundness:

Coarse sandstone portion 5020 (average composition):

	1	2	3	4	5
Al_2O_3	20.00	11.98	3.01	16.77	15.31
SiO_2	26.12	48.37	5.69	39.44	31.62
MgO	8.84	4.59	0.00	6.04	6.59
FeO	45.03	33.76	65.03	34.86	30.96
TiO_2	-	-	25.47	1.61	1.81
K_2O	-	-	1.00	1.29	-

Siltstone/phyllite portion 5020 (average composition):

	1	2	3	4	5
Al_2O_3	6.52	11.98	6.20	11.03	5.28
SiO_2	30.74	48.37	13.91	48.07	45.06
MgO	1.98	4.59	-	-	-
P_2O_5	19.93	-	17.49	6.33	16.28
K_2O	1.00	0.74	1.57	3.19	1.54
CaO	21.82	15.62	18.71	16.93	17.01
FeO	18.02	20.19	41.23	12.05	14.83
TiO_2	-	-	-	2.39	-

Sample No. 4 (5217) Siltstone/phyllite underlying iron sulfide rich sandstone; fine grained sediment composed of thin laminations which exhibit prolific fold pattern within the rock; folds are constrained to fine grained sediment while boudinage deformation occurs in the coarser sandstone.

Siltstone/phyllite portion of 5217 (average composition):

	1	2	3	4	5
Al_2O_3	12.20	13.40	10.91	11.75	13.09
SiO_2	65.94	60.19	52.44	62.24	59.51
K_2O	3.14	7.45	2.79	6.94	8.37
TiO_2	15.62	9.22	12.60	8.07	-
FeO	3.10	1.09	0.68	2.03	1.38

Sample No. 5 (5206) Pale red (5R 6/2) friable arkosic sandstone; massively bedded, moderately sorted, ranging from very fine sand to medium sand, sub-rounded to rounded.

Average rock composition:

	1	2	3	4	5	6
Al_2O_3	3.89	4.23	1.40	8.95	19.93	16.73
SiO_2	59.17	63.84	57.41	54.73	36.23	51.62
K_2O	.78	1.22	1.09	2.86	6.20	4.37
FeO	36.16	30.71	27.78	32.35	33.41	29.06
CaO	-	-	7.64	1.12	-	-

Sample No. 6 (5053) Interbedded fine grained grayish purple (5P 4/2) ash and grayish green (10GY 5/2) phyllitic siltstone; unit overlies basal conglomerate outcrop along Enchanted Creek.

Average rock composition of ash beds:

	1	2	3	4	5
Al_2O_3	24.26	25.10	26.72	24.33	23.63
SiO_2	45.66	43.61	49.88	46.21	51.09
P_2O_5	5.23	1.52	1.02	2.36	0.78
K_2O	9.53	4.30	9.90	7.41	5.72
CaO	5.00	4.07	2.00	3.36	1.05
FeO	10.33	18.27	10.48	8.92	12.61
MgO	-	1.83	2.49	7.41	5.12
TiO_2	-	2.06	-	-	-

Average composition of phyllitic siltstone:

	1	2	3	4	5	6	7
Al_2O_3	26.72	20.07	20.55	18.90	22.38	13.74	19.82
SiO_2	49.88	60.45	64.30	46.69	56.19	76.53	66.11
K_2O	10.92	10.66	10.10	7.47	12.26	6.64	8.48
FeO	12.48	8.81	5.05	24.94	9.17	3.08	4.40

Sample No. 7 (5048) Pale blue (5B 6/2) graywacke composed of angular feldspar grains and sub-rounded quartz grains ranging from coarse sand to very coarse sand; unit overlies siltstone and ash at the abovementioned outcrop along Enchanted Creek.

Average rock composition:

	1	2	3	4	5
Al_2O_2	12.29	18.01	10.37	16.21	11.35
SiO_2	82.67	72.30	85.12	80.69	72.96
K_2O	5.04	9.69	4.51	9.10	15.69

Sample No. 8 (5020) Dusky blue green shale/sandstone; quartz grains within the shale are of a low sphericity (.3) and of medium roundness (.5) while the quartz of the sandstone shows a higher degree of roundness(.7-.9) and sphericity (.7-.9); this textural condition is distinctive to the reptitious sequence of sandstone, shales and phyllites throughout the mapped area.

Average rock composition of 5020:

	1	2	3	4	5	6
MgO	4.04	2.05	1.02	2.19	3.61	2.76
Al_2O_3	27.26	19.52	16.02	17.53	22.33	28.36
SiO_2	46.09	60.02	68.22	60.61	58.11	48.86
K_2O	9.05	7.93	7.02	8.50	6.93	10.95
FeO	13.56	8.34	6.47	6.99	9.47	9.08
TiO_2	-	2.14	1.25	4.18	-	-

Samples No. 9 & 10 (5625 & 5626) Grayish blue green conglomeratic sandstone; rounded quartz, angular spilitic volcanics, crystalline basement clasts and chlorite matrix compose the rock that is locally referred to as "Brown Mountain Conglomerate".

Average rock composition of both samples:

	1	2	3	4	5	6	7	8	9
Na_2O	7.26	7.30	6.55	4.29	8.03	3.33	8.24	5.00	8.36
Al_2O_3	22.45	19.26	18.66	24.72	22.34	23.78	18.12	18.88	24.74
SiO_2	64.70	72.30	33.88	45.25	68.71	51.53	66.88	51.45	52.31
K_2O	2.55	1.25	5.36	8.03	0.92	6.13	0.85	6.03	4.29
FeO	3.04	2.89	33.56	19.24	0.58	13.11	5.91	21.25	12.30
MgO	3.01	2.82	1.99	2.72	0.44	2.11	1.04	1.40	0.75

Sample No. 11 (5055) Very dusky purple ash (5P 2/2); massively bedded; occasional thin planar laminations of yellowish gray (5Y 7/2) feldspathic phyllite.

	1	2	3	4	5
Al_2O_3	28.68	24.31	19.62	26.34	22.37
SiO_2	51.19	44.33	52.50	50.50	46.23
K_2O	11.19	9.41	7.67	11.93	10.27
FeO	8.94	20.88	18.72	11.33	18.10
TiO_2	-	1.07	1.49	-	3.03

Sample No. 12 (5627) Interbedded fine grained grayish purple (5P 4/2) ash and grayish green (10GY 5/2) phyllitic siltstone; unit is overlying "Brown Mountain Conglomerate" along Swapping Camp Creek.

Average rock composition of ash beds (5627):

	1	2	3	4	5	6	7
MgO	2.29	1.91	2.46	1.63	2.08	2.11	2.37
Al_2O_3	21.13	23.39	25.63	21.89	24.50	26.55	23.90
SiO_2	60.06	56.24	53.82	50.03	47.48	53.50	57.49
K_2O	8.58	8.63	8.11	8.86	12.15	10.79	7.60
FeO	7.05	8.61	9.46	9.49	12.97	6.88	6.89
TiO_2	0.90	1.22	0.52	3.10	0.83	0.18	1.75

Average rock composition of phyllitic siltstone (5627):

	1	2	3	4
Al_2O_3	27.82	21.78	20.67	19.58
SiO_2	49.20	61.07	63.71	52.27
K_2O	11.59	11.30	12.93	9.28
FeO	13.97	9.04	8.28	8.91

Sample No. 13 (5218) Dusky blue green shale/sandstone; similar to sample number eight in most respects except that this rock has been folded (photograph number 3).

Average rock composition:

	1	2	3	4	5
MgO	2.59	2.53	1.94	2.43	2.29
Al_2O_3	22.71	23.32	24.09	22.99	23.55
SiO_2	59.58	58.57	58.31	58.28	57.82
K_2O	6.43	6.64	6.01	5.71	6.74
FeO	8.68	8.93	9.65	10.59	9.60

Sample No. 14 (5054) Thinly laminated lacustrine sandstone composed of alternating planar beds (range from .25cm.to 2cm.) which appear as grayish olive (10Y 4/2) and yellowish gray (5Y 7/2); upper beds (2 cm. thick) are convolute in form.

Average rock composition:

	1	2	3	4
MgO	2.63	1.56	2.93	1.28
Al_2O_3	29.25	21.26	22.33	23.52
SiO_2	50.06	62.86	51.90	55.06
K_2O	11.63	15.88	18.98	14.23
FeO	6.43	5.81	6.79	7.19

Sample No. 15 (5218) Dusky blue green (5BG 3/2) chloritic coarse sandstone containing numerous pyrite crystals; sand grains are rounded and show a high degree of sphericity (0.9)

Average rock composition:

	1	2	3	4	5
MgO	5.27	8.93	7.37	9.38	1.04
Al_2O_3	12.53	21.17	20.74	22.19	8.85
SiO_2	49.93	30.04	37.11	24.88	60.94
K_2O	0.71	-	1.06	-	5.40
FeO	27.37	34.85	30.02	39.55	24.76
SO_4	4.17	5.01	3.70	4.06	1.86

Sample No. 16 (5309) Dusky blue green phyllite (5BG 3/2); matrix of chlorite supports angular quartz grains of less than 1/16mm in size.

Average rock composition:

	1	2	3	4	5
Al_2O_3	14.34	18.35	10.38	12.21	16.76
SiO_2	79.58	66.45	76.28	65.39	70.24
K_2O	6.07	7.72	4.55	6.24	5.83
FeO	3.62	7.78	8.80	15.90	7.17

Sample No. 17 (5315) Medium to coarse grained sandstone immediately overlying the Catoctin greenstone outcrop along Devil's Branch Creek just west of the basement thrust fault; trough cross-bedding indicates unit is right side up and source is to the southeast.

Average rock composition:

	1	2	3	4	5
MgO	2.19	0.87	1.79	0.78	2.13
Al_2O_3	24.48	31.68	27.09	23.14	25.31
SiO_2	57.65	55.71	52.47	49.83	47.19
K_2O	10.06	12.67	9.83	10.92	11.17
FeO	5.63	0.35	8.82	15.33	14.20

Sample No. 18 (5019) Grayish blue green phyllitic shale/siltstone; chlorite and illite matrix; poorly sorted low degrees of roundness and sphericity; however, strongly lithified.

Average rock composition:

	1	2	3	4	5
MgO	2.54	3.65	1.44	2.98	2.12
Al_2O_3	8.48	15.67	9.32	4.04	12.67
SiO_2	72.36	15.67	70.21	77.54	62.98
K_2O	4.22	9.28	6.07	1.41	9.14
TiO_2	2.20	-	1.09	1.50	-
FeO	5.23	5.74	5.31	5.24	5.88

Sample No. 19 (5043) Pale red (5R 6/2) friable arkosic sandstone; massively bedded; moderately sorted ranging from very fine sand to medium sand; quartz grains show a high degree of roundness (.8).

Average rock composition:

	1	2	3	4	5
MgO	1.44	2.45	1.92	1.55	1.71
Al_2O_3	29.90	30.10	28.76	29.81	29.43
SiO_2	49.02	46.34	45.31	48.89	48.07
K_2O	10.62	9.62	9.24	10.17	10.48
FeO	7.13	10.49	11.41	9.57	10.11
TiO_2	1.89	1.00	3.40	0.25	0.20

Sample 20 (5624) Moderate blue green (5BG 4/6) spilitic metabasaltic greenstone; pillow structures; albitic and epidotized amygdules; occasional outcrops exhibit anomalously high magnetic concentrations; angular pillow breccia located within some flows; no columnar jointing reported.

Average rock composition:

	1	2	3	4	5
Na_2O	4.45	4.42	4.34	4.89	4.26
MgO	3.18	3.76	4.53	4.54	4.11
Al_2O_3	14.79	14.98	13.57	15.75	15.01
SiO_2	55.71	51.52	50.59	52.69	50.99
P_2O_5	0.82	0.70	0.72	0.97	0.83
K_2O	0.28	0.39	0.32	0.29	0.31
CaO	7.77	8.22	7.24	7.08	7.71
TiO_2	2.72	3.34	3.68	2.51	2.83
FeO	10.34	12.67	15.00	11.28	13.95

Sample No. 21 (5614) Dusky yellow green (5GY 5/2) phyllite underlying Catoctin greenstone outcrop located along Brown's Creek. This spilite is the southernmost outcrop exposed in the map area and appears to be conformably overlying the phyllites of the Harpers.

Average rock composition:

	1	2	3	4	5	6
Na_2O	3.51	2.26	3.11	4.69	2.48	2.25
Al_2O_3	26.84	25.25	24.06	17.90	26.03	22.43
SiO_2	51.04	52.16	57.55	46.14	51.99	51.52
K_2O	10.01	11.69	6.68	7.13	9.90	11.05
FeO	5.67	6.53	6.81	21.87	5.85	10.85
MgO	2.93	2.11	1.86	2.27	3.09	1.90

Sample No. 22 (5605) Grayish purple (5P 4/2) volcanic ash; angular quartz grains supported by matrix.

Average rock composition:

	1	2	3	4	5	6
P_2O_5	2.71	-	1.82	-	2.40	1.16
MgO	-	-	-	1.89	2.90	1.73
Al_2O_3	14.63	11.99	10.00	24.69	12.35	13.57
SiO_2	66.61	75.26	56.98	50.41	54.21	60.12
K_2O	1.44	4.94	1.99	9.76	3.30	2.23
FeO	8.18	7.81	20.07	11.42	19.44	17.07
MnO	6.44	-	7.15	-	5.70	4.12

Sample No. 23 (5605) Dusky blue green (5BG 3/2) chloritic medium/fine grained sandstone containing numerous pyrite crystals; chloritic matrix;

Average rock composition:

	1	2	3	4	5	6
MgO	-	-	-	2.86	2.90	2.71
Al_2O_3	3.66	5.51	2.58	27.34	26.61	25.93
SiO_2	5.89	7.77	3.05	52.76	52.19	53.10
SO_4	3.71	4.10	2.88	1.43	2.34	1.09
FeO	86.74	80.21	89.88	5.98	6.27	7.57
K_2O	-	-	-	8.64	7.31	4.79
P_2O_5	1.49	1.70	1.61	0.25	0.71	0.48
TiO_2	-	-	-	1.00	1.21	4.86

Sample No. 24 (5511) Interbedded fine grained grayish purple (5P 4/2) ash and grayish green (10GY 5/2) phyllitic siltstone; unit is unconformably overlying basement complex.

Average rock composition of ash beds:

	1	2	3	4	5
MgO	1.50	3.15	-	2.76	3.42
Al_2O_3	24.00	27.34	24.71	24.27	26.00
SiO_2	52.27	49.95	52.31	50.58	51.93
K_2O	13.12	9.60	10.23	12.35	9.74
TiO_2	1.39	-	1.10	0.57	1.20
FeO	7.71	7.95	10.65	7.88	8.15
MnO	-	2.00	0.91	1.39	-
P_2O_5	-	-	1.15	0.91	1.23

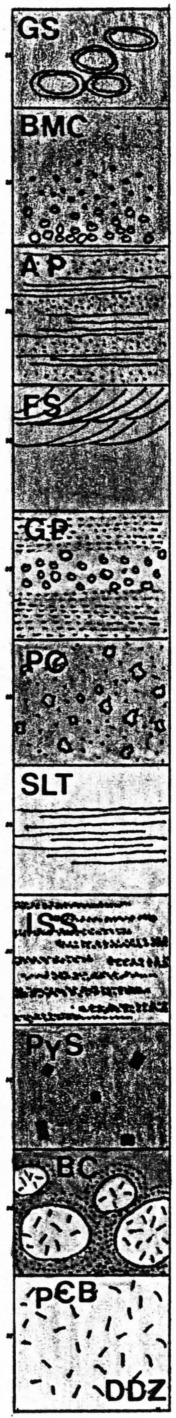
Sample No. 25 (5605) Grayish red purple graywacke; poorly sorted very coarse sandstone containing volcanic ash rip ups, basement clasts, angular to rounded quartz grains.

Average rock composition:

	1	2	3	4	5
Al_2O_3	20.82	24.96	22.67	23.00	24.89
SiO_2	54.13	48.51	49.27	48.33	49.15
K_2O	4.71	7.84	6.98	7.13	7.52
CaO	10.60	9.31	9.82	10.59	8.10
FeO	11.23	14.70	8.25	13.17	15.44

Stratigraphic Column

Lithology: Representative symbols:



Spilitic Greenstone........................

Brown Mountain Conglomerate...............

Purple Ash/Siltstone.......................

Friable Subarkose..........................

Graywacke/Phyllite.........................

Pebbly Arkose..............................

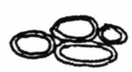
Arkosic siltstone..........................

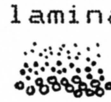
Iron Banded Sandstone......................

Pyritic sandstone..........................

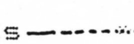
Basal Conglomerate.........................

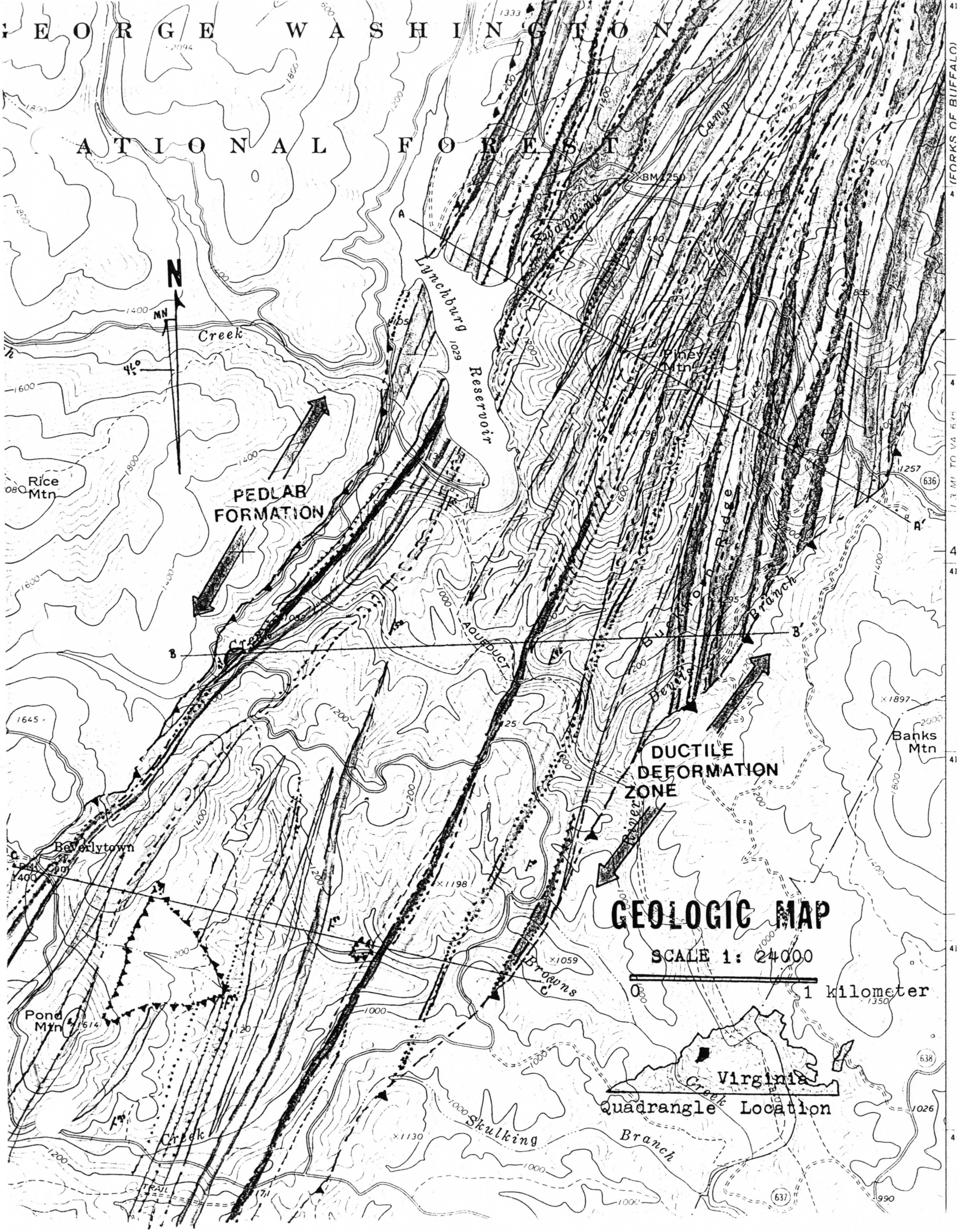
Crystalline Basement Complex...............

Structures: Pillows  ; Horizontal lamination ;

Cross-bedding  ; Graded bedding  ; Folds  ;

Faults  ; Strike/Dip of Beds 

; Boudins  ;Contacts  ;



GEORGE WASHINGTON
NATIONAL FOREST
PEDLAR FORMATION
DUCTILE DEFORMATION ZONE
Lynchburg Reservoir
AQUEDUCT
Rice Mtn
Pond Mtn
Banks Mtn
Piney Mtn
Beverlytown
Buckton Ridge
Devils Branch
Browns Creek
Skulking Branch
Snapping Camp
Creek
GEOLOGIC MAP
SCALE 1: 24000
0
1 kilometer
Virginia
Quadrangle Location
(FORKS OF BUFFALO)
1.3 MI TO VA 635
A
A'
B
B'
C
C'
N
MN

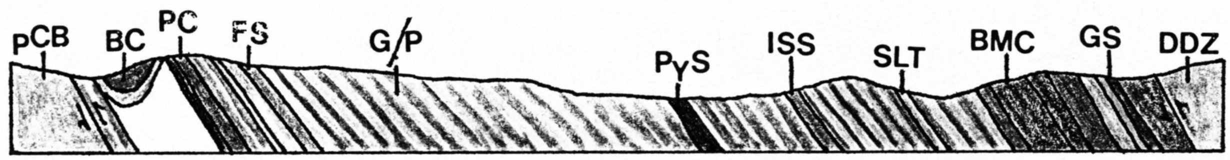
CROSS-SECTIONS

Denoted on the geologic map as: A-A', B-B', C-C'.

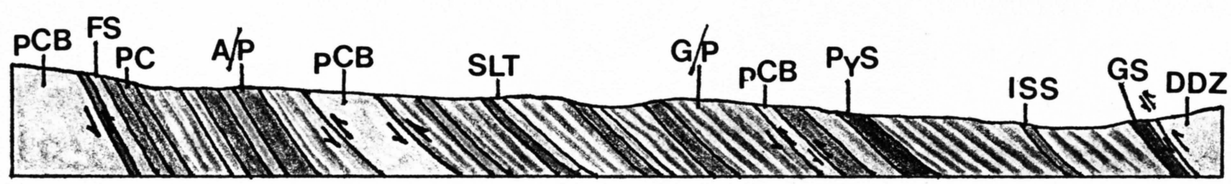
SCALE: 0______________________1 mile

Elevation in feet (datum sea level)

A Rice Mtn. Lynchburg Res. Piney Mtn. Buckhorn Rdg. A'



B Enchanted Ck. Pedlar R. Devil's Branch B'



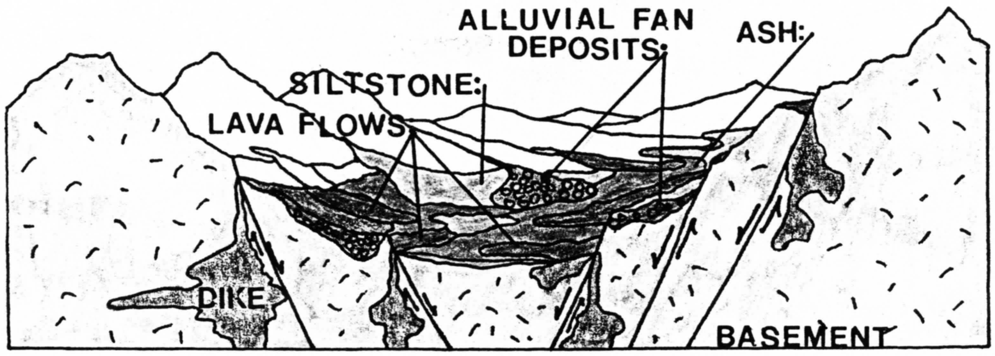
C Beverlytown Brown's Creek C'

LEGEND:

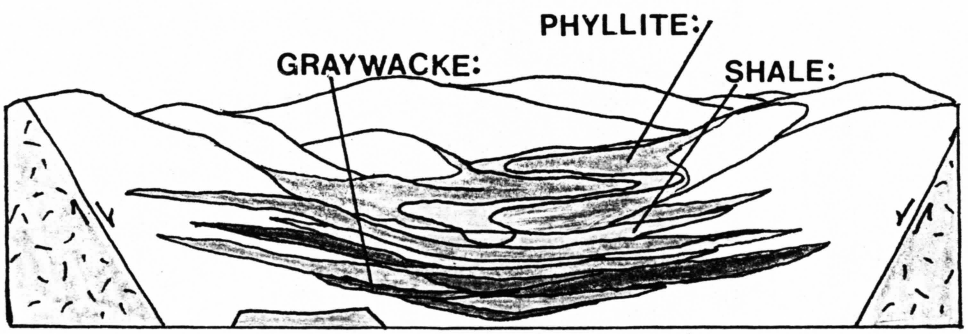
GS : spilitic greenstone
BMC: conglomerate
A/P: ash and phyllite
SLT: siltstone
FS : friable subarkose
ISS: iron-banded sandstone
: strike/dip of bedding

pCb: Precambrian basement complex
DDZ: Ductile Deformation Zone
PC: pebbly conglomerate
PyS: pyritic sandstone
G/P: graywacke and phyllite
BC: basal conglomerate
: strike/dip of faults

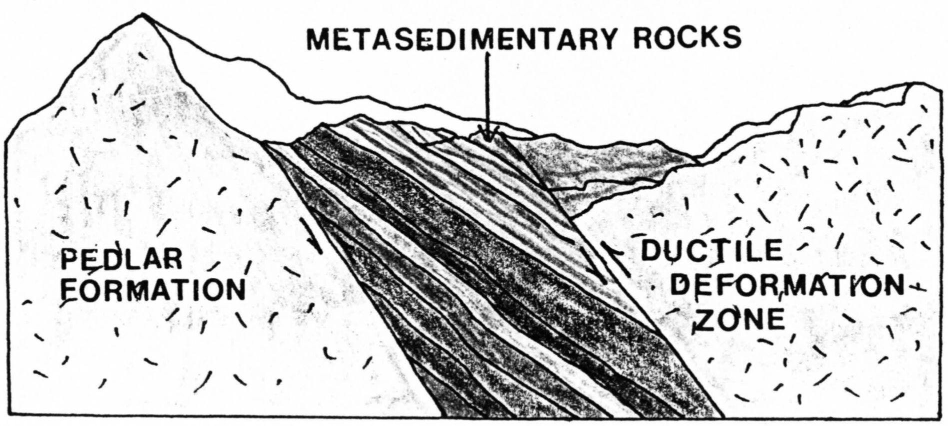
SCHEMATIC DIAGRAM ILLUSTRATING STAGES OF
DEPOSITIONAL ENVIRONMENTS
(after Chen Changming, 1981)



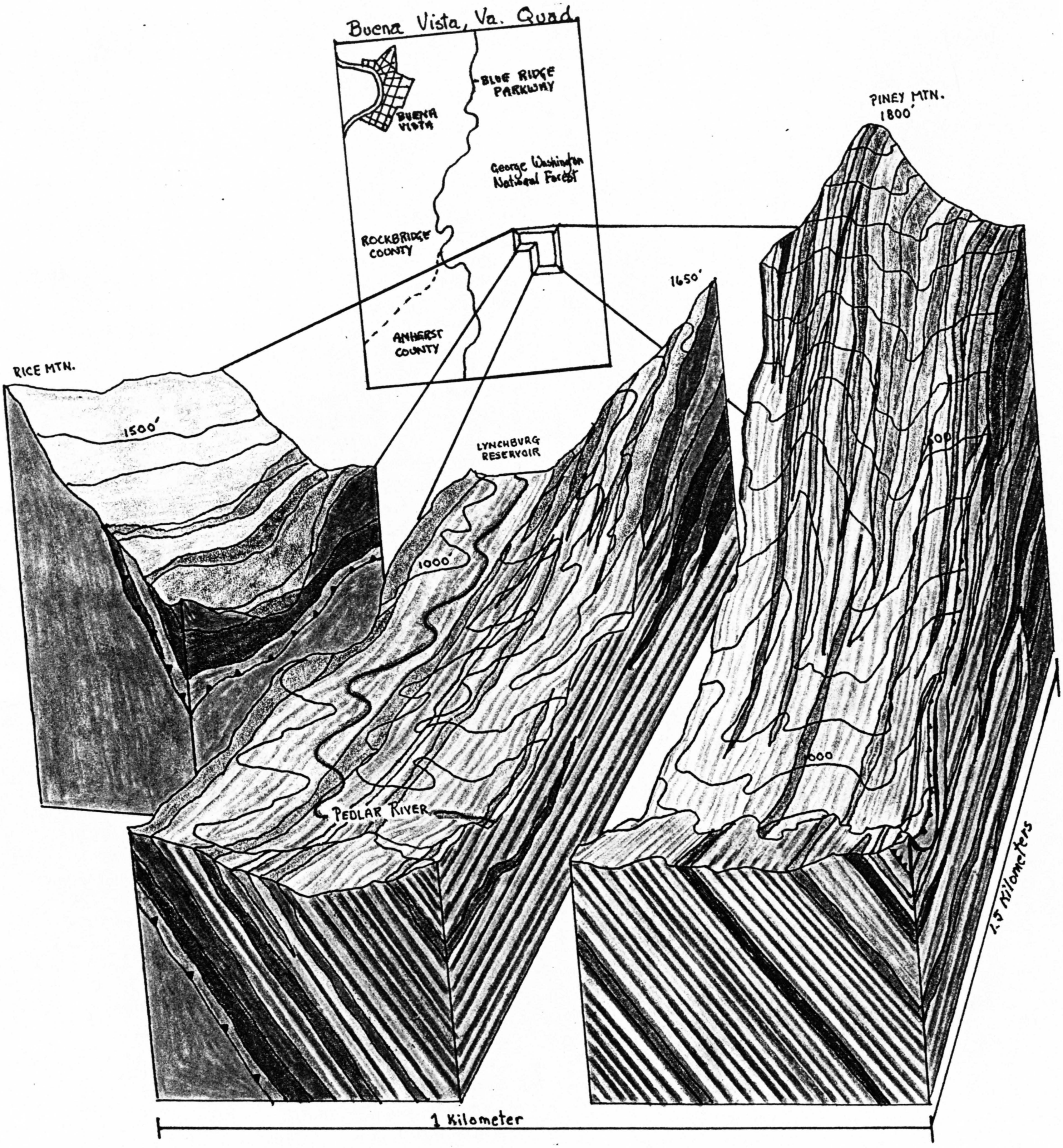
Initial period of rifting causes slump deposits, ash beds, lava flows, coarse clastic conglomerates and alluvial fanglomerates.



Second stage results in downwarping and deposition of fluvial sediments, graywacke/siltstone turbidites, mudstones and shales.



Third stage deforms basin sediments by compressional stress resulting in high-angle faults, folding and extensional features.



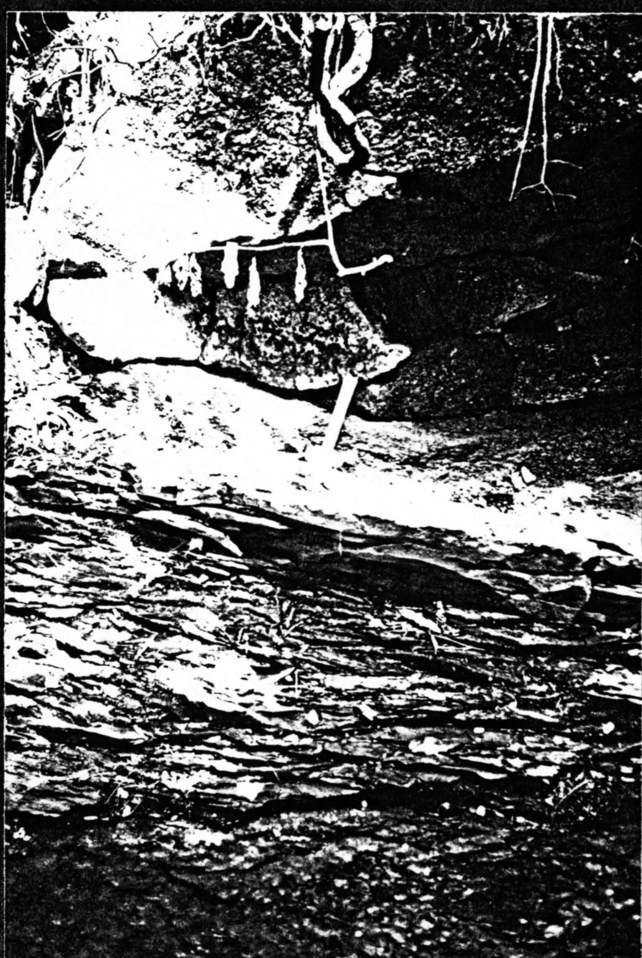
Three-Dimensional Map

Interpretation

Basement Clasts at Outcrop
on Enchanted Creek(20X15cm.

Sandstone/shale Outcrop
Boudins and cross-beds

Asymmetric overturned
phyllite beds (Dip:NW)



Fining Upward Cycle
Brown's Creek

Phyllite-Graywacke Beds
Pedlar River