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SYNTECTONIC DEPOSITION OF LOWER TO MIDDLE SILURIAN SANDSTONES, CENTRAL SHENANDOAH VALLEY, VIRGINIA

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The stratigraphy of the Upper Ordovician to Middle Silurian rocks of the Massanutten synclinorium in the Shenandoah Valley of Virginia contrasts sharply with the stratigraphy in the folded part of the Valley and Ridge province to the west (Figure 1). Five formations between the top of the Martinsburg Formation (Middle and Upper Ordovician) and the top of the Keefer Sandstone (Middle Silurian) crop out in the Cove Mountain outcrop belt to the west of the Shenandoah Valley, whereas the Massanutten Sandstone represents the same time span in Massanutten Mountain (Figure 2).

Only two of the formations that are exposed west of the Shenandoah Valley, the Tuscarora Formation and the Keefer Sandstone, contain quartz arenite in the same abundance as that found in the Massanutten Sandstone. Although the Tuscarora, Rose Hill, and Keefer are correlated with the Massanutten (Young and Rader, 1974; Figure 2), they comprise together a maximum of 330 feet (101 m) of thickness, whereas the Massanutten is 650 feet (198 m) thick near New Market Gap and about 1,200 feet (366 m) thick at the northern end of the outcrop belt (Rader and Biggs, 1976).

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It is proposed that the differences in thickness between the quartz arenite formations to the west of the Shenandoah Valley and the Massanutten Sandstone are, at least partially, a result of deformation penecontemporaneously with deposition during the Taconic orogeny. Downfolding may have begun in the Massanutten synclinorium area while an arch may have been forming to the west (Figure 2) (Rader and Perry, 1976). Assuming such a pattern of deformation, the thickness of the quartz sand deposits should be greater in the synclinal trough than over the arch. The direction of current flow should also have been influenced by the tectonics. Currents would probably flow down the axis of a synclinal trough whereas they would flow away from the crest of an arch. The crest of the Shenandoah axis was probably slightly positive—above sea level or shoaling (personal communication, E. K. Rader, 1977).

To test the validity of this hypothesis, six stratigraphic sections were described and measured in Rockingham County, Virginia and one each in nearby Page County, Virginia and Hardy County, West Virginia (Figure 1). During the description and measurement of the sections in Massanutten Mountain the dip directions of cross-strata were measured in the quartz arenite beds using the technique described by Yeakel (1962, p. 1517). Paleocurrent rose diagrams were constructed after correction of cross-strata directions for tectonic tilt (Potter and

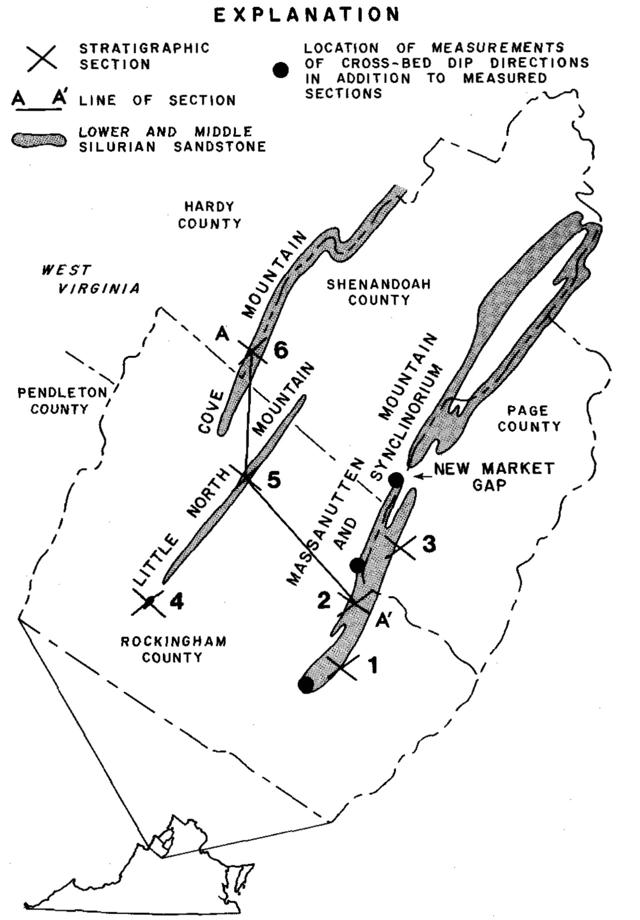

Figure 1. Index map of area being discussed.

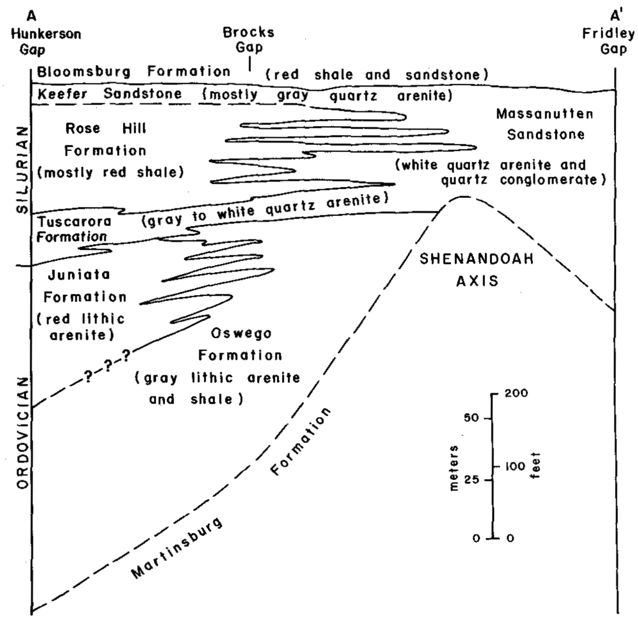

Figure 2. Stratigraphic relationships and lithology of Upper Ordovician to Middle Silurian formations in Rockingham, Page, and Shenandoah counties, Virginia (modified after Young and Rader, 1974; Rader and Perry, 1976a). See Figure 1 for line of section A-A'.

Pettijohn, 1963, p. 260). Cross-strata dip directions were also measured at three other localities on Massanutten Mountain (Figure 1), for a total of 142 separate measurements. The cross-strata measurements made on Massanutten Mountain south of New Market Gap (Figure 1) are, so far as is known, the first measurements of their kind made in that area. These data were compared to those collected by Yeakel (1962) in Massanutten Mountain north of New Market Gap and in Little North Mountain.

The authors wish to thank E. K. Rader and W. J. Perry, Jr. for their many valuable suggestions regarding field aspects of this study and E. K. Rader for his critical reading of the manuscript and suggestions for its improvement.

STRATIGRAPHY

The stratigraphy and lithologic characteristics of the Massanutten Sandstone, Tuscarora Formation, Rose Hill Formation, and Keefer Sandstone have been studied by several geologists and are well-documented (Butts and Edmundson, 1939; Butts, 1940-41; Woodward, 1951, 1955; Brent, 1960; Allen, 1967; Young and Rader, 1974; Rader and Perry, 1976a, 1976b; and Rader and Biggs, 1976).

The stratigraphic interpretation of the Upper Ordovician to Middle Silurian section at Brocks Gap (Figure 2, Table 1) here advocated is basically that of Woodward (1955) as reinterpreted by Rader and Perry (1976a, 1976b). Accordingly, the upper 75-100 feet of the "Lower Silurian and Upper Ordovician sandstone" unit (Rader and Perry, 1976a, Table 1, p. 38) is considered to be equivalent to the Tuscarora Formation rather than the Oswego Formation of Brent (1960), and the Clinch (Tuscarora) Sandstone of Brent (1960) is considered to be the Keefer Sandstone (Figure 2).

PALEOCURRENTS

The predominant paleocurrent direction in the Upper Ordovician to Middle Silurian rocks of the central Appalachians is to the northwest (Figure 3; Yeakel, 1962). In Massanutten Mountain north of New Market Gap, however, Yeakel (1962) found the primary modes of most paleocurrent roses to be northeasterly (Figure 3). Measurements made by the writers at locations south of New Market Gap (Figures 1, 3) show paleocurrent modes similar to those north of the gap. In this southern area four

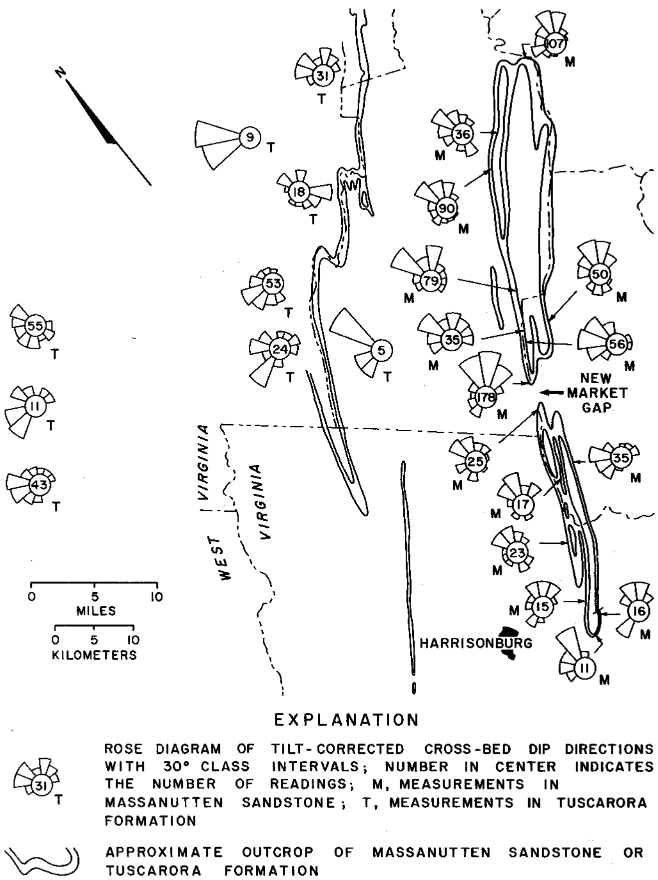

Figure 3. Rose diagrams of cross-bedding dip azimuths in the Massanutten Sandstone and Tuscarora Formation, central Shenandoah Valley, Virginia. Measurements south of New Market Gap in Massanutten Mountain were made by the writers, all others are from Yeakel (1962, Plate 3).

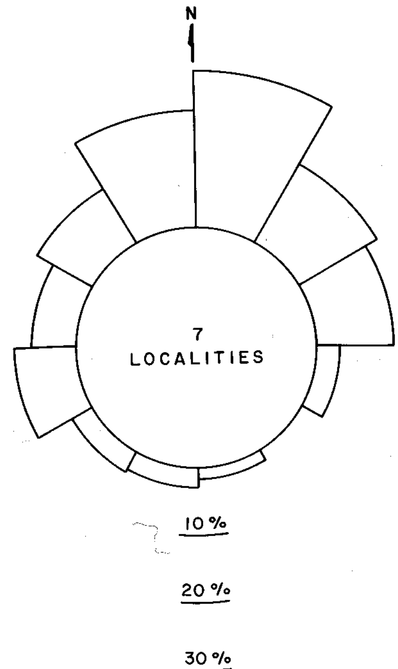

Figure 4. Composite current rose of seven equally weighted localities; measurement of 142 cross-beds in the Massanutten Sandstone south of New Market Gap.

current roses have primary modes to the northeast, one to the north, and one to the northwest. Figure 4 summarizes the paleocurrent directions in the southern part of Massanutten Mountain where a predominant northeasterly mode 60 degrees east of the regional trend, is parallel to the structural axis of the Massanutten synclinorium.

The northeasterly trend of paleocurrent directions in Massanutten Mountain contrasts markedly with the prominent northwesterly mode in most of the central Appalachians. The exposures in Little North Mountain show a scattering of paleocurrent directions that also are somewhat different from the regional trend. Not enough cross beds were exposed, however, for collection of sufficient data to allow construction of a current rose.

GEOLOGIC HISTORY

The paleocurrent data suggest that during Early Silurian time the Massanutten Mountain area was a northeastward-trending linear depocenter, probably due to the initiation in that area of synclinal folding. A few miles to the west, the adjoining anticline was beginning to form. It is apparent from the current roses (Figures 3, 4) that these folds were superimposed on the regional northwest paleoslope existing during the Taconic orogeny. Thus, many, though not all, streams carrying sand and gravel during Early Silurian time were diverted to the northeast down the incipient trough of the Massanutten synclinorium (Figure 5). The streams flowing toward the northwest were probably influenced by the arch forming to the west of the syncline, which may account for the scattering effect seen in the current roses for the Little North Mountain area. Farther to the west, the regional northwest paleoslope does not seem to have been affected by folding during this time interval (Figure 3).

The lower Massanutten Sandstone and the equivalent Tuscarora Formation to the west were forming during part of the regression caused by the Taconic orogeny to the east. The reddish sandy shale and fine sandstone (Rose Hill Formation) with marine fauna (Young and Rader, 1974, p. 23) that were formed in the Cove Mountain and Little North Mountain areas during early Middle Silurian time (Figure 2) show a marine transgression to within a

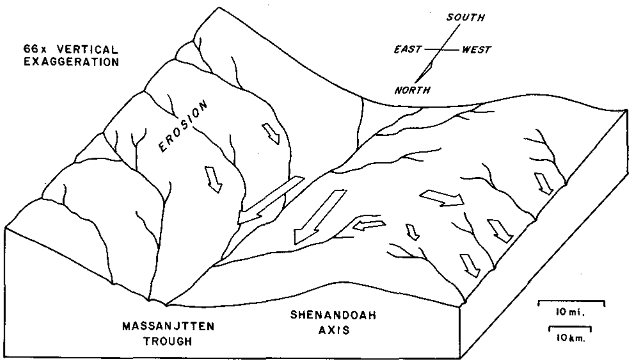

Figure 5. Paleogeography of the central Shenandoah Valley, Rockingham County, Virginia during Silurian time. The location of the Shenandoah axis may have been in the area of the present Mayland anticline (Rader and Perry, 1976a, p. 44). Sediments eroded from the rising Taconic Mountains to the southeast and to a lesser extent from the Shenandoah axis to the northwest were being transported in the direction of the arrows (measured paleocurrent directions) to the Massanutten trough, the depocenter, where they were also transported northeastward along the axis of the incipient Massanutten synclinorium.

few miles of the Massanutten synclinorium. Following this transgression, sand once again spread toward the northwest depositing the upper Massanutten and Keefer sandstones. The greater thickness of the Massanutten Sandstone and its higher proportion of conglomerate and coarse sandstone than in the Tuscarora and Keefer formations are also suggestive of the presence of a linear depocenter in the present Massanutten synclinorium area during Early and Middle Silurian time, while thinner deposits of quartz sand were being deposited over the arch to the west. The conglomerate and coarse sandstone of the Massanutten Sandstone are interpreted as point-bar and fluvial-channel deposits, whereas the finer sands of the Tuscarora and Keefer formations to the west are considered to be beaches, bar, or other tidal deposits (Rader and Perry, 1976b).

From the abovementioned data and reasoning it is concluded that deposition and deformation were occurring penecontemporaneously in the study area during Early to Middle Silurian time. Such syntectonic deposition has been demonstrated to have occurred in Virginia in the early stages of the Taconic orogeny, during or shortly after the deposition of Middle Ordovician limestones. For example, the Knox unconformity is found only on anticlines in Rockingham County and soft sediment slump structures exist in the Middle Ordovician Edinburg Formation near Harrisonburg (Lowry and Cooper, 1970). Thickness variations are associated with structural highs and lows in the Salem synclinorium near Roanoke (Tillman, 1976). Thus, it does not seem unreasonable that the Lower to Middle Silurian sandstones could have been deposited during deformation.

The distance between the linear depocenter in the Massanutten Mountain area and the incipient arch to the west may have been several miles less during the Early Silurian than is the present distance between Massanutten Mountain and Little North Mountain. Rader and Perry (1976a, p. 41) have proposed, on the basis of a reinvestigation of outcrops and new drill-hole data at Brocks Gap, that this part of Little North Mountain is "a transported slice of Upper Ordovician to Middle Devonian rocks within the Little North Mountain fault system." They propose (Rader and Perry, 1976a, p. 44) that the root zone of the inferred tectonic slice at Brocks Gap may underline the Mayland anticline, 7 miles (11 km) to the southeast. If this reinterpretation of the structural evolution of this area is correct, then the incipient arch in Early Silurian time postulated in this paper may have been only 5 to 6 miles (8 to 10 km) to the west of the trough.

SUMMARY OF CONCLUSIONS

(1) The thickness of Lower to Middle Silurian sandstones decreases from a maximum of 650 feet (198 m) on Massanutten Mountain south of New Market Gap to approximately 175 feet (53 m) at Brocks Gap on Little North Mountain approximately 13 miles (21 km) to the northwest of Massanutten Mountain.

(2) During Early Silurian time the direction of paleocurrents were predominantly to the north-northeast in the Massanutten Mountain area, both to the north and to the south of New Market Gap, although secondary paleocurrent rose modes to the northwest, southwest, and southeast have been measured. During the same time interval in the Little North Mountain area, paleocurrents appear to have been somewhat scattered, with current rose modes to the northwest, west, north, northeast, and southeast. The predominant paleocurrent directions in Lower Silurian sandstones in the remainder of the central Appalachians are to the northwest.

(3) A comparison of the thickness and paleocurrent directions of the Massanutten Sandstone with those of the Tuscarora and Keefer formations on Little North Mountain suggests that the Massanutten Mountain area was a northeastward-trending linear depocenter

Table 1. — Locations of stratigraphic sections.[1]

Number	Name	Location
1	Harshberger Gap	Along Massanutten Drive on First Mountain approximately 0.9 mile (1.4 km) northwest of intersection with State Road 647, Rockingham County, VA.
2	Fridley Gap	Along abandoned U. S. Forest Service road parallel to Mountain Run on Fourth Mountain approximately 1.5 miles (2.4 km) east of intersection of State Roads 722 and 620, Rockingham County, VA.
3	Cub Run Road	Along Cub Run Road on First Mountain approximately 1.7 miles (2.7 km) west of intersection with U. S. Highway 340, Page County, VA.
4	Cooper Mountain	Along State Road 732 approximately 0.5 mile (0.8 km) south of State Road 331, Cooper Mountain, Rockingham County, VA.
5	Brocks Gap	Along State Road 259 across from store at Brocks Gap in Little North Mountain, approximately 4.5 miles (7.2 km) west of Broadway, Rockingham County, VA.
6	Hunkerson Gap	Along Capon Run, Cove Mountain, approximately 0.5 mile (0.8 km) east of State Road 259, Hardy County, WVA.

[1] Descriptions of stratigraphic sections are on file at the Virginia Division of Mineral Resources, Charlottesville, VA.

during Early Silurian time, while an arch was beginning to form between there and the present Little North Mountain to the west. Both the incipient trough of the Massanutten Mountain area and the arch to the west were superimposed on the regional northwesterly paleoslope that existed because of the Taconic orogeny. Thus the Massanutten Mountain area was a linear trap for quartz sand and gravel which diverted many, though not all, streams to the northeast. The incipient arch to the west resulted in the deposition of thinner, finer grained quartz sand deposits of streams flowing in directions partially influenced by the structural high. Near the middle of this regressive, alluvial deposition sequence, a transgression to within a few miles of the Massanutten Mountain area resulted in shallow marine deposition of the sandy shales of the Rose Hill Formation. Following this, regression again occurred, resulting in the deposition of the Keefer Sandstone, equivalent to the upper part of the Massanutten Sandstone.

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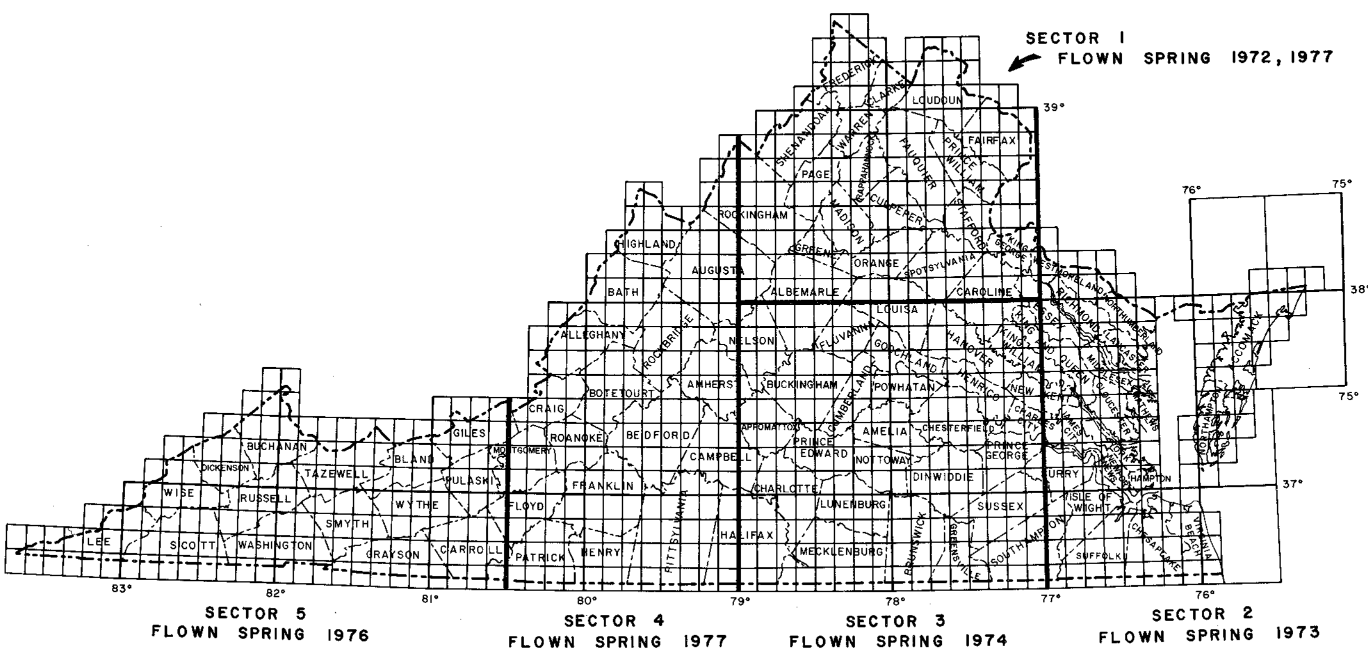
NEW AERIAL MAPPING PHOTOGRAPHY

High-altitude, quad-centered black and white aerial photography, taken during the spring of 1977, is now available for revision inspector sectors 1 and 4. These photographs are used as an evaluation source to determine which 1:24,000-scale topographic maps need to be revised. Maps of growth areas are to be updated each 5 years. As shown on the accompanying index map these sectors occupy the north-central and western portions of the Commonwealth. They include the following cities: Alexandria, Arlington, Bedford, Buena Vista, Charlottesville, Clifton Forge, Covington, Danville, Fairfax, Falls Church, Fredericksburg, Harrisonburg, Lexington, Lynchburg, Martinsville, Roanoke, Salem, and Staunton. Except for 11 quadrangles, photographs of this type are available for all 1:24,000-scale map areas in the Commonwealth. In Sector 1 growth features can be interpreted by comparison of this photography with that taken in 1972.

This photography is available as a series of overlapping prints from which stereo studies, in which the landscape appears to be three dimensional, can be made. Within the series of photographic prints there are single photographs which are uniquely centered on each 1:24,000-scale topographic map area depicted. These quad-centered 9 x 9 inch prints are about one third the size of the maps. Three-times enlargements of the prints at a size of 28 x 28 inches, when compared with the corresponding topographic maps, aid in interpretation of features on both maps and prints. Photographs are especially useful for determining types of vegetation, land use, and property lines. Photographic reproductions of prints and enlargements can be obtained *only* from the National Cartographic Information Center-East, Mail Stop 536, U. S. Geological Survey, Reston, VA 22092. As ordering aids for these quad-centered photographs, a listing of topographic maps with their respective photographs and an index showing map name and locations can be obtained on request from the Virginia Division of Mineral Resources, Box 3667, Charlottesville, VA 22903; this office also sells topographic maps.

HIGH - ALTITUDE QUAD - CENTERED PHOTOGRAPHY
REVISION INSPECTION SECTORS



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NEW PUBLICATION SERIES

The Bulletin, Mineral Resources Report, Report of Investigations, and Information Circular series of publications have been discontinued by the Virginia Division of Mineral Resources. All geologic reports will hereafter be in the newly established Publication series. Due to printing schedules, the reports in the Publication series may not be released in chronological order. The last reports in the previous series were Bulletin 86, Mineral Resources Report 13, Report of Investigations 45, and Information Circular 20.

NEW PUBLICATIONS

(Available from the Division of Mineral Resources, Box 3667, Charlottesville, VA 22903; State sales tax is applicable only to Virginia addressees.)

LIST OF PUBLICATIONS (1977-78), 41 p. No charge.

Publication 2. GEOLOGY OF THE BLAIRS, MOUNT HERMON, DANVILLE, AND RINGGOLD QUADRANGLES, VIRGINIA, by William S. Henika; 45 p., 2 maps in color, 30 figs., 5 tables, 1977. Price: $8.50 plus $0.34 State sales tax, total $8.84.

The Blairs, Mount Hermon, Danville, and Ringgold 7.5-minute quadrangles are located in the Piedmont physiographic province, Pittsylvania County, Virginia just north of the Virginia-North Carolina boundary. Precambrian metamorphic rocks are divided into two areas by the Danville basin that contains Triassic sedimentary rocks assigned to the Dry Fork Formation. Southeast of the Danville basin the Precambrian Shelton Formation, exposed in antiformal and synformal folds, forms the core of a large, refolded nappe. Precambrian metamorphosed volcanic-sedimentary rocks overlie the Shelton Formation.

The report includes two geologic maps in color at the scale of 1:24,000 (1 inch equals approximately 0.4 mile or 0.6 km). They show the Precambrian, Triassic, and Quaternary surface geologic units and environmental geology information.

Northwest of the Danville basin the Precambrian metamorphosed Fork Mountain Formation is the major rock unit. It is part of a mass of rocks that have also been deformed in a refolded nappe. The Fork Mountain formation and the metamorphosed volcanic-sedimentary rocks have been intruded by ultramafic rocks and granite dikes and sills.

Crushed stone and sand are produced. Other rocks and minerals of potential economic interest include shale, talc and soapstone, kyanite, sillimanite, and gold.

Environmental geology information for decisions concerning land use and modification is provided by derivative maps prepared from geologic data such as rock type, depth of weathering, soil type, and slope stability as well as present-day land-use patterns.

Publication 6. BOUGUER GRAVITY IN SOUTHWESTERN VIRGINIA, by Stanley S. Johnson; 27 p., 2 maps (1 in color), 1 fig., 1977. Price: $2.00 plus $0.08 State sales tax, total $2.08.

An area of approximately 5,300 square miles (13,727 sq km) in Virginia, bounded by 81°00′ west longitude on the east and the Virginia state line on the north, west, and south, was surveyed using gravimeter methods. A total of 1,440 stations, such as bench-mark, checked spot, and bridge elevations were occupied. The survey included areas in the Appalachian Plateaus, Blue Ridge, and Valley and Ridge physiographic provinces. Precambrian and Paleozoic metamorphic and igneous rocks and Paleozoic sedimentary rocks are present in the area surveyed.

A Bouguer gravity map in color at the scale of 1:250,000 (1 inch equals approximately 4 miles or 6 km) and a map showing major regional structures are included.

Correlation was found to exist between the gravity and magnetic fields. From the gravity data it seems that there is overall fairly deep basement with a gradual deepening of the basement from the northwest to the southeast. Major faulting does not appear to be present in the basement rocks (thin-skinned tectonics) as based on the absence of sharp and steep gradients.

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ADDITIONS TO STAFF

Mr. Michael L. Upchurch joined the Division staff on November 16, 1977 and will assist in the information service and topographic mapping section. He received his B.S. in geology from East Carolina University, M.S. in petrology from the University of North Carolina, and M.A.T. in education from Duke University. He was previously employed as an oceanographer and then as an earth science teacher in North Carolina before joining the Division.

Mr. Mark P. Phillips joined the Division staff on January 16, 1978 and has been assigned to the information service and topographic mapping section. He received his B.A. in geology from Albion College, Albion, Michigan in 1972 and M.S. in geology from the University of Arizona in 1976. Previous to joining the Division, he taught at Wayne State University in Detroit, Michigan.

NOTE: No revised 7.5-minute topographic quadrangle maps were published from September 15, 1977 through January 15, 1978. However, total state coverage of topographic maps is completed; index is available free. Published topographic maps for all of Virginia may be purchased for $1.25 each (plus 4 percent State sales tax for Virginia addresses) from the Virginia Division of Mineral Resources, Box 3667, Charlottesville, VA 22903.