VIRGINIA DIVISION OF MINERAL RESOURCES
PUBLICATION 116

STRATIGRAPHY OF THE WAYNESBORO FORMATION (LOWER AND MIDDLE CAMBRIAN) NEAR BUCHANAN, BOTETOURT COUNTY, VIRGINIA

JOHN T. HAYNES

COMMONWEALTH OF VIRGINIA

DEPARTMENT OF MINES, MINERALS AND ENERGY
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Robert C. Milici, State Geologist

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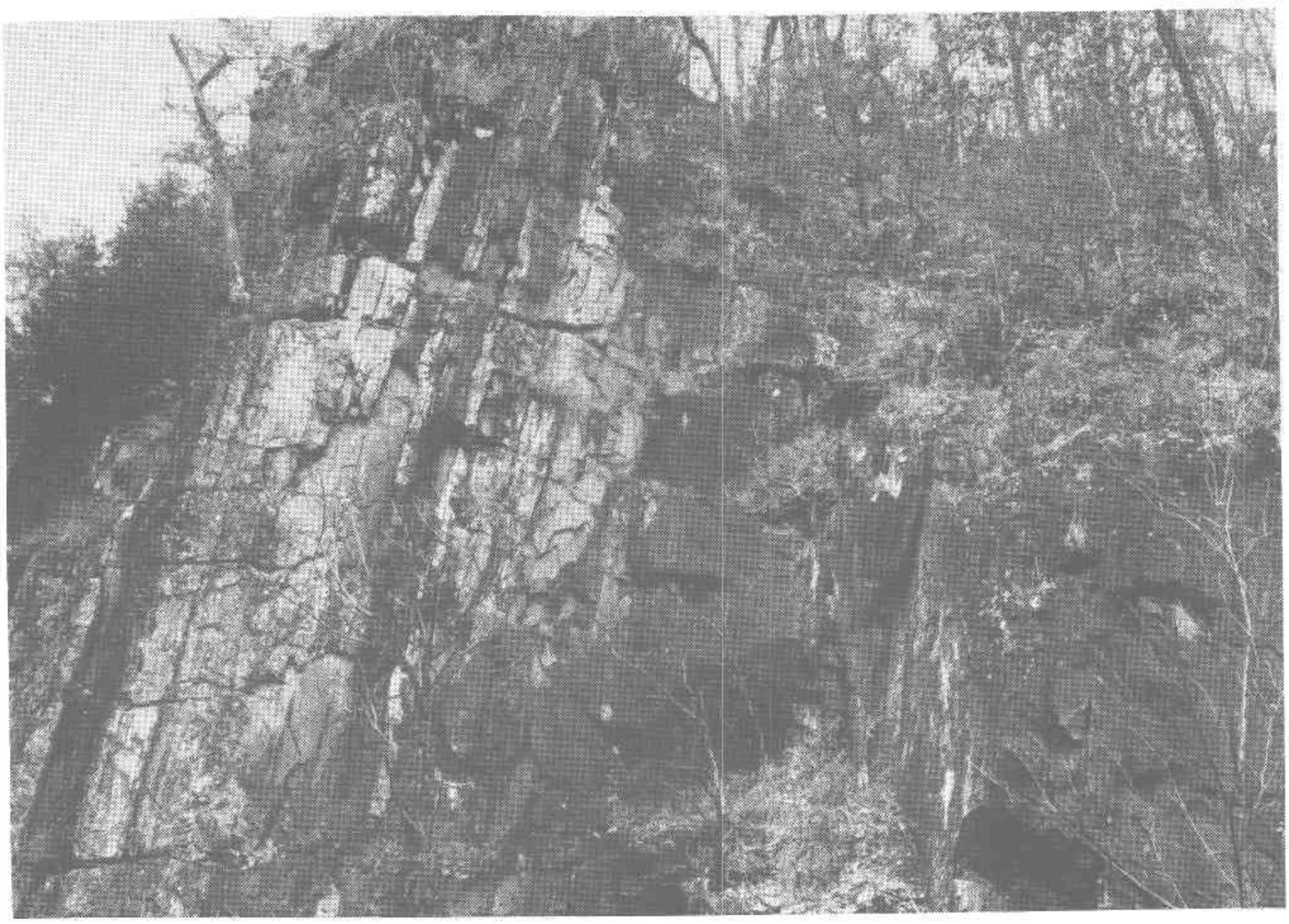

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FRONT COVER: Interbedded mudrock, ribbon rock, and "butcher-block" dolomite forming a prominent bluff at the Indian Rock section. Bedding top to the left.

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STRATIGRAPHY OF THE WAYNESBORO FORMATION (LOWER AND MIDDLE CAMBRIAN) NEAR BUCHANAN, BOTETOURT COUNTY, VIRGINIA

John T. Haynes

ABSTRACT

Three sections of the Waynesboro Formation (Lower and Middle Cambrian) in Botetourt County, Virginia were measured and described, providing data for the construction of a composite section of the entire formation. The composite section is almost completely exposed, has a minimum of structural disruption, is readily accessible, and includes the upper and lower contacts. This composite section is suitable for use as a reference section of the Waynesboro Formation in this region, where it can be compared with other, less complete, poorly exposed, more deeply weathered, and more structurally complex sections.

The Waynesboro is comprised of the rocks between the Shady Dolomite and its equivalents and the Elbrook Formation and its equivalents throughout the southern Valley and Ridge. Limestone and dolomite are the predominant lithologies of the Waynesboro. Only 10 to 20 percent of the formation is composed of clastic rocks, these being the well-known and widely recognized grayish-red and green mudrocks. The three measured sections contain several shallowing-upward sequences and two deepening-upward sequences in which the different lithologies present reflect the water depth in which they were deposited. The relative dearth of mudrocks and the abundance of marine carbonates suggests that these sediments were deposited in a peritidal environment seaward of the predominantly redbed sequence present in equivalent strata to the west and southwest. The near total lack of invertebrate fossils suggests that this was a very restricted setting. The scarcity of high-energy deposits (ooids, bioclastic debris, and peloids) suggests that energy levels were low where these sediments were accumulating.

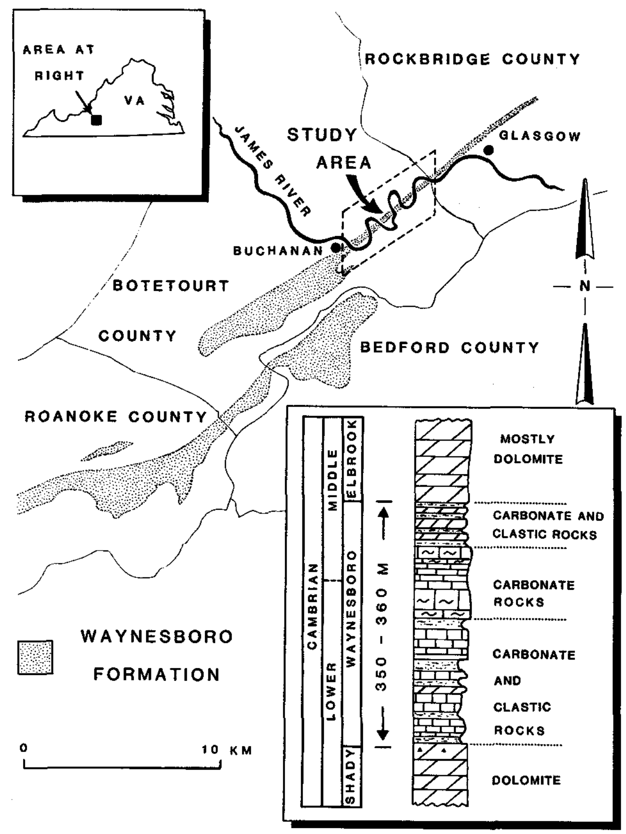


Figure 1. Map showing location of study area with a schematic stratigraphic column of the Waynesboro Formation based on three measured sections.

INTRODUCTION

In the Valley and Ridge north of Buchanan, Botetourt County, Virginia, most exposures of the Waynesboro Formation occur in a single belt along the eastern side of the Shenandoah Valley (Figure 1), which parallels the trend of the Blue Ridge Mountains. The three measured sections are located in this belt (Figure 2). Exposures in this outcrop belt contain the contact with the underlying Shady Dolomite as well as with the overlying Elbrook Formation, unlike exposures farther west and southwest, where the base of the equivalent Rome Formation is faulted out in most localities. Key beds used to correlate the three measured sections are shown in Figure 3.

Although the Waynesboro and Rome Formations are time-equivalent units, use of the name Waynesboro, rather than Rome, is preferred for the Buchanan area because there the lithologic character of the strata is more similar to the Waynesboro Formation at the type locality in Pennsylvania (Stose, 1906; Root, 1968), than it is to the Rome Formation southeast of Roanoke (Woodward, 1932; Butts, 1940; Bartholomew, 1981). As described by Root, the unit is divisible into three parts in this strike belt. Near Buchanan the three divisions are: 1) a lower sequence of interbedded carbonate rocks and grayish red and green calcareous siltstones; 2) a middle sequence of carbonate rocks bounded at top and bottom by two thick, massively bedded burrow-mottled dolomudstones, and 3) an upper sequence of interbedded carbonate rocks and siltstones (Figure 1) and the formation is about 350 m thick as determined by the composite section. This vertical sequence of mixed carbonate and clastic rocks contrasts with the Rome Formation to the west and southwest, which is predominantly a clastic sequence of non-marine redbeds with rare marine carbonates (Hayes, 1891; Woodward, 1929; Butts, 1940; Bridge, 1945; King and Ferguson, 1960; Brown, 1966; Cressler, 1970).

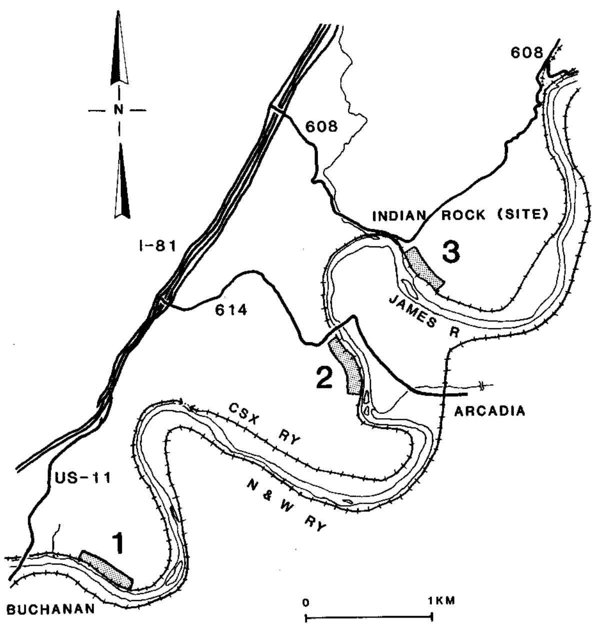


Figure 2. Map showing locations of the three Waynesboro Formation sections measured for this study.

STRUCTURE

The Waynesboro Formation in the study area is on the Pulaski thrust sheet, overriding younger strata now exposed in the Purgatory Mountain entrant near Buchanan. Unlike exposures of the Waynesboro south of Buchanan, however, where the strata are part of a structurally complex, and lithotectonically separate, broken formation carried by the Pulaski fault (Bartholomew, 1987), the strata in the three sections measured for the present research are mostly undisrupted by small-scale faults and folds. The normal stratigraphic sequence is readily identifiable, and detailed measurements and description of the entire formation are possible, even through the strata are steeply dipping or nearly vertical to overturned. Consequently, the composite section is very suitable as a reference section of the Waynesboro, which is particularly important in this region because the broken formation to the south is an extremely disrupted, mostly poorly exposed, and difficult to map assemblage of the Rome (Waynesboro) and Elbrook Formations. Nevertheless, very detailed mapping of the broken formation is required to work out the structural history of this area. During the initial search for well-exposed, relatively undisrupted exposures of the Waynesboro, no suitable exposures were found south of Buchanan. The reference section of the Waynesboro should facilitate mapping of the broken formation because it describes the detailed variations in the vertical stratigraphic sequence of this lithotectonically important formation.

As mapped by Spencer (1968), the fault that wraps around Purgatory Mountain and is part of the Pulaski fault system has been folded in this area, and recent work suggests that this structure resulted from the ramping of other thrust faults in the subsurface (Kulander and Dean, 1986). Spencer (1968), Henika (1981), and Bartholomew (1987) discuss the structural history of the area around Buchanan in greater detail.

STRATIGRAPHY

AGE

Based on the few fossils collected from the Waynesboro and Rome Formations throughout the Appalachians over the last 100 years, it is apparent that these units span the boundary between the Lower and Middle Cambrian strata in this region. Lower Cambrian fossils have been collected from these strata at various outcrops throughout the Appalachians, as have Middle Cambrian fossils (Walcott, 1892; Stose, 1909; Bassler, 1919; Resser, 1938; Resser and Howell, 1938; Butts, 1940 and 1941; Bartholomew, 1981; Henika, 1981). Butts (1940) specifically described the section at Indian Rock (Section 3, this study) as being "The only locality in Virginia where a lower limit to the Middle Cambrian can be recognized..." Butts reported that "...*Olenellus* occurs 350 feet below the base of the Honaker dolomite, which corresponds to the base of the Rutledge limestone." (The Honaker is equivalent to the Elbrook.) Lacking more recent data, this places the Lower-Middle Cambrian contact in the Buchanan area well within the upper part of the Waynesboro Formation. To the south, near Austinville, Virginia, The Lower-Middle Cambrian boundary has been identified in the Upper Shady Dolomite, a unit that is in part time-equivalent to the Rome Formation (Pfeil and Read, 1980; Barnaby and Read, 1990).

Most of the Middle Cambrian fossils from the Rome that were described by Butts (1941) were collected from exposures in outcrop belts farther west. Thus, because *Olenellus* occurs only 350 feet from the top of the unit near Buchanan, the Waynesboro Formation may contain strata that are older than the oldest part of the Rome Formation exposed in those more westerly outcrop belts. Although a careful search was made, no identifiable invertebrate fossils were collected during the present study.

LITHOFACIES AND ENVIRONMENTS

In the three measured sections, the major lithotypes are lime mudstone, dolomudstone, mottled dolomudstone, clastic and carbonate ribbon rock, cryptalgalaminite, fenestral limestone, a fine-grained, fracture-gashed dolomite locally known to Appalachian geologists as "butcher-block" dolomite, and grayish red and green mudrock. Thin grainstone and packstone beds are a minor part of the Waynesboro, but are important for the sedimentologic information they reveal. Rare thin beds of sandstone also occur.

LIME MUDSTONES AND DOLOMUDSTONES

Lime mudstone and dolomudstone are the predominant carbonate lithotypes in the Waynesboro Formation. The lime mudstones are generally medium gray to medium dark gray

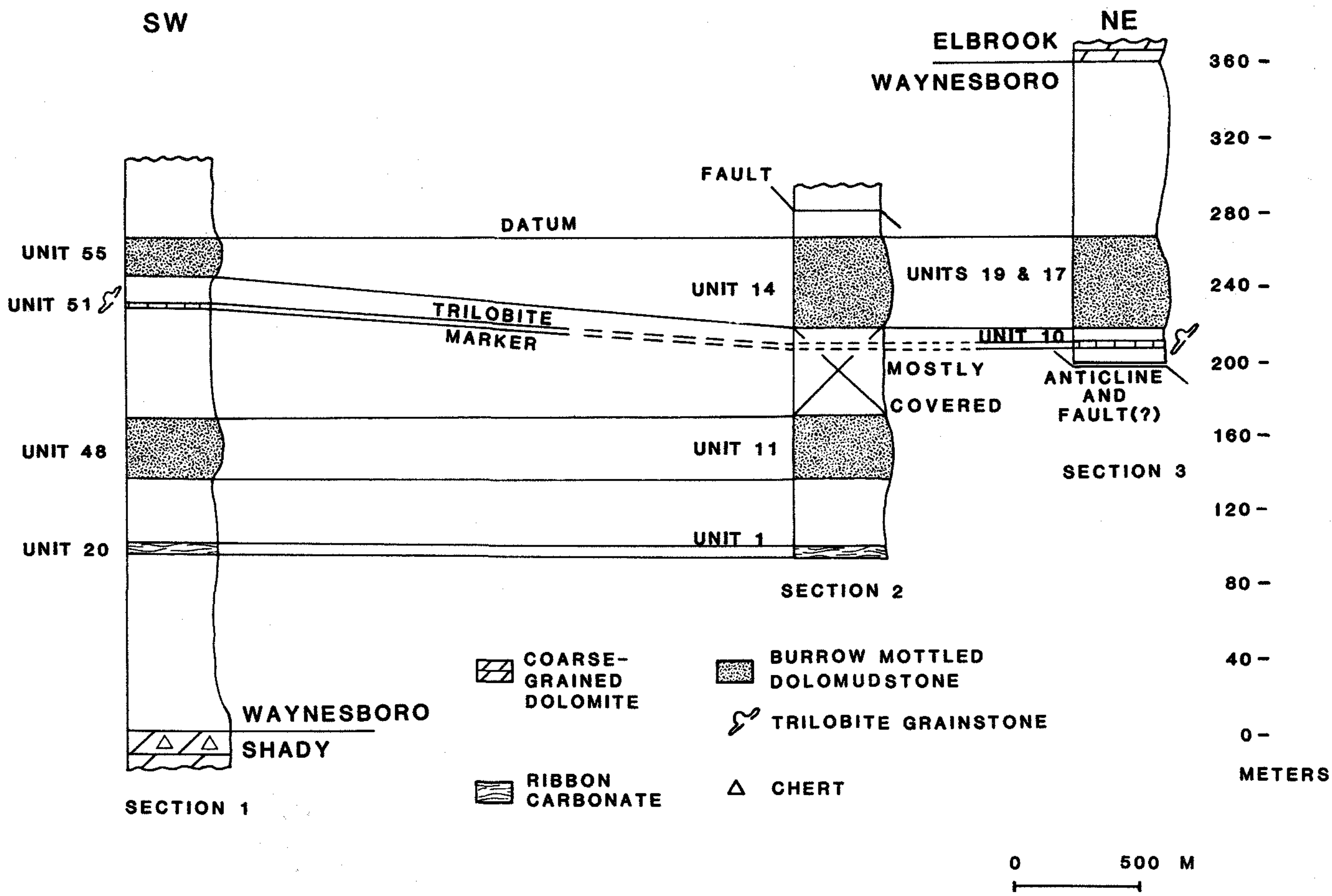


Figure 3. Diagram showing key beds used for correlating the three measured sections; unit numbers refer to the beds as numbered in the Appendix.

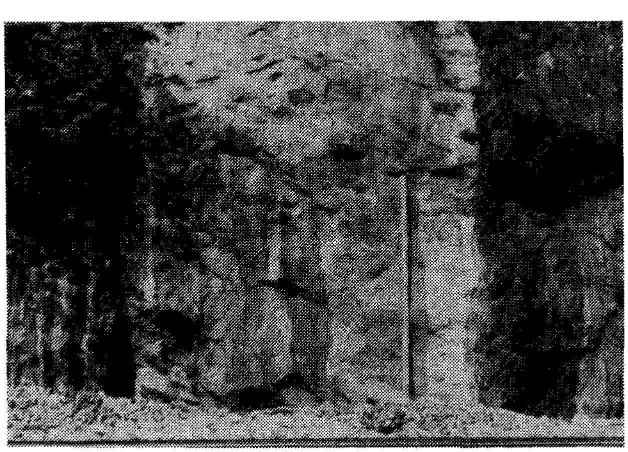
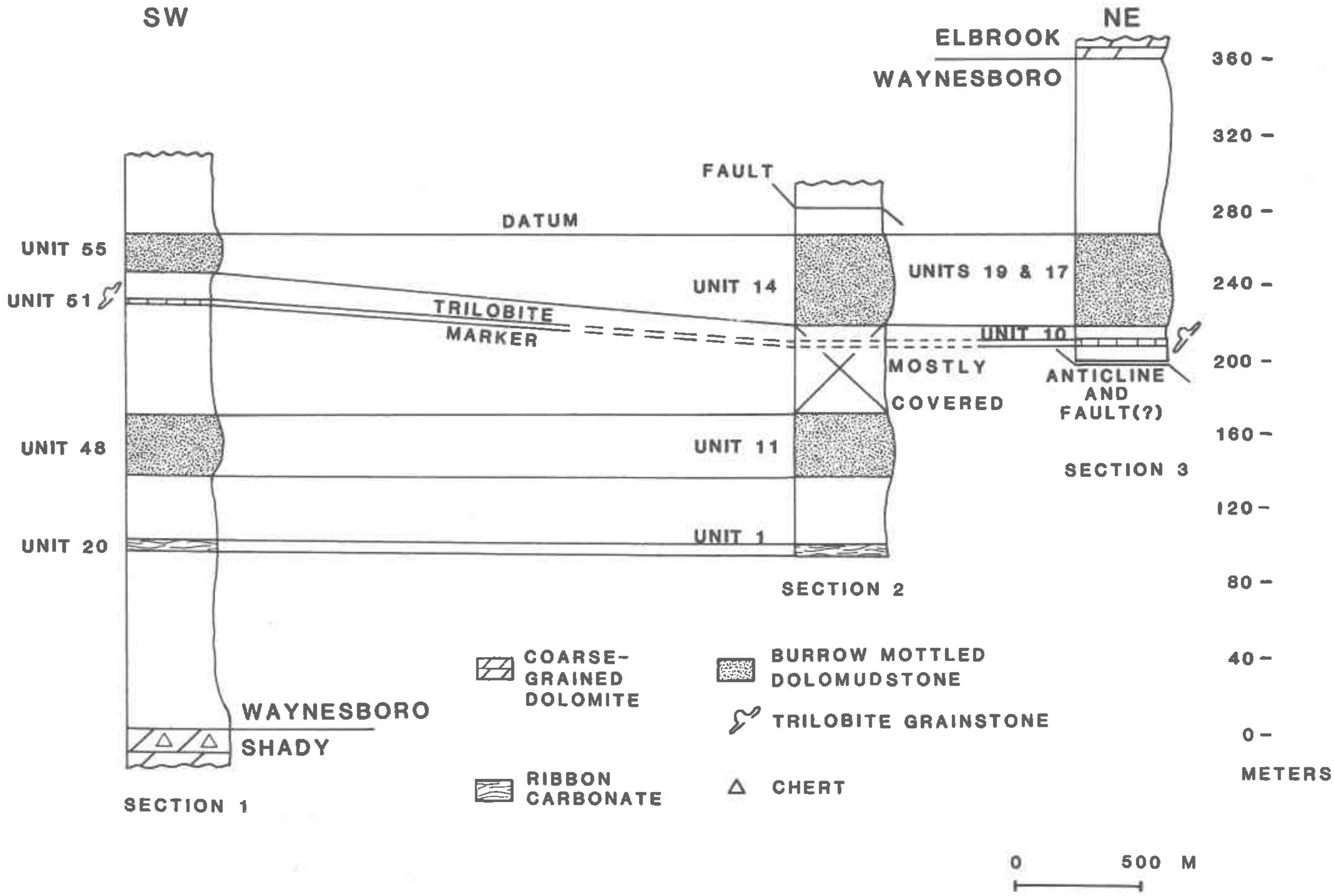


Figure 4. Lime mudstone interbedded with "butcher-block" dolomite (right) and dolomudstone and cryptalgalamite (left); bedding top to left.in

(N4-N5) on a fresh surface, weathering to a medium light gray (N6), and they commonly break with a conchoidal fracture, an indication of their fine grain size. The dolomudstones are nearly identical except for their color on weathered surfaces, which is usually yellow brown (10 YR 5/4 - 10 YR 4/2). Bedding is very thin to moderately thick, and thin, planar lamination is usually present.

These rocks are interbedded with dolomudstones, cryptalgalaminite, "butcher-block" dolomite, and a very few thin beds of peloidal, intraclastic, and bioclastic grainstones, and packstones (Figure 4). Petrographically, these rocks are composed mainly of 5-10 μm translucent microspar crystals or idiotopic-P dolomite rhombs (Gregg and Sibley, 1984), rather than opaque micrite grains, which are 2-4 μm; larger (25-100 μm) dolomite rhombs and pyrite and quartz grains also occur. Invertebrate fossils were not found in any of these rocks, but some lime mudstone beds contain dolomitized burrows.

The lime mudstones were deposited in restricted, low-energy subtidal environments based on lack of body fossils and the occasional burrows, their stratigraphic proximity with more diagnostic lithotypes such as cryptalgalaminites, and the occurrence of thin grainstone beds described below, which are storm deposits.



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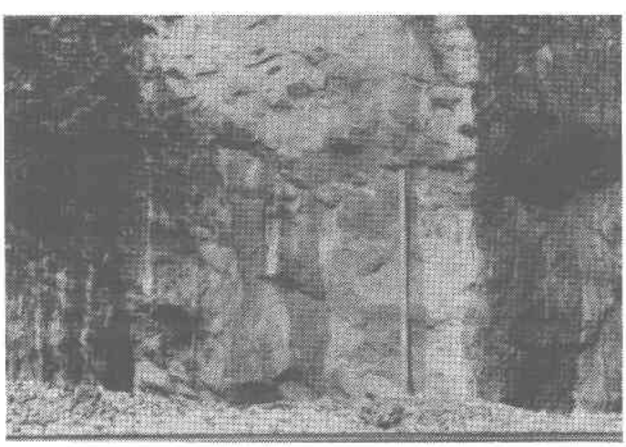

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Fine-grained dolomite is associated with supratidal conditions on modern tidal flats in which dolomite is forming (Shinn, 1983). Thin lamination in these dolomites results from the interaction between storms, high tides, and sporadic algal mat growth that occurs after wetting of the supratidal zone. Bioturbation is generally absent from these sediments because of the harsh living conditions present in this environment, and therefore the lamination is usually preserved in the rock record. The dolomudstones of the Waynesboro probably formed in a similar depositional environment as they are laminated throughout and occur in a sequence that includes the grayish red and green mudrocks.

Mottled Dolomudstosne

Two units of thickly bedded mottled dolomudstones up to 50 m thick occur in the composite section. Some thinner mottled beds also occur. The mottling is the result of selective dolomitization of irregular, patchy areas. The mottles are interconnected in three dimensions (as seen on weathered blocks; cf. Figure 5). The patchy mottling is not as apparent on fresh surfaces, but on weathered surfaces the dolomite is a medium gray (N4), which contrasts with the darker gray (N2) of the lime mudstone matrix. Bedding is commonly defined by the mottles and ranges from well-defined to absent (Figure 6). No invertebrate fossils were found, but a small domal stromatolite was observed at the Buchanan section. These rocks also lack mechanically-produced sedimentary structures such as graded bedding, ripples, or cross-lamination. The mottles are interpreted to be burrows, and as shown in Figures 5 and 6, the rock does, indeed, have a burrowed or "worm-eaten" appearance. The domal stromatolite suggests that "algae" (cyanobacteria) were present and may have contributed to the mottling in some places as suggested by Howe (1968) and Swett and Smit (1972).

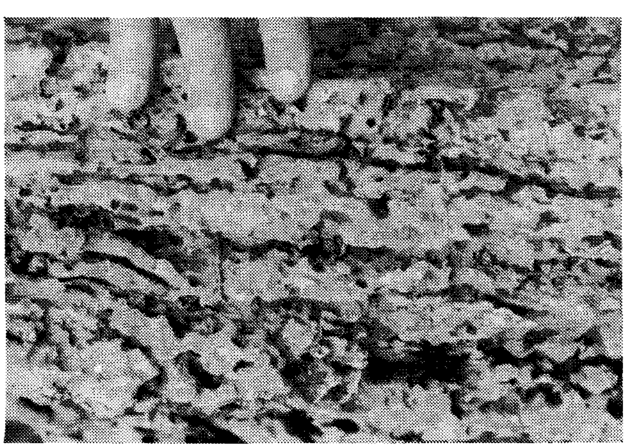

Figure 5. Weathered block of mottled dolomudstone showing the interconnected anastomosing nature of the mottles, which are interpreted to be invertebrate burrows.

These rocks were deposited in a low energy subtidal setting below storm wave base as suggested by burrow morphologies (branching, anastomosing nature and overall horizontality) and the lack of higher energy sedimentary structures indicative of reworking by waves or currents. The lack of epifauna such as trilobites or brachiopods suggests a restricted environment in which only the burrowing organisms could live.

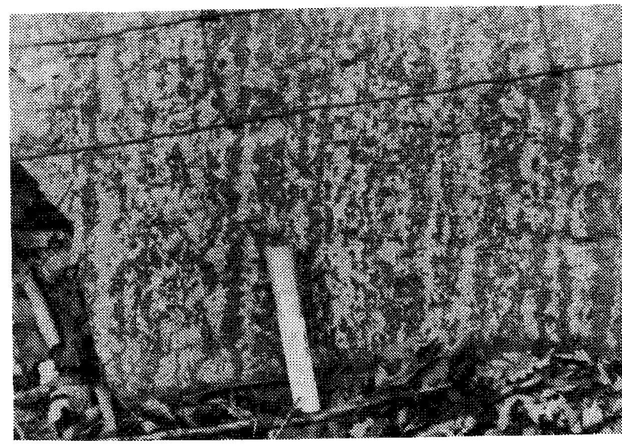

Figure 6A. Block of mottled dolomudstone showing bedding defined by the mottles; bedding top to right; hammer approximately 20 cm.

Figure 6B. Outcrop of the upper mottled dolomudstone, Indian Rock section, showing several prominent bedding planes not directly related to the mottling; bedding top to right.

Grainstones and Packstones

Thin beds (3-10 cm) of grainstone and packstone occur

Fine-grained dolomite is associated with supratidal conditions on modern tidal flats in which dolomite is forming (Shinn, 1983). Thin lamination in these dolomites results from the interaction between storms, high tides, and sporadic algal mat growth that occurs after wetting of the supratidal zone. Bioturbation is generally absent from these sediments because of the harsh living conditions present in this environment, and therefore the lamination is usually preserved in the rock record. The dolomudstones of the Waynesboro probably formed in a similar depositional environment as they are laminated throughout and occur in a sequence that includes the grayish red and green mudrocks.

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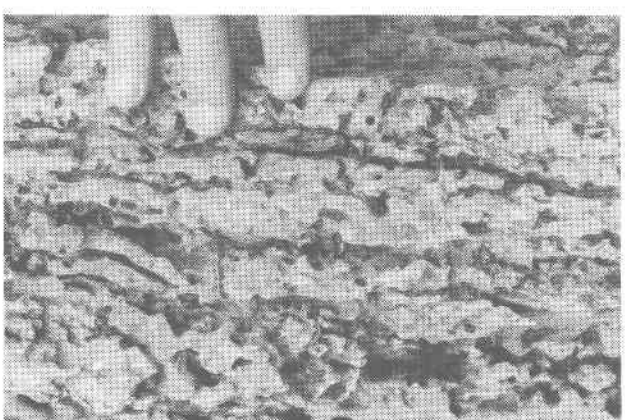

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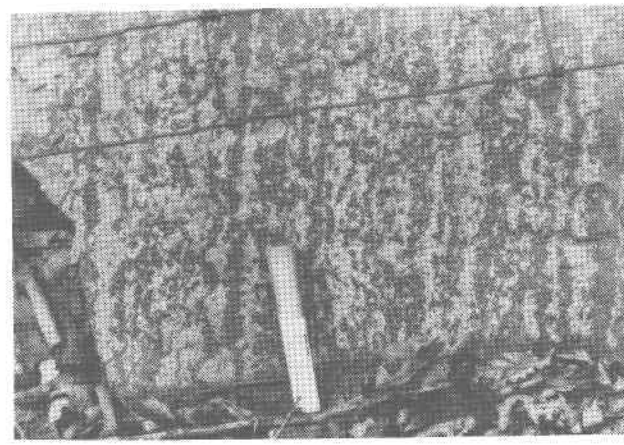

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Grainstones and Packstones

Thin beds (3-10 cm) of grainstone and packstone occur sporadically throughout the lime mudstones of the Waynesboro Formation. Peloids and intraclasts are the main allochems, with bioclastic debris occurring in one bed.

The peloids are micritic, generally well-rounded, 0.25-0.5 mm in diameter, circular to moderately ellipsoid, and they sometimes have a clotted appearance. They were probably fecal pellets of diverse origins (Enos, 1983). Quartz grains are occasionally present. Some of the peloidal grainstone and packstone beds are partly to completely dolomitized. They are very thin to medium bedded, and are interbedded with lime mudstones or dolomudstones. Ripple cross-lamination was observed in two peloidal grainstones at the Arcadia Bridge section.

A bed of intraclast grainstone (flat-pebble conglomerate) occurs in a sequence of thin-bedded strata at the Arcadia Bridge section. It consists of dark gray (N2), elongated, micrite rip-up clasts up to 1.5 cm in length, surrounded by a microspar matrix. The bed is 5.8 cm thick and lenticular, with an overall channel-like morphology. Shelter porosity, now sparry calcite, is well-developed under most of the clasts and indicates original grain support of the rip-ups. This feature is also one of the few geopetal structures observed. There is a preferred orientation to the clasts, with the long axes generally subparallel to bedding. Quartz sand grains are a minor component. Adjacent beds include a variety of carbonate rocks: cross-laminated peloidal grainstones, burrowed dolomudstones, and thinly laminated lime mudstones. Micrite rip-up clasts were also observed in other beds (eg. Section 3, Unit 10).

Only one grainstone bed found in the entire Waynesboro Formation contains bioclastic material. Broken, overpacked, recrystallized, predominantly concave-up trilobite fragments in a preferred orientation parallel to bedding are the main allochems, with a significant number of sub-rounded micrite intraclasts (Figure 7). Minor amounts of quartz sand and organic material are also present.

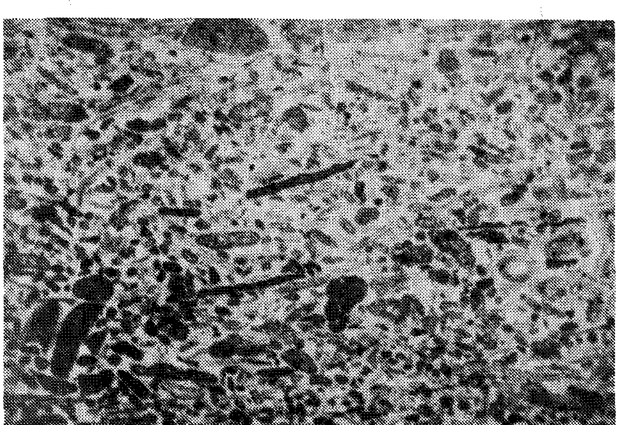

Figure 7. Photomicrograph of trilobite and intraclast debris present in a thin grainstone bed from the Indian Rock section; field of view approximately 6 mm.

Recrystallization has altered the skeletal grains, and it is not possible to discern any of the detailed wall structure in the fragments. The prismatic microstructure and sweeping extinction that are characteristic of trilobite fragments are lacking, and therefore identification is based on the presence of the diagnostic "shepard's crook" commonly seen in thin-section. This lack of detailed wall structure suggests that some of the bioclastic allochems may be fragments of archeocyathids, inarticulate brachiopods, hyolithid gastropods, and skeletal algal fragments, other organisms that were extant in the Early and Middle Cambrian.

Many of the grains have well-developed micritic envelopes, and most have first-generation isopachous-bladed marine cement (iron-poor) surrounding them; this cement is very well-developed and it grew into void space between the grains. Subsequent cementation occurred in the freshwater phreatic zone by blocky ferroan calcite. Minor dolomite cement also occurs.

The contact with the underlying lime mudstone bed is undulatory, and some of the fossil debris has filled small burrows. This bed can be found at and correlated between the Buchanan and Indian Rock sections, a distance of approximately 5 km (Figure 3). It is 6-8 cm thick at Indian Rock and 3-4 cm thick at Buchanan.

These beds are high-energy deposits as evidenced by their textures. The peloidal and bioclastic sediments were derived from a more normal-marine offshore environment, one where trilobites and other pellet-producing organisms could survive. The sediments were most likely mobilized and transported by storms to the more restricted peritidal settings represented by the bulk of the sediments in the Waynesboro Formation. A storm origin is suggested by the truncated burrows, indicative of scouring during the apex of the storm; deposition of the coarsest grains soon followed as energy levels rapidly dropped. The thin but persistent nature of the beds, particularly the bioclastic grainstone, also points to deposition as thin sheets of debris mobilized by storms. The beds show little evidence of post-depositional reworking, suggesting that post-storm burial was rapid, or that normal-weather energy levels were not intense enough to rework these deposits.

The intraclast grainstones also formed as the result of a high-energy event, perhaps a migrating tidal channel or a storm. The lenticular flat-pebble conglomerate at the Arcadia Bridge section was deposited in a small shallow channel with a scoured base. This channel was cut into a lime mud sub-

Figure 8. Ribbon carbonates bounding a bed of "butcher-block" dolomite; lenticular bedded limestone well-displayed to the right of the dolomite; bedding top to left; scale in decimeters.

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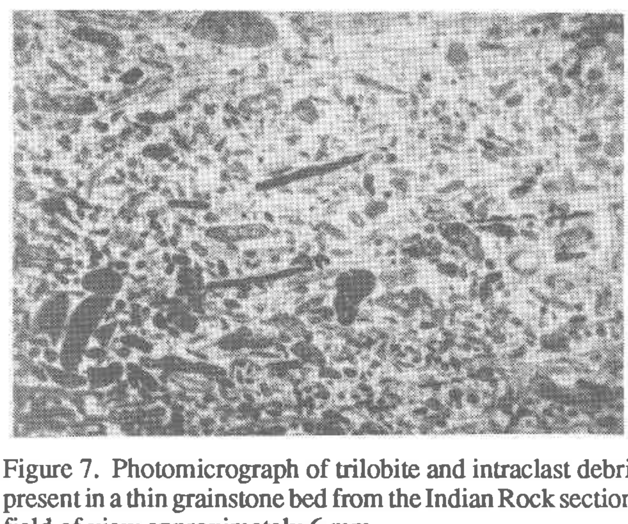

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These beds are high-energy deposits as evidenced by their textures. The peloidal and bioclastic sediments were derived from a more normal-marine offshore environment, one where trilobites and other pellet-producing organisms could survive. The sediments were most likely mobilized and transported by storms to the more restricted peritidal settings represented by the bulk of the sediments in the Waynesboro Formation. A storm origin is suggested by the truncated burrows, indicative of scouring during the apex of the storm; deposition of the coarsest grains soon followed as energy levels rapidly dropped. The thin but persistent nature of the beds, particularly the bioclastic grainstone, also points to deposition as thin sheets of debris mobilized by storms. The beds show little evidence of post-depositional reworking, suggesting that post-storm burial was rapid, or that normal-weather energy levels were not intense enough to rework these deposits.

The intraclast grainstones also formed as the result of a high-energy event, perhaps a migrating tidal channel or a storm. The lenticular flat-pebble conglomerate at the Arcadia Bridge section was deposited in a small shallow channel with a scoured base. This channel was cut into a lime mud sub-

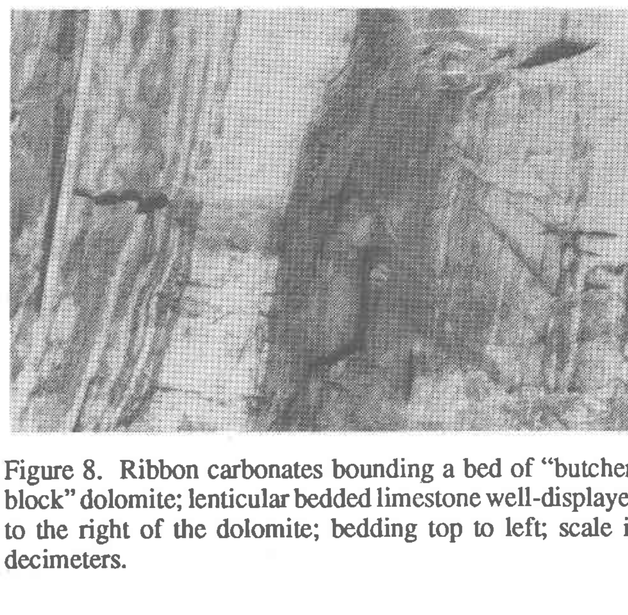

Figure 8. Ribbon carbonates bounding a bed of "butcher-block" dolomite; lenticular bedded limestone well-displayed to the right of the dolomite; bedding top to left; scale in decimeters.

strate that was moderately burrowed, and the rip-up clasts accumulated in this channel. The presence of a muddy matrix indicates that little reworking occurred.

Ribbon Rocks

Lenticularly-bedded limestone interbedded with dolomite produces a "ribbony" appearance in certain units (Figure 8). This feature is seen in some of the red mudrocks as well and results from differences in grain size and dolomitization. The interbedding is on a scale of millimeters to several centimeters. On a weathered surface the difference between dolomite and limestone is very apparent; the dolomite weathers a yellowish brown (10 YR 5/4-10 YR 4/2), and the limestone weathers a light gray (N5-N6). The dolomite is fine grained, thinly laminated to massive, and makes up most of the rock. The limestone lenses vary from grainstones to lime mudstones, with peloids and rip-up clasts occurring in the grainstones. Bioclastic debris was not observed in the limestone lenses.

The ribbon rocks probably were deposited in a shallow subtidal to intertidal setting. The lenticular bedding preserves original alternations of sand- and mud-sized particles in structures that are common on modern-day muddy tidal flats, where sand accumulates in small depressions (Weimer and others, 1982). These rocks are similar to the ribbon carbonate rocks described by Demicco (1983) from the Conococheague Limestone (Cambrian) in Maryland. The ribbon rocks in the Waynesboro however, generally lack the abundant ripples described by Demicco because of the scarcity of sand-sized sediment in the lenses, which suggests a very low energy depositional environment.

Cryptalgalaminite

These beds contain crinkly planar lamination, and rare domal stromatolites of the stacked hemispherical (SH) type (Logan and others, 1964), shown in Figure 9. The beds are dark gray (N2) to yellow gray (5Y 8/1), and weather light gray (N5-N6). Large desiccation polygon cracks that propagated upward through several beds are present (Figure 10). Ptygmatically-folded cracks (Allen, 1982) formed during post-depositional compaction are also present (Figure 11).

The cryptalgalaminites accumulated in an intertidal zone having a generally stable substrate. At times when the substrate was less stable, SH type stromatolites formed, as these columnar stromatolites grow when areas of stable substrate are scarce (Hardie and Ginsburg, 1977).

Fenestral Limestone

An outcrop of fenestral ("birdseye") limestone occurs at the Buchanan section (Figure 12). This unit, which is 7 meters thick, stands out noticeably because of the contrast between the very light gray color (SY 6/1) of the weathered surface and the surrounding darker gray (N3-N4) lime mudstones and yellowish gray cryptalgalaminites. In thin-section the fenestrae are abundant sparry calcite blebs 1-3 mm across that are irregularly shaped and surrounded by micrite. Clumps of micritic peloids occur in some of the fenestrae. Bedding is poorly defined, and the rock is very thickly bedded to massive. The lower contact of the fenestral limestone bed is gradational with the underlying mottled

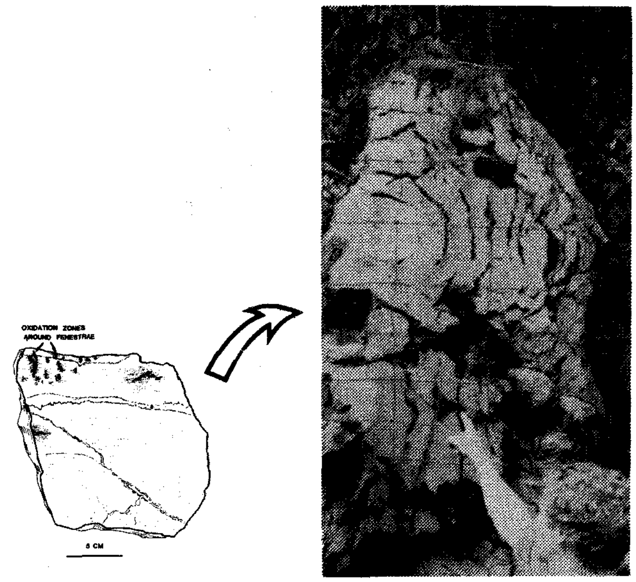

Figure 9. SH type stromatolites showing draping of the overlying sediments; bedding top to right in photograph. Drawing of slabbed rock collected from lsrge stromatolite (arrow), which is cut by several stylolites.

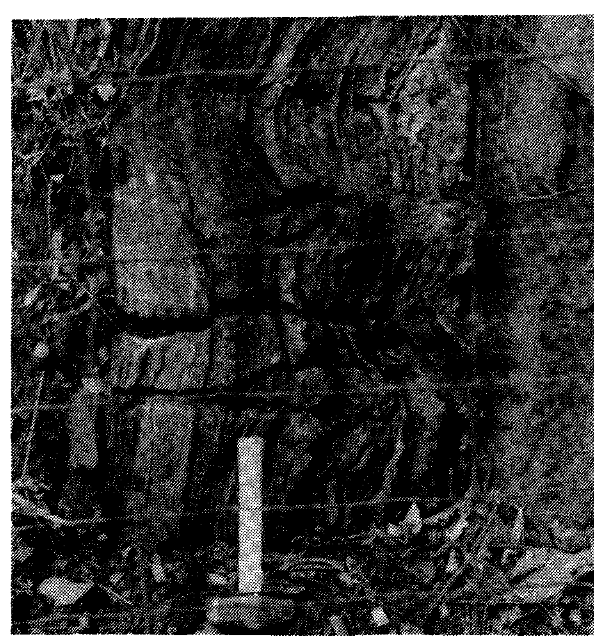

Figure 10. Mudcracked cryptalgalaminite showing the typical inverted "V" shape of desiccation cracks when viewed parallel to bedding; bedding top to right; fence same scale as Figure 8.

dolomudstone. As seen in Figure 12, however, the upper contact with a cryptalgalaminite is very sharp.

Fenestral carbonates are common in tidal flat environments. The fenestrae were voids that formed in various ways, and preservation of them in the rock record is dependent strate that was moderately burrowed, and the rip-up clasts accumulated in this channel. The presence of a muddy matrix indicates that little reworking occurred.

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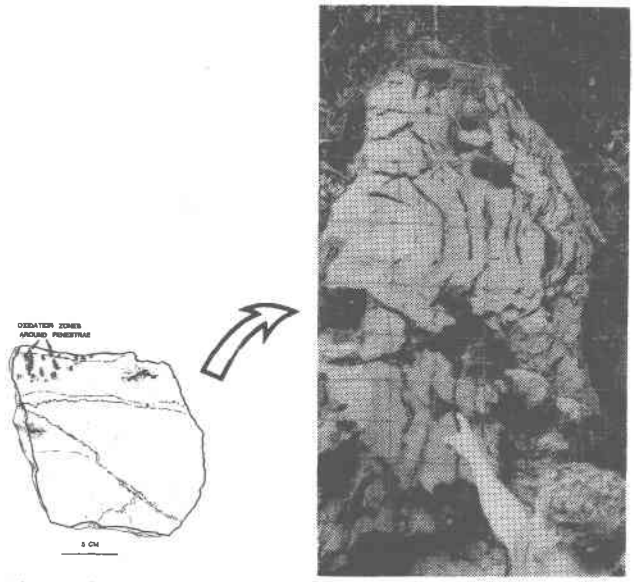

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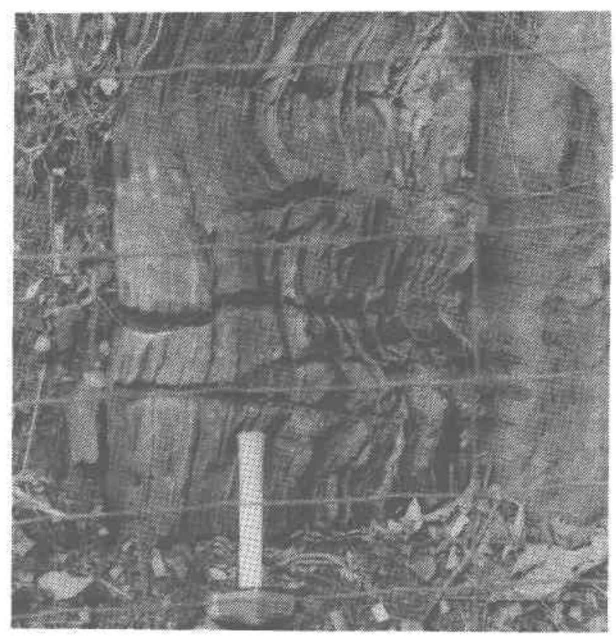

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Figure 11. Ptygmatically-folded desiccation cracks in cryptalgalaminite.

principally on early cementation, which prevents later compaction and loss of the voids. This bed of fenestral limestone was deposited in an upper intertidal to supratidal zone based on its position above subtidal dolomudstones and below shallow intertidal to supratidal mud-cracked cryptalgalaminites and red mudrocks.

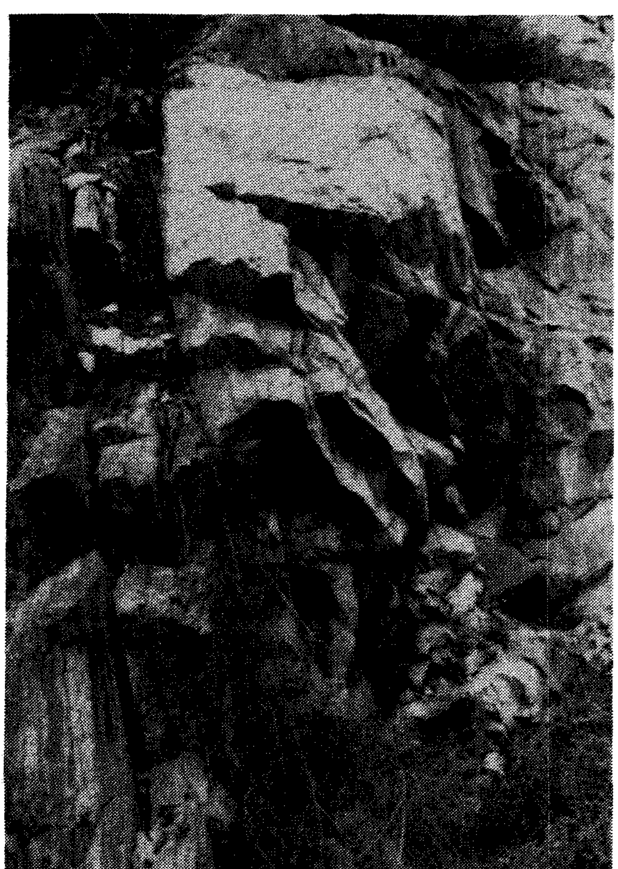


Figure 12. Fenestral limestone (light colored unit) and mud-cracked cryptalgalaminite to left; rocks are overturned, bedding top to left; scale at bottom in decimeters.

"Butcher-block" Dolomite

Throughout the Waynesboro Formation beds of pervasively fractured fine-grained gray dolomite occur (Figures 4, 8, and 13). Some contain thin laminations, and all are unfossiliferous. The fractures are the most distinctive feature of the beds, occurring at various angles to bedding, and they give this rock its informal name. The beds are most often adjacent to lime mudstones and red and green mudrocks. They were deposited in an upper intertidal to supratidal environment judging by their occurrence with these rocks and by their lack of association with subtidal lithofacies, particularly the mottled dolomudstones. The ubiquitous fractures, which do not penetrate adjacent beds, suggest that either they formed preferentially in the more competent dolomite during regional deformation, or that they are primary features such as shrinkage cracks. Elsewhere in the Valley and Ridge, similar beds have been described in Cambro-Ordovician carbonate rock sequences (Root, 1968; Rader and Henika, 1978).

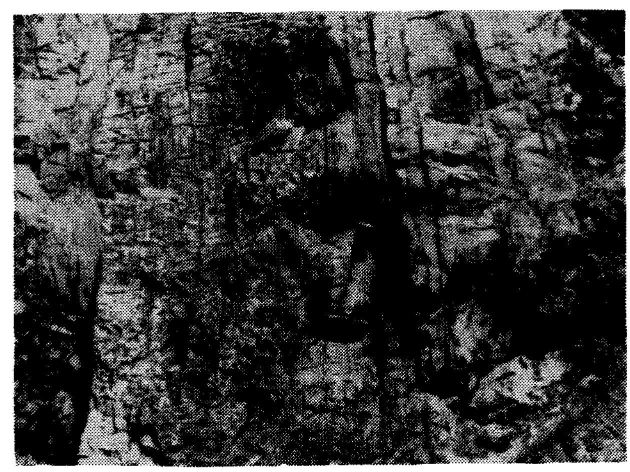
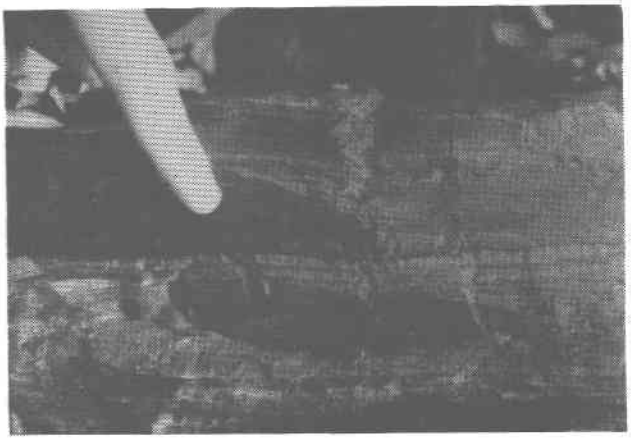


Figure 13. Exposure of "butcher-block" dolomite showing the pervasive fractures that give this rock its name; bedding top to left; hammer approximately 20 cm.

Grayish Red and Green Mudrocks

Although not abundant, these are the distinguishing strata of the Waynesboro Formation, and farther south they make up a significant part of the Rome Formation. They are typically thin-bedded with well-developed cleavage, breaking into small chips along cleavage planes on weathered surfaces. The rocks are various shades of grayish red (5R 4/2, 10R4 4/2, 10R 3/4, 5RP 4/2) and green or olive (5G 6/1, 5GY 6/1, 5Y 6/1, 5Y 4/1, 5GY 4/1, 5Y 3/2). Where bedding is well-defined, it is lenticular as in the carbonate ribbon rocks; elsewhere the rocks are massive and unbedded. Bioturbation occurs locally, and polygonal desiccation cracks are also present.

Interbedded with the mudrocks, in some places, are thin (5-10 cm) beds of fine- to medium-grained, cross-laminated sandstones. These are lithic arenites and lithic wackes, with the primary framework grains being subrounded quartz, and rounded pelitic rock fragments that are similar petro-



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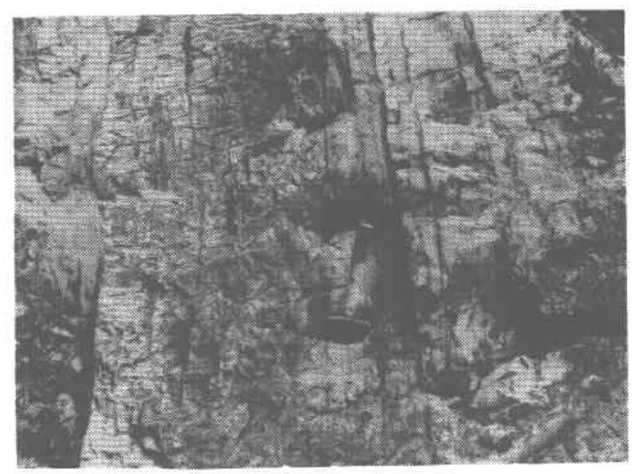

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These clastic rocks were deposited in a coastal plain setting that was landward of and transitional with the peritidal environments in which the carbonate sediments were accumulating. The colors reflect differences in oxidizing conditions in the area of deposition. The green mudrocks contain reduced iron, indicative of a subaqueous, more marine setting, while the iron in the red mudrocks is oxidized, indicating deposition in a more terrestrial environment.

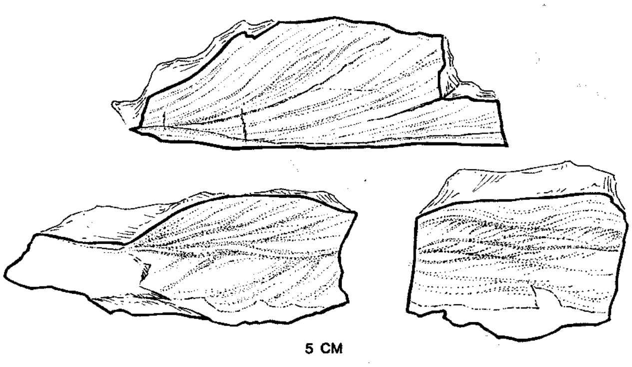


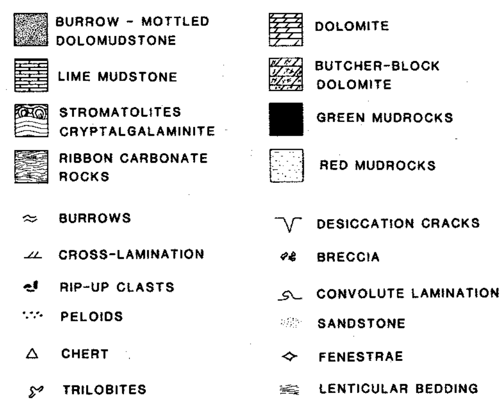
Figure 14. Drawings of slabbed sandstones showing cross-lamination, including some climbing-ripple cross-lamination.

SHALLOWING - AND DEEPENING - UPWARD SEQUENCES

Strata in the Waynesboro Formation occur in twelve repetitive sequences. Ten are interpreted to be shallowing-upward sequences, and two deepening-upward. Deepening-upward sequences are less commonly preserved in carbonate strata relative to shallowing-upward sequences and so the recognition of these two sequences is significant. Based on the observed stratigraphy, idealized shallowing- and deepening-upward sequences were developed, consisting of 6 major lithofacies. Figure 15 shows the two ideal sequences as constructed from a compilation of observed stratigraphic relations in the field. Figures 16, 17 and 18, the stratigraphic columns for the three measured sections, show the actual variations on which the ideal sequences were based. From shallowest to deepest these are: A) the grayish red and green mudrocks with occasional desiccation cracks and interbedded "butcher-block" dolomite; B) lime mudstones and dolomudstones with the interbedded "butcher-block" dolomite, grainstone beds and flat-pebble conglomerates; C) cryptalgalaminites with occasional SH type stromatolites; desiccation cracks are also present; D) fenestral limestone; E) ribbon rocks, and F) burrow mottled dolomudstone. Lithofacies D, the fenestral limestone, is included only in the shallowing-upward sequence because it was observed in only this sequence at the three measured sections, but it may be present elsewhere in the region at other outcrops of the Waynesboro. Lithofacies A and B are supratidal to shallow intertidal, and C, D, E, and F are intertidal to shallow subtidal. Cyclic peritidal sequences such as these result from the shifting of various environments through time on a carbonate shelf. Enos (1983) presents a discussion of cyclicity in carbonate shelf sequences.

The three measured sections are shown in Figures 16, 17, and 18, with the shallowing and deepening upward sequences shown in brackets and delineated by Roman numerals. Refer to Figure 3 for the beds used to correlate the three sections. None of the observed sequences contain all of the lithotypes present in the idealized sequence; all were incomplete, with

Key for Figures 15, 16, 17, and 18



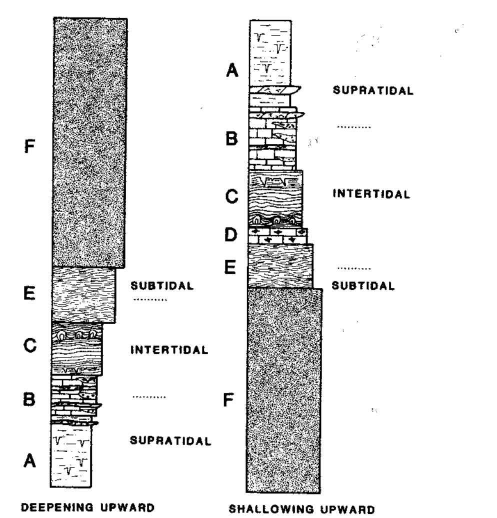
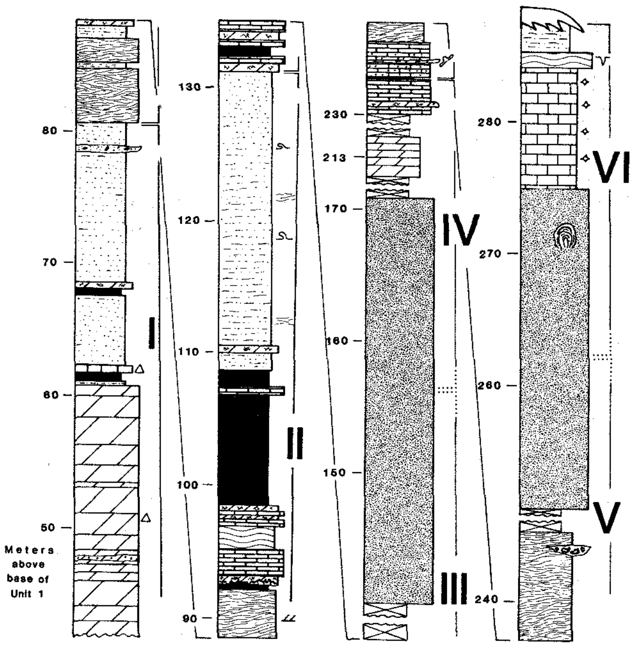


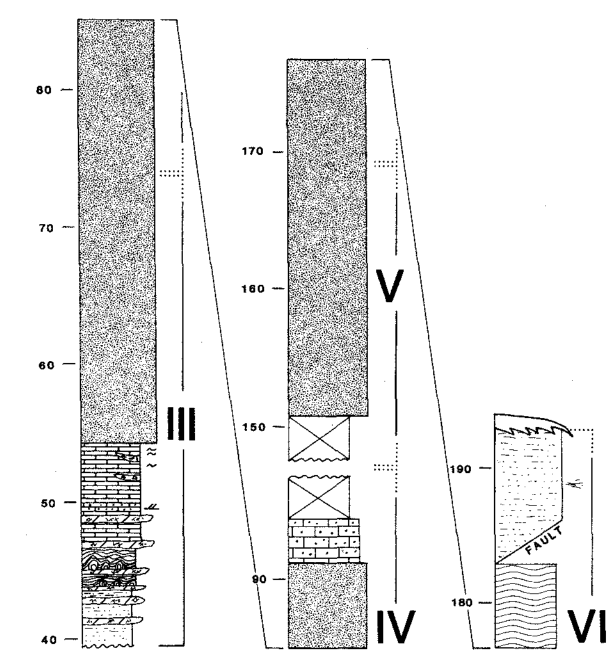
Figure 15. Idealized vertical sequences in the Waynesboro Formation. No scale; relative thickness only.

some having a few as two of the major lithotypes present, particularly in the upper part of the formation. In Figure 16, which shows the sequences of the lower half of the Waynesboro, I, II, IV, and VI are shallowing-upward sequences and III and V are deepening-upward sequences that form the



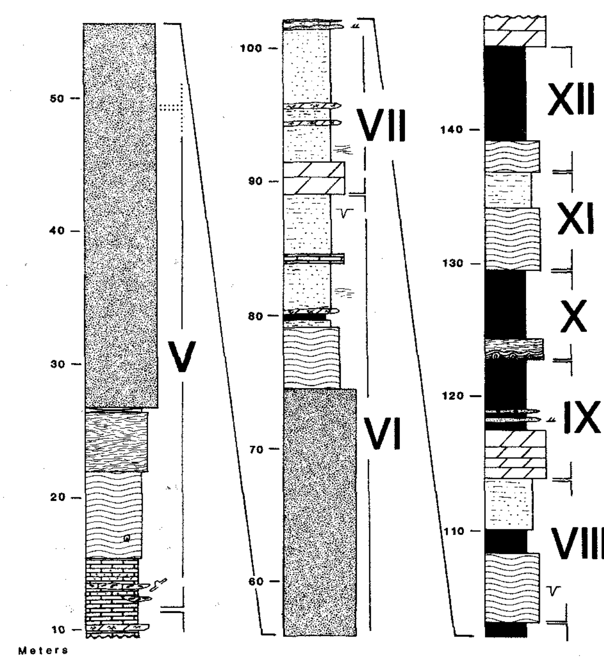
SECTION 1. BUCHANAN

Figure 16. Stratigraphic column of the Waynesboro Formation at the exposure near Buchanan; Roman numerals denote observed small scale cycles, the upper and lower boundaries of which are shown by brackets; refer to Appendix I for more detailed descriptions.



SECTION 2. ARCADIA BRIDGE

Figure 17. Stratigraphic column of the Waynesboro Formation at the exposure near the bridge to Arcadia; refer to Appendix I for more detailed descriptions.



SECTION 3. INDIAN ROCK

Figure 18. Stratigraphic column of the Waynesboro Formation at the exposure near the site of Indian Rock; refer to Appendix I for more detailed descriptions.

lower half of two universally well-preserved symmetrical cycles, III-IV and V-VI. VI is particularly well-exposed. Because the boundaries between III and IV, and V and VI are indistinct, falling in the thick-bedded mottled dolomudstones, the brackets are shown as dotted lines. Elsewhere the top and base of each sequence can be picked reasonably well, and boundaries are shown as solid lines. The lower part of the section, which is not shown on the stratigraphic column but is described in Appendix I, consists of thin- to thick-bedded dolomitized cryptalgalaminites and associated intertidal sediments. For practical mapping purposes, the contact with the Shady Dolomite is placed at the base of the first grayish-red mudrock above the massively bedded Shady Dolomite (Section 1, Unit 9). In Figure 17, the middle part of the Waynesboro is shown. IV and VI are shallowing-upward sequences, and III and V are deepening-upward sequences. III is particularly well-exposed and near its base are many small-scale cyclic sequences. In Figure 18, the upper Waynesboro is shown. VI through XII are shallowing-upward sequences and V is a deepening-upward sequence. Note that VII through XII are much thinner than the shallowing-upward sequences lower in the formation and these upper cycles are very incomplete, containing only two or three of the lithologies in the idealized sequence. VI and VII contain several small-scale cyclic sequences within the overall large scale sequence. There is also an increase in the amount of siltstone, implying overall shallowing punctuated by small scale deepening. This type of sequence, in which only two or three lithofacies occur repeatedly, is characteristic of the overlying Elbrook Formation in this area, and thus the upper Waynesboro as exposed in the Indian Rock section shows that the Waynesboro-Elbrook contact is gradational over several meters. For practical mapping purposes, the top of the Waynesboro is placed at the top of the youngest non-calcareous, green mudrock (Section 3, Unit 44).

Field observations indicate that in addition to the small-scale cycles described in the study, cyclic stratification occurs at the formation level, with the Waynesboro and Elbrook Formations making a Grand Cycle couplet of the Stephen-type described in the Cambrian of the Canadian Rockies by Aitken (1978). According to Aitken, carbonates comprising the Stephen-type Grand Cycle in Canada formed in a shelf setting behind a narrow, discontinuous reefal rim. In this setting, tidal resonance was only weakly developed, and therefore tidal energy was relatively low. This favored the accumulation of lime mud, with abundant infauna that produced a heavily burrowed sediment. These burrows have subsequently been dolomitized, resulting in a mottled dolomudstone. Occasional thin beds of grainstone and packstone consisting of pellets, intraclasts, and rarely trilobite fragments are interbedded with the thick burrow-mottled carbonate rock. Ooids are very scarce, evidently because the narrowness of the shelf-edge rim resulted in the development of only a few widely scattered ooid shoals. The sediments that accumulated in this generally quiet, low-energy environment reflect these conditions.

These rocks that make up the Stephen-type Grand Cycle are remarkably similar to the sediments of the Waynesboro and Elbrook Formations. A further parallel between the two settings is the evidence from southwestern Virginia presented by Pfeil and Read (1980), Read and Pfeil (1983), and Barnaby and Read (1990), that the sediments of the Rome Formation, the Waynesboro equivalent, accumulated in a rimmed shelf setting, behind patch reefs of calcareous algae that were developed along the rim. Ooid and skeletal shoals were rare, and lime mud was the predominant sediment that accumulated behind the reefal rim.

Additional field work will be needed to work out the details of both the small and the large scale cyclicity, which is characterisatic of the Cambro-Ordovician carbonate sequence in the Virginia Appalachians and elsewhere in the region (Read and Goldhammer, 1988; Koerschner and Read, 1989), and to determine where the Shady Dolomite would fit into a Grand Cycle. Chow and James (1987) have reported on Grand Cycles in the Cambrian of Newfoundland, so it is likely that such sequences exist elsewhere in the Appalachians.

CONCLUSIONS

Three measured sections of the Waynesboro Formation in west-central Virginia were described and correlated, and a composite section of the entire formation was produced. This composite section is almost completely exposed, and includes the contacts with the underlying Shady Dolomite and the overlying Elbrook Formation, making this an excellent reference section with which other exposures of the Waynesboro in the region can be compared.

The Waynesboro Formation is part of what has been called "The Great American Bank" (Demicco and Mitchell, 1982), a reference to the vast shallow-marine areas in which carbonate sedimentation occurred during the Early Paleozoic in much of North America. The sediments of the Waynesboro Formation in the Buchanan area, like many of the other units in the "Bank", were deposited in subtidal to supratidal environments, in an inner platform, restricted peritidal setting. Supporting this conclusion is the abundance of fine-grained, mud-rich sediment; the presence of thickly bedded, heavily burrowed limestone; the virtual lack of body fossils throughout the entire formation, the dearth or absence of "high energy" lithologies and sediment types (grainstones, packstones, sandstones, bioclastic debris, ooids, intraclasts), and the scarcity of high-energy sedimentary structures.

The rapid vertical changes in lithology within the Waynesboro reflect shifting environmental conditions in the peritidal setting where deposition occurred. This is manifested in the rock record as repetitive, cyclicly-bedded units, and in the composite section 12 such sequences were recognized. Ten are shallowing-upward, and two are deepening-upward. Although no sequence contains all the units present in the ideal sequences, this is not unlike other idealized sedimentaological sequences such as the point-bar sequence for fluvial systems or the Bouma sequence for turbidites. With these, complete sequences may be uncommon, but partial sequences can be recognized, and when placed in the proper context, a more detailed sedimentologic history can be worked out. The concept of idealized cycles and the recognition of actual partial cycles in the Waynesboro Formation should be useful for mapping and for comparison with exposures of the Waynesboro elsewhere. A comparison will also be possible with the carbonates of the overlying Elbrook Formation, which contains carbonate lithologies in partial sequences like those seen in the upper Waynesboro Formation and was probably deposited under similar depositional conditions.

A Grand Cycle sequence has been recognized, and it is similar to the Stephen-type of the Canadian Rockies. This is the first description of a Grand Cycle in the Appalachians of Virginia, and additional study will be needed to understand the sequence more completely.

ACKNOWLEDGEMENTS

This paper is based on work done for an M.S. thesis at the University of Cincinnati, which was made possible with the help and support of many persons. My parents, Dr. and Mrs. Robert C. Haynes, Jr., of Charlottesville, Virginia, encouraged me throughout the project, and provided financial support as well. I thank my sister, Barbara Cousins, for preparing several illustrations. Professor E. W. Spencer of Washington and Lee University spent two days in the field with me, and his comments and advice were quite valuable. J. Hancock, Jr., of Indian Rock allowed me unlimited access to the section there, and I learned much about the local history of the area from him. I benefited from discussions with J. Hansen, M. Roberts, D. Jennette, and K. Loos at the University of Cincinnati. I wish to thank the members of my advisory committee for their support, particularly Professor W. A. Pryor, my major advisor, for his advice and suggestions in the field, and for encouraging the writing of this paper. Photographic assistance was ably provided by S. Mesinger. Financial support was provided by a Grant-in-Aid of Research from Sigma Xi, and by the Department of Geology and the H. N. Fisk Laboratory of Sedimentology at the University of Cincinnati. Professor E. W. Spencer, Professor J. F. Read of Virginia Polytechnic Institute and State University, and Dr. R. C. Milici, Virginia State Geologist, reviewed this manuscript and contributed valuable suggestions. Finally, I thank E. K. Rader and T. M. Gathright, II of the Virginia Division of Mineral Resources for their interest and encouragement in this study, for reviewing this manuscript, and for allowing the use of petrographic equipment at the Division.

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APPENDIX I

STRATIGRAPHIC SECTIONS

Section 1: BUCHANAN SECTION

The lower and middle part of the Waynesboro Formation and the upper beds of the underlying Shady Dolomite, exposed along the northeast side of the CSX (ex-Chesapeake and Ohio Railway) right-of-way, southeast of the site of the old depot, which is located beneath the U.S. Highway 11 overpass into the town of Buchanan, Buchanan 7.5-minute quadrangle, Botetourt County, Virginia; unit 1 is about 0.5 miles southeast of the depot, where the strata are nearly horizontal because of a large flexure in a sequence of massively bedded dolomite; strike N42-48 degrees E, dip 65-90 degrees NW; parts of the section are overturned and dip is to the SE; parts of the section are covered. This section was measured by Butts (1940) and Chen (1981).

		THICKNESS IN METERS (FEET)	
UNIT	DESCRIPTION	UNIT	CUMULATIVE
60.	Covered.		
59.	Siltstone, grayish-red to dark-reddish-brown (5R 4/2 - 10R 3/4); weathers the same colors; slightly calcareous; weathers to brittle, hackly chips; poorly exposed or covered in lower 20 m.	24.0 (78.7)	311.0 (1001.1)
58.	Cryptalgalaminated dolomite, light-greenish-gray (5GY 8/1), weathers very pale-orange to grayish-orange (10YR 7/4); thin to medium bedded; large (10-12 cm across) mud-cracked polygons well exposed on one bedding plane; several polygons with turned-up edges well exposed in cross-section.	2.0 (6.6)	286.0 (922.4)
57.	Fenestral limestone, light-brownish-gray to light-olive-gray (5YR 6/1 - 5Y 6/1), weathers very-light-gray (N8); massive clear calcite-filled birdseyes throughout, 1-3 mm long; small stylolites present throughout; gradational with underlying unit.	7.0 (23.0)	284.0 (915.8)
56.	Lime mudstone, dark-gray (N3), weathers medium-gray (N5); bedding is defined by pale-yellowish-orange to grayish-orange (10YR 8/6 - 10YR 7/4) dolomitic partings that are continuous and parallel and make occasional notches in the adjacent lime mudstone; this material is the same as that in the mottles in the underlying unit, and is gradational with underlying unit.	5.5 (18.1)	277.0 (892.8)
55.	Mottled dolomudstone, dark-gray (N3), weathers to medium-gray (N5); mottles are composed of coarse-grained dolomite, medium-dark-gray (N4), weathers light-olive-gray to grayish-orange (5Y 6/1 -10YR 7/4); the mottles give the rock the appearance of worm-eaten wood; they are less distinct in the upper part of the unit as they become the partings of the overlying unit; a "cabbage-head" stromatolite is outlined by these partings at 272.8 - 273.0; some small stylolites are present throughout the unit.	19.5 (64.0)	271.5 (874.7)
54.	Covered.	5.5 (18.1)	252.0 (810.7)
53.	Ribbon carbonate, consists of interbedded limestone and dolomite layers 2-3 cm thick, both are medium-dark to medium- gray (N4-N5) but on weathered surfaces the dolomite is moderate yellowish- brown to dark-yellowish-brown (10YR 5/4 -10YR 4/2), this contrasts with the lime-stone, which is a medium- to medium-light-gray (N5-N6) on weathered surfaces; limestone layers pinch and swell and are discontinuous, sparse bioturbation (burrows) in these layers; burrows are vertical and filled with yellowish brown dolomite; breccia at 244.5 - 245.0, very limited in extent and is monomictic, consisting of broken-up lime mudstone; rip-up clasts moderately abundant in beds adjacent to the breccia.	5.2 (17.1)	246.5 (792.6)
52.	Dolomite, poorly exposed, some fine-grained "butcher-block" beds interbedded with more argillaceous units.	4.6 (15.1)	241.3 (775.5)
51.	Limestone: interbedded lime mudstone, packstone, and grainstone, grayish-black (N2), weathers medium-dark- to medium-light-gray (N4-N6); thin to medium bedded; many of the contacts are erosional scour-and-fill structures; 3-5 cm thick bed of trilobite hash grainstone at 235.5 , no whole fossils; other grainstones and packstones are peloidal, peloids are 0.25-0.5 mm; all beds are thin to thickly laminated; numerous rip-up clasts present; a small reverse fault with only slight offset is present at 235-236.	4.1 (13.5)	236.7 (760.4)
50.	Dolomite, same as unit 52, some thin beds of lime mudstone are interbedded with the "butcher-block" beds.	3.1 (10.2)	232.6 (746.9)

UNIT	DESCRIPTION	THICKNESS IN METERS (FEET) UNIT	CUMULATIVE
49.	Covered, some very thin to thin bedded fine-grained dolomite at 211.5-214.5, light-gray (N7), weathers very-pale-orange (10YR 8/2).	58.5 (192.0)	229.5 (736.7)
48.	Mottled dolomudstone, consists of relatively coarse-grained (88-125 microns) idiotopic dolomite and fine-grained lime mud; mottles dolomitic, medium-dark- to medium-gray (N4-N5), weathers medium-gray to medium-light-gray (N5-N6); lime mudstone matrix dark-gray (N3), weathers medium- dark-gray (N4); mottling extremely irregular and randomly developed in the rock, as a result the rock is very massive with bedding poorly defined, unlike unit 55; dolomitic mottles more resistant than the lime mudstone matrix and stand 3-5 mm in relief on weathered surfaces; the mottles form a three-dimensional network that closely mimics worm-eaten wood; small calcite-filled vugs 0.1-1.0 cm long present throughout the rock; where defined, bedding disrupted structurally; several small-scale faults present.	29.3 (96.1)	171.0 (544.7)
47.	Covered.	7.8 (25.6)	141.7 (448.6)
46.	Siltstone, greenish gray (5GY 5/1), weathers medium-brown (5YR 4/4); slightly calcareous; thickly bedded with laminations present but obscured by cleavage fractures; weathers to brittle, hackly chips.	1.2 (3.9)	133.9 (423.0)
45.	Lime mudstone, medium-gray (N5), weathers medium-light-gray (N6); thickly bedded with some thin laminae and numerous wavy yellowish-brown partings; contacts with adjacent units are hidden by float.	0.7 (2.3)	132.7 (419.1)
44.	Siltstone, olive-gray (5Y 3/2), weathers medium brown (5YR 4/4); calcareous; thinly bedded, undulatory; lower contact is planar and non-undulatory; weathers to brittle, hackly chips.	1.2 (3.9)	132.0 (416.8)
43.	Lime mudstone, medium-gray (N5), weathers medium-light-gray (N6); thin laminae in places, have a wavy appearance.	0.2 (3.9)	130.8 (412.9)
42.	Dolomite, medium-dark-gray to yellowish-gray (N5-5Y 8/1), weathers grayish-yellow (5Y 8/4); very fine-grained, massive; moderately fractured; faint indistinct laminae; "butcher-block" bed.	0.2 (0.7)	130.6 (412.2)
41.	Cryptalgalaminated dolomite, medium-gray (N6), weathers moderate-yellowish-orange to dark-yellowish-brown (10YR 5/4 - 10YR 4/2); argillaceous; desiccation polygons with turned-up edges are poorly exposed in cross-section	0.4 (1.3)	130.4 (411.5)
40.	Dolomite, same as unit 42; gradational with underlying unit.	0.5 (1.6)	130.0 (410.2)
39.	Cryptalgalaminated dolomite, same as unit 41; very gradational with underlying unit.	6.6 (21.7)	129.5 (408.6)
38.	Siltstone, fine-grained matrix varies from grayish red (5R 4/2 - 10R 4/2) and dark-reddish-brown (10R 3/4) to greenish-gray (5GY 6/1), coarser-grained layers and lenses are grayish orange to yellowish brown (10YR 7/4 - 10YR5/4), weathers various shades of brown and gray, including yellowish-brown (10YR 4/2) and dark-greenish-gray (5G 4/1); consists of undulating layers of thickly laminated to thin bedded quartz-rich silt and mud and gritty but finer-grained dolomitic mud giving it the appearance of ribbon rock on a smaller scale; weathers massively but breaks into brittle, hackly chips; both quartz-rich and dolomitic layers are very thinly laminated, crypt-algal(?); the laminae are wavy and parallel with abundant crinkling on a small scale; in several thick layers between 120-123 bedding and laminae are moderately crumpled on a large scale, this crumpling appears to be a primary depositional feature rather than a tectonic one.	9.6 (31.5)	122.9 (386.9)
37.	Dolomite, same as unit 42, although not as fractured; there is a noticeable wedge fault that has doubled this unit's thickness beginning about 10 feet above the ground.	1.3 (4.3)	113.3 (355.4)
36.	Siltstone, grayish-red (5R 4/2 -10R 4/2), weathers various shades of grayish-red and reddish-brown, including dark-reddish-brown (10R 3/4); dolomitic; thin to thickly laminated, weathers massively but breaks into small brittle chips; cut by cleavage planes in several places.	2.3 (7.6)	112.0 (351.1)
35.	Dolomite, same as unit 42; upper contact is slightly wavy.	0.3 (1.0)	109.7 (343.5)
34.	Siltstone, alternating bands of dark-reddish-brown (10R 3/4) and moderate-yellowish-brown to grayish-orange (10YR 5/4 - 10YR 5/6) similar to unit 38; excellent exposure of lenticular bedding, some of which has small-scale slump structures, including a small (2-3 cm across) recumbent isoclinal fold just below unit 35; gradational with underlying unit.	0.6 (2.0)	109.4 (342.5)

UNIT	DESCRIPTION	THICKNESS IN METERS (FEET) UNIT	CUMULATIVE
33.	Siltstone, same as unit 36; progressively more greenish-gray and less reddish-brown color from 107.5 - 106.6; less calcareous towards bottom.	2.2 (7.2)	108.8 (340.5)
32.	Lime mudstone, medium-dark- to medium-gray (N4-N5), weathers medium-light-gray (N6); thinly laminated with thin discontinuous partings of moderate-yellowish-brown (10YR 5/4) dolomitic mud; weathers massively.	0.4 (1.3)	106.6 (333.3)
31.	Cryptalgalaminated dolomite, medium-to medium-light-gray (N5-N6), weathers moderate-yellowish-brown to dark-yellowish-brown (10YR 5/4 -10YR 4/2); thickly laminated with several small-scale crinkles in the laminae; from approximately 104 -103.6 the rock is pock-marked by numerous small vugs, 3-5 cm across, circular to ellipsoid, most are empty but some are filled by a deeply weathered ochreous clay.	4.0 (13.1)	106.2 (332.0)
30.	Dolomite, medium-dark-gray (N4), weathers very-light-gray to light-olive-gray (N8 - 5Y 6/1); very fine-grained; massive; faint thin lamination visible on weathered surfaces; moderately fractured, "butcher-block" bed; lower contact is slightly undulatory.	0.6 (2.0)	102.2 (318.9)
29.	Peloidal wackestone to grainstone, dark-gray (N3), weathers medium-gray (N5); very thin to thinly laminated with abundant very thin partings of moderated-yellowish-brown partings (10YR 5/4); weathers massively; upper contact is jagged and appears to have been the site of some pressure solution; both upper and lower contacts are undulatory; some small stylolites are present in unit.	0.2 (0.7)	101.6 (316.9)
28.	Dolomite, same as unit 30; excellent example of a "butcher-block" bed, with the numerous fracture gashes characteristic of this type lithology.	0.5 (1.6)	101.4 (316.2)
27.	Peloidal limestones, same as unit 29.	0.1 (0.3)	100.9 (314.6)
26.	Dolomite, same as unit 30; interbedded with lime mudstone and peloidal wackestone; very thin to thin bedded; amount of limestone increases in bottom 0.2 m; abundant stylolites, some with 0.5-1.0 cm. amplitudes, developed along contacts of "butcher-block" and limestone beds.	0.5 (1.6)	100.8 (314.3)
25.	Dolomite, dark-gray (N3), weathers moderate-yellowish-brown to dark-yellowish-brown (10YR 5/4 - 10YR 4/2); thick bedded with thin laminae, cryptalgal (?); weathers massively; pyrite scattered about in unit.	2.0 (6.6)	100.3 (312.7)
24.	Lime mudstone, dark-gray (N3), weathers medium-dark-gray (N4); thickly bedded, weathers massively; some small stylolites present in unit; lower contact slightly undulatory.	2.0 (6.6)	98.3 (306.1)
23.	Dolomite, same as unit 30; white calcite fills most of the fractures that are perpendicular to bedding; lower contact is a stylolite with 1.0-1.5 cm amplitude.	0.2 (0.6)	96.3 (299.5)
22.	Lime mudstone, dark-gray (N3), weathers to medium-dark-gray (N4); thin bedded, cut out by the overlying unit in several places.	0.0-0.1	96.1 (298.9)
21.	Siltstone, yellowish-gray to greenish-gray (5Y 8/1 - 5GY 6/1), weathers dark-yellowish-brown (10YR 4/2); dolomitic; very thin to thinly laminated, cryptalgal(?); breaks into brittle, hackly chips; lower contact is undulatory.	1.1-1.2 (3.6-3.9)	96.0-96.1 (298.6-298.9)
20.	Ribbon carbonate, consists of interbedded dolomite and limestone (mudstone, wackestone, packstone), both are medium-dark-gray to olive-gray (N4 - 5Y 4/1) but on weathered surfaces the dolomite weathers dark-yellowish-orange to moderate-yellowish-brown (10YR 6/6 - 10YR 5/4) and the limestone weathers medium-gray to light-gray (N5 - N7); thin to medium bedded, with the limestone present as discontinuous lenses that pinch and swell within the dolomite matrix; these lenses are thinly laminated lime mudstone, dolomitic mud-chip and peloidal wackestone, and packstone, some lenses are faintly cross-laminated and rippled; yellowish dolomite is present in several lenses as thin wisps or strands 0.5-2.0 mm thick; sparse to moderate bioturbation, burrows filled with the yellowish dolomite; the dolomite is fine-grained and slightly argillaceous; entire unit becomes more argillaceous in lower 0.5 m.	2.0 (6.6)	94.9 (295.0)
19.	Dolomite, same as unit 30; weathers very-pale-orange (10YR 8/2).	0.4 (1.3)	92.9 (288.4)
18.	Ribbon carbonate, same as unit 20; gradational with underlying unit.	0.7 (2.3)	92.5 (287.1)

UNIT	DESCRIPTION	THICKNESS IN METERS (FEET) UNIT	CUMULATIVE
17.	Siltstone, same as unit 21; weathers slightly more dark-reddish-brown (10R 3/4) than dark-yellowish-brown (10YR 4/2); a 0.4-0.6 cm bed of discontinuous dolomite present at 90.9 weathers very-pale-orange (10YR 4/2), which contrasts sharply with the reddish-brown siltstone.	1.9 (6.2)	91.8 (284.8)
16.	Dolomite, same as unit 30; weathers very-pale-orange (10YR 4/2); upper contact is sharp and undulatory, lower contact is gradational.	0.2 (0.7)	89.9 (278.6)
15.	Ribbon carbonate, same as unit 20; more argillaceous near top; more bioturbation near middle and base; poorly exposed in lower 3 m.	5.8 (19.0)	89.7 (277.9)
14.	Siltstone, same as unit 36; poorly exposed; very coarse-grained lithic wacke at 79.7, subangular to sub-rounded quartz grains up to 2.0 mm are floating in a greenish-gray to dark-greenish-gray (5G 6/1 - 5G 4/1) mud matrix; abundant mud chips, pyrite, siltstone grains, and black chert grains make up the rest of the framework; much of the matrix has been oxidized and has weathered dark-yellowish-orange (10YR 6/6) and the pyrite in these zones has weathered a dusky- red to dark-reddish-brown (5R 3/4 - 10R 3/4).	13.9 (45.6)	83.9 (258.9)
13.	Siltstone, greenish-gray (5G 6/1 - 5GY 6/1); upper 0.5 m very fractured with abundant calcite as fracture fill; breaks into brittle, hackly chips.	1.7 (5.6)	70.0 (213.3)
12.	Siltstone, same as unit 36; deeply weathered and poorly exposed.	0.6 (2.0)	68.3 (207.7)
11.	Breccia, dolomitic and calcareous, contains large (10 - 15 cm) broken light-colored chert nodules floating in a muddy matrix.	0.3 (1.0)	62.7 (205.7)
10.	Siltstone, same as unit 13.	0.5 (1.6)	62.4 (204.7)
9.	Siltstone, same as unit 36.	0.5 (1.6)	61.9 (203.1)

Note: The contact of the Waynesboro and the Shady is placed at the base of Unit 9, the first grayish-red mudrock above the massively bedded dolomite the characterizes the Shady Dolomite.

UNIT	DESCRIPTION	UNIT	CUMULATIVE
8.	Cryptalgalaminated dolomite, dark-gray (N3), weathers light- to very-light-gray (N7 - N8) to light- olive-gray (5Y 6/1); medium to coarse grained; thick to very thick bedded, with thin to thick laminae throughout, massive; chert nodules and pebbles (5-30 cm long) at 58.8, and 52.5 - 52.4; nodules are pale-yellowish-brown (10YR 6/2), laminae continue unbroken through nodules; gradational with underlying unit.	13.6 (44.6)	61.4 (201.5)
7.	Dolomite, dark gray (N3), weathers light- to very-light-gray (N7 - N8); medium to coarse grained; hin bedded, beds are unlaminated to thinly laminated with sparse crinkly cryptalgal laminae in places; some beds are relict peloidal grainstones, peloids are 0.25-0.5 mm; gradational with underlying unit.	2.5 (8.2)	47.8 (156.9)
6.	Cryptalgalaminated dolomite, same as unit 8; medium to thick bedded; zone of chert nodules as in unit 8 between 44.2-44.7, and at 40.6; thin bedded at base and slightly argillaceous with greenish-gray (5G 6/1) partings; distinct sinusoidal bedding plane at 40.5 separating the cherty zone from a pure dolomite zone.	5.7 (18.7)	45.3 (148.7)
5.	Dolomite, zone of soft-sediment deformation; contains slumped and brecciated layers of cryptalgalaminated carbonate and cryptalgalaminated mud chips floating in a dolomitic matrix; small slump also at 37.9 -38.0, these slump zones sandwich a zone of undeformed cryptalgalaminated dolomite; a cherty zone as in unit 8 is present at 39.0 - 39.1.	1.7 (5.6)	39.6 (130.0)
4.	Cryptalgalaminated dolomite, same as unit 8; thin to thick bedded to massive; moderately argillaceous in upper 1 m.; domal laminae and chert zone at 36.0; gradational with underlying unit.	1.9 (6.2)	37.9 (124.4)
3.	Cryptalgalaminated dolomite, same as unit 8; very massive; zone of thin bedded, more fissile argillaceous dolomite between 28.7 - 29.0.	10.35 (34.0)	36.0 (118.2
2.	Dolomite, grayish-black (N2), weathers dark- to medium-dark-gray (N3 - N4); very fissile, weathers to thin, brittle, shale-like chips; contains siliceous -calcareous nodules 2-6 cm in diameter, very abundant between 24.1 - 24.4, the nodules show displacive "chicken-wire" or "cauliflower" texture with the surrounding fine-grained matrix.	1.55 (5.1)	25.65 (84.2)

UNIT	DESCRIPTION	THICKNESS IN METERS (FEET) UNIT	CUMULATIVE
1.	Cryptalgalaminated dolomite, same as unit 8; generally very massive, but thin to medium bedded between 9.5 and 15.0 and very thinly bedded at 10.8 and 12.2; dolomitized mud-chip rip-up clasts scattered about at 14.5 - 14.7, cryptalgal laminae show evidence of having been compacted around the mud chips; zones of black (N1) chert nodules and blebs at 2.6 - 2.9 and 6.6, the nodules have a frayed or tattered look around their edges, they are composed of silicified peloids that are 0.25-0.5 mm in diameter; a large homoclinal flexure between 6.0 - 9.0 changes the dip of the beds from near vertical to near horizontal.	24.1 (79.1)	24.1 (79.1)
0.	Base of section, remainder of Shady Dolomite not measured.	0.0	0.0

Section 2: ARCADIA BRIDGE SECTION

The middle part of the Waynesboro Formation, exposed along the southwest side of the CSX (ex-Chesapeake and Ohio Railway) right-of-way near the bridge across the James River that takes County Road 614 to the town of Arcadia, Buchanan 7.5-minute quadrangle, Botetourt County, Virginia; unit 1 is at a zone of mudcracked cryptalgalaminites and ribbon carbonate rocks about 300 yards southeast of the bridge; strike N 42-48 degrees E, dip 80-90 degrees SE; section is overturned; much of the section is partly covered.

UNIT	DESCRIPTION	THICKNESS IN METERS (FEET) UNIT	CUMULATIVE
16.	Fault zone, vertically dipping yellowish-brown siltstones adjacent to less steeply dipping thinly bedded reddish-brown siltstones and gray carbonates; the fault zone is well- exposed, and is marked by the development of some small karst openings, which have small speleothems in them.	1.4 (4.6)	177.5 (582.4)
15.	Cryptalgalaminated limestone, medium-gray (N5); thin bedded; several poorly exposed mud-cracked polygons with turned-up edges are visible in cross-section; minor occurrences of inter-bedded thinly laminated reddish-brown siltstones.	4.2 (13.8)	176.1 (577.8)
14.	Mottled dolomudstone, consists of relatively coarse-grained dolomite (88-125 microns and fine-grained lime mud; dolomitized mottles medium-dark to medium-gray (N4 - N5) and weathers a medium-gray to dark-yellowish-brown (N5 - 10YR 4/2); lime mudstone dark-gray (N3), weathers medium-gray (N5); the mottling is the result of this difference in composition and is developed as patches throughout the rock that do not define bedding; the dolomitic zones stand out in relief to the lime mud on weathered surfaces; the mottles form a three-dimensional network that mimics worm-eaten wood; the rock is very massive and forms a large high cliff; a moderately large cave opening approximately 3 m across is present about 3-4 m above the ground at 115-120; lower contact not exposed.	20.9 (68.6)	171.9 (564.0)
13.	Covered, some scattered outcrops back in against the hill around 90-95; deeply weathered.	56.6 (185.7)	151.0 (495.4)
12.	Lime mudstone, medium-dark-gray (N4), weathers medium- to medium-light-gray (N5 - N6); thick bedded; very fine-grained and slightly dolomitic with relict peloidal grainstone textures in places; gradational with underlying unit.	3.3 (10.8)	94.4 (309.7)
11.	Mottled dolomudstone, same as unit 14; lower 10 m exposed against the hill away from the railroad tracks.	37.0 (121.4)	91.1 (298.9)
10.	Interbedded lime mudstone, packstone, and grainstone, dark- to medium-dark-gray (N3 - N4), weathers medium-light- to light-gray (N6 - N7); thin bedded, with thin dark-reddish-brown partings (10YR 3/4) between most beds; rock types, including thinly laminated lime mudstones, mottled dolomudstones, cross-laminated peloidal grainstones and packstones, flat-pebble conglomerate with rounded micrite clasts ranging in length up to 1.5 cm, and a breccia containing angular to subrounded lime mudstone clasts up to 2.0 cm large set in a white calcite matrix; all beds are very slightly argillaceous; lower contact is poorly exposed.	5.2 (17.1)	54.1 (177.5)
9.	Dolomite, poorly exposed and deeply weathered to shades of reddish-brown including 10R 3/4.	1.2 (3.9)	48.9 (160.4)

UNIT	DESCRIPTION	THICKNESS IN METERS (FEET) UNIT	CUMULATIVE
8.	Lime mudstone, dark- to medium-dark-gray (N3 - N4), weathers medium-gray to light-olive-gray (N4 - 5Y 6/1); thin to medium wavy bedded; some pale-yellowish partings (10YR 8/6); numerous reddish-brown specks of weathered iron oxide throughout the rock.	1.7 (5.6)	47.7 (156.5)
7.	Dolomite, medium-dark-gray (N4), weathers dark-yellowish-brown to dusky-yellowish-brown (10YR 4/2 - 10YR 2/2); very fine-grained; moderately argillaceous.	0.6 (2.0)	46.0 (150.9)
6.	Cryptalgalaminated limestone, dark-gray (N3), weathers medium-light- to light-gray (N6 - N7); thin to medium bedded; 3 well-developed "cabbage-head" stromatolites are exposed about 2.5-3.0 m above the ground; overlying sediment is draped over the individual stromatolite heads.	1.1 (3.6)	45.4 (148.9)
5.	Lime mudstone, same as unit 8.	0.1 (0.3)	44.3 (145.3)
4.	Cryptalgalaminated limestone, dark-gray (N3), weathers dark-yellowish-brown (10YR 4/2); dolomitic; some low domal algal structures faintly visible on the weathered surface.	0.6 (2.0)	44.2 (145.0)
3.	Dolomite, medium-gray (N5), weathers very-pale-orange (10YR 8/2); very fractured, "butcher-block" beds, a thin (10 cm) bed of lime mudstone is sandwiched by the "butcher-block" beds at 43.5.	1.1 (3.6)	43.6 (143.0)
2.	Siltstone, dark-reddish-brown (10R 3/4), weathers grayish-red (5R 4/2 - 10R 4/2); thick bedded, massive; thin to thickly laminated; weathers to brittle, hackly fragments; very poorly exposed to covered in lower 20 m.	30.6 (100.4)	42.5 (139.4)
1.	Ribbon carbonate and cryptalgalaminated carbonate, generally poorly exposed; consists of interbedded dolomite and limestone with the limestone present as discontinuous lenses in the dolomite; both are medium-dark-gray (N4), but the dolomite weathers dark-yellowish-orange to moderate-yellowish-brown (10YR 6/6 - 10YR 5/4) and the limestone weathers medium- to light gray (N5 - N7); excellently exposed cross-sections of mud-cracked polygons at 0.0 and 11.5.	11.9 (39.0)	11.9 (39.0)
0.	Base of section, just below the small block of ribbon carbonate with the well-exposed crinkly cryptalgal laminae.	0.0	0.0

Section 3: INDIAN ROCK

The upper part of the Waynesboro Formation and the lower beds of the overlying Elbrook Formation, exposed along both sides of the CSX (ex-Chesapeake and Ohio Railway) right-of-way, southeast of the site of Indian Rock, Buchanan 7.5-minute quadrangle, Botetourt County, Virginia; section begins with unit 1 at small anticline on southwest side of railroad, in cut through the bluff, section continues along northeast side of the right-of-way after the cut; strike N 42-45° E, dip 65-75° NW. This section was measured by Edmundson (1958).

UNIT	DESCRIPTION	THICKNESS IN METERS (FEET) UNIT	CUMULATIVE
46.	Elbrook Formation continues.		not measured
45.	Dolomite, dark-gray (N3), weathers light-gray (N7); thick bedded to massive; predominantly coarse-grained, idiotopic (sucrosic) texture; abundant small calcite-filled fractures; stylolites present in varying amounts.	13.9 (45.6)	160.0 (528.0)

Note: The contact of the Waynesboro and the Elbrook is placed at the top of Unit 44, the uppermost olive-gray or grayish-red mudrock in the section.

UNIT	DESCRIPTION	UNIT	CUMULATIVE
44.	Siltstone, poorly exposed, light-olive-gray to olive-gray (5Y 6/1 -5Y 3/2); thin bedded; weathers to brittle, hackly chips.	6.8 (22.3)	146.1 (482.4)
43.	Argillaceous dolomite, light-olive-gray to greenish-gray (5Y 6/1 -5GY 6/1), weathers to a moderate-yellowish-brown (10YR 5/4); thin, parallel, undulatory laminae; gradational with underlying unit.	2.9 (9.5)	139.3 (460.1)

UNIT	DESCRIPTION	THICKNESS IN METERS (FEET) UNIT	CUMULATIVE
42.	Siltstone, grayish-red (5R 4/2 to 10R 4/2); thin to thick bedded with thin laminae throughout as in unit 43; shaly in places; progressively less red and more dolomitic near top, and light-olive-gray (5Y 6/1) replaces red color.	2.5 (8.2)	136.4 (450.6)
41.	Dolomite, light-olive-gray to medium-gray (5Y 6/1 - N5) grades downward into dolomitic limestone, medium-dark-gray to dark-gray (N3-N4), thin to medium bedded, beds weather to various shades of dark-yellowish-brown including (10YR - 4/2); very thin laminae show up well on the weathered surface, parallel and continuous; pyrite in lower section; gradational with underlying unit.	4.5 (14.8)	133.9 (442.4)
40.	Siltstone, dark-greenish-gray (5GY 4/1), moderately calcareous; very thin to medium parallel bedded with wavy lenticular bedding in places; weathers to brittle, hackly chips; pyritic; 5-10% sandy siltstone/silty sandstone beds, 3-5 cm thick, discontinuous.	5.0 (16.4)	129.4 (427.6)
39.	Lime mudstone, dark-gray to medium-dark-gray (N3 - N4), weathers dark-yellowish- orange to moderate-yellowish-brown (10YR 6/6 - 10YR 5/4); dolomitic; weathers massively; wavy discontinuous lenticular bedding in places, 0.5-4.0 cm thick and up to 25 cm long; crinkly cryptalgal laminae in lower 2 m; pyritic; numerous small spar-filled vugs, 0.5-2.0 cm in diameter.	2.3 (7.6)	124.4 (411.2)
38.	Silty shale, olive-gray to dark-greenish-gray (5Y 4/1 - 5GY 4/1), weathers to shades of yellowish-brown (5YR4/4 - 10YR 4/2); bedding obscured by cleavage, weathers along cleavage planes to form elongate chips; thin dolomitic bed (5-10 cm thick) near 118.0 composed of channel fill material (micritic and dolomitic mudchips and peloids); thin fine-grained cross-bedded sandstone bed (3-5 cm thick) at 117.4, greenish-gray to dark-greenish-gray (5GY 6/1 - 5GY 4/1), quartz grains are 88-125 microns; runzelmarken present on some silty beds at 117.5 - 118.	5.0 (16.4)	122.1 (403.6)
37.	Dolomite, medium-gray (N5); highly fractured with calcite fills; thick bedded; cryptalgal laminae disrupted by small (1-2 mm) spar-filled vugs.	1.6 (5.2)	117.1 (387.2)
36.	Lime mudstone, light-olive-gray (5Y 6/1); thick bedded; deeply weathered.	1.6 (5.2)	115.5 (382.0)
35.	Shaly siltstone, grayish red to dark-reddish-brown (5R 4/2 - 10R 3/4); no distinct bedding or or lamination; very fractured by cleavage; weathers massively but recessively as a long trough with a pile of hackly chips at the base.	3.9 (12.8)	113.9 (376.8)
34.	Siltstone, greenish-gray (5GY 5/1); calcareous with red silt/mud partings; thin bedded with thick to thin laminae; weathers to hackly chips.	1.9 (6.2)	110.0 (364.0)
33.	Argillaceous dolomite, medium-dark-gray (N4); very thin to thin bedded; with very thin to thick cryptalgal laminae of alternating mud and quartz silt; 10-30% $CaCO_3$ by vigor of effervescence in HC1; silt-rich layers weather out like fins; well-exposured desiccation cracks, some show ptygmatic folding, between 103.8 - 104.5.	4.5 (14.8)	108.1 (357.8)
32.	Silty shale, greenish-gray (5GY 5/1), weathers to a medium-brown (5YR 4/4 -5YR 3/4); bedding obscured by cleavage, but a gradation upwards into a shaly siltstone can be seen.	0.9 (3.0)	103.6 (343.0)
31.	Siltstone, grayish-red (5R 4/2 - 10R4/2) to dark-reddish-brown (10R 3/4); calcareous and/or dolomitic; lenticular lamination and bedding similar to ribbon carbonate rock but on a smaller scale; weathers massively; lenses are yellowish-gray (5Y 7/2) and contain quartz silt and sand; red matrix is gritty but finer-grained than the lenses; the lenses pinch and swell and they are discontinuous.	0.7 (2.3)	102.7 (340.0)
30.	Sandstone, 177-350 microns, moderately to well sorted; internal cross-lamination of light and dark laminae; bed is 2-6 cm thick; sharp contact at base with flame structures in underlying silt; upper contact is sharp and top of bed is characterized by hummocky cross-stratification, causing pinching and swelling of the bed.	0.05 (0.2)	102.0 (37.7)
29.	Siltstone, same as unit 31; thin to thickly laminated with greenish-gray (5GY 5/1) dolomitic siltstone beds at 98, 94.8, and 93.6. Part of a resistant pinnacle of rock jutting out from the bluff.	11.5 (37.7)	101.95 (337.5)
28.	Dolomite, greenish-gray (5GY 5/1 - 5GY 7/1); weathers to yellowish-gray (5Y 7/2); thick bedded with thin to thick laminae; fine-grained; breaks with a brittle sound; transitional with under -lying bed.	2.05 (6.7)	90.45 (299.8)

UNIT	DESCRIPTION	THICKNESS IN METERS (FEET) UNIT	CUMULATIVE
27.	Siltstone, same as unit 31; includes grayish-red-purple (5RP 4/2); desiccation cracks at 88-89.	4.2 (13.8)	88.4 (293.1)
26.	Lime mudstone, yellowish-gray (5Y 7/2); moderately weathered; thick bedded.	0.8 (2.6)	84.2 (279.3)
25.	Siltstone, same as unit 31; greenish partings near top.	2.9 (9.5)	83.4 (276.7)
24.	Dolomite, yellowish-gray (5Y 7/2) ;thick bedded to massive; very fine-grained; "butcher-block" bed.	0.3 (1.0)	80.5 (267.2)
23.	Silty shale, greenish-gray (5GY 6/1); moderately calcareous.	0.4 (1.3)	80.2 (266.2)
22.	Siltstone, same as unit 31.	0.5 (1.6)	79.8 (264.9)
21.	Argillaceous dolomudstone, grayish-yellow (5Y 8/4) with yellowish-gray partings (5Y 7/2); top and bottom contacts are very gradational with adjacent units.	1.2 (3.9)	79.3 (263.3)
20.	Cryptalgalaminated limestone, yellowish-gray (5Y 7/2), weathers grayish-orange (10YR 7/4); dolomitic; very thick bedded.	3.7 (12.1)	78.1 (259.4)
19.	Mottled dolomudstone, consists of relatively coarse-grained dolomite (88-125 microns) and fine-grained lime mud; dolomitized mottles medium-dark- to medium-gray (N4-N5) and weather a dark-yellowish-orange to medium-gray (10YR 6/6 - N5); lime mudstone dark gray (N3); the mottling is the result of this difference in composition and varies from being concentrated along bedding planes to being developed randomly and irregularly throughout the rock; the mottles stand out in relief on weathered surfaces; where the rock is deeply weathered and the iron-rich dolomite has weathered out it is apparent that the mottles form a three-dimensional network which closely mimics worm-eaten wood; very thick bedded and resistant to weathering; where bedding is not defined by the mottling it is absent as a result of thorough mottling; numerous small (0.5-1.5 mm) calcite-filled vugs are present in the matrix throughout the rock. This unit to unit 15 is the massive cliff through which the railroad right-of-way is cut.	14.9 (48.9)	74.4 (247.3)
18.	Lime mudstone, dark gray (N3); thin bedded with black shaly partings; upper contact is deeply weathered and thus poorly exposed.	0.8 (2.6)	59.5 (198.4)

Note: The section continues across the railroad tracks at 46.5 m of the section; this is at the northwest end of the cut through the massive bluff of mottled dolomudstone.

17.	Mottled dolomudstone, same as unit 19.	34.5 (113.2)	58.7 (195.8)
16.	Covered, contact not exposed.	0.1 (0.3)	26.2 (82.6)
15.	Ribbon carbonate rock, consists of interbedded lime mudstone and dolomite layers, 2-3 cm thick; both are medium-dark-gray to medium gray (N4-N5) but on weathered surfaces the dolomite shows up distinctly as various shades of brown to grayish-orange to tan that contrast with the gray or olive-gray lime mudstone layers; these pinch and swell and are wavy, lenticular, and discontinuous; dolomite layers commonly surround the lenses and dolomite occurs in the lime mudstone layers as wisps and stringers; these layers contain quartz silt and mud; limestone layers near base change from lime mudstones to both mudstones and peloidal packstones and grainstones, and many of these limestone lenses are disrupted by sparse bioturbation; the burrows are filled with yellowish gray dolomitic mud and give the layers a nodular appearance where the burrows cut across the entire lense.	4.2 (13.8)	26.1 (82.3)
14.	Lime mudstone, dark-gray (N3), weathers dark-yellowish-brown (10YR 4/2); dolomitic; very thick bedded to massive; sparse cryptalgalamination; sparse to moderate amounts of pyrite.	2.4 (7.9)	21.9 (68.5)
13.	Cryptalgalaminated limestone, medium-light-gray (N6), weathers very-pale-orange (10YR 8/2); thick bedded; cryptalgalaminae are broken and disrupted throughout the rock.	4.2 (13.8)	19.5 (60.6)
12.	Dolomite, dark-gray (N3), weathers pale-yellowish-orange to dark-yellowish-orange (10YR 8/6 - 10YR6/6); slightly to moderately calcareous; very fine grained; thin to medium bedded with cryptalgal lamination in several beds; there is abundant calcite spar along joint planes as thin layers, and a breccia zone is present near the base of the unit.	1.4 (4.6)	15.3 (46.8)

UNIT	DESCRIPTION	THICKNESS IN METERS (FEET) UNIT	CUMULATIVE
11.	Cryptalgalaminite, grayish-black (N2); argillaceous; thick bedded.	0.1 (0.3)	13.9 (42.2)
10.	Limestone, interbedded grainstones, packstones, and lime mudstones; grayish-black (N2), weather medium-gray to grayish-yellow (N5 - 5Y 8/4); thin to medium bedded, undulatory; trilobite hash grainstone bed 6-8 cm thick at 13.3, no whole fossils; micrite intraclasts scattered about at 14.1 and 12.1; small algal domes 2-3 cm high at 12.5; peloidal grainstones and packstones form the remainder of the coarse-grained beds, peloids are 0.25-0.5 mm long; peloidal grainstones and packstones are distinguished from the lime mudstone by their lack of a conchoidal fracture and presence of sparry cement.	1.5 (4.9)	13.8 (41.9)
9.	Argillaceous lime mudstone, grayish-black (N2), weathers grayish-yellow (5Y8/4); dolomitic; thin to medium bedded with thick laminae in places.	1.7 (5.6)	11.3 (37.0)
8.	Dolomite, medium-dark-gray (N4), weathers grayish-yellow (5Y 8/4); very thick bedded, massive, with thin faint laminae in places; very fine grained; extensively fractured, fractures filled with spar, a "butcher-block" dolomite.	0.5 (1.6)	9.6 (31.4)
7.	Dolomite, medium-light-gray (N6), weathers grayish-yellow to dark-yellowish-orange (5Y 8/4 -10YR 6/6); very fine grained; thin to very thick bedded with thin to medium lamination visible on weathered surfaces; abundant pyrite on bedding planes and moderate amounts scattered about in the rock itself.	1.7 (5.6)	9.1 (29.8)
6.	Dolomite, medium-light-gray to light-gray (N6-N7), weathers to a splotchy gray/brown-orange; very fine grained; slightly calcareous; thick bedded with thin yellowish gray partings (5Y 7/2); extensively fractured by cleavage planes.	2.9 (9.5)	7.4 (24.2)
5.	Deeply weathered clay, dark-yellowish-orange (10YR 6/6); non-calcareous; very lightweight.	0.5 (1.6)	4.5 (14.7)
4.	Dolomite, intensely folded into slightly rounded chevron folds; medium-light -to light-gray (N6-N7); thin to very thin bedded with yellowish gray partings (5Y 7/2); thinly laminated; slightly argillaceous.	0.65 (2.1)	4.0 (13.1)
3.	Dolomite, not folded, same as unit 4; pyrite scattered around 2.5.	1.4 (4.6)	3.35 (11.0)
2.	Silty shale, greenish-gray (5GY 6/1); deeply weathered; thickly laminated; 5 cm thick bed of carbonate at 1.6, also deeply weathered.	1.1 (3.6)	1.95 (6.4)
1.	Dolomite, medium- to medium-light-gray (N5-N6), weathers to light-gray to very- light-gray (N7-N8); very fine grained; thin to medium bedded with thin to thick laminae; unit is on the northwest limb of a small, well-exposed anticline.	0.85 (2.8)	0.85 (2.8)
0.	Anticline and fault (?).	0.0	0.0

APPENDIX II

ANNOTATED BIBLIOGRAPHY

The following is an annotated bibliography of publications containing measured sections of the Waynesboro Formation and equivalent strata in west-central Virginia. These sections are all from the easternmost outcrop belt of the formation, the same belt in which the sections in Appendix I are located. This listing does not include publications that focus on the Rome Formation in belts to the northwest of the Saltville fault, where the sequence contains mostly clastic rocks, nor does it include publications dealing with the upper Shady Dolomite near Austinville, Virginia. The reader is referred to Butts (1940) for description of the Rome Formation in the western belts, and to Barnaby and Read (1990) for a description of the strata in the Austinville area.

Anderson, E. R.,1968, Stratigraphy and petrography of the Wytheville Formation in southwest Virginia [M.S. thesis]: Blacksburg, Virginia Polytechnic Institute and State University, 120 p.

This thesis describes the strata in the transition zone between the Shady Dolomite and the Rome Formation near Wytheville, Virginia. Anderson proposed that the thin-bedded carbonate rocks and shales of the transition zone were distinctive enough to warrant formation status, and he proposed the name Wytheville Formation for the several good exposures in the vicinity of Wytheville. The zone of transition exposed at Buchanan is similar to the zone described from the Wytheville area, 80 miles to the southwest.

Butts, Charles, 1940, Geology of the Appalachian Valley in Virginia - Part I, Geologic text and illustrations: Virginia Geological Survey Bulletin 52, 568 p.

This is the classic reference on the stratigraphy of the Valley and Ridge in Virginia. The description of the Rome and Waynesboro Formations is still widely quoted. A description of the Buchanan section is included.

Chen, Ping-fan, 1981, Lower Paleozoic stratigraphy, tectonics, paleogeography, and oil/gas possibilities in the Central Appalachians (West Virginia and adjacent states), Part II, Measured sections: West Virginia Geologic and Economic Survey Report of Investigations no. RI-26-2, 300 p.

Contains a description of the Buchanan section measured in 1961 using old carbonate rock terminology.

Currier, L. W., 1935, Zinc and lead region of southwestern Virginia: Virginia Geological Survey Bulletin 43, 122 p.

Currier's description of the Porters Crossroads section is more detailed than Butts' description (1940).

Edmundson, R. S., 1958, Industrial limestones and dolomites in Virginia; James River District west of the Blue Ridge: Virginia Division of Mineral Resources Bulletin 73, 137 p.

Several partial sections are described, including the Indian Rock section.

Hewett, D. F., 1916, Some manganese mines in Virginia and Maryland, *in* Ransome, F. L., and Gala, H. S., eds., Contributions to economic geology: U.S. Geological Survey Bulletin 640, pt. 1, p. 37-71.

In a ravine near a small manganese mine in Rockbridge County, Virginia, Hewett mesured approximately 1800 feet of the Watauga Shale and about 500 feet of the Shady Dolomite. The Watauga is considered to be equivalent to the Waynesboro and the name has been discarded.

King, P. B., 1950, Geology of the Elkton area, Virginia: U.S. Geological Survey Professional Paper 230, 82 p.

The only locality in Virginia other than the Buchanan area where a complete section of the Waynesboro Formation has been described in the easternmost outcrop belt north of Roanoke is near Ingham, Virginia. The descriptions of the strata are very brief, althrough it is clear that a significant amount of carbonate strata is present. The estimated thickness of the formation here is 1600 feet.

VIRGINIA DIVISION OF MINERAL RESOURCES – PUBLICATION 116 – STRATIGRAPHY OF THE WAYNESBORO FORMATION (LOWER AND MIDDLE CAMBRIAN) NEAR BUCHANAN, BOTETOURT COUNTY, VIRGINIA