2 Geology of the Greenbrier Valley

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Abstract

The Greenbrier Karst is located in the Appalachian Highlands in the boundary region between the strongly folded rocks of the valley and ridge province and the gently folded rocks of the Appalachian Plateau. The outcrop of the karstic Greenbrier Limestone occupies portions of Pocahontas, Greenbrier, and Monroe Counties in southeast West Virginia. The Greenbrier Formation is subdivided into the Alderson Limestone, the Greenville Shale, the Union Limestone, the Pickaway Limestone, the Taggard Formation, the Patton Limestone, the Sinks Grove Limestone, and the Hillsdale Limestone. Intermediate shale beds exert an important controlling influence on cave development. Below the limestone is the Maccrady Shale which acts as an aquiclude. A sequence of relatively gentle north–south folds controls the limestone outcrop area at the land surface. Fractures provide further controls over the drainage pathways.

2.1 Introduction

The objective of this chapter is to provide a regional scale description of the geological substrate on which the caves and karst landforms are developed. The information that follows is summarized from existing accounts of West Virginia geology. The West Virginia geological survey was a pioneer in providing detailed investigations of the geological features of the state. The products of these efforts were a series of thick volumes describing the geology, county by county. Of relevance are Pocahontas County (Price and Reger 1929), Greenbrier County (Price and Heck 1939), and Mercer, Monroe, and Summers Counties (Reger and Price 1926). More recent studies of the geology were obtained as part of hydrogeologic investigations for the limestone portions of Monroe County (Ogden 1976) and Greenbrier County (Heller 1980). The present-day geology of the Greenbrier Valley is the end product of a long sequence of sedimentary, and tectonic processes that extend back through the long and complicated history of the Appalachian Mountains. The tectonic events that produce the structural setting are mostly the result of the Allegheny Orogeny (Hatcher et al. 1989).

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2.2 Appalachian Geology—The Place of the Greenbrier Valley

2.2.1 Tectonic History

For the north-central Appalachians, Faill (1997–98) has provided a detailed overview of the tectonic history (Fig. 2.1). Events begin in Grenville time, 1200–1000 Ma ago, with the formation of the supercontinent Rodinia. A long period of erosion and then rifting of Rodinia provided an ocean basin for the deposition of an extensive carbonate shelf in Cambrian and Ordovician time. Further orogenic events, the Potomac Orogeny, the Taconic Orogeny, and the Acadian Orogeny, provided the basins for other carbonate deposition in the Silurian/Devonian and in the Mississippian as well as a complex of clastic sediments separating the carbonates.

The last and most important major tectonic event was the Allegheny Orogeny in early Permian time. This was a convergence between the North American plate and the

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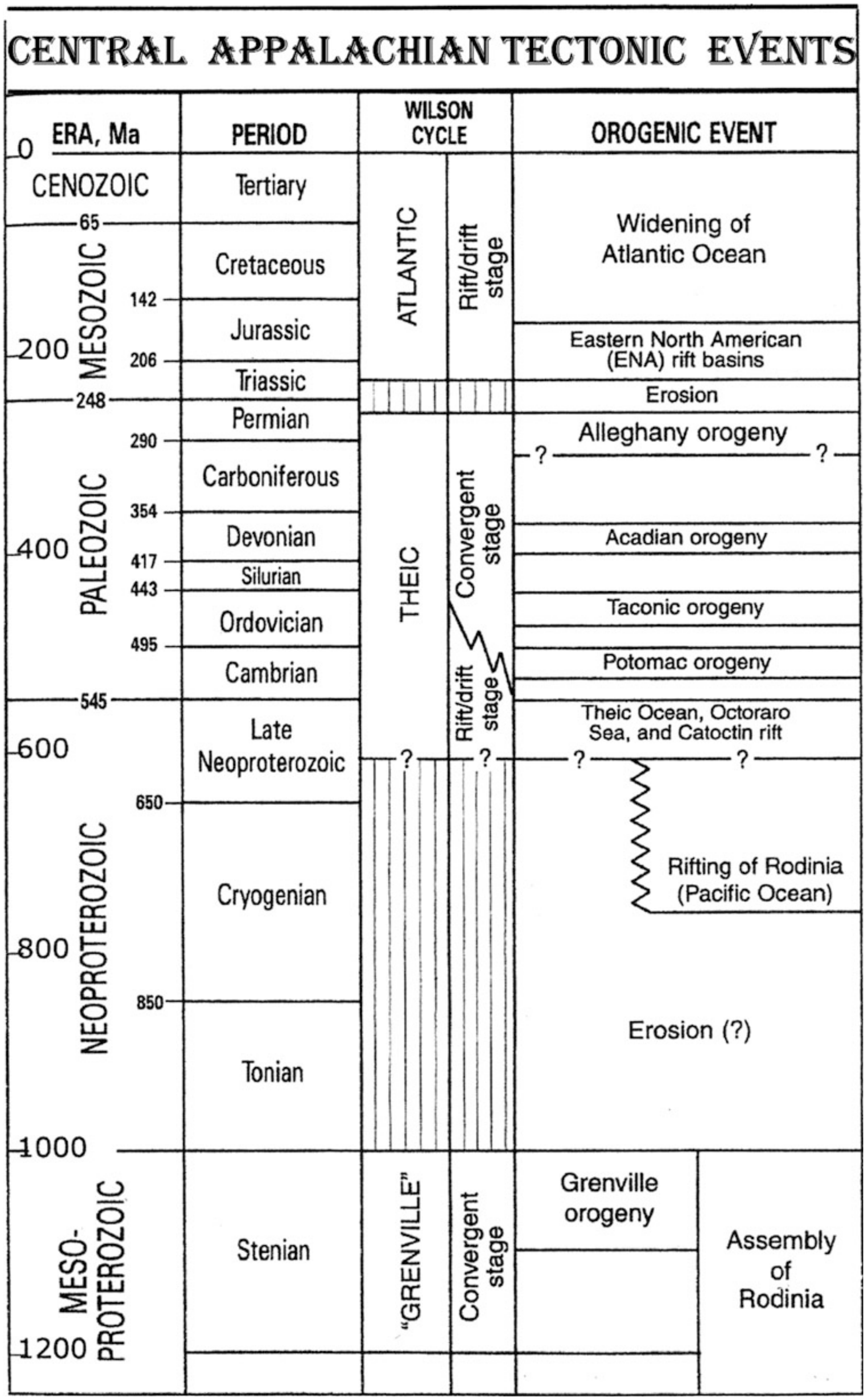


Fig. 2.1 Tectonic events in the Appalachians since Grenville time. Adapted from Fail (1997–1998)

African plate. The southeastern core of the Appalachians was metamorphized, and various igneous bodies were created. Sediments were piled up to form a mountain range estimated to be 3500–4500 m in elevation (Slingerland and Furlong 1989). To the northwest, low angle thrust faults in the middle crust splayed upward, deforming, and transporting Paleozoic sediments and building ramps of sediments one on top of the other (Kulander and Dean 1986). Riding the main thrust faults were sequences of folds. Intense folds later became the Valley and Ridge Provence but less intense folds extended well back into the Allegheny Plateau. Paleomagnetic measurements suggest that the Allegheny Orogeny occurred over a fairly short time period between 275 and 255 Ma ago (Stamatakos et al. 1996).

Rifting of the continental plates in Triassic and Jurassic time produced some extensional normal faulting and infilling of Triassic sediments with the opening of the Atlantic Ocean. Erosion since the Cretaceous has worn down the Appalachians, exposing carbonate rocks of various ages as well as the igneous and metamorphic rocks in the Piedmont and the Blue Ridge, the core of the high Appalachians. Caves and karst landscapes have come and gone as carbonate rocks have been exposed and then eroded away. The present-day karst landscapes date from only the late tertiary.

2.2.2 Physiographic Setting

The usual physiographic provinces and sub-provinces of the Appalachian Mountains are sketched in Fig. 2.2 which also show the position of the Greenbrier Karst.

From central Pennsylvania southward through Maryland and West Virginia, the Appalachian Plateau is separated from the Valley and Ridge by a steep escarpment, the Allegheny Front. The escarpment increases in elevation from 550 m at its northern limit near Williamsport, Pennsylvania and gradually rises to the south. However, the folding induced by the low angle thrust sheets of the Valley and Ridge continues beneath the plateau resulting in a series of anticlines and synclines in the eastern section of the plateau. Erosion has produced a series of ridges known as the Allegheny Mountains that extend from Pennsylvania to east-central West Virginia. The high point of the Alleghenies is Spruce Knob in West Virginia with an elevation of 1480 m. Although the structural deformation is much less severe than in the Valley and Ridge, the Alleghenies are among the most rugged mountains in the Appalachians. West of the Allegheny Mountains, the structural deformation decreases into the central core of the Appalachian Plateaus, a broad synclinal trough with clastic rocks and coal measures but no karst.

Spruce Knob (USGS Spruce Knob Quadrangle) is an important 3-way drainage divide. On the eastern side is the Allegheny Front which drains to the North Fork of the South Branch of the Potomac River. To the northwest, drainage is into tributaries of the Cheat River which flows north into the Monongahela River, a tributary of the Ohio River. To the southwest is the Greenbrier River which joins the New River which flows westward as the Kanawha River to the Ohio River. These interfingering drainage systems have dissected the plateau and exposed the Mississippian limestones. With the high relief, the geologic setting is optimized for the development of large cave systems.

In the northern portions of the Greenbrier Karst, the limestone exposures follow the Greenbrier River along the structural trend of the Allegheny Mountains in the zone between the topographic front and the structural front. The Allegheny Mountains march to an end in Monroe County, and the Greenbrier Limestone becomes part of the dissected edge of the plateau. The narrow band of Greenbrier Limestone widens to the southwest, and the topography changes from high gradient karst drainage basins such as the Swago Creek Valley to the sinkhole plain called the Little Levels in southern Pocahontas County to a wide sinkhole plain north and south of the Greenbrier River in Greenbrier and Monroe Counties called the Big Levels. To the southeast, the Greenbrier Karst is cut off sharply by the line of the structural front where the St. Clair Fault brings up Ordovician carbonates in southeastern Monroe County.

2.3 Stratigraphy

2.3.1 The Greenbrier Limestone

The Mississippian Greenbrier Limestone varies in thickness from about 100 m in the northern limits of the Greenbrier Karst to 365 m at the southern limit in Monroe County (Fig. 2.3). Many descriptions of the Greenbrier Limestone have been reported. The descriptions that follow are a composite but depend largely on the report by McCue et al. (1939) and the geologic map of the limestone exposures in Greenbrier County Heller (1980). The Greenbrier Limestone is equivalent to the Mississippian carbonates of the Cumberland Plateau to the south and the Mammoth Cave area to the southwest but it has retained different stratigraphic names and varies somewhat in lithology. The names assigned to the units of the Greenbrier by Price, Reger, and other early West Virginia geologists were derived from type localities in Monroe County.

Alderson Limestone

The type locality is south of the town of Alderson in Monroe County. It is characteristically a thin-bedded, very variable limy shale to impure shaley or argillaceous limestone that weathers in outcrop into yellow shaley banks. In Greenbrier County, the Alderson is a series of siliceous, coarse-grained, fossiliferous, oolitic beds interspersed with fine-grained argillaceous limestone units. Caves form in the Alderson but tend to be isolated from caves in the underlying limestones.

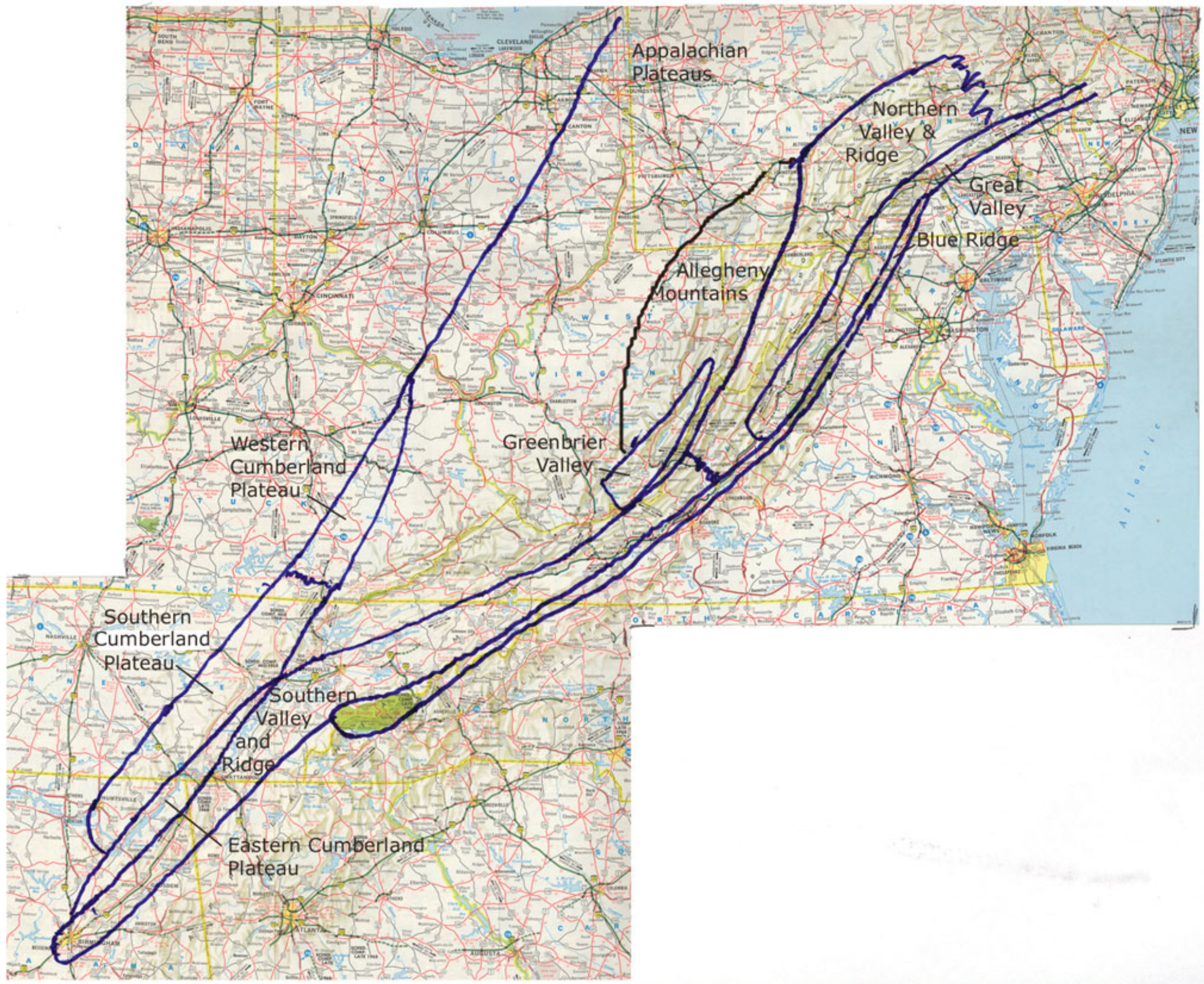


Fig. 2.2 Physiographic provinces of the Appalachians

Greenville Shale

The type locality is near Greenville in Monroe County. The Greenville is a dark fissile shale that acts as a very effective aquiclude. It is a calcarous shale, weathering tan, that contains many marine fossils. The Greenville is rarely (if ever) breached underground.

Union Limestone

The type locality is at the west edge of the town of Union, Monroe County. It is a white to gray, hard limestone, shaley at the top, thick-bedded, and oolitic in part. The Union is one of the most persistent units of the Greenbrier Limestone and is the object of many quarrying operations. The Union is nearly bisected by a shaley or sandy clastic unit identified with the Bethel Sandstone. The Bethel Sandstone is better developed to the north and is represented in the Greenbrier area by a more shaley unit.

Pickaway Limestone

The type locality is the town of Pickaway, Monroe County. The Pickaway is a dark, variegated, silty impure limestone with occasional red streaks and sandy lenses (Fig. 2.4). The unit can be identified by extensive stylolite development. It weathers to a wavy, banded appearance due to the silty and shaley partings. Heller (1980) divides the Pickaway into three members: a lower fossiliferous calcilutite member, a middle superficial oolite member, and an upper laminated calcilutite member. A highly detailed section of the Pickaway was measured in Greenbrier County, 2 km west of Lewisburg (Heller 1980).

Taggard Formation

The type locality for the Taggard Formation is along Taggard Creek in Monroe County. It is a complex formation with a limy red shale on top, a shaly limestone in the middle,

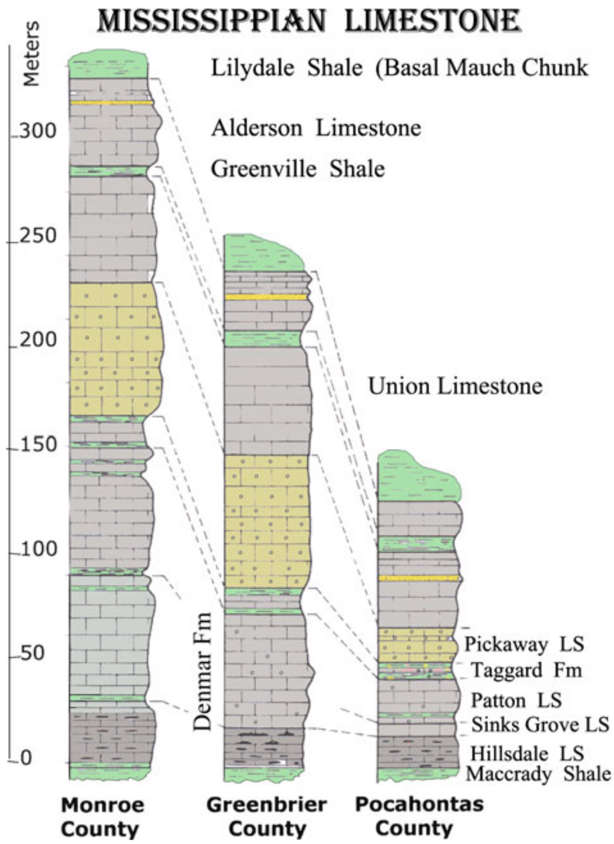


Fig. 2.3 Stratigraphic sections for the Greenbrier Limestone

and a second limy red shale at the bottom. As a shale, the Taggard acts as an aquiclude but because of the high carbonate content, it is frequently breached in the subsurface. It weathers to a red shale which identifies the formation in surface outcrop. These and other details were measured in an exposure on Elk Mountain just north of the Swago Creek Basin (Fig. 2.5). A detailed column of the Taggard was also measured in Greenbrier County (Heller 1980).

Denmar Formation

In some recent literature, the Patton Limestone and the Sinks Grove Limestone are combined into a single unit called the Denmar Formation. We retain the older nomenclature.

Patton Limestone

The type locality for the Patton Limestone is on the south side of Second Creek just south of the village of Patton. It is a hard, gray, pure limestone that usually contains a 2–3 m layer of oolite. There may be a thin shale at the base of the Patton Limestone.

Sinks Grove Limestone

The type locality of the Sinks Grove Limestone is near the town of Sinks Grove, Monroe County. It is a blue, hard, siliceous limestone that often contains nodules of black chert.

Fig. 2.4 Exposure of the Pickaway Limestone at the highway intersection downstream from Fort Spring. Photo by the author

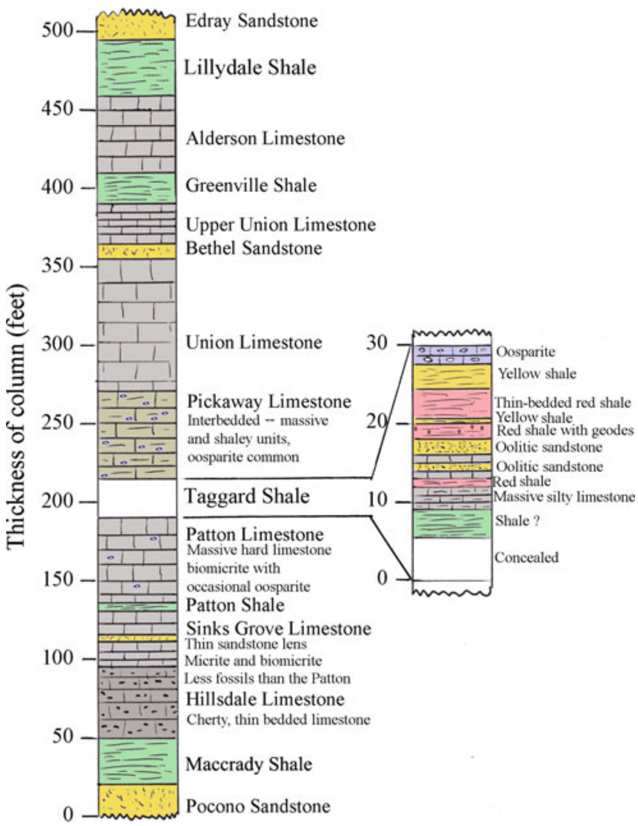


Fig. 2.5 Stratigraphic section of the Taggard Formation measured by the author along US Highway 219 on Elk Mountain north of Marlinton

Hillsdale Limestone

The type locality for the Hillsdale Limestone is just east of the town of Hillsdale, Monroe County. The basal unit of the Greenbrier series is a grayish-blue hard, massive somewhat dolomitic limestone with interbedded chert. The Hillsdale rests unconformably on the underlying Maccrady Shale. The Hilldale Limestone is easy to recognize underground because the insoluble chert layers stand out in relief on cave walls.

2.3.2 Clastic Rocks Above and Below the Karstic Limestone

The highly karstic limestones of the Greenbrier series are bounded above and below by thick sequences of clastic rocks. The overlying clastics provide the catchments for allogenic streams that drain into the karst. The underlying clastics form a lower limit for ground water circulation.

Pottsville Group (Pennsylvanian)

The Pottsville Group is a complex sequence of quartzites, quartz conglomerates, shales, and thin coal beds. The Pottsville is a strongly erosion-resistant formation that provides the resistant caprock for the mountains west of the karst area.

Mauch Chunk Group (Mississippian)

The rocks immediately overlying the Greenbrier are a thick sequence of shales, siltstones, and sandstones and some thin limestones. In sequence, these are:

- Bluestone and Princeton Formations—red, green, and gray shales and sandstones.
- Hinton formation—red, green, and gray shales and sandstones with a few thin limestone beds. The Avis Limestone at the base is thick enough to develop small maze caves.
- Bluefield Formation—red and green shales and sandstones with thin limestone lenses, such as the Reynolds Limestone. The bottom unit is the Lilydale Shale that merges conformably into the Alderson Limestone.

Although the clastic rocks below the limestone are also Mississippian, there is an unconformity between the basal Hillsdale unit and the underlying shale and sandstone. Below these units, the section is composed of thousands of meters of Devonian shale and sandstone.

Maccrady Shale

The Maccrady is a red shale and mudrock with some sandstone. It is present only south of Pendleton County. Although this is a clastic rock, the cave passages of the contact caves are often cut deep into the Maccrady Shale (Fig. 2.6).

Pocono Sandstone

Predominantly hard, massive, but dirty sandstone. The Pocono Sandstone is the resistant rock that forms the eastern boundary of the Greenbrier Karst.

2.3.3 Depositional History

From the broad history of the Appalachians, it is of interest to reconstruct the details of the geologic history that provided the geological substrate on which the Greenbrier Karst was developed. The account that follows was extracted and to some extent paraphrased from a more extensive geologic history of West Virginia limestones (Springer 2000).

The relevant story begins with the Devonian Acadian Orogeny caused by the collision of the North American plate with the Avalon Terrane followed by a collision with the small continent known as Baltica. The Avalon Terrane was crushed into a large mountain chain—the Acadian Mountains—in what is now northeastern North America. Erosion of the Acadian Mountains produced a wedge of Devonian clastics—the Catskill Wedge. The wedge extended into West Virginia which at that time was largely covered by a shallow sea. The clastic sediments deposited in West

Fig. 2.6 Exposure of the Maccrady Shale along highway 219 just south of the Greenbrier River bridge near Ronceverte. Photo by the author

Virginia are known as the Brallier, Chemung, Hampshire, Pocono, and Maccrady formations. The thick Brallier shale was deposited in deep water while the Maccrady was formed by terrestrial rivers.

A period of erosion and folding followed the deposition of the Maccrady Formation. North of Pocahontas County, the Maccrady was completely eroded away. The area appears to have been broadly tilted to the south or southeast with resulting greater erosion in the north. The result was the unconformity between the Maccrady and the basal Hillsdale Limestone. The period of erosion marked by the unconformity was followed by sea level rise as a large portion of the region began to subside in response to the Allegheny Orogeny. Mississippian sea water flowed into the area from the southwest.

The Appalachian Basin has the crude geometry of a trough. The Appalachian Mountains were beginning to rise (again) in the east and the trough paralleled the first range of mountains. Subsidence was greatest east of a hinge line that ran across central West Virginia (Fig. 2.7) with thicker limestones to the south and thinner limestones to the north. The limestones were thin because the northern part of the trough contained deltas created by rivers flowing from the young Appalachian Mountains. These deposits of sandstone, siltstone, and shale are called the Mauch Chunk Group. While the Mauch Chunk was being deposited in the north, the Greenbrier Limestone was being deposited in the south. The sediments inter tongue where they meet. One of these tongues is the Taggard Formation.

The shallow sea produced the Pickaway and Union limestones during a period when sea level and associated tectonics were stable. As the deposition of the Union waned, deltas of the Mauch Chunk began to prograde into the Greenbrier Sea forming the thick red shales and sandstones. The first indication of advancing clastics is the Greenville Shale, followed by the shaley Alderson Limestone, and finally, the sedimentary section was dominated by the shales and sandstones of the Mauch Chunk.

2.4 Structure

2.4.1 Regional Folds

The structural motif of the Valley and Ridge Province extends to the fold structures beneath the plateau but with reduced amplitude. The folds of the Allegheny Mountain sub-province are oriented more or less north to north-northeast, and this orientation is continued into Greenbrier and Monroe Counties. These weak folds are cut off along the southeast boundary of the area by northeast–southwest (52°) trend of the structural front. Identification of the fold structures in the low-dipping rocks requires very careful mapping but they have an important influence on the rocks that crop out at the land surface (Fig. 2.8). The list below contains only a few of the more important structures that have an influence on cave and karst development. These were taken from the geologic maps of Greenbrier County

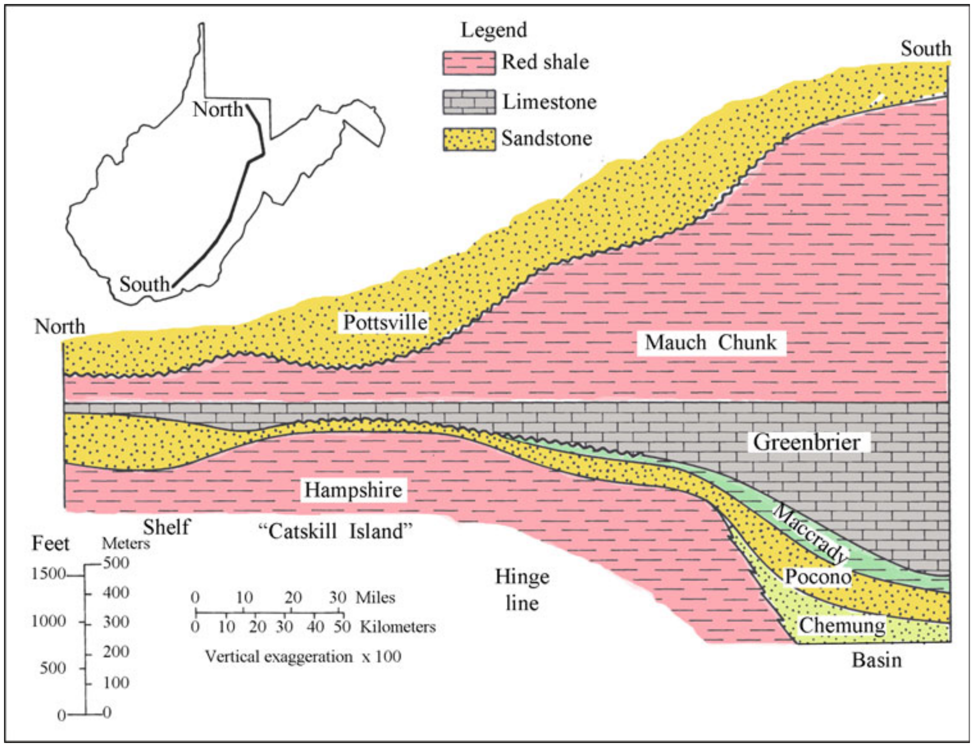


Fig. 2.7 North–south stratigraphic profile through West Virginia showing the hinge line that marks the deposition of thicker limestone units. From Arkle et al. (1979)

(Price and Heck 1939) and Monroe County (Reger and Price 1926). Later, mapping in Monroe County (Ogden 1976) and Greenbrier County (Heller 1980) reveals other fold structures as well as some corrections to the structures previously mapped (Fig. 2.9).

Browns Mountain Anticline

The Browns Mountain Anticline is the largest fold west of the structural front. In character, it is more like the intense folds of the valley and ridge than the much gentler folds of the Allegheny Plateau. It is somewhat domed with the peak of the dome east of Marlinton. The Browns Mountain anticline is strongly folded with dips up to the vertical. The westward dipping limestones of the Swago Creek and Little Levels areas are formed on the west limb of the anticline.

Caldwell (Patton) Syncline

The Caldwell Syncline (Patton Syncline in Monroe County) has its northern limit north of Anthony. The axis follows the course of the Greenbrier River southwestward to Caldwell where the river veers westward, and the syncline axis continues southwestward, passing beneath the Organ Cave Plateau and continuing into Monroe County. The Caldwell Syncline is the structural trough underlying the Organ Cave system. Northeast of Caldwell the surface rocks is the Pocono Sandstones; southwest of Caldwell the Greenbrier Limestone is exposed.

Sinks Grove Anticline

The Sinks Grove Anticline is a major structure of the Greenbrier Karst. The axis trends south-southwest passing 1½ miles east of Maxwellton, just east of Lewisburg, then curves around Ronceverte and continues south to Sinks Grove in Monroe County. The northern segment marks the eastern edge of the Greenbrier Karst where the Maccrady Shale is exposed on the crest of the anticline.

Muddy Creek Mountain Syncline

The Muddy Creek Mountain Syncline is a broad structure with the west limb steeper than the east limb. The syncline axis follows the western edge of Muddy Creek Mountain. The dip in the syncline axis beneath Muddy Creek Mountain carries the Greenbrier Limestone to depth and exposes the basal units of the Mauch Chunk as the surface rocks. The synclinal structure of Muddy Creek Mountain accounts for the steep scarp slopes on the east and west sides.

Williamsburg (Brushy Ridge) Anticline

The Williamsburg Anticline is a narrow but strongly folded structure. The structure begins east of Trout, trends southwest west of sunlight, east of Williamsburg, and follows the crest of Brushy Ridge. Near Asbury, there is an offset to the east. The structure axis then passes through the south end of Muddy Creek Mountain and reaches the Greenbrier River

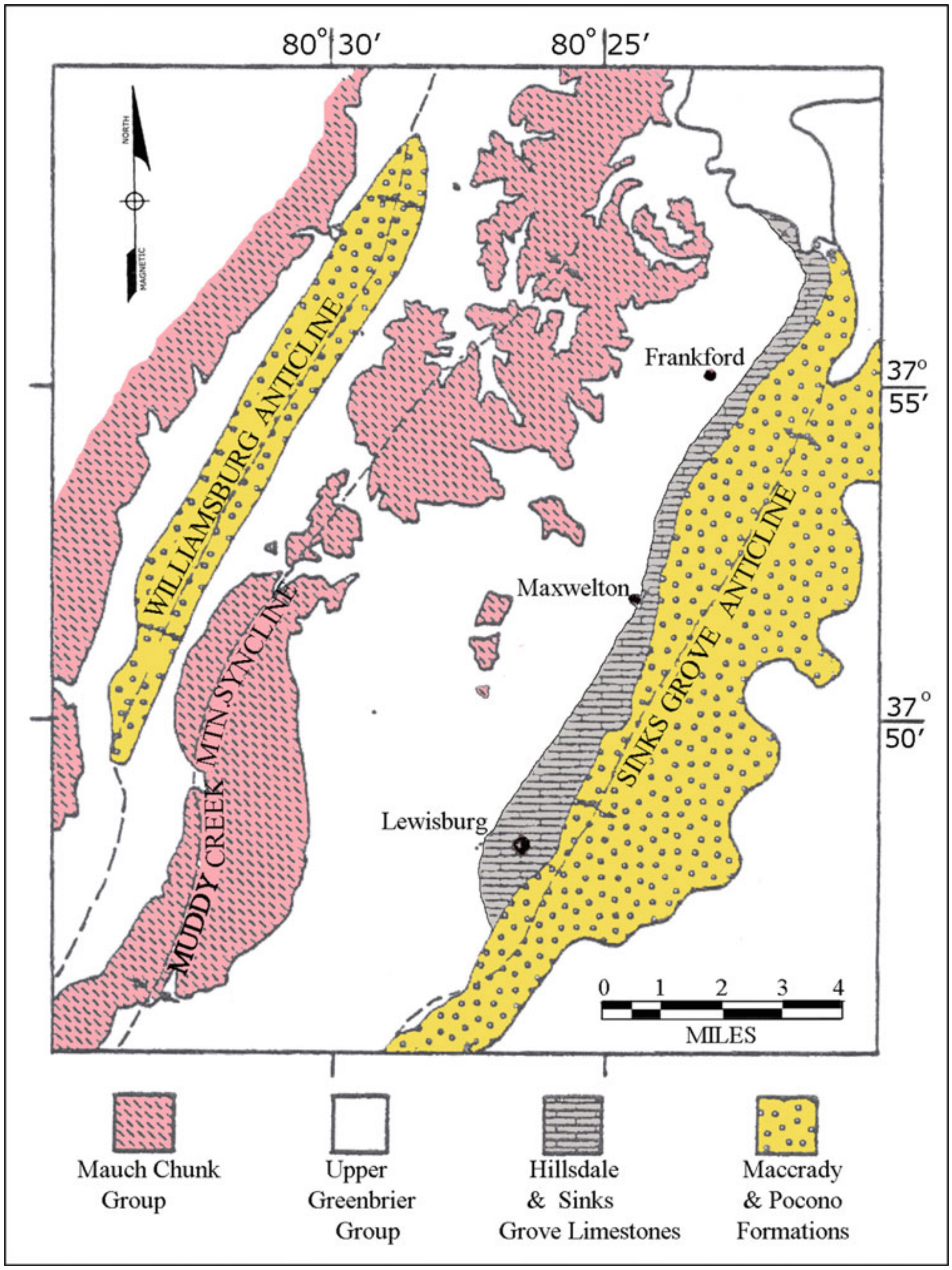


Fig. 2.8 Geologic map of a portion of the Greenbrier and Monroe County karst illustrating the effect of fold structures on the outcrop pattern of the Greenbrier Limestone

east of Alderson. The profile of the structure axis is undulating. From Trout to a point 2 km northeast of Williamsburg, the entire thickness of the Greenbrier Limestone is exposed at the surface. From this point to Asbury, the outcropping rocks belong to the Pocono Series with a thin band of Maccrady at each end. In the structural saddle near Asbury, the basal Greenbrier is exposed. Further south along the axis, the entire thickness of the Greenbrier Series dips below the surface and on the south end of Muddy Creek Mountain, rocks of the Bluefield group form the surface exposures.

Abbs Valley Anticline

The Abbs Valley Anticline is the diminishing northern tail of a major structural feature, the Richlands Fault, in Tazewell County, Virginia. Developing into an anticline, the structure axis crosses Mercer County, a corner of Summers County, and enters Monroe County where it extends through Greenville, veering north and becoming a monocline east of Wolf Creek. The Abbs Valley Anticline is responsible for bringing up the island of Greenbrier Limestone in which the Laurel Creek System is located.

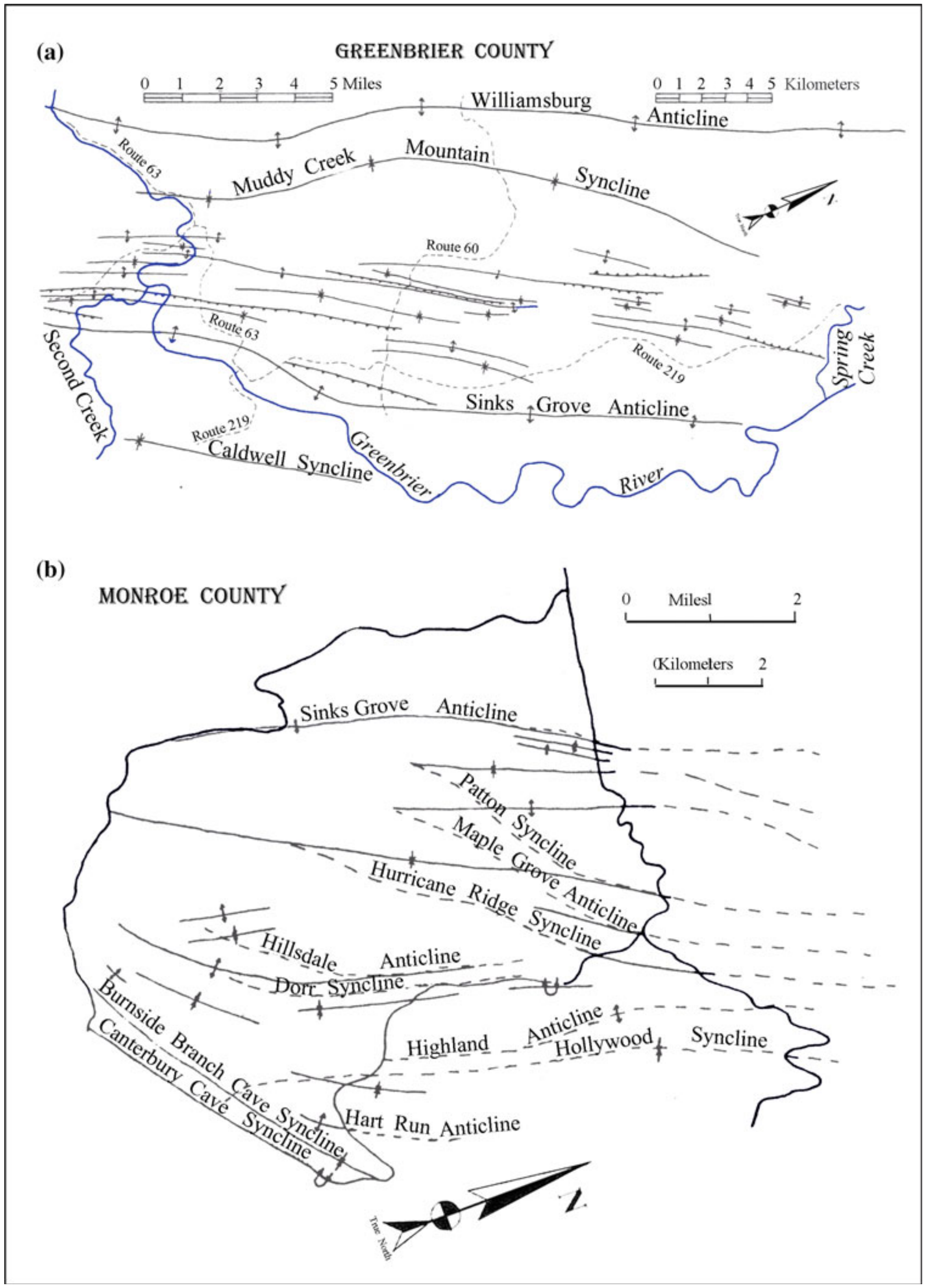


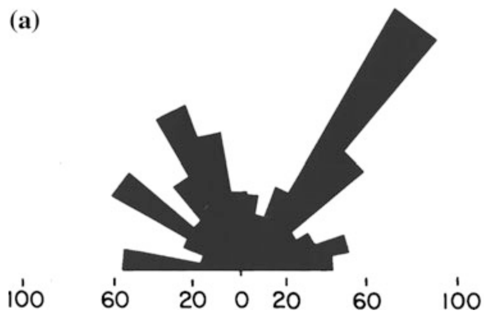
Fig. 2.9 Structure maps for the Greenbrier Karst: **a** Greenbrier County, **b** Monroe County. Adapted from Heller (1980)

2.4.2 Faults, Fractures, and Lineaments

Minor faults occur throughout the Greenbrier Karst. Most are small with displacements in the range of 5–10 m. Some were specifically identified in Greenbrier County (Heller 1980). Their influence on cave and karst development seems to be small.

The Greenbrier Limestone is well jointed, and many cave passages are oriented along joint traces with the guiding joint clearly visible in cave walls or ceiling. However, the overall correlation of cave passages with joint orientations is not good, primarily because in the low-dip limestone, bedding plane partings rather than vertical joints tend to be the initiating pathways. Measured joint orientations in Monroe County (Fig. 2.10a) show a dominant northeast trend which is more nearly parallel to the orientation of the structural front rather than the secondary anticlines and synclines.

Fracture control of surface features takes the form of aligned sinkholes and related features. These can be mapped from aerial photographs. Features visible on aerial



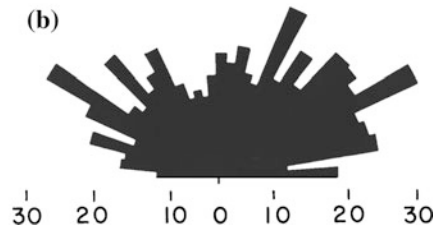


Fig. 2.10 **a** Orientation of 873 joints taken from Greenbrier Limestone, Monroe County. Scale is number of joints sorted by 10° intervals, **b** Accumulated lineament length versus orientation for 749 mapped lineaments. Scale is in thousands of feet using a 5° interval. From Ogden (1974)

Fig. 2.11 Aerial photograph of the monitor lineament, Monroe County. Photo by William K. Jones

photographs are known as fracture traces or photolineaments and have proved useful in locating zones of high permeability for the drilling of water wells. Measurement of photolineaments in Monroe County (Ogden 1976) and Greenbrier County (Heller 1980) does not show any preferred direction (Fig. 2.10b). On the scale of topographic maps, alignments of sinkholes and other karst features can be drawn (Lessing 1979). The major trends parallel the pattern of folding and are simply guided by the local geology. Others, usually strings of sinkholes, cut across the regional structure and appear to be a reflection of the local fracture patterns, which, as seen in the aerial photograph mapping, seem to have no preferred direction.

The term "lineament" is used in several senses. The photolineaments described above are usually spatially limited with lengths of a kilometer or less. But scattered through the Appalachians are major lineaments with lengths measured in tens of kilometers and which appear to be major structural features that usually cut across the characteristic structural grain of the Appalachians. One such is located north of the Greenbrier Karst in Randolph County. The Simmons-Mingo Cave system is developed on the lineament and crosses the spur of a mountain ignoring local geologic structure. In the Greenbrier Karst, the monitor lineament (Fig. 2.11) is identified on the surface by an obvious line of sinkholes.

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