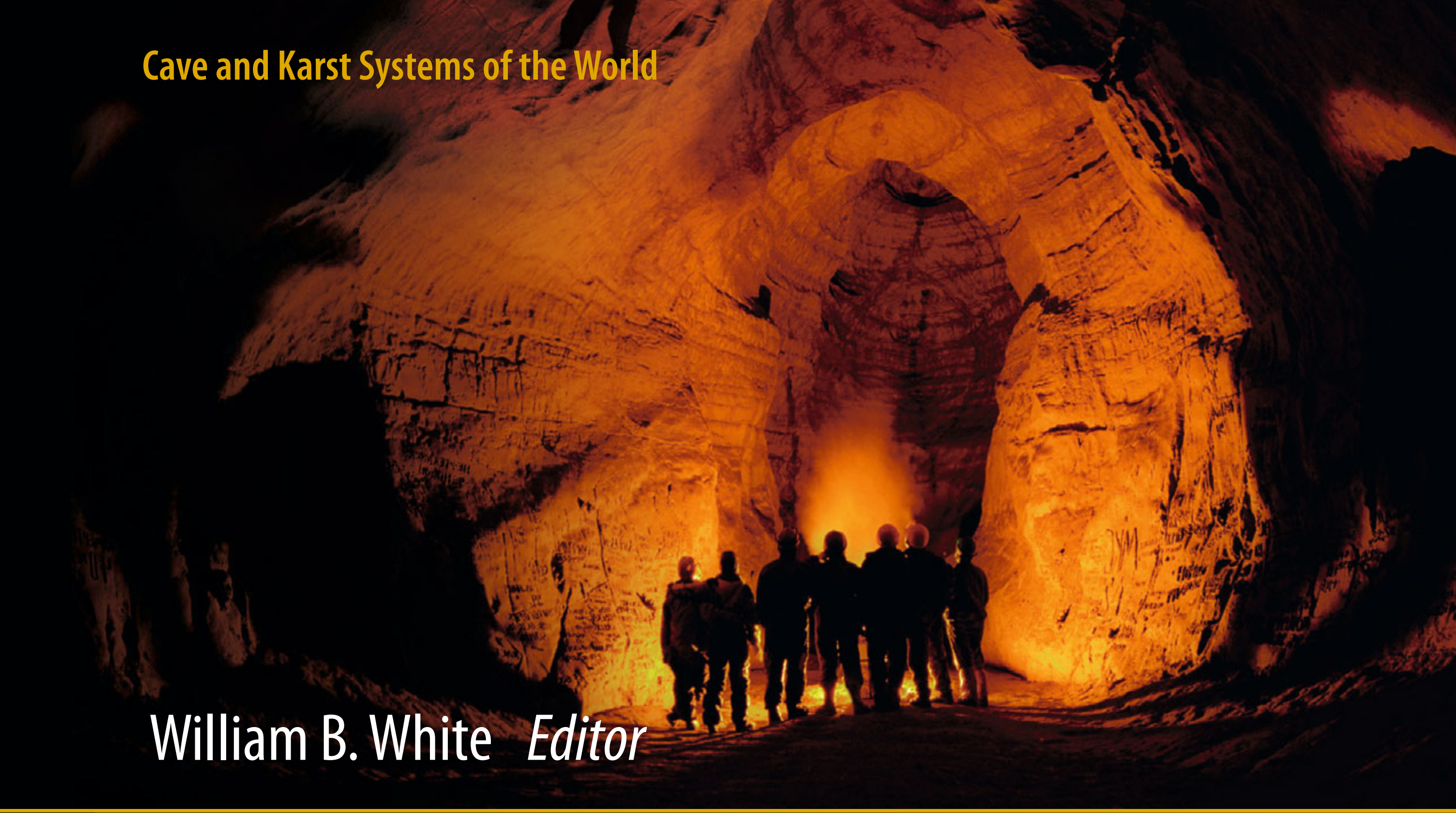
Cave and Karst Systems of the World



William B. White *Editor*

Caves and Karst of the Greenbrier Valley in West Virginia

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Editor

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Preface

In a series documenting the important cave and karst systems of the world, one could hardly overlook the karst of the Greenbrier Valley in West Virginia, USA. The valley exposes the Mississippian Greenbrier Limestone, and in the Greenbrier Limestone are developed some of the most extensive caves in the USA. Within a three-county area, there is a pattern of karst drainage basins, each with one or more associated long caves. There are more than 2000 caves so far discovered, and of these, there are 24 caves with surveyed lengths greater than 5 km, adding up to 508 km of cave passage. Because of the similarity of geologic setting and the similarity of the processes of cave development, it seemed reasonable to base the book on a series of descriptions of the long caves and to show how they fit into a pattern of cavern development dictated by the local geology.

The structure of the book is as follows: Chaps. 2–4 lay out the geology, hydrology, and geomorphology of the region in broad terms as background for the more detailed cave descriptions and interpretations that follow. Cave exploration in the Greenbrier Valley has a rich history, and this is the subject of Chap. 5. Then, follow Chaps. 6–17 that describe in detail the individual drainage basins and their associated caves beginning with Swago Creek on the north and proceeding southwestward to the Laurel Creek Basin in the southernmost exposure of the cavernous limestone. The final three chapters address the biological and paleontological aspects of the cave systems.

The authors for the chapters were chosen for their detailed knowledge of the cave systems that they were describing. However, quite different approaches were used. Some authors chose to write a scientific treatise on their assigned cave. Others provided highly detailed passage-by-passage descriptions, most profusely illustrated. Both approaches have advantages and disadvantages, so it seemed inappropriate to attempt to force the discussion into some re-determined template. Those readers who want a very close-up-and-personal feel for the inside of a Greenbrier Valley cave are urged to read Chap. 10 with its detailed description of the Culverson Creek System.

In describing the history of cave exploration and in following the exploration history of individual caves, there is a considerable text devoted to who did what, when. The authors and the editor offer no apology. The exploration and survey of these long and sometimes difficult caves require skill, time, and dedication. Those who pursued these tasks deserve at least the small recognition that they receive in this volume.

There is an inconsistency in the units used in the chapters. Some authors converted all measurements into metric units; some did not. However, it must be remembered that some of the cave surveys and cave descriptions date back as much as 60 years to the early 1950s. All such maps and descriptions were in the English units of feet and miles, not meters and kilometers. Much of the surface topography is described from the US Geological Survey's series of 7.5-min quadrangle maps. These are scaled in both miles and kilometers, but the essential parts of the maps, the contour lines that describe elevation, are in intervals of 20 or 40 ft. The editorial decision—which is likely to satisfy nobody—was to allow authors to choose their own units. Those who felt comfortable in metric wrote in metric. Those who felt comfortable in English units used English units.

University Park, USA
June 2017

William B. White

Acknowledgements

The factual information underlying these descriptions, particularly the cave maps, has been obtained by many explorers and surveyors whose work extends back over many decades. Primary explorers of the Greenbrier Valley Caves have agreed to write chapters so that the accounts are based on first-hand knowledge—knowledge often acquired by many lengthy and difficult exploration trips. But behind the few names that appear on chapter headings are many other individuals all of whom have made important contributions. Our present-day knowledge of the caves of the Greenbrier Valley is due to tens of thousands of person-hour spent in exploration and the grueling business of surveying. Thanks are due to them all.

Thanks are due to the West Virginia Speleological Survey for permission to reproduce their maps and to extract much written material from their publications. The West Virginia Speleological Survey Bulletins are the primary repository for the detailed knowledge of West Virginia Caves.

The caves of the Greenbrier Valley are on private land. The landowners are owed an immense debt of gratitude for their allowing access to their land and their caves over many years. As is noted in several of the historical accounts in the chapters that follow, the landowners have not always been well-treated for their generosity and as a result some caves are now closed to all exploration.

A large thank-you is owned to the photographers whose images illustrate the caves. The images are credited individually, but it must be said that without the generosity of the photographers, a book such as this would not be possible.

The editor expresses his personal thanks to the authors for their hard work. He also thanks Elizabeth L. White for her invaluable assistance with proofreading and with improving the appearance of many of the figures.

Contents

The Greenbrier Karst

1

William B. White

Abstract

The segment of the Appalachian karst known as the Greenbrier karst is located in the lower valley of the Greenbrier River in southeastern West Virginia. The karst is developed in the Mississippian Greenbrier Limestone which thickens from 100 to 365 m northeast to southwest. The region can be subdivided into drainage basins which drain by subterranean routes to big springs. The Greenbrier karst contains more than 2000 caves of which 24 have surveyed lengths exceeding 5 km. The accumulated length of those 24 caves is 503.7 km.

1.1 Introduction

The Greenbrier Valley in southeastern West Virginia contains some of the longest caves in the USA. The Greenbrier karst is part of the extensive Appalachian karst and is located in Pocahontas, Greenbrier, and Monroe Counties, West Virginia (Fig. 1.1). For an overview showing the relationship of this karst area to other karst regions in the Appalachians and in the USA overall, see Palmer and Palmer (2009). A state-wide description of the karst of West Virginia is given by Dasher (2012). Details of the topography are provided by the US Geological Survey 7.5 min (1:24,000) for which an index is provided in Fig. 1.2.

1.2 Regional Setting

The Appalachian Mountains are usually divided into the Valley and Ridge Province with strongly folded and faulted strata and the Appalachian Plateaus Province where the strata are only slightly deformed. The two provinces are separated by a steep escarpment, called the Allegheny Escarpment (or Allegheny Front) in the north and the Cumberland Escarpment in the south. In eastern West Virginia, there is substantial deformation in the rocks on the eastern margin of the plateau so that the topographic front and the structural front do not coincide. East of the main plateau and west of the mountains that form the topographic front, the Greenbrier Valley has developed in the intermediate geological setting.

The Greenbrier River has its headwaters in the Allegheny Mountains near Spruce Knob, West Virginia, and flows south and southwest following the regional strike for 278 km to its confluence with the New River. The total basin area is 4290 km^2. For much of its length, the Greenbrier Valley is underlain by the Greenbrier Limestone which forms a karstic zone between the Allegheny Mountains to the east and the main Appalachian high plateau to the west (Fig. 1.3). The controlling structural features include the Browns Mountain Anticline and other folds which are formed west of the Allegheny Escarpment. To the west, the limestone dips beneath the younger rocks of the plateau. What is here described as the Greenbrier karst occupies the middle section of the Greenbrier River Valley. Omitted is the headwaters region where the limestone is thinner, and although it contains significant caves, the karst is less well developed. Also omitted is the downstream section where the river is flowing on clastic rocks.

In the northern part of the Greenbrier karst, the river flows along the eastern margin of the valley where it has incised a secondary valley into the clastic rocks that underlie the limestone. Because of the westerly dip, these clastics form a groundwater dam that prevents direct discharge from the karst into the river. Thus, tributary streams entering the river from the east flow entirely on clastic rocks, whereas the

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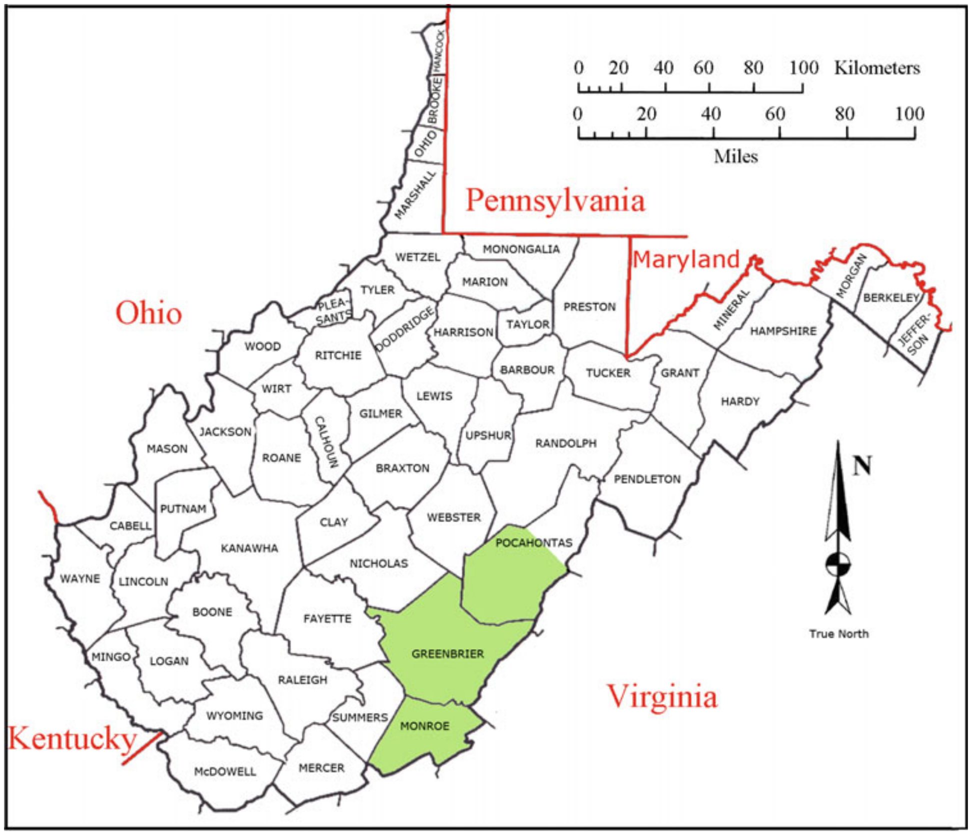

Fig. 1.1 Location map for the Greenbrier karst. Outline map from the US Department of Commerce, 1990

tributaries entering from the west have a pronounced fluviokarstic component.

The limestone thickness varies from about 100 m in the headwaters of the Greenbrier River to 365 m at the southern limit in Monroe County (McCue et al. 1939). The narrow band of Greenbrier Limestone widens to the southwest, and the topography changes from high-gradient fluviokarst basins such as the Swago Creek Valley in central Pocahontas County to the sinkhole plain called the Little Levels in southern Pocahontas County to wide sinkhole plains north and south of the Greenbrier River in Greenbrier and Monroe Counties (Fig. 1.4).

The interbedded shales within the Greenbrier Limestone are important controls on cave development. Near the top of the section, the Greenville Shale is rarely penetrated so that caves in the overlying Alderson Limestone tend to be perched on the shale. The Taggard Formation, a limey shale, is sometimes breached underground and sometimes not. Perched underground drainage is common.

1.3 Karst and Karst Hydrogeology

The Greenbrier karst can be subdivided into a sequence of small drainage basins nearly all of which ultimately drain through springs to creeks tributary to the Greenbrier River. The character of the individual basins changes north to south. The Swago Creek basin, the northernmost basin, is predominantly fluviokarst with primary recharge from mountain streams sinking at the limestone contact. The basins are of more mixed character in the intermediate region of southern Pocahontas and northern Greenbrier Counties. The Locust Spring basin receives surface stream recharge from Millstone Creek and from Hills and Bruffey Creeks and also an extensive recharge from the doline karst of the Little Levels. The Friars Hole System, separated from the Little Levels by Droop Mountain, is recharged primarily by mountain runoff with drainage to the south into Spring Creek. The Culverson Creek basin has a large surface catchment feeding into a very large cave system.

The thickening of the limestone beds and the development of additional anticlinal structures cause the karst region to widen in Greenbrier and Monroe Counties (Fig. 1.4). The result is a broad region of doline karst with mainly internal drainage and most recharge through closed depressions. The close depressions form on a range of size scales and appear to be guided by fractures and faults (Lessing 1979). The southern section of the karst is split into two segments by the Greenbrier River which east of Lewisburg changes from its generally southern course to a generally westward course. The northern segment was subdivided into smaller drainage basins by a series of tracing experiments with fluorescent

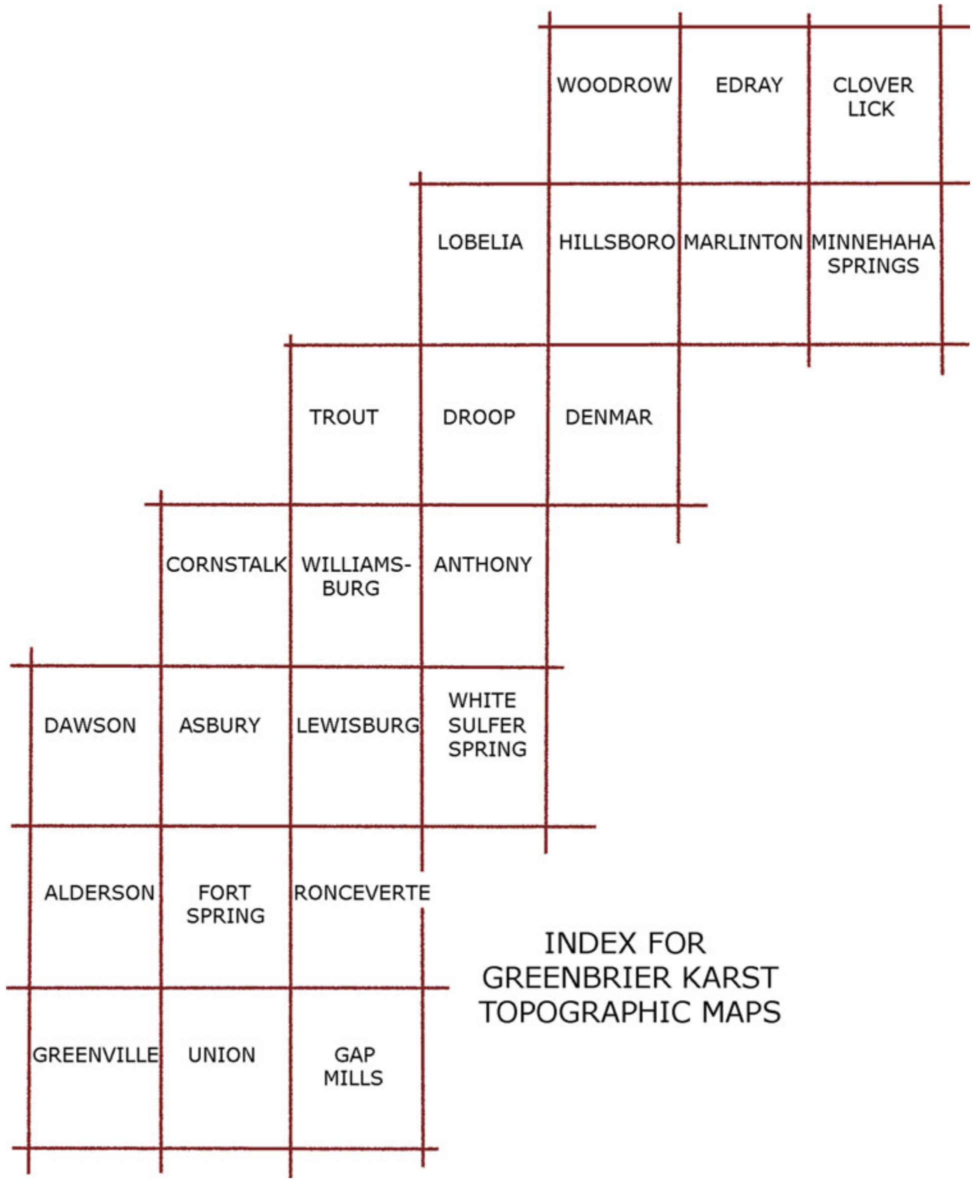

Fig. 1.2 Index map for US Geological Survey 7.5 min quadrangle maps spanning the Greenbrier karst

dyes (Jones 1973). These subbasins have associated large cave systems. The southern segment is also subdivided into distinct groundwater basins (Jones 1997). Further detail is provided by two PhD theses written on the hydrogeology of Greenbrier County (Heller 1980) and Monroe County (Ogden 1976).

1.4 Caves

Many exceptionally large caves occur in the thick and gently dipping limestone in the southern reaches of the Greenbrier Valley along with hundreds of smaller caves. Early cave descriptions for West Virginia were compiled by Davies (1949, 1958). Later, many cave explorers and their organizations contributed to the exploration and mapping of West Virginia caves. The two most prominent organizations were the West Virginia Association for Cave Studies (WVACS) and the West Virginia Speleological Survey (WVASS). The Bulletins of the West Virginia Speleological Survey are the primary documentation for West Virginia caves. The history of exploration in the Greenbrier karst is given in some detail in Chap. 5.

The three counties of the Greenbrier Valley karst are the most cavernous in the State. Dasher (2012) lists the number of caves in each county:

Pocahontas County	621 caves
Greenbrier County	1375 caves
Monroe County	435 caves

Fig. 1.3 Relief map of Pocahontas, Greenbrier, and Monroe Counties, West Virginia. Extracted from US Geological Survey 1:500,000 shaded relief man of West Virginia, 1968

The total is 2431 caves although some of the Pocahontas County caves are north of the area considered in this volume.

Table 1.1 lists the caves with surveyed lengths exceeding 5 km. The rank on the US long cave list is given for those with lengths greater than 20 km and the world rank for those with lengths greater than 30 km. Adding up the lengths produces a total of 503.7 km (312.9 miles) of mapped cave passage, making the Greenbrier Valley one of the most cavernous regions on the planet. A complete tally would require adding in the accumulated length of more than 2000 smaller caves, many of which are of substantial length. Most, but not all of the listed caves appear somewhere in the description chapters.

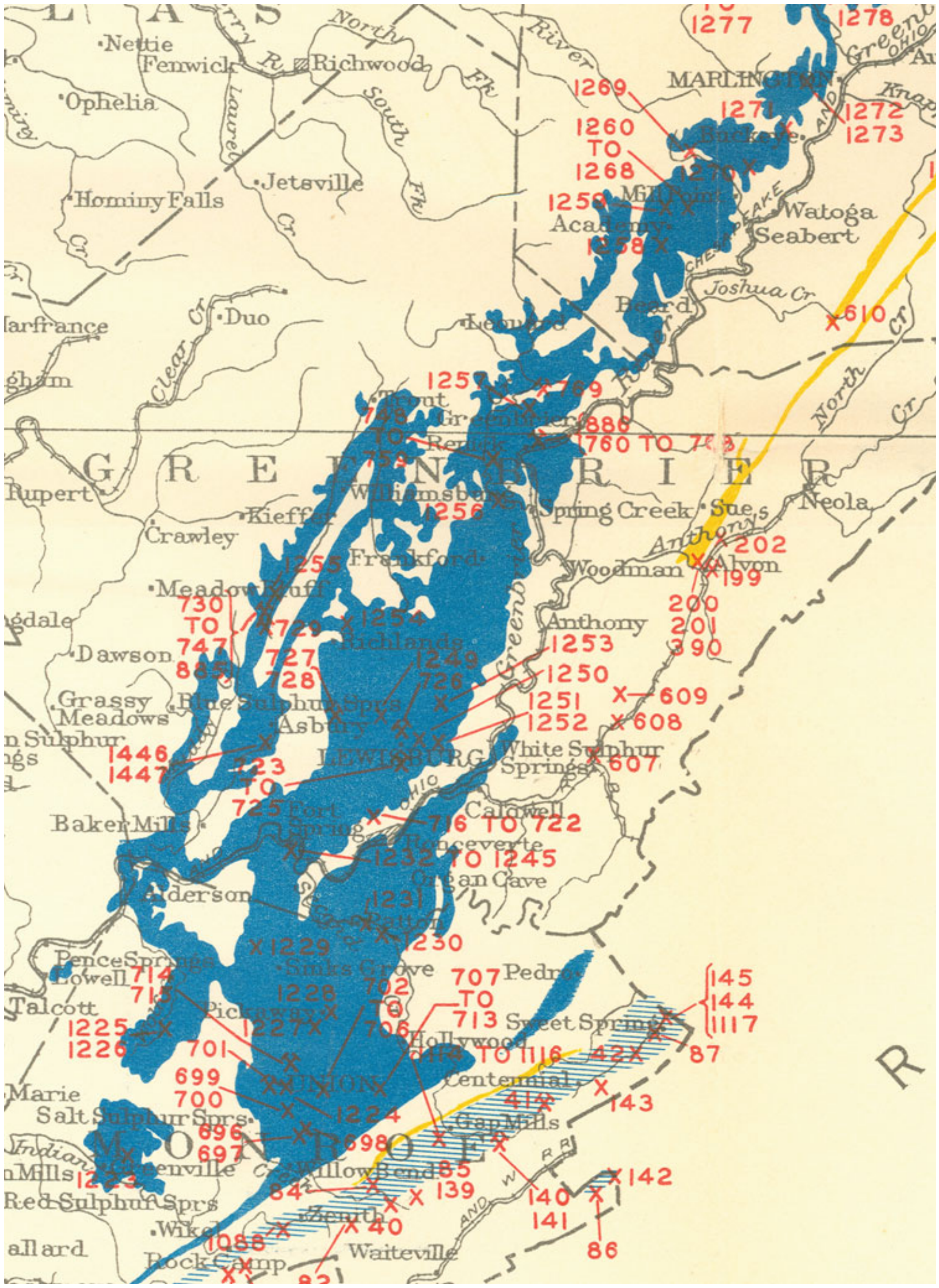

Fig. 1.4 Outcrop area of Greenbrier Limestone in Pocahontas, Greenbrier, and Monroe Counties, West Virginia. *Red numbers* refer to limestone quarries. Extracted from the limestone map of McCue et al. (1939)

1.5 Presentation of the Greenbrier Karst

For purposes of description, the Greenbrier karst was subdivided partly by drainage basins and the large cave systems. These subdivisions become the individual descriptive chapters.

The northernmost basin, Swago Creek (Chap. 6) is an isolated basin connected directly with the Greenbrier River and separated by Rogers Mountain from the next basin to the south. The Little Levels (Chap. 7) is a limestone upland with caves along the perimeter but which does not function as an integrated drainage basin. Separated from the Little Levels by Droop Mountain, but hydrologically interconnected, are the valleys of Hills and Bruffey Creeks. To the south extends the abandoned karst valley of Friars Hole beneath which is the longest cave in West Virginia (Chap. 8).

Moving south into the Big Levels, the wide doline karst on the Greenbrier Limestone, dye-tracing studies have defined drainage basins and their associated cave systems. Some basin boundaries are created by geologic barriers and other by the west-trending Greenbrier River which bisects

Table 1.1 Long caves of the Greenbrier Valley

Cave	Length (km)	US rank	World rank
Friars Hole System	73.4	6	31
Organ Cave	61.9	10	42
Scott Hollow Cave	47.5	17	68
The Hole	37.0	24	104
Culverson Creek System	33.7	30	134
McClung Cave System	29.1	36	
Windy Mouth Cave	29.0	37	
Benedict's Cave	23.9	52	
Bone-Norman System	22.7	55	
Maxwelton Sink Cave	18.8	64	
Portal-Boar Hole System	16.8	71	
Ludington's Cave	14.7	81	
Acme Quarry Cave System	13.6	87	
Overholt Blowing Cave	12.6	98	
Dry Cave	9.2		
Destitute Cave	8.0		
Union Cave	7.4		
Buckeye Creek Cave	7.2		
Carpenter's—Swago System	7.0		
Greenville Saltpetre Cave	6.7		
Wades Cave	6.4		
Laurel Creek Cave System	5.8		
Zicafoose Blowhole	5.8		
Plastic Bag Cave	5.5		

the region. The area is large and complex, and the subdivision into chapters is to some extent arbitrary.

North of the River, there is a major divide between caves that drain eastward to Spring Creek and those that drain southwest to Davis Spring. The Buckeye Creek-Rapps Cave System (Chap. 9) and the Culverson Creek System (Chap. 10) drain to Spring Creek and have large surface catchments making these caves very dynamic during flood flow conditions. Along the eastern edge of the area, the limit of the limestone is formed when the contact with the underlying clastics reaches the land surface. Along this extensive contact zone are formed a sequence of very large caves, the contact caves (Chap. 11). These collect drainage from the clastic terrain between the contact and the Greenbrier River and collectively drain to Davis Spring. To the west, the linear karst valley of Sinking Creek forms an independent basin (Chap. 12).

South of the Greenbrier River, the Organ Cave area (Chap. 13) is an isolated plateau bounded on the north by the river, on the east by the limestone contact, and in the south by the incised valley of Second Creek. Dickson Spring (Chap. 14) is one of the largest karst springs in the area. Its basin contains significant caves but not the exceptionally long ones. Scott Hollow Cave and associated Windy Mouth Cave are in a north-flowing drainage basin that drains directly into the Greenbrier River (Chaps. 15 and 16). Finally, at the extreme southern edge of the Greenbrier karst is an isolated island of limestone surrounded by clastic rock, the Laurel Creek system (Chap. 17). Laurel Creek is a south-flowing tributary of Indian Creek which flows westward into the New River below its confluence with the Greenbrier River and so is part of the Greenbrier Limestone karst but not a tributary of the Greenbrier River.

Not every detail of every cave is described in these chapters, but in broad brush terms, at least, there is a reasonable picture of the type of cave systems and associated karst drainage patterns that developed in this particular geologic and geomorphic setting.

References

Dasher, G.R. 2012. *The Caves and Karst of West Virginia*, vol. 19, 264pp. Barrickville, WV: West Virginia Speleological Survey Bulletin.

Davies, W.E. 1949. *Caverns of West Virginia*, vol. 19, 353pp. Morgantown, WV: West Virginia Geological Survey.

Davies, W.E. 1958. *Caverns of West Virginia*, 2nd ed., vol. 19A, 330pp. West Virginia Geological and Economic Survey.

Heller, S.A. 1980. A hydrogeologic study of the Greenbrier Limestone karst of central Greenbrier County, 167pp. West Virginia. Ph.D. Thesis, West Virginia University.

Jones, W.K. 1973. *Hydrology of limestone karst*, vol. 36, 49pp. Morgantown, WV: West Virginia Geological and Economic Survey Bulletin.

Jones, W.K. 1997. *Karst hydrology atlas of West Virginia*, vol. 4, 111pp. Charles Town, WV: Karst Waters Institute Special Publication.

Lessing, P. 1979. *Karst subsidence and linear features, Greenbrier and Monroe Counties, West Virginia*. Morgantown, WV: West Virginia Geological and Economic Survey Environmental Geology Bulletin EGB-17, one sheet.

McCue, J.B., J.B. Lucke, and H.P. Woodward. 1939. *Limestones of West Virginia*, vol. 12, 560pp. Morgantown: West Virginia Geological Survey.

Ogden, A.E. 1976. The hydrogeology of the central Monroe County karst, West Virginia, 262pp. Ph.D. Thesis, West Virginia University.

Palmer, A.N., and M.V. Palmer. 2009. *Caves and Karst of the USA*, 446. Huntsville, AL: National Speleological Society.

Geology of the Greenbrier Valley

2

William B. White

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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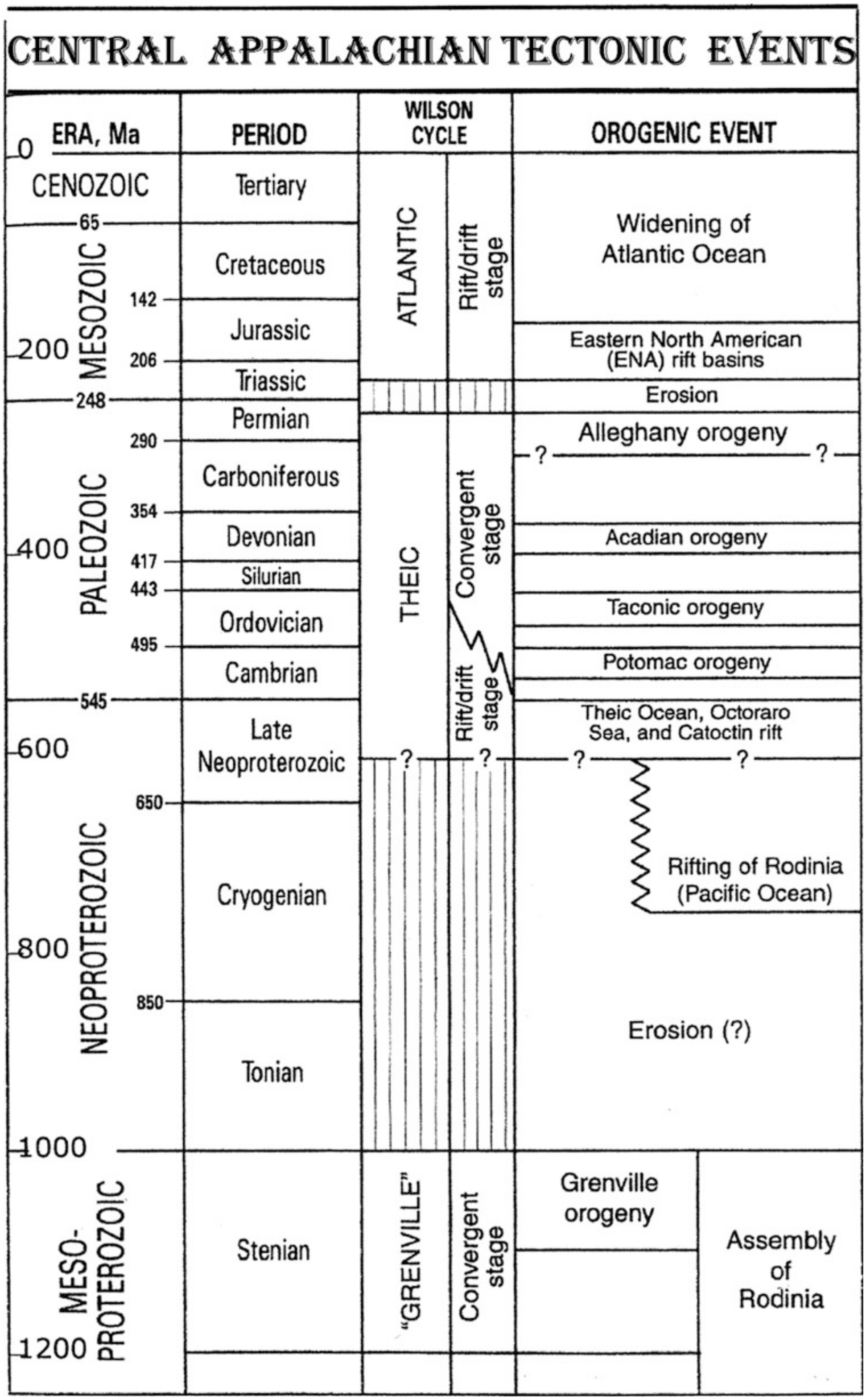

Fig. 2.1 Tectonic events in the Appalachians since Grenville time. Adapted from Fail (1997–1998)

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.

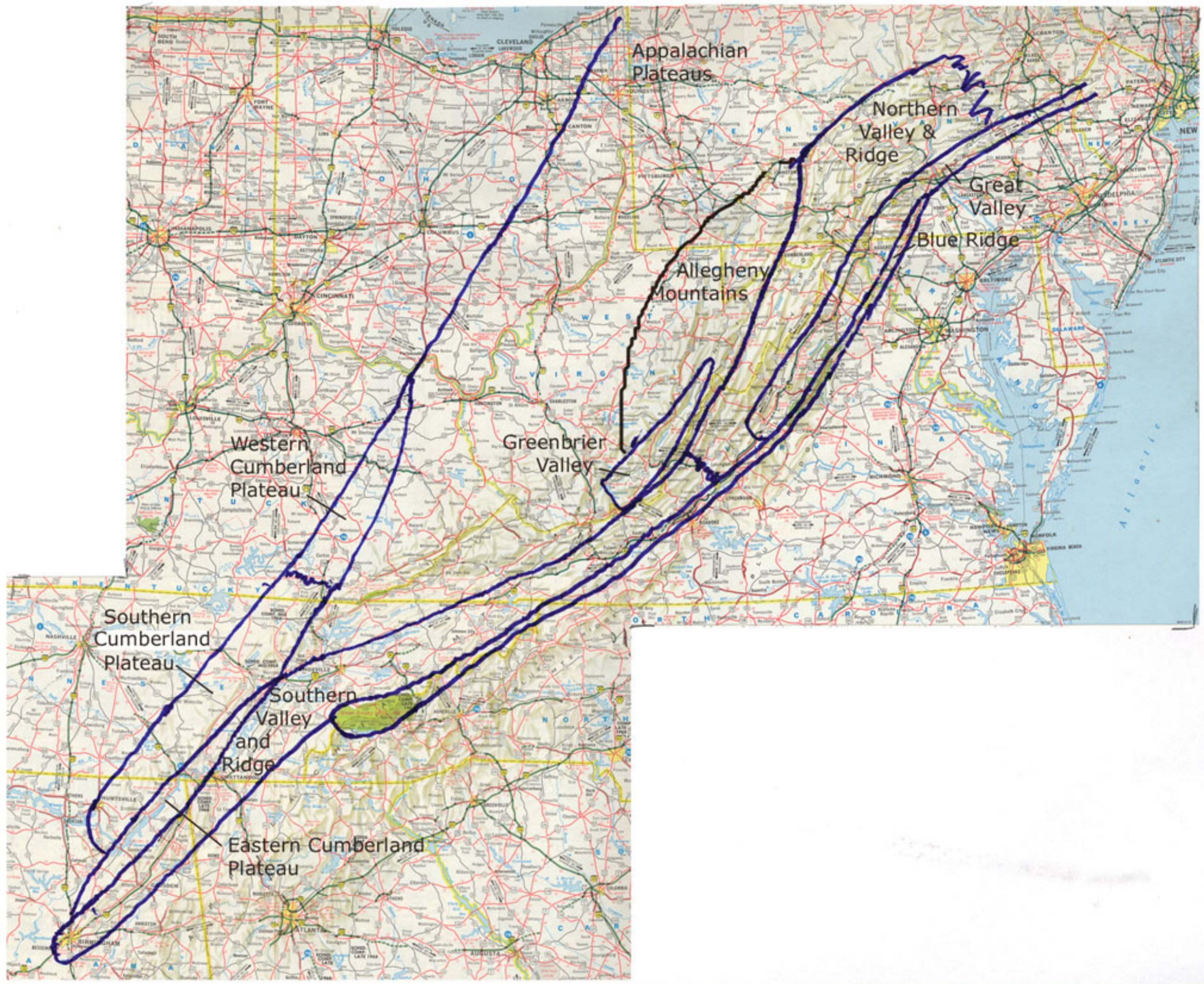

Fig. 2.2 Physiographic provinces of the Appalachians

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,

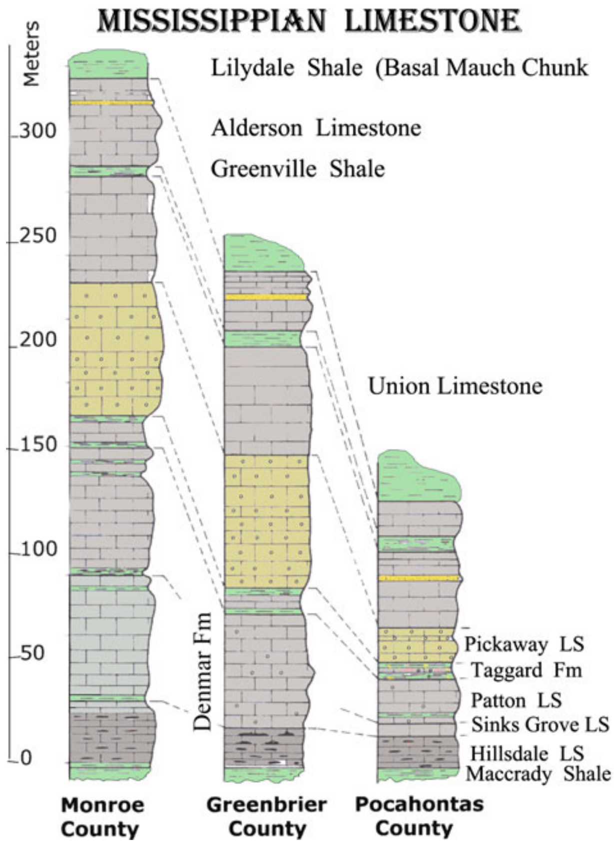

Fig. 2.3 Stratigraphic sections for the Greenbrier Limestone

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

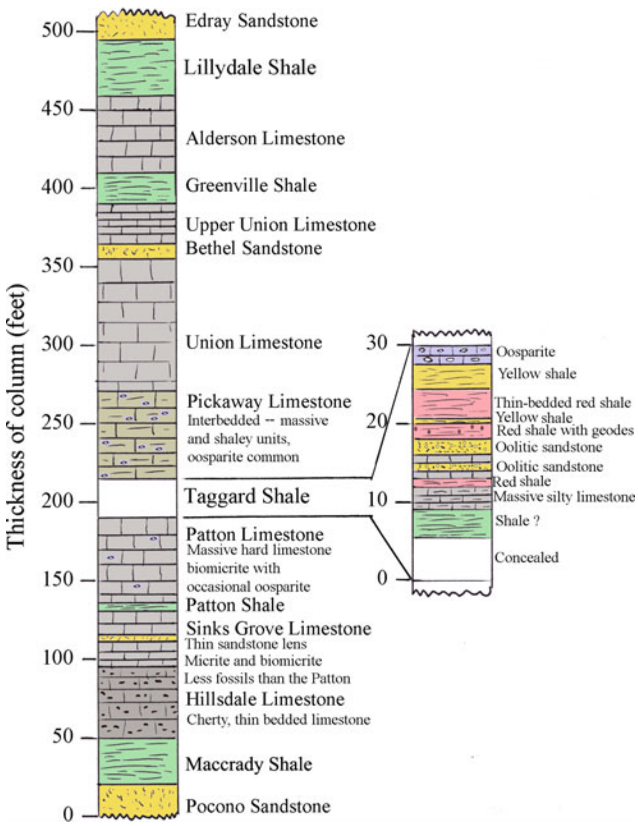

Fig. 2.5 Stratigraphic section of the Taggard Formation measured by the author along US Highway 219 on Elk Mountain north of Marlinton

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

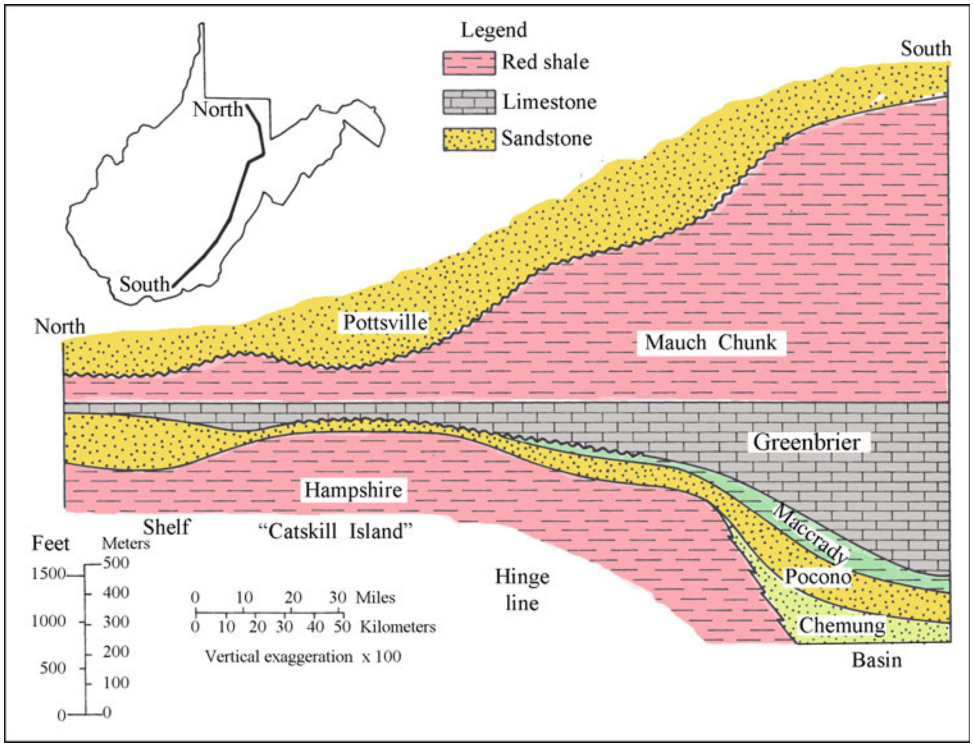

Fig. 2.7 North–south stratigraphic profile through West Virginia showing the hinge line that marks the deposition of thicker limestone units. From Arkle et al. (1979)

(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

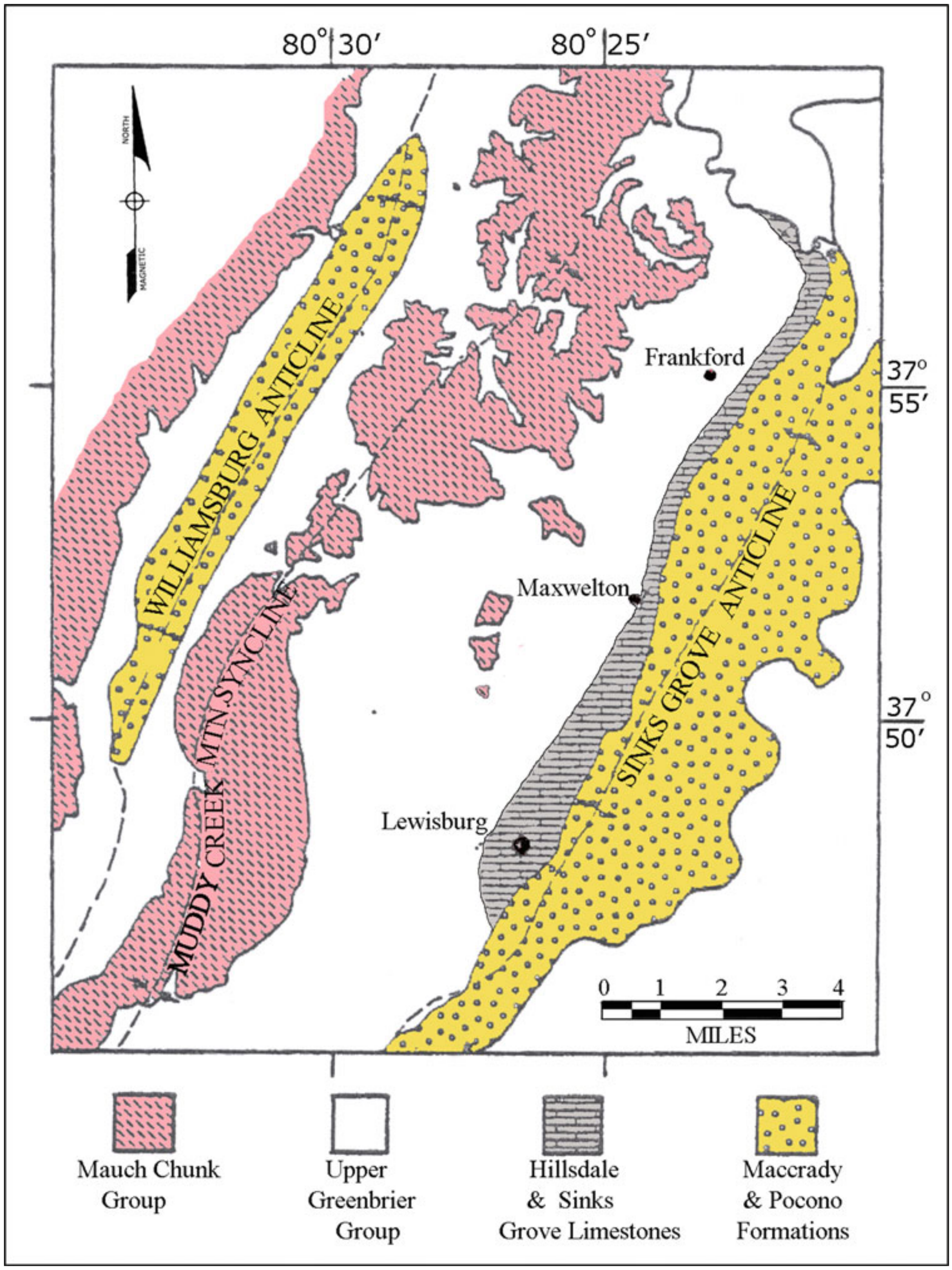

Fig. 2.8 Geologic map of a portion of the Greenbrier and Monroe County karst illustrating the effect of fold structures on the outcrop pattern of the Greenbrier Limestone

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.

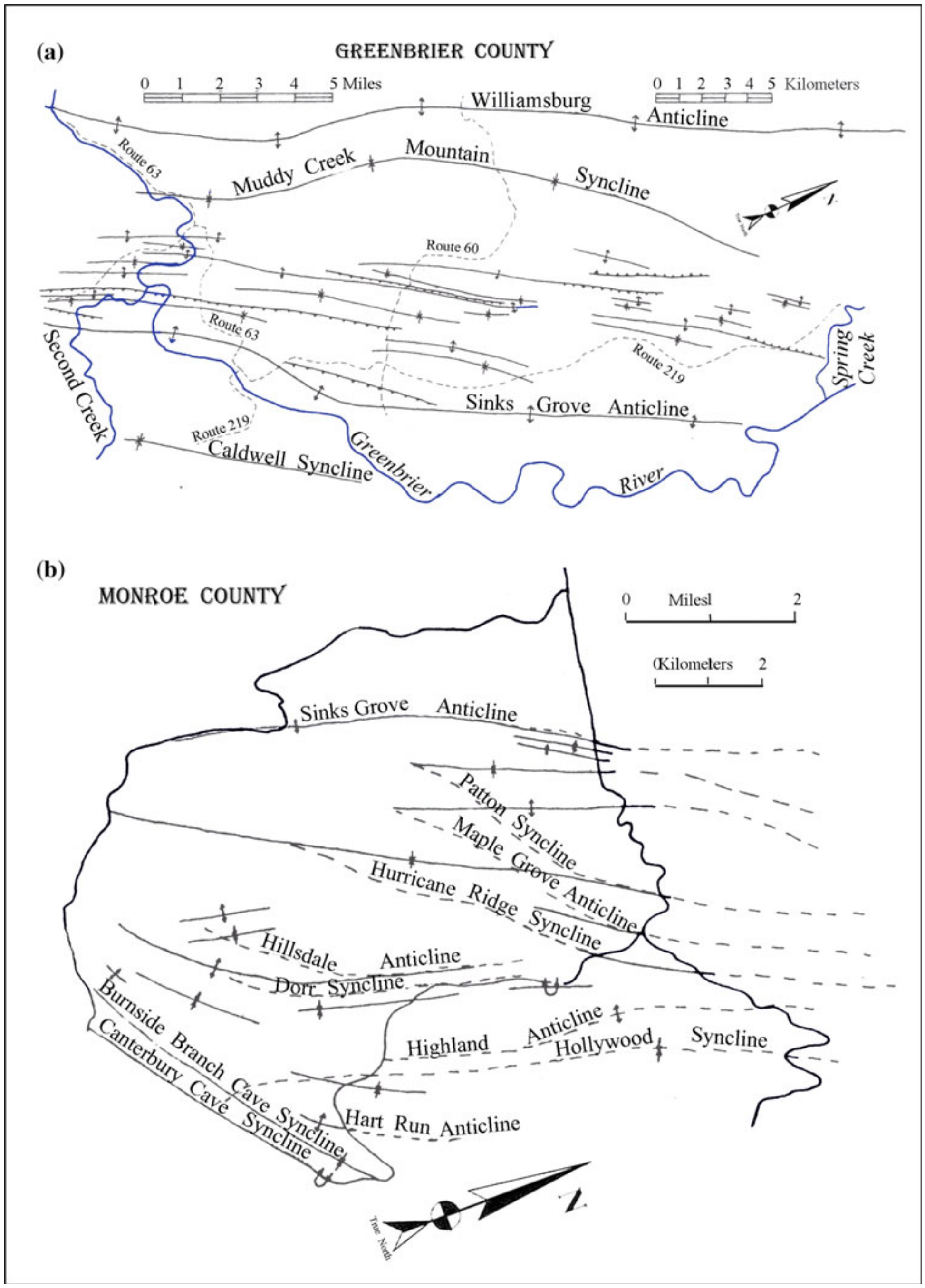

Fig. 2.9 Structure maps for the Greenbrier Karst: **a** Greenbrier County, **b** Monroe County. Adapted from Heller (1980)

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

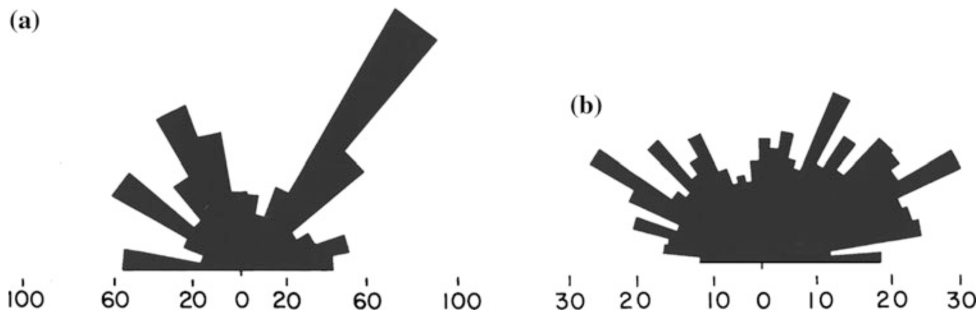

Fig. 2.10 **a** Orientation of 873 joints taken from Greenbrier Limestone, Monroe County. Scale is number of joints sorted by 10° intervals, **b** Accumulated lineament length versus orientation for 749 mapped lineaments. Scale is in thousands of feet using a 5° interval. From Ogden (1974)

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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References

Arkle, T. Jr., D.R. Beissel, R.E. Larese, E.B. Nuhfer, D.G. Patchen, R. A. Smosna, W.H. Gillespie, R. Lund, C.W. Norton, and H.W. Pfefferkorn. 1979. The Mississippian and Pennsylvanian (Carboniferous) systems in the United States—West Virginia and Maryland. *U.S. Geological Survey Professional Paper* 1110-D: 35pp.

Faill, R.T. 1997–98. A geologic history of the north-central Appalachians. Part 1: Orogenesis from the Mesoproterozoic through the Taconic orogeny. *American Journal of Science* 297, 551–619; Part 2: The Appalachian Basin from the Silurian through the Carboniferous. 297: 729–761; Part 3: The Alleghany orogeny. 298: 131–179.

Hatcher, R.D., Jr., W.A. Thomas, P.A. Geiser, A.W. Snoke, S. Mosher, and D.V. Wiltschko. 1989. Alleghanian orogen. In: *The Appalachian-Ouachita Orogen in the United States*, ed. R.D. Hatcher Jr., W.A. Thomas, and G.W. Viele, 233–318. Boulder, CO: Geological Society of America, The Geology of North America, F-2.

Heller, S.A. 1980. A hydrogeologic study of the Greenbrier Limestone karst of central Greenbrier County, West Virginia, 167pp. Ph.D. Thesis, West Virginia University.

Kulander, B.R., and S.L. Dean. 1986. Structure and tectonics of central and southern Appalachian Valley and Ridge and Plateau Provinces, West Virginia and Virginia. *The American Association of Petroleum Geologists Bulletin* 70: 1674–1684.

Lessing, P. 1979. *Karst subsidence and linear features, Greenbrier and Monroe Counties, West Virginia*. Morgantown, WV: West Virginia Geological and Economic Survey Environmental Geology Bulletin EGB-17, one sheet.

McCue, J.B., J.B. Lucke, and H.P. Woodward. 1939. *Limestones of West Virginia*, vol. 12, 560pp. Morgantown, WV: West Virginia Geological Survey.

Ogden, A.E. 1974. The relationship of cave passages to lineaments and stratigraphic strike in central Monroe County, West Virginia. In *Fourth conference on Karst geology and hydrology proceedings*, ed. H.W. Rauch, and E. Werner, 29–32. West Virginia Geological Survey: Morgantown.

Ogden, A.E. 1976. *The hydrogeology of the central Monroe County karst, West Virginia*, 262pp. Ph.D. Thesis, West Virginia University.

Price, P.H., and E.T. Heck. 1939. *Greenbrier county*, 846. Morgantown, WV: West Virginia Geological Survey.

Price, P.H., and D.B. Reger. 1929. *Pocahontas county*, 531. Morgantown, WV: West Virginia Geological Survey.

Reger, D.B., and P.H. Price. 1926. *Mercer, Monroe, and Summers counties*, 963. Morgantown, WV: West Virginia Geological Survey.

Slingerland, R., and K. Furlong. 1989. Geodynamic and geomorphic evolution of the Permo-Triassic Appalachian Mountains. *Geomorphology* 2: 23–37.

Springer, G.S. 2000. The historical geology of West Virginia limestones: an introduction. *West Virginia Speleological Survey Bulletin* 14: 139–151.

Stamatakos, J., A.M. Hirt, and W. Lowrie. 1996. The age and timing of folding in the central Appalachians from paleomagnetic results: *GSA. Bulletin* 108: 815–829.

Hydrology of the Greenbrier Karst

3

William K. Jones

Abstract

Studies of the karst drainage systems of the Greenbrier limestone in southeastern West Virginia began in the early 1960s and were the first to make extensive use of water-tracing techniques and cave mapping in the USA. The carbonate aquifer is about 400 ft (120 m) thick in the Swago Creek area west of Marlinton (Pocahontas County) increasing to 1000 ft (300 m) in southern Monroe County. The basic hydrogeologic setting for the region consists of relatively flat-lying limestones exposed in valleys or plateaus and surrounded by higher elevation clastic units. Recharge to the conduit aquifer system is by capture of surface streams originating on the clastic rocks (allogenic recharge) and water infiltrating through the extensive areas of dolines (autogenic recharge). Only a few surface streams cross the carbonate outcrop, and even, these tend to loose water into the karst drainage systems. Much of the flow through the aquifer is through conduits under open channel conditions much like a surface stream with a roof. Discharge is concentrated at large springs that typically display rapid response to storm events, and the ratio of maximum to minimum discharge exceeds 100:1 for most of the springs. The karst caves and conduits are generally decoupled from surface topographic features, and the patterns of mapped cave passages are influenced by structural and stratigraphic characteristics. Insoluble beds within the Greenbrier Group may perch underground streams well above the apparent base level, and the underlying Maccrady Shale acts as an aquitard with several large caves developed along the contact of the shale and the overlying limestone. Much of this area can be considered a "contact karst" with the clastic rocks delivering concentrated recharge water onto the soluble limestones and the underling shales eventually forcing the return of conduit flow to the surface. The available data on water wells in the limestone suggest that most are actually producing from shaley units with the limestones acting as confining beds. The Greenbrier River and its tributaries represent base level for most of the area, and the relief of several hundred feet provides the hydraulic gradient. The area is underdrained by a well-integrated network of caves.

3.1 Introduction

This chapter presents an overview of studies of the karst hydrology of the Greenbrier limestone in southeastern West Virginia. The area ranges from Swago Creek west of Marlinton in Pocahontas County to Greenville in Monroe County (Fig. 3.1). The Greenbrier Group is exposed in an upland valley or plateau trending northeast/southwest. This is a mature karst aquifer with few surface streams making it across the width of the carbonate outcrop. The Greenbrier limestone outcrop area is less than one-mile wide (1.6 km) in the northern part to about 10 miles (16 km) wide in Monroe County, and the thickness increases from about 400 ft (120 m) in the Swago Creek area to 1000 ft (300 m) in the Greenville area. The sinking streams and caves drain to the

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Cave and Karst Systems of the World, https://doi.org/10.1007/978-3-319-65801-8_3