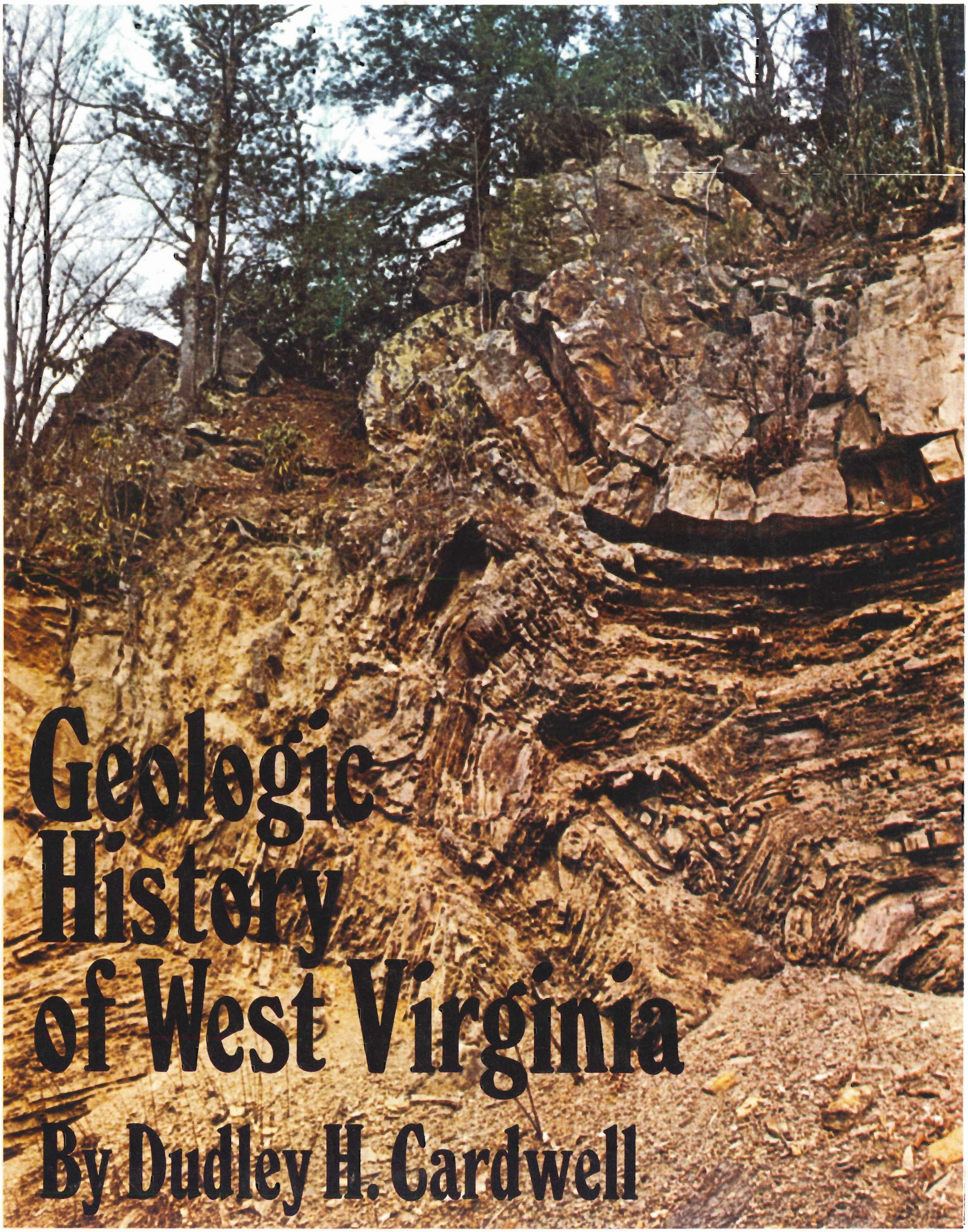

Geologic History of West Virginia

By Dudley H. Cardwell

EDUCATIONAL SERIES

West Virginia Geological and Economic Survey
Robert B. Erwin, Director and State Geologist

ON THE COVER: A *thrust fault* in the making. State Highway 39 one mile northwest of Minnehaha Springs, Pocahontas County. The strata (predominantly shale) in this photograph have been squeezed to the breaking point due to extreme lateral pressure from the southeast (right). If such pressure had continued over a long period of geologic time a segment of rocks from the southeast would have been pushed northwestward over strata of the same or younger age, to form a thrust fault, of which there are many in the Appalachian region (see Figure 2-d). The strata in this photograph were formed from sediments laid down in a shallow sea during Silurian time, about 400 million years ago. Photo by Dudley H. Cardwell.

CREDITS: Illustrations other than those specifically acknowledged in this booklet were drawn by Ray Strawser, Technical Photographer and Draftsman, and Dan Barker, Geologic Draftsman. Composition was done by Deborah Lawson, Editorial Assistant. Printing was done by Joanne Harris, Key Machine Operator. Collating and binding were done by Joanne Harris and Eddie Friel, Machine Operator.

Geologic History of West Virginia

An Important Note Please Read

Much has been learned about the geologic history of West Virginia and indeed the earth in general since this book was published in 1977.

For more up-to-date information, please consult the West Virginia Geological Survey at:

www.wvgs.wvnet.edu

Email info@geosrv.wvnet.edu

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Geologic History of West Virginia

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Dudley H. Cardwell

Educational Series

West Virginia Geological and Economic Survey
Robert B. Erwin, Director and State Geologist

November, 1975

Preface

This account of the geologic history of West Virginia is designed primarily to provide interested laymen, such as naturalists, teachers, students, or hobbyists, with a general treatment of the subject. It is not designed as a definitive scientific work on the subject. Accordingly, the author has tried as far as possible to avoid technical terms. Wherever such terms are used an attempt has been made to give adequate explanation.

Any geologic history must take account of the various periods of geologic time, terms with which the reader may not be familiar. Therefore, the reader must become acquainted with them. Figure 1 was designed to fulfill this purpose. It shows the chronological order of the periods, their duration, the most important events that took place, and the forms of life that existed during each period.

The author first conceived the idea of preparing this booklet when editing the Geologic Map of West Virginia that was published in 1968. This map shows the areas of outcrop of 60 geologic units or groups of units. In order to have a simpler map on a much smaller scale, these units have been combined and reduced to eight. This simplified map is termed a Systemic Map and appears as Figure 3 of this booklet. The eight units correspond to the rocks of the various periods important in the geologic history of West Virginia.

It is hoped that the professional geologist who is not acquainted with West Virginia geology will find in this booklet a way to rapidly summarize the important events of the various geologic periods, as applied to this State.

It also is hoped that the lay reader who has previously had no occasion to think of events prior to the time of human history will gain some conception of the vast expanse of time the earth has been in existence and of how infinitesimal is the portion of this time during which man has occupied this planet.

Acknowledgments

The author extends thanks to Dr. Robert B. Erwin, State Geologist and Director of the Survey, for supporting and encouraging him in this undertaking, and for his helpful suggestions. Thanks are also extended to Doctors J. A. Barlow, Peter Lessing, D. G. Patchen, and R. A. Smosna, and to Mrs. Mary Behling, all of the West Virginia Geological and Economic Survey, for having carefully read the manuscript and for their helpful criticisms and suggestions. Acknowledgment is also extended to Doctors Hugh Buchanan and Steven Warshauer of the Department of Geology of West Virginia University for some of the paleontological information used.

Photographs and diagrams used in preparation of many of the figures were obtained from miscellaneous sources. Specific acknowledgment for permission to use each of these is made on the figures involved.

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GEOLOGIC HISTORY OF WEST VIRGINIA

By

Dudley H. Cardwell

Introduction

In ancient literature we read of the "everlasting hills." Even up into the present century it was generally believed that the mountains, hills, oceans, continents, streams, lakes, and all other physical features of the earth were unchanged from "the way God made them" in a sudden act of creation only a few thousand years ago.

Now we know that the age of the earth is so great that it must be measured in billions of years, and even short intervals of geologic time are measured in tens of millions of years. We also know that there are no "everlasting hills," and that in spite of the apparent slowness of most of the forces of nature, vast and significant changes have taken place. Sediments that were deposited on the sea floor have been elevated to form some of our highest mountains. Some of the highest mountains of the past, through the processes of erosion, have been reduced nearly to sea level. Not only that, but vast areas are known to have been reduced by erosion and re-elevated several times.

Not all of the changes have been slow and imperceptible. Some of the changes that take place on our planet are swift and violent. On March 27, 1964, stresses that had been building up within the earth for centuries suddenly resulted in the great Alaskan earthquake that killed at least 66 people, injured more than 100, and caused property damage estimated at $500,000,000. Not only were large segments of such cities as Anchorage, Valdez, Kodiak, and Cordova destroyed, but tsunamis (seismic sea waves) spread as far as Japan and Hawaii, and Crescent City, California, experienced a water wave 12 feet high that resulted in the death of 12 persons.

An even more spectacular event began on February 20, 1943, in a quiet farmland area near Michoacan, Mexico, when a volcano, later named Parícutin, suddenly erupted. For 9 years this volcano spread tremendous flows of lava and volcanic ash over a hitherto volcanically inactive area. And finally, in 79 A.D. in Italy, the well known but long inactive volcano Vesuvius suddenly erupted and completely destroyed the cities of Pompeii and Herculaneum.

Some areas of the earth are particularly active volcanically. A good example is the unstable Circum-Pacific belt that extends northward from the southern tip of Chile, along the Pacific Coast of South, Central, and North America to Canada and Alaska, west across the Aleutian Chain of volcanic islands, then southward down the Pacific Coast of Asia to New Guinea and New Zealand. In this Circum-Pacific belt earthquakes, volcanic eruptions, and accompanying earth changes take place with startling frequency. However, activity is not confined entirely to designated unstable portions of the earth. Even the most stable areas have undergone perceptible change, and many have undergone huge changes only partly understood by students of the subject.

Compared with the active areas mentioned above, West Virginia is relatively stable. However, a small amount of volcanic activity has occurred in extreme eastern West Virginia during the last 200 million years, and during the interval from about 200 million to 500 million years ago violent movements caused the wrinkling of the earth's crust and the movement of various segments with respect to others which resulted in the formation of the Appalachian Mountains.

Geologic Principles

Geochronology

Scientific estimates of the age of the earth range from 4 billion to more than 6 billion years. To the author's knowledge, the oldest rocks thus far dated are some gneisses from West Greenland that were determined to be 3.98 ± 0.17 billion years old (Black and others, 1971, p. 253). Mintz (1972, p. 355) placed the age of the earth at 4.5 to 5 billion years. Other estimates have been somewhat higher.

For purposes of this booklet the author will use a figure of 5 billion years as an approximate age for our planet.

Not until the discovery of natural radioactivity, in 1895, did we have a reliable method for determining the age of the earth, nor could we date specific events in geologic history with any degree of accuracy. Now it is known that radioactive change, or decay as it is ordinarily termed, takes place in certain minerals at a constant rate, more or less independent of external conditions such as temperature, pressure, and chemical environment. Common minerals in which these changes can be measured are potassium feldspars, micas, hornblende, pyroxenes, and zircon. Less common radioactive minerals are glauconite and those containing uranium. It is now possible to make careful scientific studies of rocks containing these minerals and to determine with relative accuracy how long such rocks have been in existence. This is the technique of radiometric dating.

In the development of the science of geology, it has been customary to divide geologic time, particularly the last billion years, into eras, periods, epochs, and even smaller divisions (Figure 1).

Geologists still speak of the ages of rocks and events according to the period of geologic time in which they were formed or took place. With the advent of radiometric dating methods, the time of existence and the duration of each of the periods can be determined with far more accuracy than was the case a few decades ago (Figure 1 and Table 1).

To get a limited concept of the vast extent of geologic time, let us use an analogy and let 1 year correspond to the entire period of the Earth's existence. In such case, man in his most primitive form would not appear until approximately 8:25 p.m. on New Year's Eve. The most ancient Egyptian pyramid would appear about one-half minute before midnight, King Solomon's temple just 19 seconds before midnight, and Christ at 12 seconds before midnight, all on New Year's Eve (Table 2). Thus, with this analogy the entire period of recorded human history would correspond to less than 1 minute out of an entire year. The lifetime of a person who reaches the Biblical "three score and ten" would be about ½ second. Using the same analogy, the very first traces of known life would represent organisms living about May 12. The lava flow that later became the oldest rock known at the surface in West Virginia would have been laid down on October 18 or later.

Kinds of Rocks

In order to understand earth history, it is necessary to have some knowledge of the three classes of rocks occurring in nature and how they are formed. These classes are igneous, sedimentary, and metamorphic.

Igneous rocks were formed by solidification from the molten or liquid state, at or below the surface of the earth. If the solidification took place below the surface, the rocks are considered as ***intrusive***. Usually, because crystallization was slow, the mineral crystals of such rocks are sufficiently large to be dis-

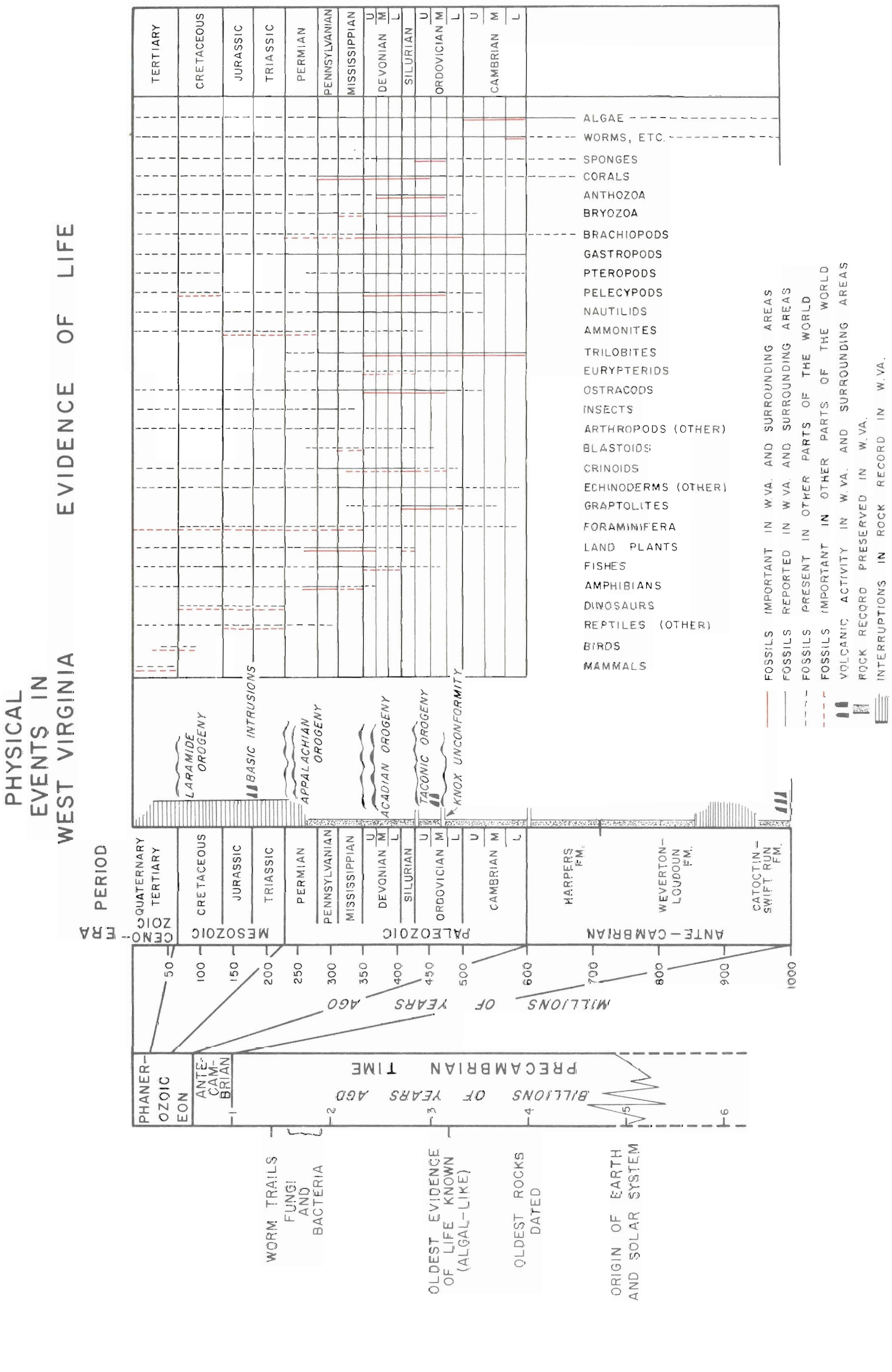


Figure 1. Geologic Time Scale Showing Major Events in the Geologic History of W. Va.

Table 1. Table of Ages (modified from several recent sources)

Period	Duration*	Began**	Ended**
Quaternary	2.5	2.5	
Tertiary	63.5	66	2.5
Cretaceous	69	135	66
Jurassic	50	185	135
Triassic	40	225	185
Permian	45	270	225
Pennsylvanian	45	315	270
Mississippian	30	345	315
Devonian	60	405	345
Silurain	25	430	405
Ordovician	70	500	430
Cambrian	100	600	500
Ante-Cambrian	400	1,000	600
First evidences of life known		3,200	

* Millions of years. ** Millions of years ago.

Table 2. Geochronology

Using the analogy: Let 1 year equal the entire time of existence of the earth (5 billion years).

First traces of life known	May 12
Begin "Ante-Cambrian"	Oct. 18
Begin undisputed Cambrian	Nov. 18
Begin Ordovician	Nov. 25
Begin Silurian	Nov. 30
Begin Devonian	Dec. 2
Begin Mississippian	5 p.m., Dec. 6
Begin Pennsylvanian	12:30 a.m., Dec. 9
Begin Permian	7:00 a.m., Dec. 12
Begin Triassic	2 p.m., Dec. 15
Begin Jurassic	12 m., Dec. 18
Begin Cretaceous	2:30 a.m., Dec. 22
Begin Tertiary	4:00 a.m., Dec. 27
Begin Quarternary	7:00 p.m., Dec. 31
Man's first appearance	8:25 p.m., Dec. 31
Most ancient Egyptian pyramid	11:59:27, Dec. 31
King Solomon's temple	11:59:41, Dec. 31
Christ	11:59:48, Dec. 31

cernible to the unaided eye. A good example is granite. If the solidification took place at the surface, the rocks are considered as ***extrusive***. These are the rocks formed by solidification of material emitted from volcanoes. Such rocks are abundant in the volcanically active portions of the earth. A good example is Hawaii, which is composed predominantly of lava that has hardened into the black volcanic rock, basalt. Crystallization has been so rapid that individual crystals are usually so small as not to be recognizable with the unaided eye.

Sedimentary rocks are formed at or near the surface by the consolidation of sediments laid down through the agency of water, wind, glaciers, or organisms. Sediments are derived from the weathering and destruction of preexisting rocks and usually are deposited in a more or less finely divided state, either physically, chemically, or organically. Sediments may be laid down close to the source of the material or they may be transported for considerable distance. Common sedimentary rocks are: ***shale***, formed from the consolidation of clay; ***sandstone*** from the consolidation of sand; ***conglomerate*** from the consolidation of gravel; and ***limestone*** and ***dolomite***, which may be chemical (precipitated from solution), organic (shells, etc.), or strictly physical in origin.

Metamorphic rocks are formed from preexisting rocks by processes within the earth such as heat, pressure, and chemical change. To be classified as a true metamorphic rock the change from the original character must be sufficient to form a completely new type of rock. Examples of metamorphic rocks are schist, gneiss (pronounced "nice"), slate, quartzite, and marble. Metamorphic rocks known to have been derived from preexisting igneous rocks are designated ***meta-igneous***. Those known to have been derived from pre-existing sedimentary rocks are designated ***meta-sedimentary***. Normally ***slate*** is formed from the metamorphism of shale, ***quartzite*** from the metamorphism of sandstone, and ***marble*** from the metamorphism of limestone. ***Schist*** and ***gneiss*** may be either meta-sedimentary or meta-igneous. Many times it is impossible to determine the character of the original rock.

Correlation and Age Determination

As previously stated, only since the discovery of radiometric dating methods have reliable estimates of the actual age of rocks been possible. Also, such determinations are in most cases of igneous rather than sedimentary rocks. Sedimentary rocks do not usually contain the necessary minerals for radiometric dating, and when such minerals are present, they were in most cases derived from preexisting rocks and, therefore, are older than the sedimentary rock itself.

Geologists have long been accustomed to designating the ages of sedimentary rocks and extrusive igneous rocks in terms of the period or other division of geologic time during which the rock was laid down. A number of tools are available to aid in making these determinations. Some of the more important are the following:

1. ***Superposition of Beds***—Almost all sedimentary rocks are laid down in nearly horizontal layers, the younger beds being laid down above the older ones. Where no appreciable disturbance of the beds has taken place, the lower beds may be assumed to be older than the overlying beds.
2. ***Lithologic Character***—In following a succession of beds vertically one usually encounters a distinct lithologic change in passing from one formation to another. A similar succession of beds at a nearby locality may be assumed to have been laid down under similar conditions and at the same or nearly the same time. The beds of the same lithologic character in the two localities may then be considered as correlative. If it is possible through continuous exposure to trace the beds from one locality to the other, this correlation is confirmed. Even if the lithologic character changes and one type of

bed can be traced directly to the other, the two beds may be assumed to have been deposited at the same or nearly the same time, and therefore to be correlative.

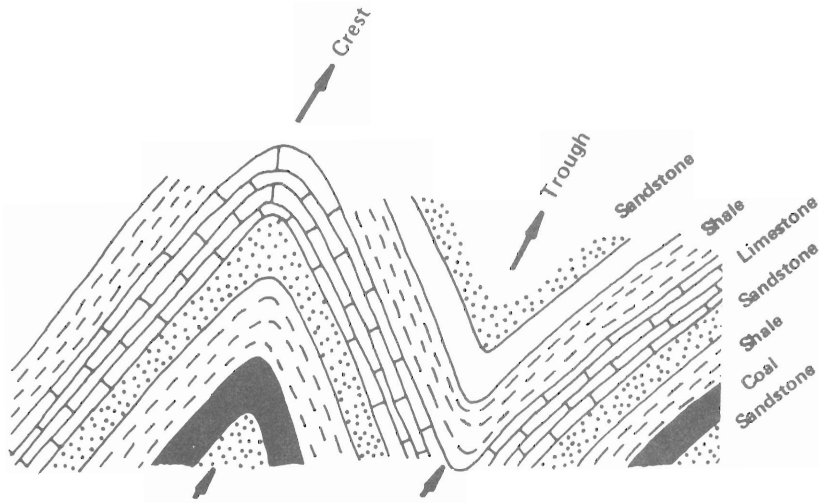
3. ***Assemblage of Fossils***—Where successions of beds are far apart, there are seldom sufficient lithologic or physical characteristics to establish a correlation. In such cases, there may be similar assemblages of fossils (evidences of life) that will enable the geologist to say that the beds were laid down or deposited at approximately the same time, and therefore that they are correlative. Such methods have even enabled geologists to correlate the rocks of Europe with their time equivalents in North America.
4. ***Mechanical Well Logging***—The correlation of formations in the subsurface is of great importance in the drilling of wells for oil and gas. In addition to the use of lithologic characteristics and fossil assemblages described above, mechanical logs, using mostly electric or radioactive properties of the formations penetrated, are being used with great success. Development of these techniques was begun in the early 1930s and now forms the basis for a tremendous business serving the oil and gas industry. Well logging is most valuable in correlating wells in a thickly drilled area, but also has been extensively used regionally in setting up good and easily understood correlations.

Structural Geology

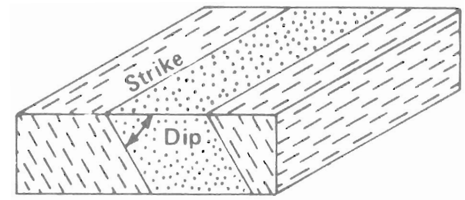
Subtle forces, still only partially understood, are constantly at work within the earth's crust. Sediments are laid down in horizontal or nearly horizontal beds, usually below or near sea level. These may later be elevated and found in our highest mountains. They may be tilted, folded, squeezed, and broken, and are sometimes found in vertical or nearly vertical position, or even overturned. When beds are folded, the arches are known as ***anticlines*** and troughs as ***synclines*** (Figure 2a). In the case of tilted beds, two terms are important. The amount of inclination, measured in degrees from the horizontal , is called ***dip***. A horizontal line along the surface of the bed gives the direction of ***strike***, which is always at right angles to the direction of dip (Figure 2b). The horizontal direction in which the crest of an anticline or trough of a syncline trends is approximately the same as the strike of the beds involved.

Vast segments of the earth may move with respect to adjacent segments along shear zones referred to as ***faults***. Displacements along these faults may range from bare perceptibility to thousands of feet. Normally, one segment slides downward along an inclined surface to form a ***normal*** or ***gravity*** fault (Figure 2c). However, as in several localities in the Appalachian region, vast segments of the earth's crust have been pushed for miles up and over younger beds, forming ***reverse*** or ***thrust*** faults (Figure 2d). After beds have been uplifted and eroded, they may again sink to or below sea level and additional beds can be deposited thereon. The result is an ***unconformity*** that marks the break in sedimentation (Figure 2e).

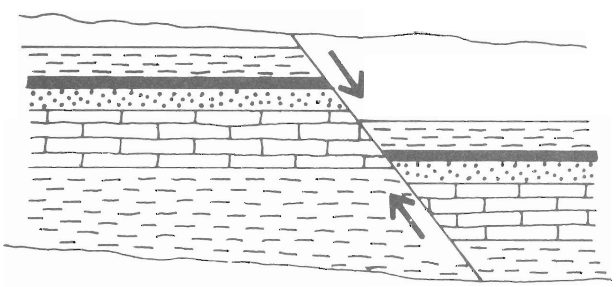
Following uplift, long periods of erosion may expose rocks formed from solidification of molten igneous masses well below the surface. High mountains have been eroded and gradually worn nearly to sea level, only to be later elevated again and the cycle repeated.



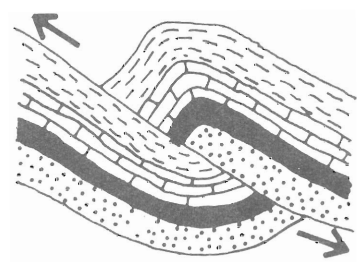
(a) Anticline and syncline



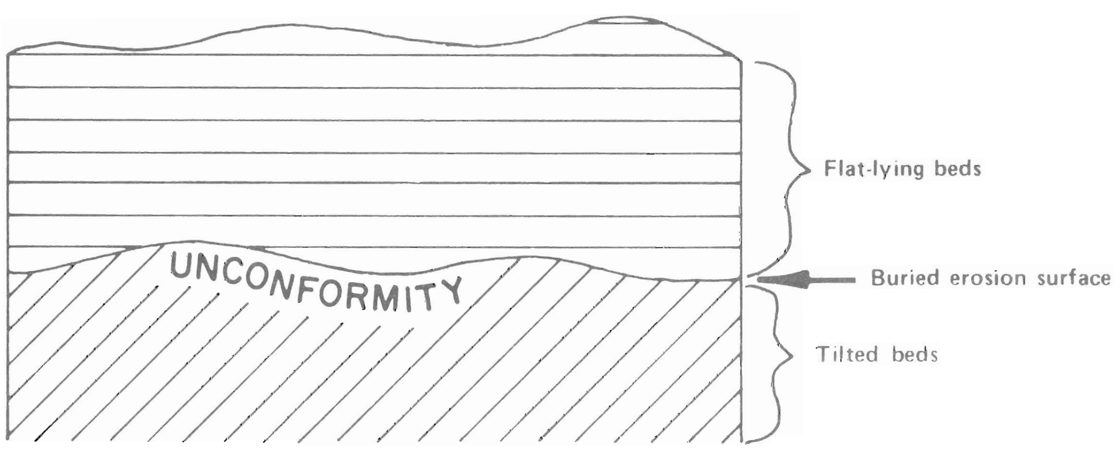
(b) Attitude of beds



(c) Normal or gravity fault



(d) Reverse or thrust fault



(e) Unconformity

Figure 2. Structural Features

Geologic History—Preliminary Comments

In writing the geologic history of our planet, we give an account of a succession of inundations of the continental areas by the sea, the deposition of vast thicknesses of sediments, uplift and erosion of land masses, folding and faulting, the development and evolution of the various forms of life, intrusions of igneous masses, volcanic activity, the covering of vast portions of the earth by glaciers or ice sheets, and even the shifting of the continents, all of which are repeated again and again over the vast span of geologic time.

Until quite recently there was no single, generally accepted, unifying concept to explain the occurrence and succession of many of these phenomena throughout geologic time. It was not until the late 1960s that such a unifying concept emerged, based in large part on observations made during the course of modern oceanographic investigations. The grand concept called "plate tectonics" or the "new global tectonics" holds that the earth's crust consists of a number of large and smaller, relatively rigid lithospheric "plates" that move about relative to each other over a more mobile underlying zone of material in the earth's interior called the astheosphere. It is the relative motion of these "plates" and their resultant interactions (e.g., collisions, pull-aparts, "side-swipes") that result in the succession of earthquakes, volcanic activity, mountain building with subsequent erosion, and subsidence of other areas and attendant deposition of sediments recorded in the geologic record. Although many aspects of the concept are still less than perfectly understood (e.g., the exact nature and cause(s) of the driving forces deep within the earth causing the motion of lithospheric "plates"), the "new global tectonics" gives us a powerful new tool for deciphering earth history.

The succeeding pages deal with this history, particularly as it applies to the state of West Virginia. For the most part they describe the physical conditions, events, and life of the individual periods of geologic time.

It is beyond the scope of this booklet to put all of the events described in their actual perspective in the grand scheme of things on a continental or intercontinental scale. The reader, however, should always bear in mind that the fundamental causes of many of the events described are directly related to the larger-scale evolution of the earth resulting from the relative motion and interaction of large lithospheric "plates."

Figure 3 shows in a generalized way the distribution of rocks of the various systems as exposed at the surface in West Virginia. This map is a condensation of the 1968 Geologic Map of West Virginia (Cardwell and others), which shows in considerable detail the distribution of smaller units or rock formations. Figure 4 is a generalized stratigraphic column which shows the vertical succession of the various rock formations and the ages thereof.

GEOLOGIC MAP OF WEST VIRGINIA

WEST VIRGINIA GEOLOGICAL AND ECONOMIC SURVEY

Robert B. Erwin, State Geologist

1969

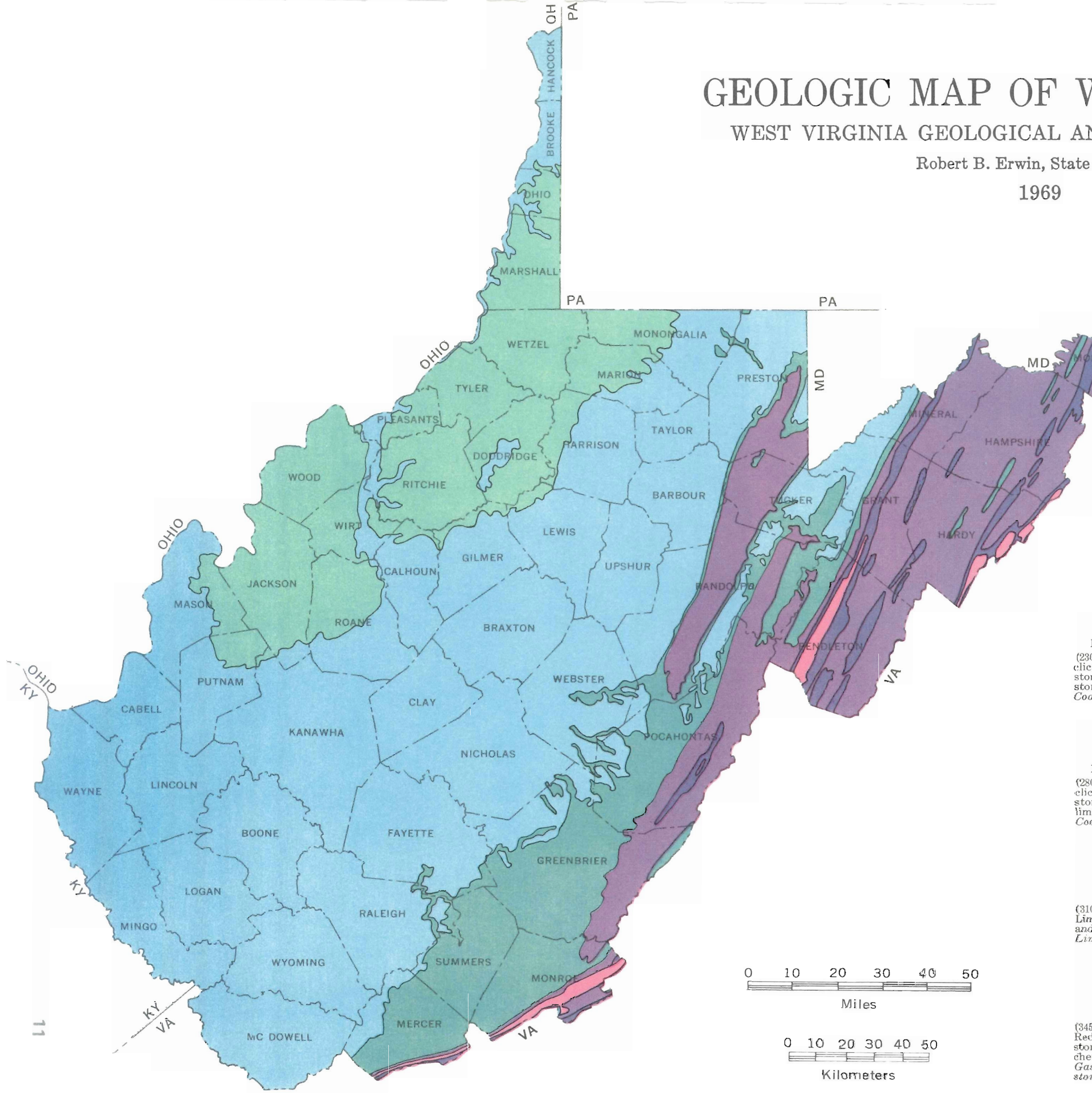


Figure 3.

LEGEND

PERMIAN OR PENNSYLVANIAN
(230+ mil. yrs. ago). Cyclic sequences of sandstone, red beds, shale, limestone and coal.
Coal.

PENNSYLVANIAN
(280-310 mil. yrs. ago). Cyclic sequences of sandstone, shale, clay, coal, and limestone.
Coal, gas, oil, brine.

MISSISSIPPIAN
(310-345 mil. yrs. ago). Limestone, red beds, shale, and sandstone.
Limestone, gas, oil, brine.

DEVONIAN
(345-405 mil. yrs. ago). Red beds, shale, sandstone, limestone, and chert.
Gas, silica sand, limestone.

SILURIAN
(405-425 mil. yrs. ago). Sandstone, shale, limestone, rock salt, and ferruginous beds.
Gas, limestone, artificial brine.

ORDOVICIAN
(425-500 mil. yrs. ago). Limestone, dolomite, sandstone, shale, and metabentonite.
Limestone (particularly low silica), building stone, clay-shale.

CAMBRIAN
(500-600 mil. yrs. ago), Limestone and dolomite, some sandstone and shale.

PRECAMBRIAN
(More than 600 mil. yrs. ago). Greenstone. Present only in extreme eastern Jefferson County.

GEOLOGIC ERAS, PERIODS AND EPOCHS			ROCK TERMINOLOGY	HISTORY
CENOZOIC ERA				Lake deposits and drainage changes due to glaciation to north
MESOZOIC ERA	CRETACEOUS JURASSIC TRIASSIC			Igneous activity in Pendleton and surrounding counties
PALEOZOIC ERA	PERMIAN		DUNKARD GROUP	Appalachian Orogeny. West Virginia was uplifted and became an erosion surface. For more than 200 million years it has never been invaded by the sea and no extensive sediments have been deposited.
	PENNSYLVANIAN	LATE	MONONGAHELA GROUP CONEMAUGH GROUP	
		MIDDLE	ALLEGHENY FORMATION	Swamp conditions throughout most of the State resulted in the preservation of plant remains which were altered to peat and in turn altered to the many coal seams.
		EARLY	POTTSVILLE GROUP: KANAWHA FM.; NEW RIVER FM.; POCAHONTAS FM.	
	MISSISSIPPIAN	LATE	MAUCH CHUNK GROUP	Nonmarine environment. Shale and sandstone predominate, red beds very predominant near top.
		MIDDLE	GREENBRIER GROUP	Shallow sea once again covered most of West Virginia. Carbonate deposition predominates. Last important marine deposition in West Virginia.
		EARLY	MACCRADY FORMATION POCONO GROUP	Uplift continued and a nonmarine environment existed. Sandy shales predominate.
	DEVONIAN	LATE	HAMPSHIRE FORMATION CHEMUNG GROUP BRALLIER FORMATION	Shoreline gradually shifted westward, causing abundant continental beds which were deposited farther and farther westward throughout the epoch. (Acadian Orogeny with main uplift to northeast)
		MIDDLE	HARRELL SHALE MAHANTANGO FORMATION MARCELLUS FORMATION	Uplift to east provides clastic sediments for marine dark shale with sandstone layers.
			ONESQUETHAW STAGE: TIOGA BENTONITE	Volcanic activity to east results in thin bentonite zone.
			ONESQUETHAW STAGE: ONONDAGA LIMESTONE / HUNTERSVILLE CHERT / NEEDMORE SHALE	Slight subsidence. Shale deposition predominant in northeast, chert in southeast, passing to cherty limestone in west.
		EARLY	ORISKANY SANDSTONE	Sea somewhat shallower. Blanket sandstone deposition.
			HELDERBERG GROUP	Slight submergence creates a predominantly carbonate-producing environment, but with invasions of sand and clay.
	SILURIAN	CAYUGAN — LATE	TONOLOWAY FORMATION (BLOOMSBURG FACIES)	Sea covered most of the State. Carbonates predominate in southwest. Evaporite deposition in restricted sea of northern West Virginia.
			WILLS CREEK FORMATION (BLOOMSBURG FACIES)	Red delta deposits in northeastern West Virginia; marine shale and limestone to southwest.
			WILLIAMSPORT FORMATION (BLOOMSBURG FACIES)	Red bed deposition continues in northeast; shallow sea sandstone deposition in rest of State.
		NIAGARAN — MIDDLE	MCKENZIE FORMATION (BLOOMSBURG FACIES)	Tidal flat in northeast marks beginning of red bed deposition. Shallow marine carbonates in southwest.
			ROCHESTER SHALE KEEFER SANDSTONE ROSE HILL FORMATION	Predominantly a shallow marine environment with clastic deposition.
		EARLY	TUSCARORA SANDSTONE	Shallow sea covered the State. Sandstone deposition.
	ORDOVICIAN	LATE	JUNIATA FORMATION	Delta-type environment throughout State. (Taconic Orogeny formed an area of high mountains to the east, the source of most of the sediments of the Late Ordovician and Silurian.)
			OSWEGO FORMATION	Delta-type environment in eastern West Virginia.
			REEDSVILLE SHALE	Clastic deposition in marine environment.
		MIDDLE	TRENTON GROUP / MARTINSBURG FM. NEALMONT LS. BLACK RIVER GROUP ST. PAUL GROUP	Carbonate deposition continues to predominate. (Volcanic activity caused deposition of bentonite beds.)
		EARLY	KNOX: BEEKMANTOWN GROUP	Knox unconformity; predominant in Ohio and western West Virginia.
	CAMBRIAN	UPPER	KNOX: CONOCOCHEAGUE FM. (EAST) / COPPER RIDGE DOL. (WEST)	Carbonate deposition.
		MIDDLE	ELBROOK FORMATION	
		LOWER	WAYNESBORO FORMATION	Clastic deposition.
			TOMSTOWN DOLOMITE	Shallow sea carbonate deposition.
			CHILHOWEE GROUP: ANTIETAM FM.	First fossils in West Virginia rocks.
	Ante-Camb. (?)		CHILHOWEE GROUP: HARPERS FM. WEVERTON-LOUDOUN FORMATION	Clastic deposition in narrow trough in eastern West Virginia; beginning of Appalachian Geosyncline.
			CATOCTIN FORMATION	Volcanic activity in eastern West Virginia.
PRECAMBRIAN			CRYSTALLINE ROCKS	History complex and obscured.

Figure 4. Generalized Stratigraphic Column

Precambrian Basement Rocks

No rocks of definite Precambrian age are exposed in West Virginia, but the entire State is underlain by them. These are the crystalline rocks, ordinarily classified as basement rocks, which have undergone a very high degree of metamorphism involving recrystallization, rearrangement of some minerals, and the formation of new minerals such as garnet and chlorite. They belong to such rock types as schist, quartzite, slate, and gneiss, and may have been formed from either igneous or sedimentary rocks. These crystalline rocks are abundantly present in that part of Virginia adjacent to the Eastern Panhandle. Also, they have been found in the few West Virginia wells drilled to sufficient depth to encounter basement, and would be found in any well drilled to sufficient depth anywhere in the State. From the geological and geophysical data available, this depth should range from near zero in eastern Jefferson County to nearly 25,000 feet in the basinal area in the central part of the State.

On the 1968 State Geologic Map, we designate the basement rocks as being of undisputed Precambrian age, in contrast to those described in the next section under "Ante-Cambrian," whose Precambrian age is somewhat in doubt.

Hadley (1964) made radiometric determinations and reported ages of crystalline rocks in the Central Appalachians to be approximately 1.1 million years. He reported some in the Southern Appalachians at 800 million years.

In the wells of West Virginia, the youngest reported age for Precambrian rocks is that by Davis and others (1960) from the Sandhill well of Wood County, 870 million years. However, Bass (1959, p. 157) made age determinations from the same well, and placed the age at 940 ± 20 million years, a figure which may be more realistic. For purposes of this booklet, the rough estimate of one billion years will be considered as the age of the youngest definitely Precambrian rock. Since the earth is considered as having been in existence for 5 billion years, the geologic history of definitely Precambrian time may be considered as covering a period of roughly 4 billion years, or about four-fifths of the entire time of existence of the earth. But, because of the intense metamorphism the rocks have undergone and the various factors described below, our knowledge of the history of this long interval of time is for the most part obscured.

Earthquakes and volcanic activity must have been intense throughout Precambrian time. Land masses in the form of mountains were elevated and eroded down many times before the general continental outlines were established. However, it appears that these general outlines were established by the end of Precambrian time, for every continent or important land mass today has at least one Precambrian terrane, known as a ***shield area***, which seems to have remained more or less permanent, and never to have been covered deeply by later sediments. These have remained as near-permanent land masses and constitute the cores of our present-day continents.

In North America, by far the most important of these land masses is the Canadian Shield, which today is exposed at the surface over an area of approximately 3 million square miles, mostly in Canada, but which extends south of the Great Lakes into the northern part of the United States. At the close of Precambrian time, it is believed that this continental mass covered all but the peripheral portions of the present continent, including most of West Virginia.

Precambrian history is further obscured by intense folding and faulting. There were probably several periods of widespread granite intrusion, with the rocks solidifying well below the surface of the earth. This was followed by long periods of metamorphism and erosion, leaving exposed these deep-seated rocks. Processes of this type produced such rocks as the granite gneiss found at a depth of 13,272-13,331 feet in the Sandhill well of Wood County, West Virginia (Shearrow, 1959, p. 52).

In Precambrian time, there were no land plants to hold the soil in place. Torrential rains and terrific dust storms must have been abundant, producing and transporting soil at a rapid rate. The sediments thus formed were consolidated to form sedimentary rocks, and later metamorphosed to form such rocks as slate, quartzite, and schist.

Life in its most primitive form began sometime during the Precambrian. The high development of the first Cambrian forms of life indicates that a substantial part of all evolution that has taken place during the entire history of the earth had already taken place. Hence, the simpler forms of life must have been abundantly present in the seas prior to Cambrian time. However, so far as is known, evidences of Precambrian life in the vicinity of West Virginia, if ever present, have been completely destroyed by metamorphism.

Considering the earth as a whole, it may be stated that there are scattered traces of life in the Precambrian, but for the most part evidence of this life has been either obliterated by metamorphism, or the simple forms of life then in existence were so deficient in hard parts that no evidence of their existence remains. According to Stokes (1973, p. 225) the oldest suspected fossil organisms are an algalike form from the 3.2- to 3.3-billion-year-old Onverwacht Series of South Africa. Fungi and bacteria are reported in rocks 1.6 to 1.8 billion years old. Trails and burrows of worm-like creatures are reported in rocks approximately 1.4 billion years old and sponges have been reported from rocks approximately 1 billion years old.

"Ante-Cambrian"

Precambrian time is generally defined as extending from the birth of the planet to the time when fossils first became abundant in rocks, about 600 million years ago. In West Virginia the oldest formation that qualifies as Cambrian under the above definition is the Antietam Sandstone (Figure 3). Below the Antietam there are two older sedimentary units that, so far as is presently known, are nonfossiliferous, and below these there is a metamorphosed igneous flow. From bottom upward these units are the Catoctin-Swift Run, the Weverton-Loudoun, and the Harpers Formations. All of these lack the intense metamorphic characteristics exhibited by the underlying definitely Precambrian basement rocks as described in the previous section. Although the consensus of opinion among geologists seems to be that these rocks should be classed as Precambrian, there is a difference of opinion among geologists as to the proper age designation of these pre-Antietam formations.

In 1949, the late Dr. Herbert P. Woodward described the above units as "Paleozoic and Older Rocks," and suggested the term "Ante-Cambrian" to cover this interval, which is believed to have extended from about 1 billion to 600 million years ago. Thus, these formations are here being discussed under the separate heading "Ante-Cambrian" (Figures 1 and 4).

In continuing our geologic history let us picture West Virginia and surrounding territory as it was prior to the volcanic activity that produced the rock later to form the Catoctin Greenstone, the basal member of the "Ante-Cambrian." It is probable that all of West Virginia and even most of the United States was a land area, and that the then existing rocks (described in the previous section) had already undergone a considerable degree of metamorphism. The Canadian Shield was surrounded by shallow ancient seas with fringing, volcanic island arcs.

During Catoctin time, a huge basaltic lava flow spread over northern and central Virginia and extended into Pennsylvania, Maryland, and eastern West Virginia. It is not known how far this flow extended into West Virginia, but perhaps it covered most of the eastern part of the State. This lava hardened to form a basalt that was later altered by metamorphism to a greenstone, in places sufficiently schistose to have been designated the Catoctin Schist by some geologists. The two dominant metamorphic minerals are chlorite, which causes the distinct dark green color, and locally epidote, producing a lighter green to yellow color. The maximum thickness of the Catoctin in West Virginia is estimated to be about 1,000 feet, but it is known to be as thick as 1,400 feet in some localities in other states.

Local occurrences of sedimentary material (Swift Run Formation) similar to the Weverton-Loudoun (described in subsequent paragraphs), but below or along with the Catoctin, suggest that limited sedimentation took place during the Catoctin interval.

The author as well as the majority of geologists familiar with the Catoctin Formation have classified it as Precambrian in age. However, Woodward (1949, p. 49) pointed out that the degree of metamorphism of the Catoctin Formation is distinctly less than that of the underlying rocks, indicating that the latter probably underwent considerable metamorphism before deposition of the Catoctin lava. Because of this doubt as to proper age classification, we include the Catoctin with the so-called "Ante-Cambrian," and on the 1968 Geologic Map of West Virginia designated it by the symbol **ЄPЄ** (Cambrian-Precambrian) to indicate this questionable age. Only two small areas of outcrop are present in West Virginia, both on the Virginia line in extreme eastern Jefferson County (Nickelsen, 1956).

After the Catoctin lava flow, West Virginia remained a land surface for an indefinite period of time. Erosion and further metamorphism took place, and thus we find a pronounced unconformity or buried erosion surface in our rock section. This is in addition to one at the base of the Catoctin Formation that seems to be more pronounced.

After erosion of the Catoctin Greenstone, the area of eastern West Virginia became part of a rapidly sinking linear belt (***geosyncline***) that formed the locus for the beginning of a tremendous accumulation of sediment that continued almost uninterrupted throughout Paleozoic time. This trough covered roughly the area between the Central Lowlands and the Canadian Shield on the west and the Coastal Plain and Atlantic Ocean on the east and extended from central Alabama north-northeastward into Canada (Figure 5). Both the Canadian Shield and the postulated ancient volcanic islands and land areas that lay somewhere to the east have been cited as source areas for this vast accumulation of sediments.

In West Virginia and vicinity, the first sediments deposited after post-Catoctin erosion accumulated in this narrow trough that extended through parts of Georgia, Tennessee, North Carolina, Virginia, West Virginia, Maryland, Pennsylvania, New York, Vermont, and into Canada. This area coincides roughly with the Valley and Ridge Province as indicated on Figure 5. Rapid erosion and relatively short distances of transportation brought in tremendous quantities of sediment and deposited the material that now forms the Weverton-Loudoun Formation and its equivalents. Thicknesses of this formation in excess of 10,000 feet have been reported from Georgia and North Carolina, but the thickness is considerably less in West Virginia, where it is estimated at 1,000 to 1,400 feet.

The Weverton-Loudoun is predominantly an ***arkosic*** coarse-grained sandstone (that is, it contains an abundance of feldspar), indicating the nearness of the source area. Some shaly material is present. Also, fragments of epidote and other Catoctin-derived material are found within the Weverton-Loudoun, supporting the possibility of an unconformity between the two formations.

After the deposition of Weverton-Loudoun sediments, there was further subsidence and widening of the Appalachian trough. Whether or not there was a break in the sedimentation is not known, but much finer material in the form of sandy clays dominated. When consolidated, this material formed a sandy shale that, with varying degrees of metamorphism, became the Harpers Formation. In West Virginia and adjacent portions of Virginia and Maryland, limited metamorphism has produced a phyllite or micaceous schist with thin ***sericitic*** (finely micaceous) sandstone streaks. In West Virginia, the Harpers is exposed only as a narrow band passing through Harpers Ferry in Jefferson County. The westward extent of the formation in the subsurface is unknown due to lack of wells to sufficient depth in eastern West Virginia. However, it is believed to be quite limited.

The Harpers and its equivalents are found in West Virginia, Virginia, Maryland, Pennsylvania, and extend southward into Tennessee. The thickness at Harpers Ferry is estimated at 1,200 feet. At Waynesboro, Pennsylvania, this thickness is reported to be 2,750 feet.

The Harpers has so far proven of no economic importance but is important geologically in that it exhibits a rather typical example of limited metamorphism. The original character of the rock is partly preserved. Both bedding and cleavage, the latter produced by metamorphism and deformation, can be distinctly identified. This is in contrast to the highly metamorphosed rocks below the Catoctin in which the bedding planes have been almost entirely obliterated and many completely new metamorphic minerals formed.

Fossils, although absent in Harpers and older rocks, abound in sediments above the Harpers, and are of species found elsewhere in the world at the base of the fossil-bearing section. Hence, although we have no age determination on which to base our belief, it seems logical that the 600-million-year mark, now considered as the beginning of the true

Cambrian, occurred between the deposition of the Harpers and Antietam Formations. Hence, the base of the Antietam Formation should be considered the base of unquestionable Cambrian beds, although lower, unfossiliferous rocks may still be Cambrian in age.

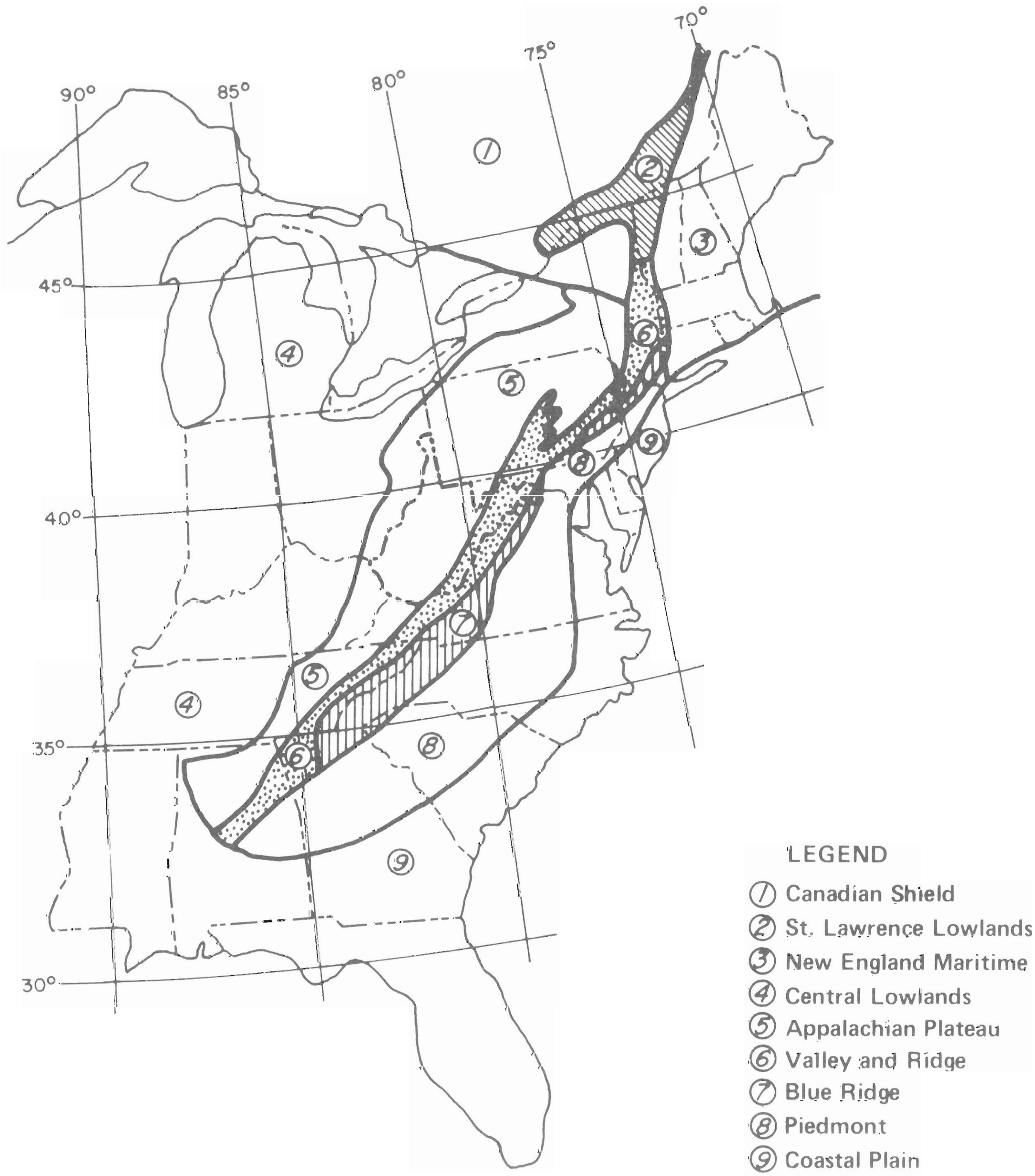


Figure 5. Physiographic Provinces of Eastern United States and Canada

Cambrian Period

We come now to a section of rocks of unquestionable Cambrian age. At the base of this section is the Antietam Formation, predominantly sandstone, exposed in West Virginia only as a narrow band in Jefferson County. The Antietam contains fossils of unquestionable Early Cambrian age. No fossils from an older formation have ever been found in West Virginia. In the Antietam, fossils of ***Scolithus***, an ancient worm, are abundant. ***Olenellus***, a trilobite (Figure 6) considered as a key Lower Cambrian fossil, is also sparsely present, as are primitive gastropods and brachiopods (Woodward, 1949, p. 123).

Little or no break in sedimentation is to be observed at the contact between the Harpers and the overlying Antietam Sandstone. However, not only does a relative abundance of fossils suddenly appear, but the Harpers and Weverton-Loudoun Formations exhibit a noticeably greater degree of metamorphism than the overlying formations. This would suggest a hiatus (interruption in the rock succession) of limited extent at the Harpers-Antietam contact.

Throughout Cambrian time, the shallow sea in which the Antietam Formation (predominantly sandstone) was laid down gradually transgressed westward, as did the environment that favored such deposition, so that the unit actually is younger as one proceeds westward from the Appalachian geosyncline. According to Calvert (1962), the Antietam Sandstone can be traced as a lithologic unit from the Great Valley westward far into Ohio, and northward through Maryland, Pennsylvania, and New York. In central Ohio and northward to the Great Lakes and into Ontario where this unit is designated the "Basal Sandstone," it contains fossils of definite *Late* Cambrian age. Thus, we have an ideal example of a lithologic unit or geologic formation that transgresses a long period of geologic time (Figure 7).

Referring back to the Great Valley where the only Cambrian exposures in West Virginia are found, at the end of Antietam deposition the sea continued its encroachment into the area that is now the Great Valley. As the waters became slightly deeper, deposition of carbonates began, the first being the Tomstown Dolomite. The contact is an abrupt break from the quartz sandstone of the Antietam to the dolomite of the Tomstown, suggesting another limited hiatus. The extent of the Tomstown westward in the subsurface is unknown, but it is presumed to cover the eastern portion of the State.

The Tomstown Dolomite forms the basal carbonate member of what, in the early days of the study of Appalachian geology, was considered simply the "Valley Limestone," and marks the beginning of a long period of carbonate deposition, the predominant rocks being limestone and dolomite. Carbonate deposition predominated throughout a long period of time, which included part of the Early Cambrian and extended on through the Middle Ordovician, representing a probable time interval of more than 100 million years. The maximum total thickness of this complete carbonate sequence is approximately 10,000 feet. The extent of outcrop is the entire Great Valley area from the Champlain Valley in New York and Vermont to the Cahaba Valley in Alabama. It should be emphasized that carbonate deposition, although predominant, was not continuous throughout this time; the carbonate rocks are interrupted by unconformities and bodies of shale and some sandstone.

Mention should here be made of a very high quality, nearly pure dolomite occurring near the top of the Tomstown in Jefferson County. This dolomite has been quarried extensively in the vicinity of Millville. As stated by Woodward (1949, p. 239), "When it attains this purity it has a number of commercial uses, particularly as refractory furnace lining, for flux in open-hearth furnaces, or when burned to make high-magnesia lime."

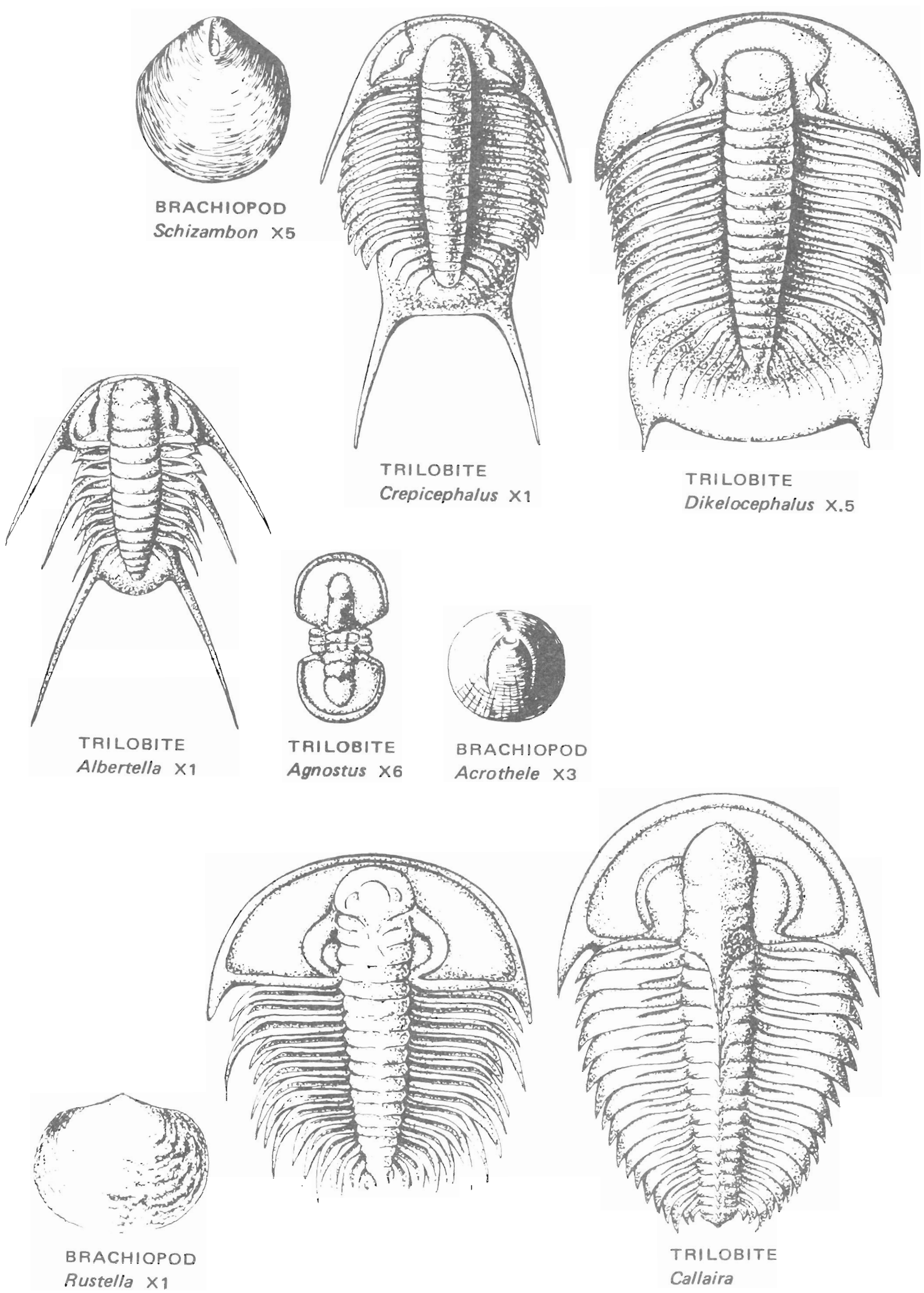


Figure 6. Guide Fossils for the Cambrian Period. The fossils depicted on this illustration are common guide fossils for the Cambrian. Those on the bottom row are guides to the Lower Cambrian, etc. While these are guide fossils, the range of some of them far exceeded the part of the period they are here related to. (From **BASIC CONCEPTS OF HISTORICAL GEOLOGY** by Edgar W. Spencer, Copyright ©1962 by Thomas Y. Crowell Company, Inc. With permission of the publisher.)

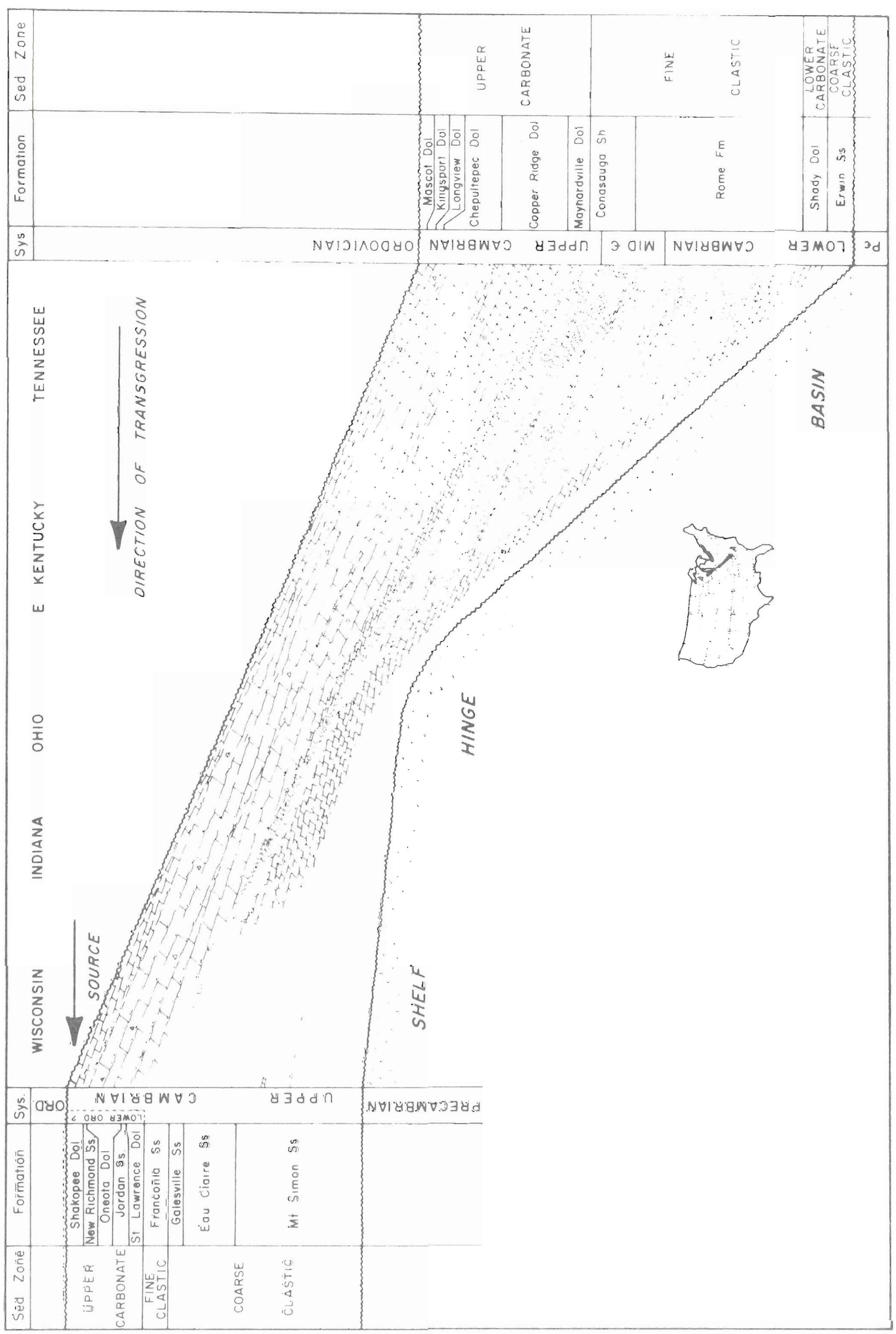


Figure 7. Generalized Diagram of Cambrian Sedimentary Relationships from Wisconsin to Tennessee. (Courtesy of the Ohio Geological Survey.)

Immediately overlying the Tomstown Dolomite is one of the predominantly clastic formations, the Waynesboro, which forms a sequence of beds more than 1,000 feet thick in West Virginia. The Waynesboro consists predominantly of green shales with streaks of impure sandstone. However, carbonates, usually in the form of dolomite, are also present. There must have been some regression and restriction of the inland sea, for not only is there a change to dominantly clastic deposition, but evidence of shallow-water deposition is present in the form of ripple marks in the sandstone.

The presence of ***Olenellus*** (trilobite) fossils (Figure 6) in the Rome Formation of Virginia, which is correlative with the Waynesboro, indicates an Early Cambrian age, but the upper portion may well be a part of the Middle Cambrian.

After deposition of the Waynesboro, the sea again deepened or sedimentary supply to the basin diminished, and a predominantly carbonate-forming environment was established. A gradational contact is the result, as indicated by the presence of purple shale layers near the base of the Elbrook Formation.

The Elbrook, predominantly a limestone unit, is estimated to be from 2,000 to 2,400 feet thick in West Virginia. On the basis of fossils found in Virginia and Pennsylvania, it has been assigned to the Middle Cambrian and, except for possibly the upper portion of the underlying Waynesboro, appears to be the sole representative of that epoch.

Carbonate deposition continued into the Upper Cambrian Epoch to form the Conococheague Formation that contains both limestone and dolomite and that is the sole representative of the Upper Cambrian in the Great Valley of West Virginia where it is 1,800 to 2,000 feet thick. The Conococheague, however, carries an abundance of thin clastic zones in the form of sandstone and shale layers. Southward into Virginia and westward into Kentucky, the Conococheague passes into the Copper Ridge Dolomite. Sandstone beds in the Upper Cambrian become coarser to the west and northwest, indicating the source material in the Late Cambrian to be in a westerly direction (Woodward, 1949, p. 173).

The Conococheague or Upper Cambrian passes without noticeable hiatus or change of character into the Lower Ordovician Beekmantown Group. These two carbonate units are very difficult to distinguish. They were originally combined and designated the Knox, a term still in use by the drillers.

Cambrian beds are not exposed in West Virginia west of the Great Valley. Also, subsurface information is very scant. The Sandhill deep well in Wood County indicates that the thickness of the entire Cambrian section thins across the state from a probable 10,000 feet in the Eastern Panhandle to about 2,000 feet near the Ohio boundary, where it is all of Late Cambrian age. This further enhances the conclusion that there was a gradual encroachment of the inland sea westward across the State throughout Cambrian time (Figure 7).

Ordovician Period

The Ordovician Period comprised approximately 70 million years, beginning at the close of the Cambrian about 500 million years ago (Figure 1). Its beginning is marked by the time at which graptolites (Figure 8) became abundant. It ended at the close of a period of mountain building known as the Taconic Orogeny.

Throughout Ordovician time, the entire North American continent had a very low profile, most of it at or below sea level, and with no imposing ranges of mountains, so that the agents of erosion were not very active. Shallow seas covered a large portion of the continent, the shore lines shifting and varying greatly at different times. Fluctuations of sea level afforded different environments of deposition, producing various rock types, the predominant ones being limestone, dolomite, and shale. Some important sandstones and limited amounts of coarser sediments were deposited.

The principal guide fossil for the Ordovician Period is the graptolite. Brachiopods and trilobites were abundant, the latter reaching their climax during this period (Figure 8). Toward the close of the period the first vertebrates, in the form of primitive fish, appeared. The presence of warm-water animals, especially corals, in widely separated areas, suggests a mild equable climate.

Exposures of Ordovician rocks in West Virginia are essentially confined to the Eastern Panhandle and to a narrow belt along the southeastern border of the State (Figure 3). These form only a minute part of the very extensive outcrops of the Valley and Ridge Province, which extends all the way from New York to Alabama. Going westward, eight wells scattered over West Virginia have drilled either through or into the lower part of the Ordovician section. These essentially prove the presence of Ordovician rocks below the surface throughout the rest of the State, but with some breaks in deposition, particularly in western West Virginia.

Three extensive submergences in North America conveniently divide the Ordovician Period into Early, Middle, and Late Ordovician Epochs.

Early Ordovician

The close of the Cambrian Period for North America generally is considered to have been a time of emergence and uplift, followed in the Early Ordovician by a distinct submergence. However, in West Virginia, for the most part, any break in sedimentation can scarcely be detected. The dolomite and limestone of the Lower Ordovician are essentially of the same character as those of the underlying Cambrian.

The Lower Ordovician Series of West Virginia comprises essentially only the Beekmantown Group which is predominantly a dolomite, but in part limestone. In the outcrop areas of eastern West Virginia, the Stonehenge Formation forms the base of the series. The lower part of this formation is a relatively pure limestone, but in the upper part an abundance of this sandstone is present (Woodward, 1951, p. 62). In western West Virginia the entire series is predominantly dolomite. A very sandy dolomitic unit is found in some wells. This unit is known as the Rose Run sand and has produced oil in eastern Kentucky.

Surface measurements indicate a thickness of approximately 3,900 feet for the Lower Ordovician rocks of the Eastern Panhandle. The series thins to approximately 980 feet in the Sandhill well of Wood County. According to Woodward (1951, p. 115) it is entirely absent in the Caldwell well of Wayne County, southwestern West Virginia.

This thinness of the section in western West Virginia is the result of continental emergence near the end of Early Ordovician time that produced the Waverly arch, an uplift that extends in a northeast-southwest direction through central Ohio (Woodward, 1961,

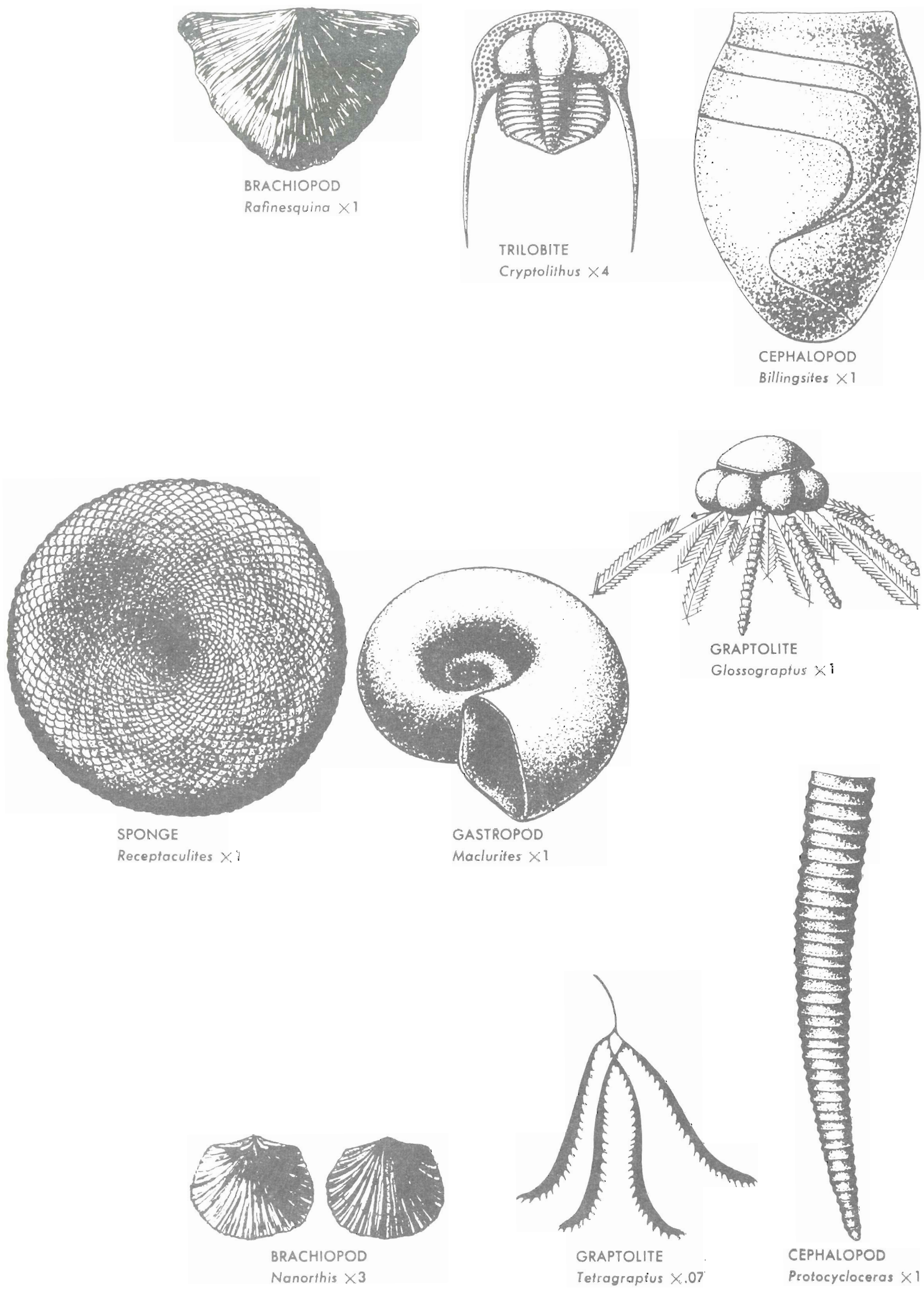


Figure 8. Guide Fossils for the Ordovician System. (From **BASIC CONCEPTS OF HISTORICAL GEOLOGY** by Edgar W. Spencer, Copyright ©1962 by Thomas Y. Crowell Company, Inc. With permission of the publisher.)

p. 1652). This uplift affected a large area, extending eastward at least into western West Virginia. Its influence contributed to producing the very pronounced Knox Unconformity.

Although to date no oil or gas associated with this unconformity has been found in West Virginia, it is the dominant factor in the formation of the oil reservoir traps of north-central Ohio. The unconformity, however, becomes of lesser and lesser importance eastward in West Virginia, where very few wells have penetrated this horizon. It is entirely possible that the break in sedimentation extends throughout the State, but to a lesser degree than in Ohio, closer to the Waverly uplift.

Middle Ordovician

When deposition began in Middle Ordovician time in extreme western West Virginia, it was with a clastic unit, predominantly sandstone, present also just above the unconformity in Ohio. This unit is 64 feet thick in the Sandhill well of Wood County and 93 feet thick in the Caldwell well of Wayne County. It has been considered by many geologists as correlative with the St. Peter Sandstone, a thick sheet of sandstone that has produced oil and gas in central United States. The correlation with St. Peter is somewhat doubtful. It seems more probable that it is merely a local clastic unit developed upon the unconformity.

In eastern West Virginia, a lesser break in sedimentation is to be noted in passing from Lower to Middle Ordovician rocks. Essentially a carbonate-producing environment continued throughout West Virginia and prevailed into and throughout Middle Ordovician time.

Strata of the Middle Ordovician include, in ascending order, the St. Paul, Black River, and Trenton Groups. The St. Paul and Black River consist predominantly of limestone with some dolomite and chert. Near the base of the St. Paul is a high-grade, nearly pure limestone or vaughanite, which has been quarried extensively in Berkeley County. This is perhaps the most important economic product of the Ordovician in West Virginia.

In Later Middle Ordovician time (lower Trenton), streams brought limited quantities of clay and other clastics into the shallow sea, so that much clay accumulated along with the carbonates, producing thick layers of black to dark-gray shale along with the dark-gray limestone. The percentage of clastic material coming into the basin increased in late Trenton time, resulting in the shales that predominate in the upper part of the Trenton section. This part is now considered to be of Late Ordovician age. The thickness of the Middle Ordovician Trenton varies from about 800 to 1,000 feet.

During Middle Ordovician time, a limited amount of volcanic activity was widespread in the Appalachian region, signifying the beginning of mountain-building activity to the east. Volcanic ash spread over a large area of West Virginia which, upon decomposition, resulted in the formation of thin ***bentonite*** beds. These occur abundantly, particularly in the Black River and Lower Trenton Formations, and are present down to the very base of the Middle Ordovician (Woodward, 1951, p. 120). This ". . . wind-wafted volcanic dust . . . rarely occurs in beds more than a few inches thick and cannot successfully be used for individual bed correlation" (Woodward, 1951, p. 45). These thin beds, commonly called "metabentonite," are found in fair abundance in wells of Ohio, indicating an extent considerably beyond the Appalachian region. Specific locations of volcanic vents have not yet been found.

Late Ordovician

At the close of Middle Ordovician time, the borderlands to the east began to rise and form an increased supply of terrigenous material for deposition in the still-submerged area of

West Virginia. This marked the beginning of Late Ordovician time. The upper Trenton beds deposited at that time are predominantly black to dark-gray shale with thin limestone and sandstone interbeds. These beds are followed by a section still more predominantly composed of black to dark-gray shale with some thin sandstone interbeds. This section, known as the Martinsburg Formation, is approximately 1,450 feet thick in the Great Valley area, 1,800 feet thick in Pendleton County, 1,200 feet thick in Mercer and Monroe Counties, and 1,000 feet thick in the Wood County well.

Later during the Late Ordovician Epoch, eastern West Virginia rose and a delta-type nonmarine environment caused the deposition of the Oswego Formation, which is actually a facies of the Martinsburg. The Oswego is predominantly a gray to gray-brown, non-fossiliferous, arkosic sandstone. In West Virginia, it has been recognized only in the Eastern Panhandle and in Pendleton County, where it varies in thickness from 200 to 400 feet (Woodward, 1951, p. 376).

Toward the end of Ordovician time, the entire State of West Virginia had risen above sea level, and a predominantly delta-type environment prevailed. The Juniata Formation was deposited and now forms the uppermost unit of the Ordovician throughout the State. It is predominantly a non-marine red to reddish-brown sandstone with some shale. It is entirely non-calcareous and mostly, if not entirely, non-fossiliferous, varying from 150 to 800 feet in thickness. It crops out over a wide area in eastern and southeastern West Virginia and is present below the surface throughout the remainder of the State. It overlies the Oswego Formation wherever this unit is present and overlies the Martinsburg Formation in other areas.

The Oswego, Juniata, and the overlying Tuscarora Sandstone of the Silurian were formerly designated the "Gray Medina," "Red Medina," and "White Medina," respectively. All of these were originally considered of Silurian age. Based on West Virginia information alone, this would be a logical determination. However, in other states, especially to the northeast where the influence of the Taconic Orogeny is in evidence, formations correlative with the Oswego and Juniata have essentially been proven to be of Ordovician age, so that we now consider only the Tuscarora or "White Medina," to belong to the Silurian System.

Taconic Orogeny

During the Ordovician Period, especially in Late Ordovician time, a chain of folded and thrust faulted mountains, extending from Newfoundland to Alabama (Dunbar, 1959, p. 132), was formed. The area of direct influence passed approximately along the east and southeast side of what is now the Blue Ridge, and therefore did not directly affect West Virginia, except to accelerate uplift in the late part of the period and furnish a source of sediments. The termination of this mountain-building episode known as the Taconic Orogeny marks the end of Ordovician time.

Silurian Period

The Silurian Period lasted about 25 million years following the Ordovician, the period beginning about 430 million years ago and ending about 405 million years ago (Figure 1). Although the shortest of the Paleozoic periods, the Silurian is nonetheless of great importance because of its particular type of deposits.

At the beginning of Silurian time, most of the North American continent, including West Virginia, was a relatively flat land area (Dunbar, 1959, p. 156). The Appalachian basin in general was covered with the red delta deposits of the Late Ordovician (Juniata Formation). However, immediately to the east and southeast, beginning approximately with what is now the Blue Ridge, was an area of high rugged mountains formed in large part by the Taconic Orogeny of Late Ordovician time. These high mountains served as the source of much of the Silurian sediment of the Appalachian basin.

Early Silurian

During Early Silurian time, a shallow sea encroached from the south and covered all of West Virginia as well as a wide belt of the surrounding states. Sediment continued to come in from the east, but during this epoch the material was predominantly sand. The first and only formation to be deposited was the Tuscarora Sandstone, mostly a clean white sandstone ranging in thickness in West Virginia from more than 250 feet at some localities in the east to 32 feet in a well in the extreme western part of the State. Small quantities of natural gas have been produced from this sandstone. Very prominent ridges of this resistant sandstone are more or less continuous for miles along the strike in eastern West Virginia. A good example is Cacapon Mountain, which extends almost continuously for more than 20 miles from the Potomac River south of Hancock, Maryland, southwestward along the strike into Hampshire County. In Germany Valley, Pendleton County, the Tuscarora is in a vertical position and forms a very prominent ridge for many miles along the South Fork of the Potomac River where it forms some of the most spectacular scenery of the State. Seneca Rocks is a portion of this ridge.

Middle Silurian

At the beginning of Middle Silurian time in West Virginia, there seems to have been a slight break in sedimentation and an irregular emergence. Afterwards, the area was again invaded by the sea, but this time predominantly clay with lesser amounts of sand was brought into the basin. A succession of shales and thin sandstones was thus laid down to form the Clinton Group, which consists in ascending order of the Rose Hill Formation, Keefer Sandstone, and Rochester Shale (Figure 4).

The Rose Hill is mostly shale but contains thin sandstone layers. Some of these sandstones, deposited in restricted areas near the shoreline, have a high iron-oxide content and are thus red in color. In other parts of the Appalachian area, such as in the vicinity of Birmingham, Alabama, these are rich enough to have served as iron ores, but in West Virginia they are too thin to be of importance under present economic conditions.

The Keefer, a thin sheet sandstone 5 to 30 feet in thickness, immediately overlies the Rose Hill Formation. It is present in outcrops in the eastern part of the State and has been recognized in most of the wells in other parts of the State. However, it has its best development in western West Virginia, especially in Wayne County where it has produced commercial quantities of natural gas. It is commonly called the "Big Six" sand.

The Rochester Shale that overlies the Keefer is predominantly dark gray, and contains several thin limestone beds. Woodward (1941, p. 107-111) describes a number of outcrops scattered throughout the Eastern Panhandle, where it has a maximum thickness of approximately 30 feet and an average thickness of about 25 feet. The Rochester has also been identified in wells in Kanawha, Wayne, and Boone Counties. Its marine origin is definitely established by its abundance of fossils, for it perhaps contains the greatest number of invertebrate species of all Silurian formations.

After deposition of the Rochester, a carbonate-producing marine environment prevailed over most of the Appalachian area. During this time the Lockport Dolomite was deposited as the predominant formation. However, in West Virginia a mixed clastic and carbonate environment resulted in the deposition of the McKenzie Formation. This formation consists of "dark calcareous shales and thin-bedded fossiliferous limestones," the fossils being predominantly ostracods (Woodward, 1941, p. 116). Present over most of the State, the McKenzie reaches a maximum thickness of more than 400 feet in north-central West Virginia.

During the deposition of the McKenzie Formation an oscillating shoreline resulted in alternating clastic and carbonate beds in southeastern West Virginia. As the epoch drew to a close, the sea retreated westward. Carbonates continued to prevail in western West Virginia. In northeastern West Virginia, the retreat of the sea resulted in a tidal flat. This marked the beginning of the deposition of the Bloomsburg red shale facies, described in the succeeding section.

Late Silurian

At the beginning of Late Silurian time, the sea retreated westward leaving the extreme eastern part of West Virginia a land area. This was part of a large and important area of similar environment extending into Virginia, Maryland, eastern Pennsylvania, and New York. Here the extensive Bloomsburg red shale facies, at the base of the Upper Silurian and the top of the Middle Silurian, was laid down in a predominantly deltaic environment. An excellent exposure of the Bloomsburg is present along the Western Maryland Railway southwest of Hancock, Maryland, just across the Potomac River from West Virginia.

Westward, the Bloomsburg passes into a shallow marine facies, near the middle of which is the Williamsport Sandstone, exposed at a number of localities in eastern West Virginia. This sandstone is the basal unit of the Upper Silurian. It has been traced westward in the subsurface and is believed to correlate with the Newburg sand that has recently become important as a gas-producing zone in western West Virginia.

After deposition of the Williamsport Sandstone, the deltaic environment resulted in continued deposition of the Bloomsburg facies in northeastern West Virginia. This facies is believed to have reached its maximum southwestward extent during this interval.

To the southwest, near-shore and shallow marine environments produced the Wills Creek Formation. In central West Virginia, nearest the shoreline, this is a predominantly clastic section of shale with sandstone interbeds. Southwestward, carbonates become more important, and upon reaching southwestern and western West Virginia they form the dominant rock type, being mostly dolomite with some limestone. Sandy zones are present in the dolomite.

Over the greater part of West Virginia, a marine environment existed throughout the Late Silurian Epoch. During this interval, the Tonoloway Limestone was deposited. This formation is mainly thinly laminated, interbedded, argillaceous limestone and calcareous shale (Woodward, 1941, p. 207).

In contrast to the Upper Silurian environment described above, north-central West Virginia became a part of a closed basin that extended well into Pennsylvania, Ohio, and

New York. This area became a "dead sea," with very restricted access to the open ocean. As evaporation progressed through time, the concentration of various salts increased, so that thick beds of anhydrite and rock salt were chemically precipitated. During the same interval, clay periodically swept in from the northeast and became intercalated with the evaporites causing the formation of a succession of shales, dolomites, rock salt, and anhydrite. The salt thus formed is the basis for a considerable industry, very important in Ohio, New York, and Pennsylvania, and extending well into the Upper Ohio Valley in West Virginia.

At the close of the Silurian Period, the open sea once again invaded this late Silurian evaporite basin and started again the precipitation of limestone. Except in north-central West Virginia, which was a part of the evaporite basin, there is no distinct break to mark the end of Silurian and beginning of Devonian deposition.

Life of the Silurian

The fauna of the Silurian (Figure 9) is essentially the result of a continued evolution of Ordovician invertebrates. Most abundant are the ostracods, so abundant at places in West Virginia as to form a coquina (a limestone composed chiefly of shell fragments, corals, etc., cemented together). Brachiopods are common. Next in importance perhaps were the bryozoa and trilobites (although the trilobites were definitely on the wane), and the bizarre eurypterids, some of which reached a length of 8 to 10 feet. Corals, crinoids and mollusks, although important in the Silurian in other parts of the world, are poorly represented in West Virginia. Primitive fishes, occurring first in Late Ordovician time, continued to appear but did not become abundant until the succeeding Devonian Period. Indications of the beginning of terrestrial plant life have been found in the Upper Silurian at scattered localities of the world, but such indications are extremely rare and are uncertain. For the most part the Silurian was a period of evolution of the forms of life already in existence.

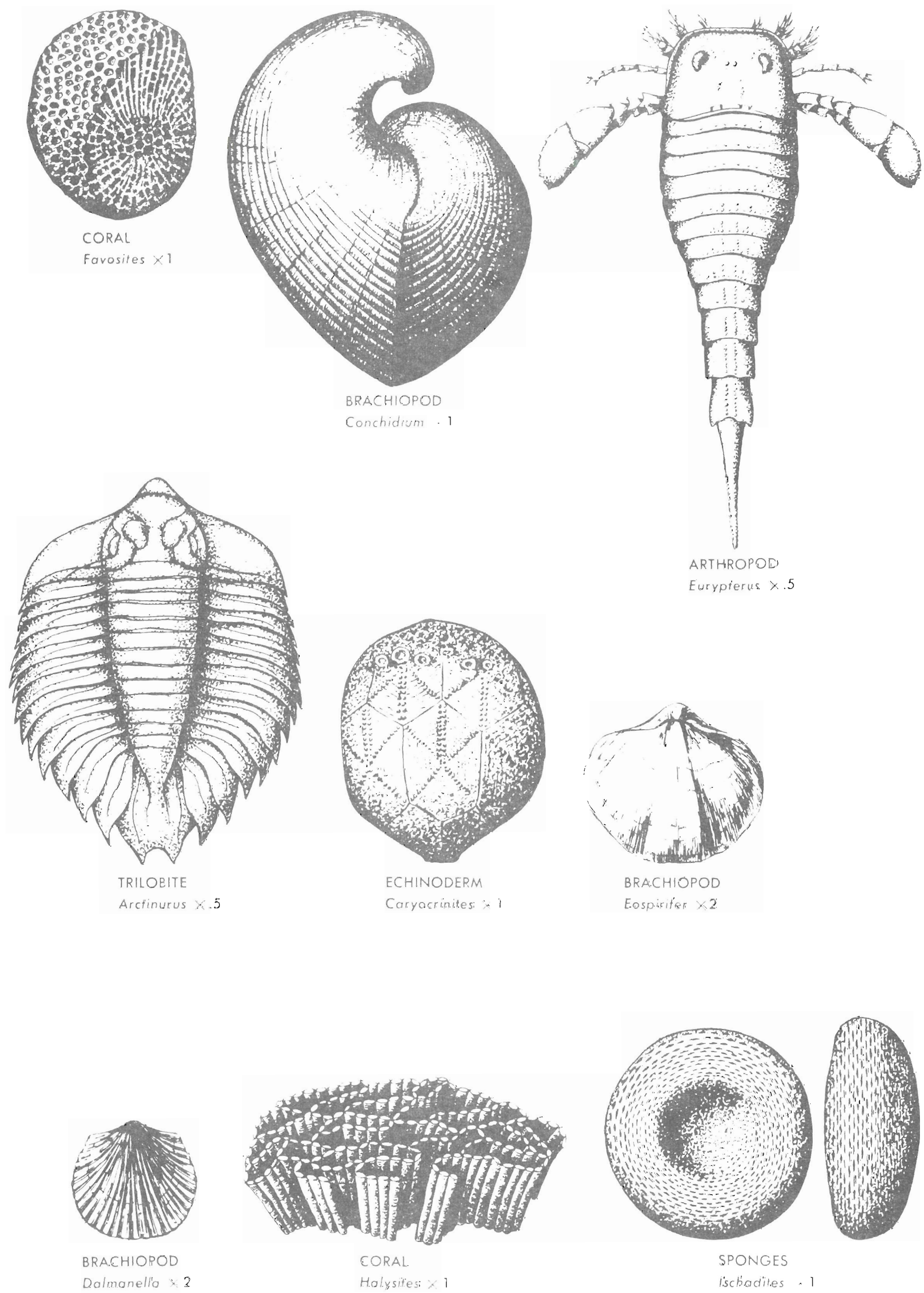


Figure 9. Guide Fossils for the Silurian System. (From **BASIC CONCEPTS OF HISTORICAL GEOLOGY** by Edgar W. Spencer, Copyright ©1962 by Thomas Y. Crowell Company, Inc. With permission of the publisher.)

Devonian Period

The Devonian Period began approximately 405 million years ago and lasted about 60 million years (Figure 1). In West Virginia, there seems to have been little or no break in sedimentation in passing from the Silurian into the Devonian Period. According to Woodward (1943, p. 25), in the Early Devonian:

> . . . a long relatively narrow sea-way extended northeastward for a total distance of at least 2,000 miles; it opened into Atlantic Ocean at the northeast and connected, possibly, with Pacific water at the southwest.

This "sea-way" covered the greater part of West Virginia. A shallow marine-shelf environment existed at the beginning of the period, extending from the highlands to the east westward to the vicinity of the present Ohio River.

There is disagreement among geologists as to the exact contact between Silurian and Devonian rocks, but for the purpose of this report it will be placed at the base of the Keyser Formation. Thus, the Tonoloway is the upper formation of the Silurian System (Figure 4). Although there appears to be no break in sedimentation, the characteristic knobby character of the Keyser usually enables one to distinguish it from the underlying thinly laminated Tonoloway.

According to Woodward (1943, p. 7 and 21), the entire thickness of West Virginia Devonian rocks ranges from approximately 13,000 feet along the Virginia boundary in Hardy and Pendleton Counties to 1,200 feet or less in the extreme western part of the State. Surface exposures are confined to the eastern part of the State, but the Devonian rocks are found in all wells that have been drilled to sufficient depth to encounter them. Devonian rocks crop out abundantly all along the Allegheny Front near the trough of the Appalachian basin. Devonian outcrops extend through Pennsylvania and into New York where they are very widely exposed (Broughton and others, 1966, p. 26-29).

Early Devonian

The first rocks deposited in Early Devonian time belong to the Helderberg Group. This group is composed essentially of limestone, in part cherty, thus indicating a predominant carbonate-producing environment. However, several invasions of sand and clay from the east resulted in the formation of sandstone and shale units. The Helderberg Group contains a number of formations that are generally not separated except for the purpose of making detailed stratigraphic studies. According to Woodward (1943, p. 39) the thickness of the Helderberg reaches a maximum of more than 600 feet in the trough of the Appalachian basin.

In the latter part of the Early Devonian Epoch, the sea over West Virginia became shallower. Shifting shore lines caused the deposition of the Oriskany Sandstone, also known as the Ridgeley, a blanket sandstone that extends over much of the Appalachian area and covers most of West Virginia, where thicknesses sometimes exceed 200 feet. The Oriskany is normally a clean and somewhat porous sandstone that is believed to be primarily a beach sand, and to be derived from pre-existing sandstones to the east. The Oriskany is a very important gas-producing formation in West Virginia. There are a number of important fields in the eastern part of the State. However, by far the most important is the prolific Elk-Poca field in the west-central part of the State, which has produced approximately one trillion cubic feet of gas to date.

The Oriskany crops out abundantly in eastern West Virginia where it is for the most part a resistant ridge-forming unit. In Morgan County it has been quarried ever since the late 19th century and used as a glass sand of very high quality. This sand has served as the basis for the glass industry of the eastern United States.

Middle and Late Devonian

At the beginning of Middle Devonian time, a slight subsidence of the sea occurred throughout West Virginia. The first rock unit to be laid down was designated by Dennison (1961, p. 9, 10) the Onesquethaw Stage, rather than the Onesquethaw Group. The three rock facies that comprise this stage intertongue with one another, but are each characteristic of its particular environment, and do not have a definite vertical succession. The Onesquethaw was formerly termed the Onondaga Group, an undesirable name, since the term "Onondaga" was already in use to designate the cherty limestone phase of western West Virginia. The Onesquethaw has been recognized either in outcrop or in subsurface throughout most of the State. It reaches a maximum thickness of more than 250 feet in north-central West Virginia and is less than 50 feet thick in some of the wells of Wyoming and McDowell Counties. The three facies of the Onesquethaw may be described as follows:

1. The Needmore Shale is the clastic facies that is characteristic of northeastern West Virginia. According to Dennison (1961, p. 19) it represents "the earliest incursion into the central Appalachian basin of the Acadian Orogeny." Hence, its predominance is in the northeastern part of the State, nearest the uplift. The Needmore is generally a very dark shale, not easily distinguished from the overlying Marcellus.

2. The Huntersville Chert, according to Woodward (1943, p. 257), is mostly ". . . a highly silicified black shale which contains many beds that have been brecciated and recemented with amorphous silica." According to Dennison (1961, p. 27), ". . . Every gradation is present between pure chert and pure shale." The chert was deposited in waters containing a high concentration of colloidal silica. The Huntersville Chert facies predominates in southeastern West Virginia, with the best outcrops in Pocahontas County. However, it is present in limited thicknesses in the greater part of the State. The Huntersville Chert has been used locally as an excellent road material. Limited but important quantities of gas have also been produced from the chert and cherty limestone.

3. The Onondaga Limestone, the predominant facies of western West Virginia, is an argillaceous and cherty limestone, deposited in a carbonate-producing environment with a high content of colloidal silica. In general, it may be considered gradational westward from the Huntersville Chert, but is frequently found intercalated with it. The top of the Onondaga forms an important marker horizon in wells of western West Virginia, Ohio, and Kentucky. Here the Onondaga has been designated a part of the "Corniferous," the drillers' term for a section in which limestone predominates, and which in places extends as far down as the Keefer Sandstone of the Middle Silurian section.

At the top of the Onesquethaw, mostly in northeastern West Virginia, is the Tioga Bentonite, often called metabentonite. Dennison (1961, p. 36) considers it a separate formation, since bentonite may occur in a distinct shale zone with a maximum thickness of about 30 feet in Pocahontas County. At the close of the time during which sediments of the Onesquethaw were deposited, volcanic activity was taking place in the uplifted area to the east. The ash produced by this volcanic activity spread into West Virginia, particularly in the northeastern part, where it was altered to bentonite. This thin but extensive bed now forms what is known by the drillers as the "brown break" and is important because it separates the overlying Marcellus Shale from the underlying Needmore Shale, thus forming an important marker for the gas wells of the area.

Near the end of Onesquethaw time, subsidence began in the Appalachian basin and continued until near the close of Devonian time. At the same time, the highlands to the east continued to rise, thus furnishing the source of an abundance of clastic sediments for the Middle and Upper Devonian Epochs. Throughout Middle Devonian time, the shoreline slowly retreated westward. However, most of West Virginia was still below sea level. The remainder of the epoch was characterized by the deposition of marine dark-gray and black shales with numerous siltstone and sandstone layers.

This type of deposition continued into the Late Devonian Epoch. However, in the latter part of this epoch the sea retreated rapidly westward, so that at the end of Devonian time it seems that little or none of the State was below sea level, and only nonmarine sediments were being deposited. The formations overlying the Onesquethaw Stage (Figure 4), in ascending order, are:

1. The Marcellus Shale, a distinct black fissile shale 200 to 500 feet thick. Many outcrops are very black and give the appearance of coal. However, tests have been run, and the carbon content has been determined to be extremely low and thus of no commercial importance. The Marcellus weathers to a very infertile soil.

2. The Mahantango Formation, varying in thickness from zero in the Sandhill well to approximately 1,200 feet in the Eastern Panhandle, is predominantly a dark-gray shale with sandstone lenses.

3. The Harrell Shale, the upper unit of the Middle Devonian, is for the most part a black shale somewhat similar to the Marcellus. Although largely noncalcareous, a highly calcareous zone occurs near the base. This is believed to correlate with the Tully Limestone of Pennsylvania and New York. The Harrell Shale is very thin (5 to 20 feet) in the Eastern Panhandle, but the thickness increases westward. It was described as approximately 300 feet thick in the Wood County well (Woodward, 1959, p. 17).

4. The Brallier Formation, the basal unit of the Upper Devonian, formerly known as the Portage, consists of olive-gray to dark shale with numerous siltstone and sandstone lenses. Its thickness ranges widely, but is usually from 1,000 to 1,500 feet.

5. The Chemung Group is essentially a gray shale with layers of siltstone, sandstone, and some conglomerate. It is essentially the marine portion of the combined Chemung and the overlying Hampshire Formation. From 2,000 to 3,000 feet thick in the Eastern Panhandle, the Chemung decreases in thickness to 1,665 feet in the Wood County well.

   It will be noted that sandstone and siltstone layers increase in abundance in the younger rocks listed above.

6. The Hampshire Formation was laid down in a nonmarine depositional environment as the shoreline retreated westward. The Hampshire extends northeastward through Pennsylvania and into the Catskill Mountains area of New York. In this area, a thick section of nonmarine shales, mostly red but partly green, was deposited. Many sandstone beds are present. The Hampshire, formerly known as the Catskill, reaches a thickness of more than 3,000 feet in the Eastern Panhandle of West Virginia. Simultaneously, to the west, a marine depositional environment still prevailed so that in extreme western West Virginia, if deposition was still taking place, it was of the marine Chemung. Also, the complete Chemung and Hampshire section thins westward from a thickness of more than 5,000 feet in the Eastern Panhandle to 1,665 feet in the Wood County well.

In north-central West Virginia and adjacent parts of Pennsylvania, a number of gas-producing sands are present in the Upper Devonian section, mostly in the Chemung and Hampshire. Important among these are the Benson, Riley, Balltown, Speechley, Bayard, Gordon, Fifty-Foot, and Gantz sands.

These sands are not present in southern West Virginia where the Upper and Middle Devonian section is nearly all shale. This shale is locally highly fractured, forming reservoirs that have produced a considerable quantity of gas and oil.

Life of the Devonian

The Devonian Period is commonly known as the Age of Fishes (Figure 10). From a few primitive forms in the early part of the period, the number and variety increased throughout the period. By Middle Devonian time, fish dominated the seas. Toward the end of the period, sharks were abundant and certain species of lungfish came into existence. The first land vertebrates, amphibians, were also present before the end of Devonian time.

Among the invertebrates, pelecypods became more abundant, cup corals were at their peak, and very large crinoids were locally abundant. Starfishes and other echinoderms were on the increase, gastropods and cephalopods were present, and trilobites were declining but still present (Figure 11). Primitive ammonites appeared before the end of the period.

Land plants rapidly gained in importance during Devonian time. Even in Early Devonian time, evidence of extensive forests of primitive plants have been found (Dunbar, 1959, p. 200). The Devonian forests can well be considered the forerunners of the great forests of Pennsylvanian time that produced the bulk of our vast coal deposits.

Acadian Orogeny

In the eastern United States, the principal orogenic disturbance of the Devonian Period is known as the Acadian Orogeny. The principal area of disturbance extends from the maritime provinces of Canada, through New England, and into the Piedmont Province, at least as far south as North Carolina. Although West Virginia was not in the zone of the main uplift, it was strongly affected in that this uplift furnished a large part of the material for the vast thickness of clastic deposits, particularly of Middle and Upper Devonian strata. As indicated above, in the latter part of the Devonian Period much of West Virginia, as a result of the Acadian Uplift, had become a land area with vast clastic deposits being formed to produce the Hampshire Formation.

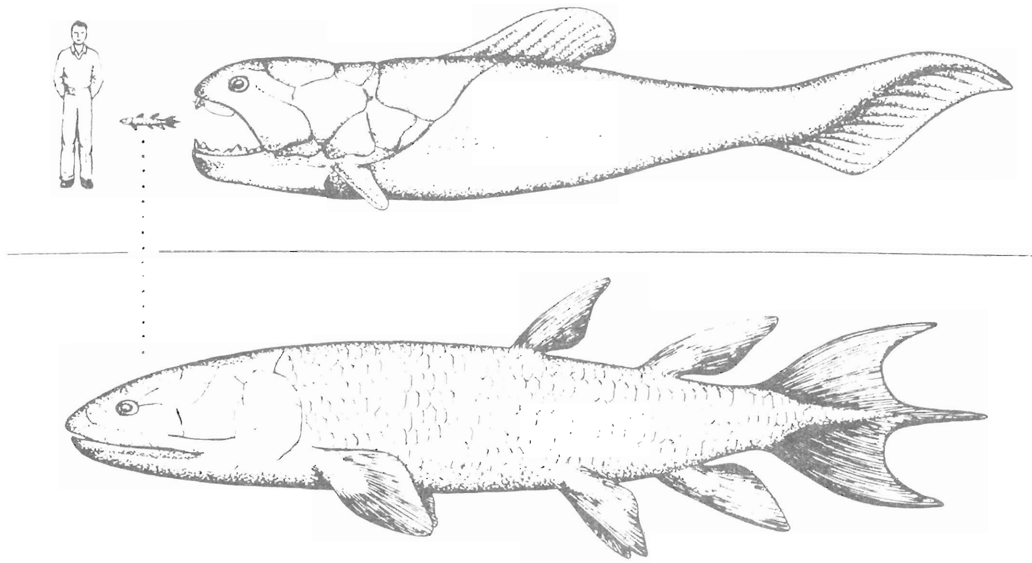


Figure 10. **Devonian Fishes.** At the top is a restored placoderm, Dinichthys, which grew to lengths of 30 feet. The head region was heavily armored with external bony plates that were jointed. Below is a Devonian crossopterygian. The fish was only about 2 feet long. The crossopterygians were probably the connecting link between the fishes and the first four-legged, air-breathing vertebrates. The basal lobe is the forerunner of the limb of the tetrapods. Other fish did not have such a lobe. (From **BASIC CONCEPTS OF HISTORICAL GEOLOGY** by Edgar W. Spencer, Copyright ©1962 by Thomas Y. Crowell Company, Inc. With permission of the publisher.)

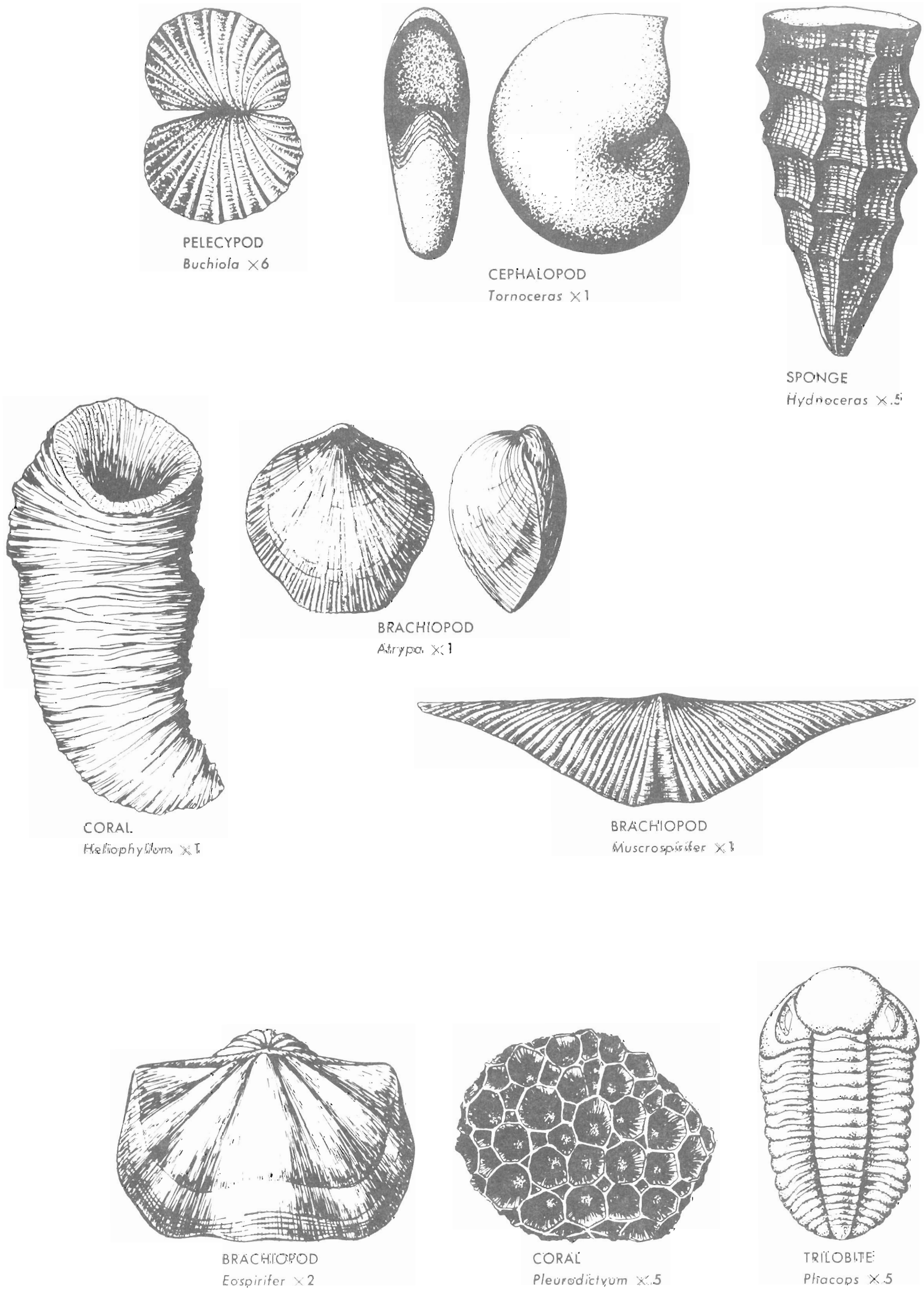


Figure 11. Devonian Guide Fossils. (From **BASIC CONCEPTS OF HISTORICAL GEOLOGY** by Edgar W. Spencer, Copyright ©1962 by Thomas Y. Crowell Company, Inc. With permission of the publisher.)

Mississippian Period

The Mississippian Period began about 345 million years ago and lasted approximately 30 million years (Figure 1). Its beginning is marked by the close of the Acadian Orogeny described above. It ended when the coal swamps of the subsequent Pennsylvanian Period spread over West Virginia and adjacent Appalachian states.

Early Mississippian

At the beginning of Mississippian time, most of the North American continent was a low area centered along the present Mississippi River Valley where a thick series of mostly marine limestones was being deposited.

West Virginia was sufficiently affected by the Acadian Uplift to cause a mixed, but predominantly nonmarine environment. The highlands immediately east of West Virginia were more or less steadily rising, thus furnishing a source of sediments for the basinal areas to the west. As expressed by Dunbar (1959, p. 207): "This whole province [Appalachian] . . . was dominated by detrital sediments poured into the geosyncline from Appalachia." The predominantly nonmarine environment continued throughout Early Mississippian time. During this time, sediments of the Pocono Group were laid down. Overlying these, mostly in southeastern West Virginia, sediments of the Maccrady Formation were deposited.

The Pocono Group, at the base of the Mississippian, is abundantly exposed in eastern West Virginia and is probably present below the surface throughout the western part of the State. It reaches a thickness of about 900 feet in some of the southeastern counties, and is 525 feet thick in the Sandhill well of Wood County. The rocks are predominantly nonmarine sandstone, siltstone, shale and sandy shale, formed from the detrital material washed in from the highlands to the east. A few poorly developed noncommercial coal seams and a few thin limestones have been reported. In spite of the predominantly deltaic environment, marine fossils have been found in abundance in several thin zones.

In West Virginia only a few well-defined formations of the Pocono are present. Perhaps the most important is the Berea Sandstone that is locally present at the base. This has proved a very important gas-producing zone in certain localities. The Big Injun sand, at the top of the group and partly in the overlying Greenbrier Group, is the most important shallow gas- and oil-producing zone of the State. Squaw and Weir are drillers' terms for locally porous and important intervening oil and gas "sands."

Early Mississippian time ended in West Virginia with the deposition of the ***Maccrady Formation*** that is present only in southern West Virginia, particularly in Mercer, Summers, Monroe, Greenbrier, and Pocahontas Counties. The Maccrady is predominantly a red shale and mudstone, partly calcareous, that ranges in thickness from zero to 350 feet. According to Reger (1926, p. 493) scanty marine fossils have been found in West Virginia, although the formation is essentially a deltaic deposit. In adjacent Virginia where the formation reaches thicknesses in excess of 700 feet, a partly marine environment and a more diverse marine fossil assemblage are encountered (Reger, 1926, p. 493). Thus, a deltaic nonmarine environment predominates in the western part of the area of occurrence, whereas a more marine environment is present to the east.

Middle Mississippian

At the beginning of Middle Mississippian time, the West Virginia area in general subsided and a marine environment predominated throughout most of the time. The Greenbrier

Group was then deposited. The predominant rock type is limestone, which is abundantly present and extensively quarried wherever it crops out within the State. Layers of dark calcareous shale, some red shale, and some sandy zones are present. The limestone is in part highly oölitic. Cherty layers occur locally near the base. Although for the most part the Greenbrier has been described as one unit, in the southeastern part of the State it has been divided into several distinct formations.

The Greenbrier is over 1,000 feet thick in extreme southeastern West Virginia, about 200 feet thick in north-central West Virginia, and is locally entirely absent in parts of northwestern West Virginia.

The principal product of the Greenbrier is limestone, which is quarried for various uses at several localities in the State. Local gas- and oil-producing zones include the Big Lime, the Blue Monday and Keener sands, and locally the upper part of the Big Injun sand.

Late Mississippian

At the close of Middle Mississippian time, the sea once more retreated from West Virginia and never again, except locally for short intervals of geologic time, was there a marine environment of deposition in the State. The Greenbrier was the last thick carbonate unit. Hence, a nonmarine environment existed during Late Mississippian time. The sediments laid down during this time comprise the Mauch Chunk Group that has been divided into four formations. In ascending order these are the Bluefield, Hinton, Princeton, and Bluestone Formations. The thickness of the Mauch Chunk Group reaches a maximum of possibly 3,450 feet in the Hurricane Ridge Syncline of southeastern West Virginia.

The sediments of the Late Mississippian in West Virginia are for the most part clastic, with sandstone and shale predominating. Scattered thin coal seams occur, but they are not of economic importance. In the lower part of the section, a number of thin argillaceous limestones are present.

The Mauch Chunk is about 1,000 feet thick in Grant and Mineral Counties, thins to less than 800 feet in southeastern West Virginia, and is thin to entirely absent, due to erosion, in extreme western West Virginia.

The Mauch Chunk Group contains the important Maxon gas sand. "Maxon" is a drillers' term that may represent any of several locally developed gas-producing sands in the lower formations of the group. Other gas-producing zones are the Ravencliff sand, the Princeton Sandstone, and the Little Lime, a local limestone development near the base of the section.

The Bluestone Formation at the top of the Mississippian is characterized by an abundance of bright-red shale that contrasts sharply with the sandstone, gray shale and coal of the overlying Pennsylvanian.

As the Mississippian Period ended, West Virginia emerged and became for the most part a land surface, thus subjecting the area to erosion. With the possible exception of extreme southeastern West Virginia, Pennsylvanian sediments seem everywhere to lie unconformably upon those of the Mississippian.

Life of the Mississippian

Among the invertebrates, crinoids and blastoids reached their climax during the Mississippian Period (Figure 12). Lacy bryozoa and spiny brachiopods expanded. Foraminifera became important for the first time. Gastropods and pelecypods were also important. Corals became less important, and trilobites were approaching extinction.

Among the vertebrates, fish were less important than in the Devonian but were still abundant. Among the Mississippian fish were sharks who fed on crustaceans and were equipped with teeth that could crush the shells of their prey. The principal land animals were amphibians whose footprints have been found in the terrestrial deposits, but remains of these are scarce.

Although no important evidences of abundant forests have been found, the land plants are believed to have increased in abundance as time progressed from the Devonian through the Mississippian and into the Pennsylvanian when they played such an important part in the geologic history of the earth.

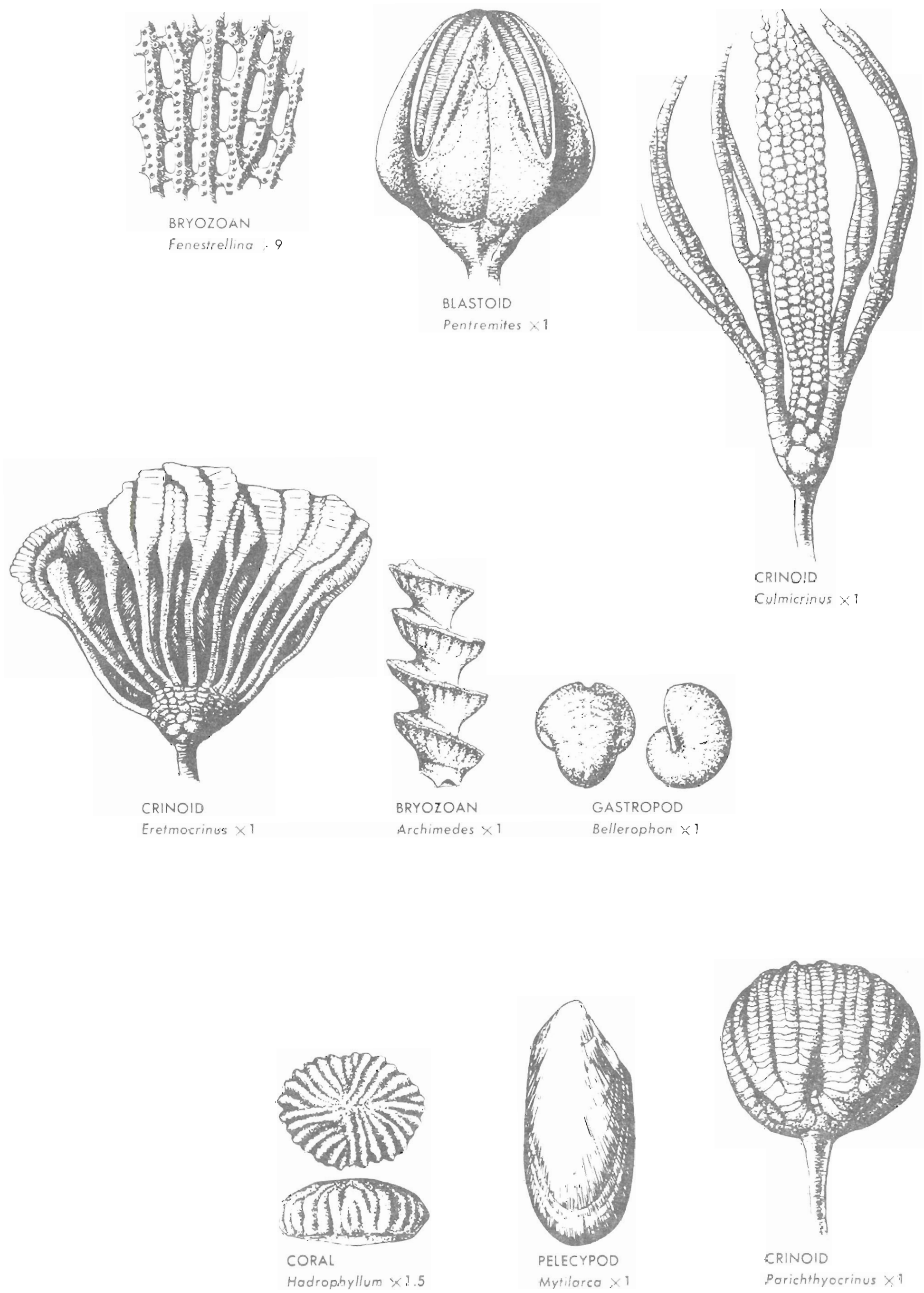


Figure 12. Mississippian Guide Fossils. (From **BASIC CONCEPTS OF HISTORICAL GEOLOGY** by Edgar W. Spencer, Copyright ©1962 by Thomas Y. Crowell Company, Inc. With permission of the publisher.)

Pennsylvanian Period

The Pennsylvanian Period began about 315 million years ago and lasted approximately 45 million years. The Pennsylvanian is particularly important to West Virginia because it was during this period of extensive and luxuriant swamp forests that our important coal deposits originated.

At the beginning of the Pennslyvanian Period, a mountainous belt extending from Newfoundland to Alabama roughly occupied the area some distance to the east of what is now the State of West Virginia. This highland formed the principal source of material for the vast deposits of the State. The seas of the continental interior withdrew at the close of Mississippian time, thus leaving the soft sediments exposed to rapid erosion. Erosion cut many channels, some as much as 300 feet deep, and then the first Pennsylvanian strata were laid down, burying the old erosion surface at the top of the Mississippian. This unconformity is exposed at a number of localities in West Virginia. At some localities in western West Virginia the entire Mauch Chunk Group has been eroded away. In eastern West Virginia the unconformity is far less pronounced. It is not recognizable and probably not present in the Hurricane Ridge Syncline in Mercer County.

A broad basin that included essentially all of West Virginia and much of the continental interior began forming early in Pennsylvanian time and continued throughout the period and into the Permian Period that followed. Subsidence was slow, and sediment from the Appalachian highlands was transported to the basin and deposited in large deltas. The rate of deposition was essentially the same as the rate of subsidence so that only very occasionally did any of the area of West Virginia drop below sea level. It was essentially a low, swampy area, close to but not below sea level, where lush, green, swamp forests abounded at intervals over the surface of the deltas. As time went on, the remains of these forests accumulated in stagnant water to form vast deposits of peat that were subsequently gradually altered by heat and pressure through the ages to form the extensive coal deposits we know today.

Peat deposition was periodically interrupted by vast quantities of sand, gravel, silt, clay, and some calcareous material. Thus were formed the immense thicknesses of sandstone, conglomerate, siltstone, and shale that, along with the coal seams and a few limestone layers, make up the Pennsylvanian section. Many of the sandstones, particularly the Salt sands of the Pottsville, have formed important shallow reservoirs for oil and gas production.

The various deposits occurred for the most part in cycles, the marine limestone formed at times when the delta surface was below sea level, the peat during long periods of swamp conditions when little sediment was coming in from the source to the east, and the clastic materials were washed in at times of vigorous clastic supply to the deltas.

It is interesting to note the rhythmic arrangement of Pennsylvanian rocks as so well described by Cross and Schemel (1956, p. 36):

> In most of the coal areas in midcontinental and eastern United States, as well as in many other areas containing Upper Paleozoic coals, a number of geologists have observed that the various thin layers of different kinds of rocks associated with these coal seams are deposited in groups or sequences which are repeated in a particular order over and over again. These repetitive cycles or rock types arranged in particular sequence are called ***cyclothems***.

Figure 13 illustrates a typical cyclothem with the section as exposed along the Little Kanawha River near Falls Mill. Starting with the underclay at the base the units in ascending order are: (1) under clay; (2) coal seam; (3) bony shale; (4) roof shale, usually dark gray to nearly black, commonly termed slate by the miners; (5) sandstone and siltstone; (6) another roof shale; (7) clay shale; (8) a thin rider coal; (9) a third roof shale; and (10) a large thickness of sandstone.

With modifications, a very similar sequence of beds is repeated for the various important coal seams, the cyclothems being caused by the rhythmic oscillation of sea level throughout the Pennsylvanian Period.

The Pennsylvanian of West Virginia has been divided into four main parts that are, from bottom upward, the Pottsville Group, the Allegheny Formation, the Conemaugh Group, and the Monongahela Group. The Pottsville Group in turn consists of three formations, which are in ascending order the Pocahontas, New River, and Kanawha.

In describing the deposition of Pennsylvanian beds in West Virginia, the State should be divided into Southern and Northern basins (or fields) as indicated in Figure 14. The hinge line dividing the two basins extends in a southwest-northeast direction from central Wayne County to extreme southeastern Preston County, dividing the State into two approximately equal areas. According to Barlow (1971, p. 3):

> These two coal fields, or coal basins, are quite different, mutually exclusive, and yet interrelated in many ways. . . . The important coal seams of one generally cannot be traced satisfactorily into the other. . . .

During the time of Pottsville deposition, the northern basin was more of a platform receiving much less deposition than the deeper southern basin. The hinge line, a concept originated by Arkle (1969), is essentially a belt of predominant sand deposition. According to Barlow (1971, p. 5), "The southern basin is essentially a Pottsville basin in the sense that by the end of Pottsville (Kanawha) time, the Pottsville Trough had been filled."

The ***Pocahontas Formation***, the lowest unit of the Pottsville Group, is known only in southeastern West Virginia where it reaches a reported maximum thickness of about 720 feet. It contains several important coal seams, including the famous Pocahontas coals.

The ***New River Formation*** extends somewhat farther northwest, into the northern basin but is important only in the southern basin where it reaches a probable maximum thickness of 1,000 feet. A thickness of about 100 feet has been reported for Mineral and Grant Counties of the Eastern Panhandle. The New River contains, among others, the Iaeger, Sewell, Welch, Raleigh, Beckley, and Fire Creek coal seams.

The ***Kanawha Formation*** is extensively exposed in a belt extending northeastward from the Kentucky line to the Deer Park anticline in Randolph and Upshur Counties. The outcrop belt is about 50 miles wide at the Kentucky boundary, narrows to about 12 miles in Upshur County, and is present as a narrow belt of outliers (detached remnants of younger rocks) in Tucker and Randolph Counties east of the Deer Park anticline. It reaches a maximum thickness of about 2,100 feet in McDowell County.

The Kanawha is about 50 percent sandstone (in part conglomeratic), along with shale, siltstone, and coal. It includes the Stockton, Coalburg, Winifrede, Chilton, Williamson, Cedar Grove, Alma, Peerless, Campbell Creek, Powellton, Eagle, Gilbert, and Douglas coal seams, as well as several minor and unimportant ones. Many of the sandstones have been quarried for building stone and other uses.

In north-central and northwestern West Virginia, the entire Pottsville section seldom exceeds 200 feet in thickness. All of the section there is believed to belong to the Kanawha Formation.

Thus, it is concluded that deposition in West Virginia during Pennsylvanian time began in southern West Virginia with the Pocahontas Formation, with deposition ex-

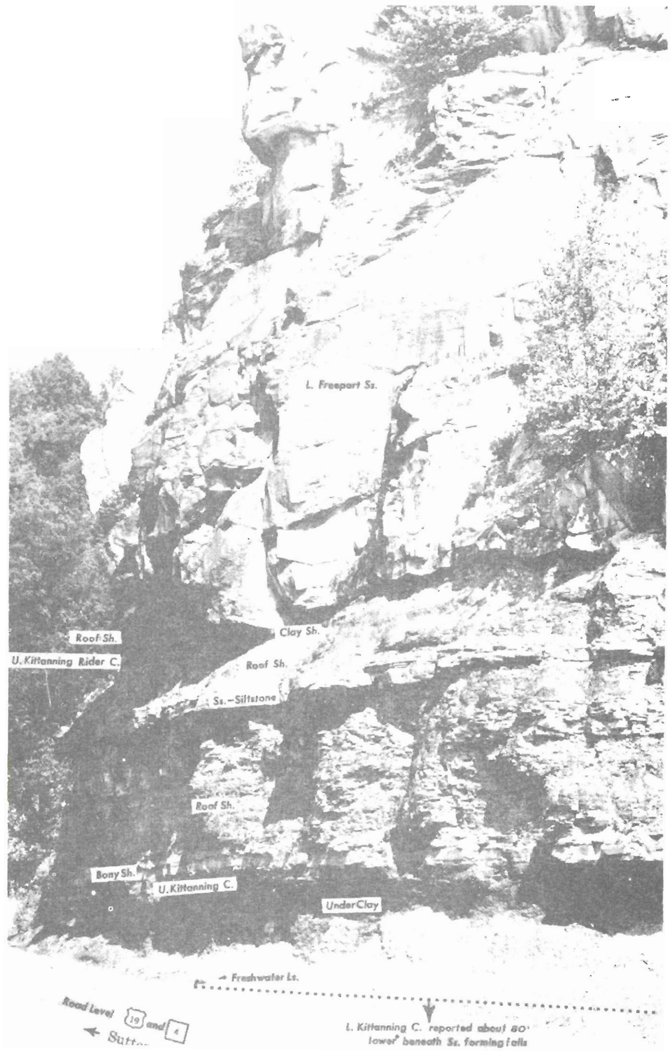


Figure 13. **Exposure of the Allegheny Strata from the Upper Kittanning Coal to the Lower Freeport Sandstone at Falls Mill.** The sequence of rocks illustrates a common type of Allegheny cyclothem. (From Cross and Schemel, 1956.)

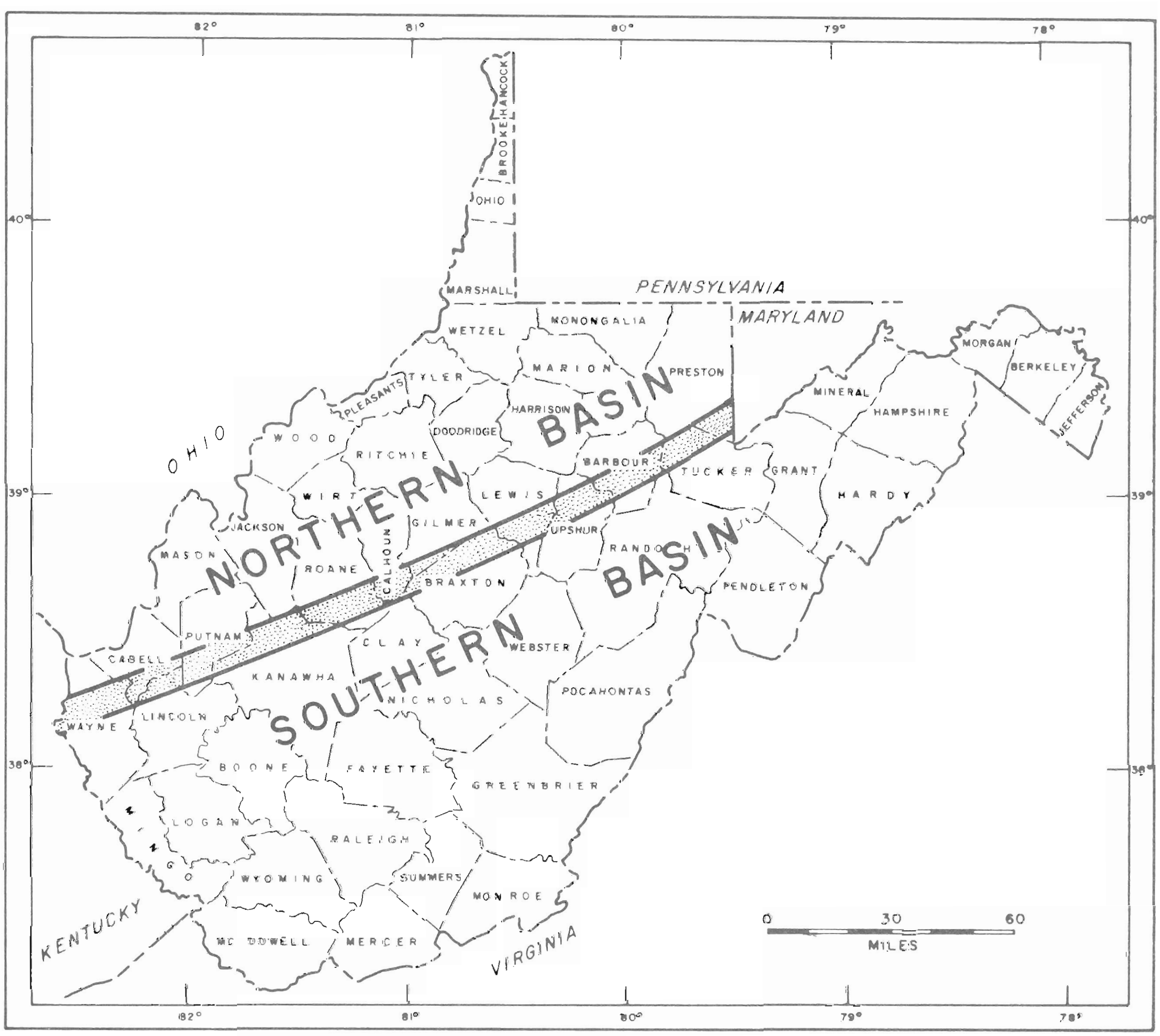


Figure 14. Map of West Virginia Showing Coal Basins. (Modified from Barlow, 1971, p. 3.)

tending farther and farther north as time went on. By the end of Pottsville time, deposits were being formed throughout essentially all of the State. The total maximum thickness of the Pottsville Group reaches about 3,850 feet.

After the Kanawha Formation was deposited, the principal deposition shifted from the southern to the northern basin. It is here that the younger Pennsylvanian beds are of importance. If they were ever present to any extent in the southern basin they have since been eroded away.

Overlying the Pottsville is the ***Allegheny Formation***. Cyclic deposits of the same general character as described for the Pottsville continued, although the Allegheny contains less sandstone. This formation contains the Freeport, Kittanning, and Clarion coal seams. Although in the Sandhill well a thickness of 325 feet was assigned to the Allegheny, thicknesses greater than 250 feet are unusual. The Upper Freeport coal has been established as the top bed of the Allegheny Formation.

The ***Conemaugh Group*** extends from the top of the Upper Freeport coal to the base of the Pittsburgh coal. Red bed deposition began about the beginning of Conemaugh time; at the same time there was a decrease in peat accumulation. Consequently, today fewer commercial coal seams are in the Conemaugh than in the underlying Pennsylvanian rocks. The main belt of Conemaugh outcrops extends across the State from Cabell and Wayne Counties to the northeastern corner of Preston County. The width of this belt of outcrops in general ranges from about 10 to 25 miles. The most important coal seams of the group are the Elk Lick, Bakerstown and Mahoning, all of which have been mined but none of which has been of outstanding importance commercially. The Conemaugh ranges in thickness from about 500 to 1,000 feet.

The uppermost unit of the Pennsylvanian, the ***Monongahela Group***, is of considerable importance in northwestern West Virginia, because it contains extensive deposits of the Pittsburgh coal, the basal bed of the group. This coal is the most extensively mined of all the coals of West Virginia. A thickness approaching 10 feet is not uncommon. Other coals of the group are the Waynesburg (at the top), Uniontown, Sewickley, and Redstone. The normal thickness of the Monongahela is about 300 feet.

Life of the Pennsylvanian

Most characteristic of the life of the Pennsylvanian are the fast-growing, soft-tissued trees and other plants that formed the vast swamp forests of this period. Perhaps nowhere else on the continent were these more important than in West Virginia, for it was from these that almost all of the commercial coal deposits of the State were formed. Although seed-bearing plants were present, the spore-bearing plants were more abundant. Ferns, horsetails, rushes and the like, which we know only as relatively small plants, commonly grew to large tree size (Figures 15 and 16). Conifers were still very primitive, and flowering plants had not yet come into existence.

Primitive insects, including many of the largest known, were abundant. Also important were the centipedes, spiders, scorpions, and small land snails. Fishes continued to be important. Various clumsy amphibians and even a few small reptiles roamed the swamps and land areas.

Invertebrate marine life continued in abundance. Most important were the brachiopods, lacy bryozoa, pelecypods, and gastropods (Figure 17). Foraminifera, mostly of very small size, were also abundant and are important in correlation of Pennsylvanian rocks outside of West Virginia. Corals and echinoderms were also present. Blastoids made their last stand.

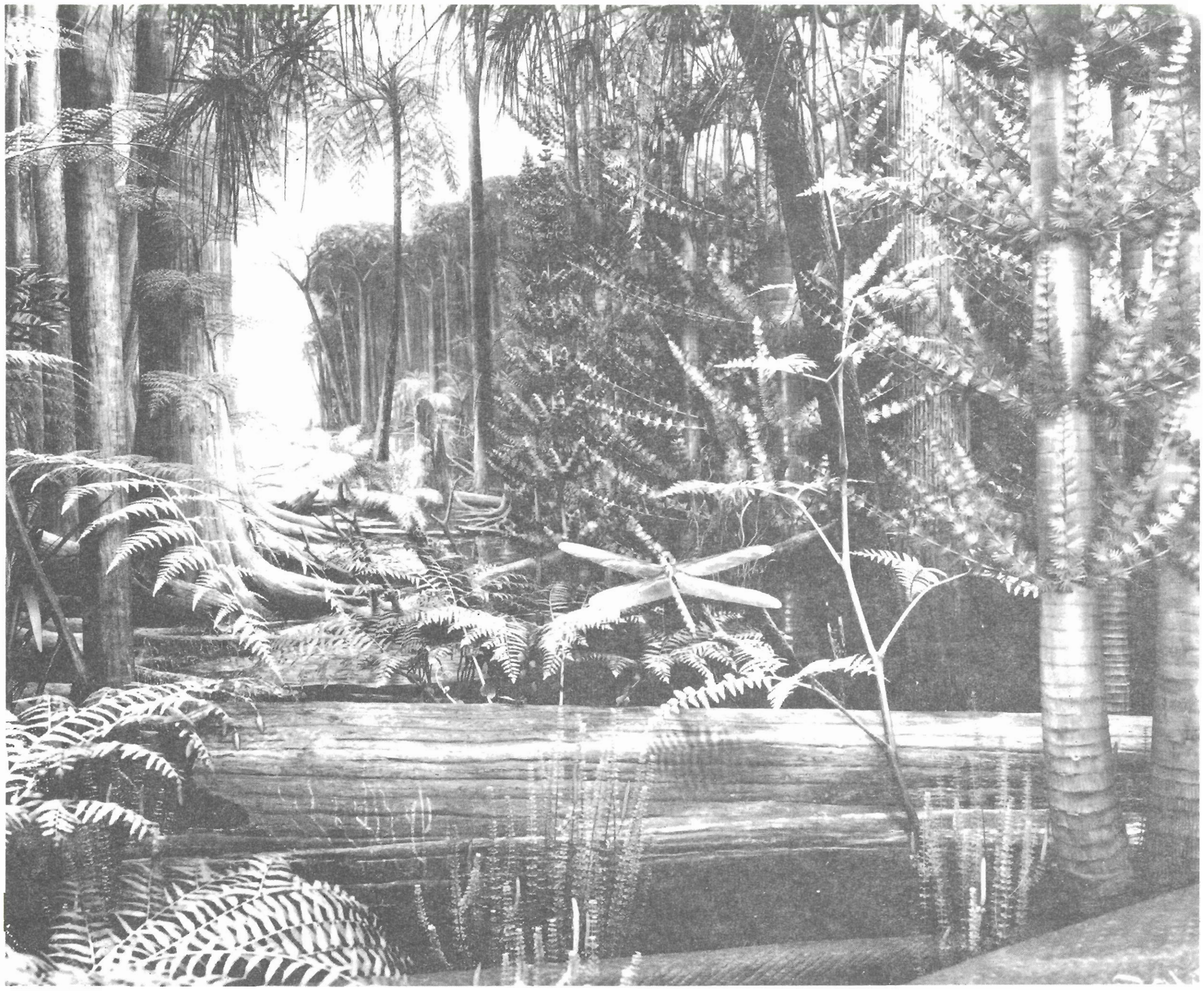


Figure 15. Pennsylvania Coal Forest Restoration. A large dragonfly with a wing span of nearly 3 feet dominates the center of this view into a Carboniferous coal swamp. Also present are ferns: (1) *Sigillaria,* (2) *Lepidodendron*, (3) *Calamites,* (4) a large rush that grew to be as much as 30 feet tall, and (5) smaller rushes, *Sphenophyllum.* (Photo by courtesy of the Chicago Natural History Museum.)

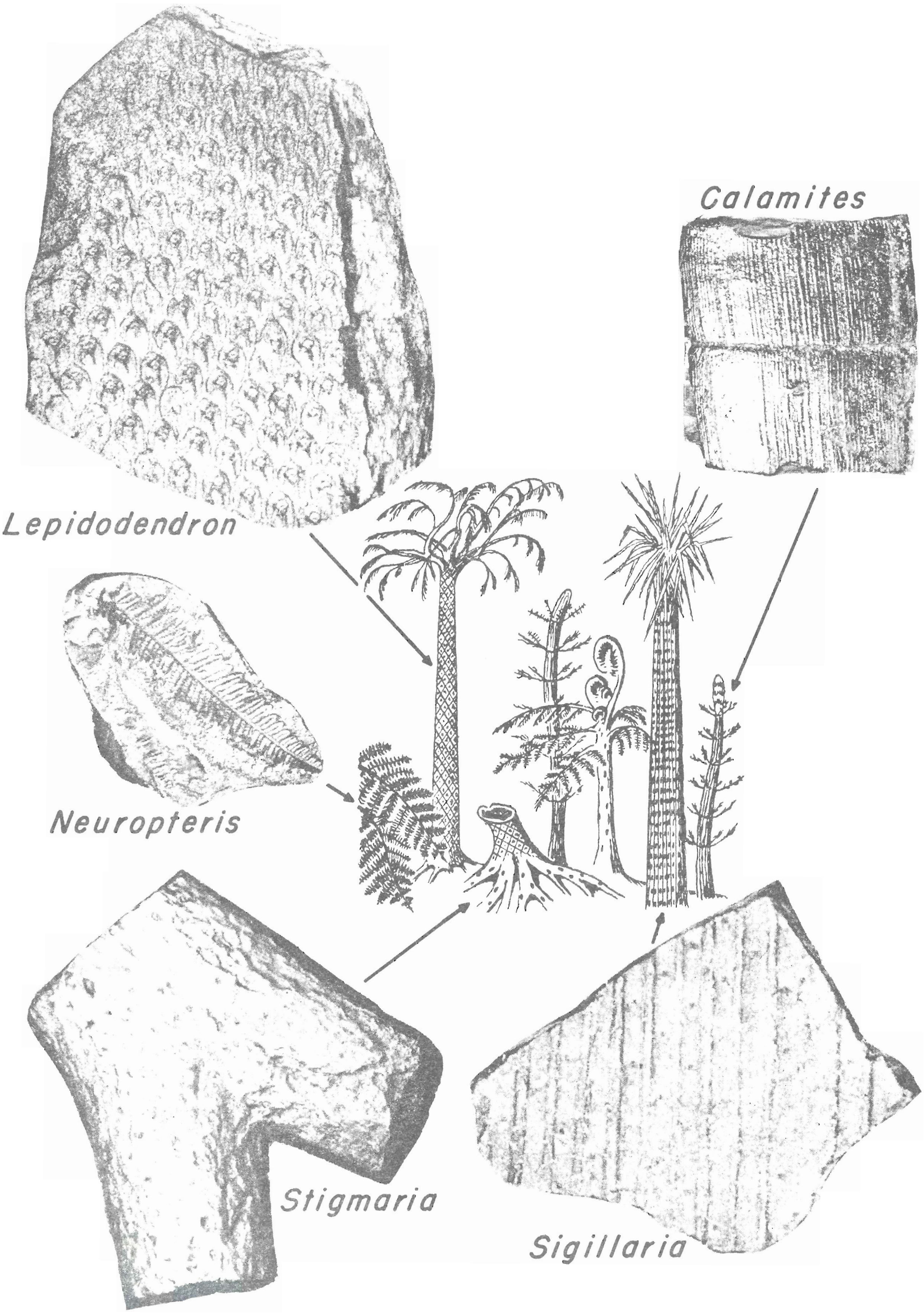


Figure 16. Plant Fossils—Common Constituents of Coal. (Haught, 1964, p. 4.)

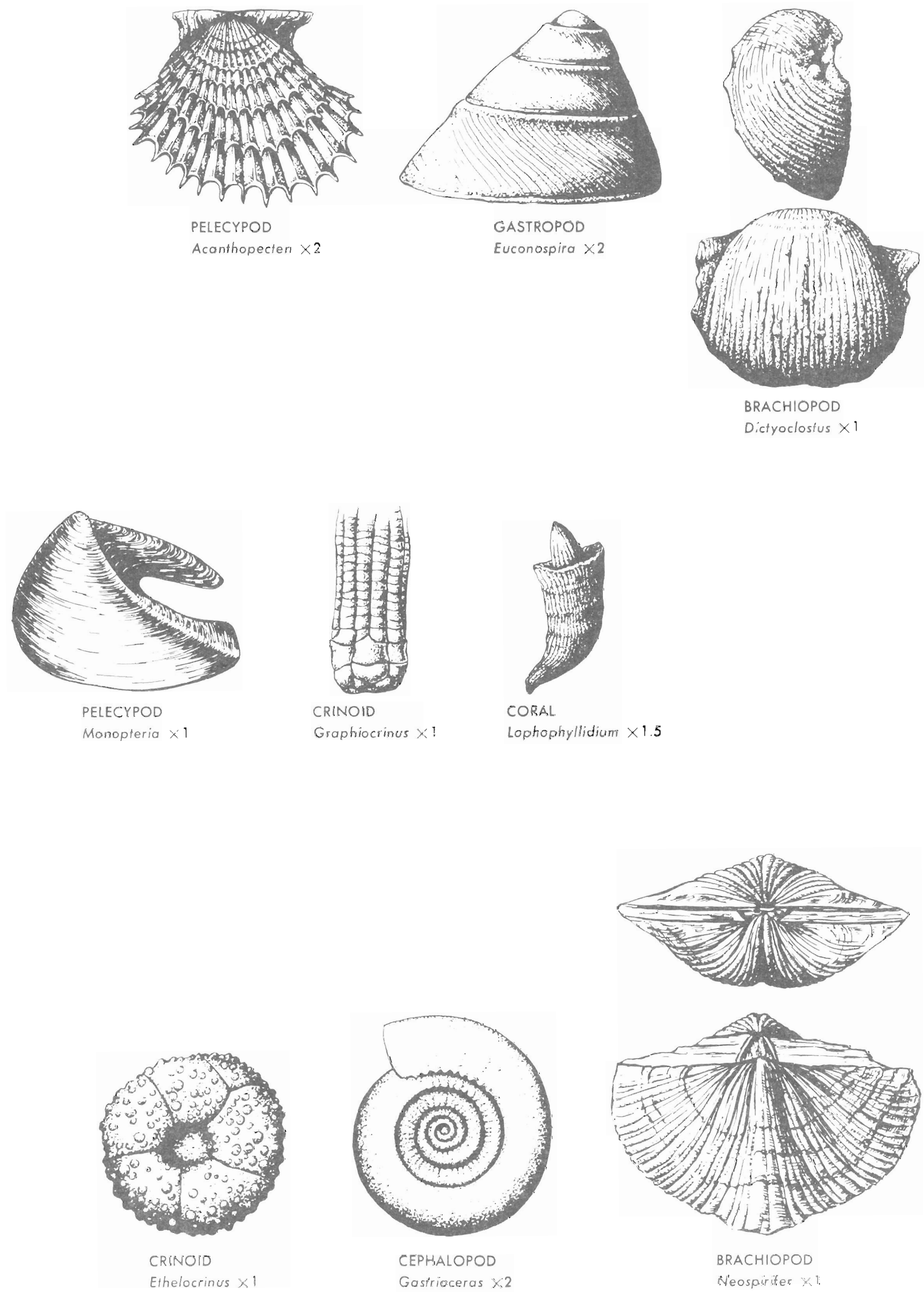


Figure 17. Pennsylvanian Guide Fossils. (From BASIC CONCEPTS OF HISTORICAL GEOLOGY by Edgar W. Spencer, Copyright ©1962 by Thomas Y. Crowell Company, Inc. With permission of the publisher.)

Permian Period

The Permian, the youngest period of the Paleozoic Era, began about 270 million years ago and lasted approximately 45 million years.

The beginning of the Permian in West Virginia or even in the entire Appalachian region is not marked by any catastrophic event. The rocks are so similar to those of the preceding Pennsylvanian Period that there is as yet strong disagreement among geologists as to where the Pennsylvanian-Permian contact should be placed. For purposes of this booklet we shall consider this contact to be the base of the Dunkard Group, although some geologists believe it should be placed considerably higher in the section.

Rocks of the Dunkard Group, the only ones of Permian age remaining in West Virginia, are only exposed in the State in a belt adjacent to the Ohio River, extending northward from the Kanawha River to Brooke County in the Northern Panhandle. This belt of outcrop is in places as much as 40 miles wide and marks the Dunkard basin, the last remnant of the Appalachian geosyncline between the Blue Ridge on the east and the Cincinnati arch on the west.

The maximum thickness of the Dunkard Group present in West Virginia is about 1,200 feet. It is not possible to determine how much more Permian may have been deposited and later removed by erosion, nor is it possible to determine how much of the State was at one time covered by sediments of Permian age.

Sandstones, siltstones, and shales of similar character to those of the Pennsylvanian predominate, thus indicating an environment similar to that of the Pennsylvanian. Vast thicknesses of red shale are present and crop out abundantly along Interstate 77 for many miles south of Parkersburg, along U. S. Highway 50 east of Parkersburg, and in many other localities throughout the outcrop area. Although several coal seams are present, they are generally thin and impure as opposed to the minable coal seams of the underlying Pennsylvanian. The only coal seam of economic importance in the Dunkard Group is the Washington.

Arkle (1959, p. 122) divided the Dunkard and Monongahela into the red, transitional, and gray facies. The red facies predominates in the southern part of the basin, and is composed essentially of oxidized sediments of red to brown color deposited near the source area to the south. The gray facies, which was deposited in the northern part of the basin, is composed essentially of gray shale and sandstone, with a little coal and a few beds of limestone and calcareous shale. Deposition was in the deepest part of the basin farthest from the source. The transitional facies was deposited in the central part of the basin between the red and gray. Here the red to brown oxidized sediments and the gray sediments grade into and intertongue with one another.

In describing the fossils found within sediments of the gray facies, Arkle states, "These remains are believed to be entirely of fresh water origin except for a few scattered brackish water representatives. . . ." Thus we conclude that the lowest part of the basin sank to or only slightly below sea level, and that deposition in the central and southern parts of the basin was entirely continental.

Life of the Permian

The vast forests of the Pennsylvanian Period continued to exist in the Permian but became less and less important as time passed. This was particularly true of the coal-producing plants. A very dry climate developed during the period, the result being a strong decline of the seed ferns and scale trees. Surviving and gaining greater importance were the conifers, which were more adapted to the drier climate. By the end of the period, coal-producing plants had become unimportant. No more important coal was formed in the entire world until the Cretaceous Period almost 100 million years later.

Animal fossils are found in the exclusively nonmarine sediments of West Virginia. By studying these fossils and those found in other parts of the world, we can make some generalizations.

Vertebrate life of the Permian was marked by the advance and diversification of reptiles (Figure 18). Relatively rare at the close of the Pennsylvanian, reptiles had advanced to the predominant form of vertebrate life by the end of the Permian Period. This advance continued into the subsequent Mesozoic Era. Conspicuous among Permian reptiles were a number of fin-backed forms such as the ***Edaphosaurus*** and ***Dimetrodon***. Amphibians continued to be abundant.

Marine invertebrates became fewer and fewer and were almost nonexistent in West Virginia. Bryozoa and brachiopods disappeared, while corals and echinoderms were very much diminished. Pelecypods and gastropods continued to be important. Rapid evolution produced a variety of ammonites (Figure 19), some of which were very specialized or ornate. As a consequence of this specialization and subsequent radical changes in environment, only a few of the species survived into the subsequent Triassic Period.

Appalachian Orogeny

Sometime during the Permian Period, perhaps near the beginning, a very important mountain-building event known as the Appalachian Orogeny began. This disturbance lasted throughout Middle and Late Permian time and possibly well into the subsequent Triassic Period. The most strongly affected region was what is now the Appalachian Mountains region, extending from Newfoundland to Alabama. In West Virginia, the western boundary of this region is essentially the Allegheny Front that separates the strongly folded and faulted beds to the east from the less folded and relatively flat beds of the Appalachian Plateau region to the west.

The highly folded belt includes the Eastern Panhandle of West Virginia, extends southwestward through Virginia, and includes a narrow strip of West Virginia along the Virginia boundary in Monroe and Mercer Counties. This Appalachian folded belt differs strongly from the Appalachian Plateau Province that covers the greater part of West Virginia (Figure 20). The Appalachian Orogeny caused tremendous folding and thrusting of the older Paleozoic rocks northwestward and played the major role in the formation of the Appalachian Mountains. In this region of steeply dipping folded beds, the harder layers–particularly the sandstones–tend to form distinct ridges, whereas the softer shale beds–particularly shale and shaly limestone–tend to form valleys. This fairly distinct pattern of valleys and ridges has given the name of Valley and Ridge to the province lying between the Blue Ridge and the Allegheny Front (Figures 5 and 20). The Great Valley that is located in the eastern part of the Valley and Ridge Province is predominantly an area of carbonate outcrops, with only minor sandstone beds present. Hence, there are few ridges of any size in this part of the province.

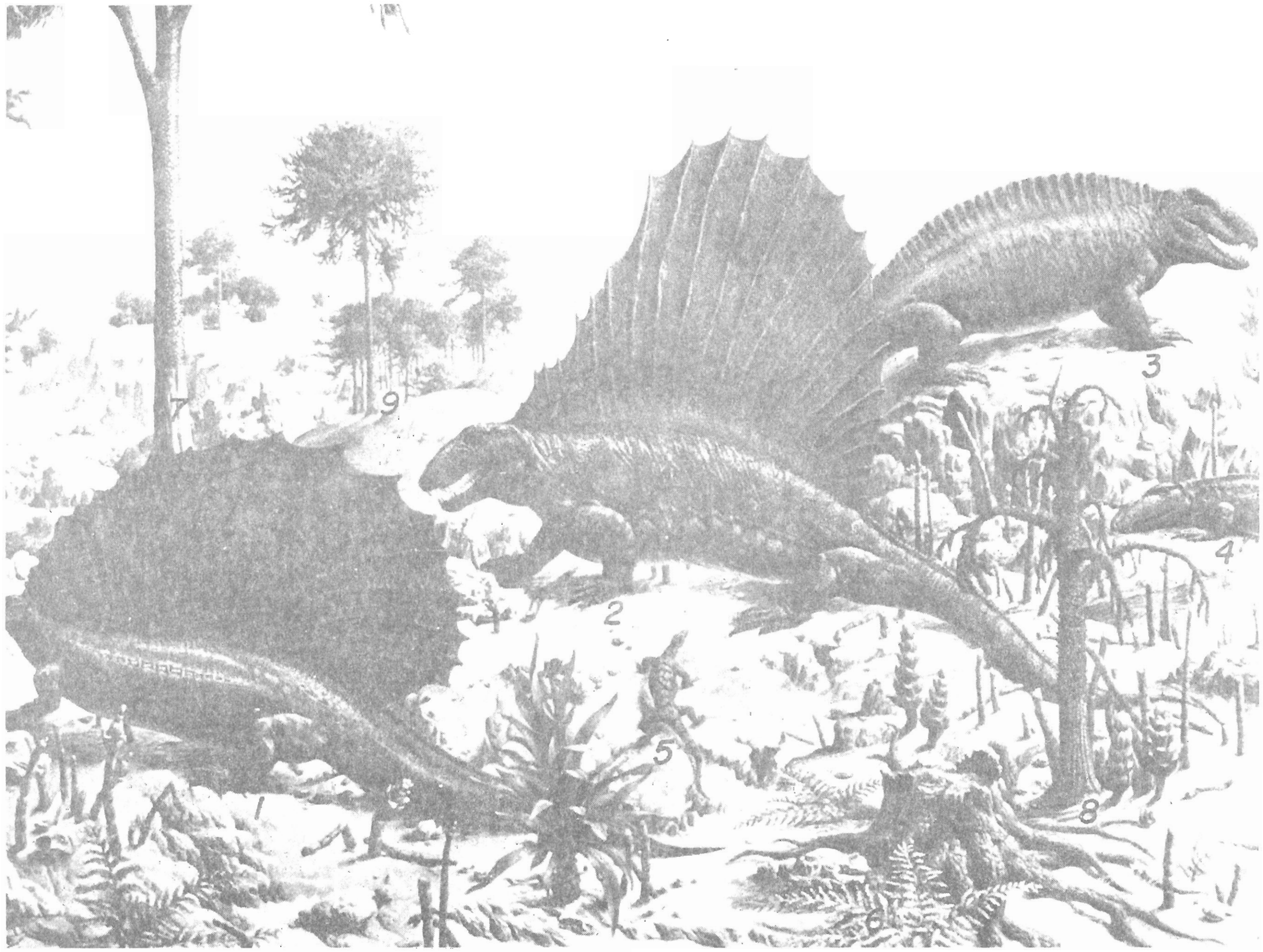


Figure 18. **A Permian Landscape Showing Characteristic Animals and Plants.** (1) a fin-back reptile, *Edaphosaurus;* (2) another fin-back, *Dimetrodon;* (3) *Sphenacodon;* (4) a pelycosaur, *Ophiacodon;* (5) another primitive reptile, *Araeoscelis;* (6) ferns; (7) *Lepidodendron;* (8) *Sigillaria;* (9) a conifer, *Walchia.* Part of a great mural by Rudolph F. Zallinger in Yale Peabody Museum. (From **HISTORICAL GEOLOGY** by Carl O. Dunbar, Copyright ©1960 by John Wiley & Sons, Inc. With permission of the publisher.)

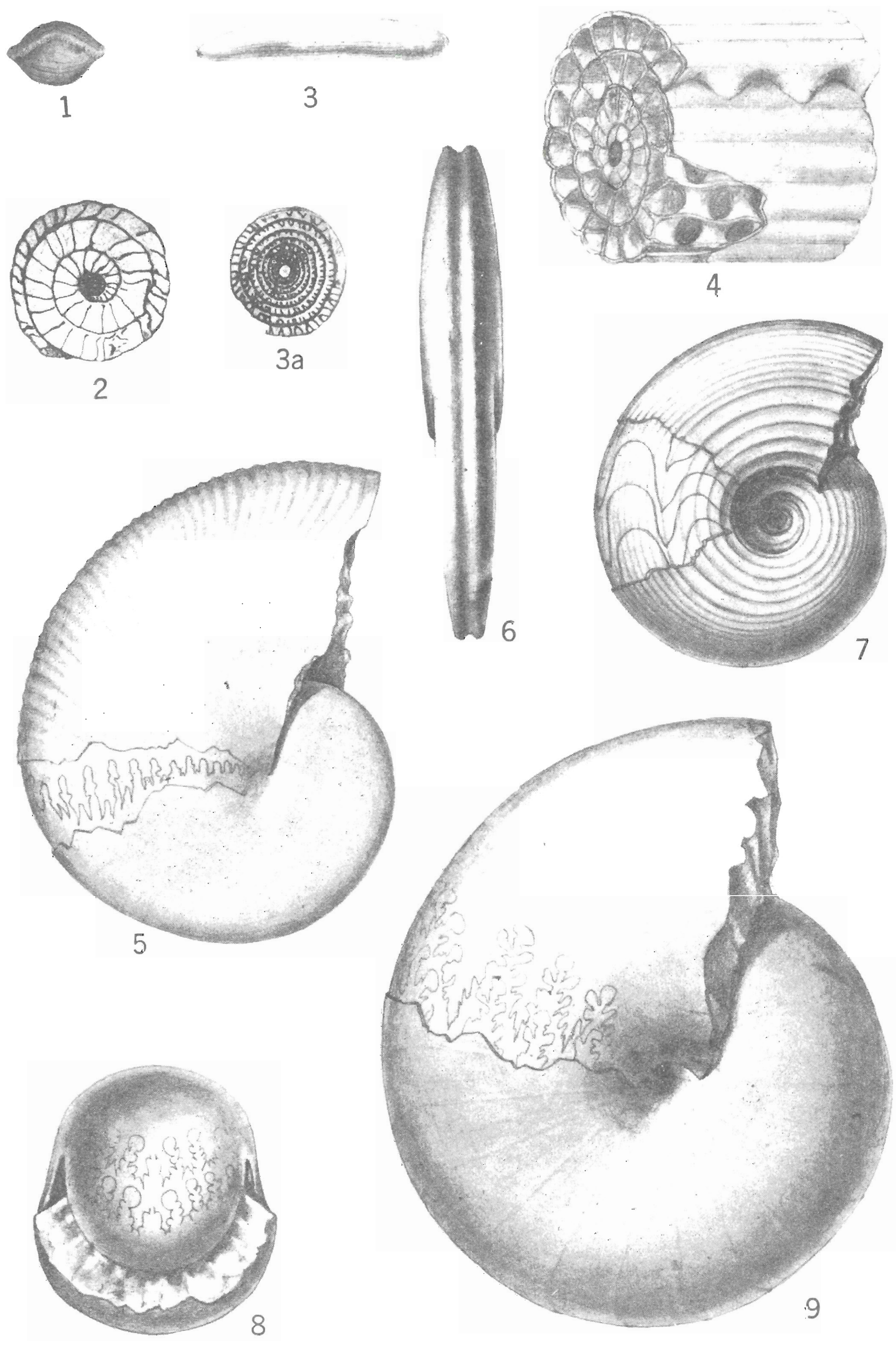


Figure 19. Permian Fusulinids (1-4), and Ammonites (5-9). (1) *Pseudoschwagerina uddeni*, (2) enlarged section of same, (3) *Parafusulina wordensis,* (3a) enlarged section of same, (4) model of a portion of a shell showing septa, (5 & 6) *Medicottia whitneyi* (lateral and edge views), (7) *Gastrioceras roadense,* (8) *Waagenoceras dieneri,* (9) *Perrintes vidriensis.* All natural size except (2) and (4). Drawn by L. S. Douglass. (From **HISTORICAL GEOLOGY** by Carl O. Dunbar, Copyright ©1960 by John Wiley & Sons, Inc. With permission of the publisher.)

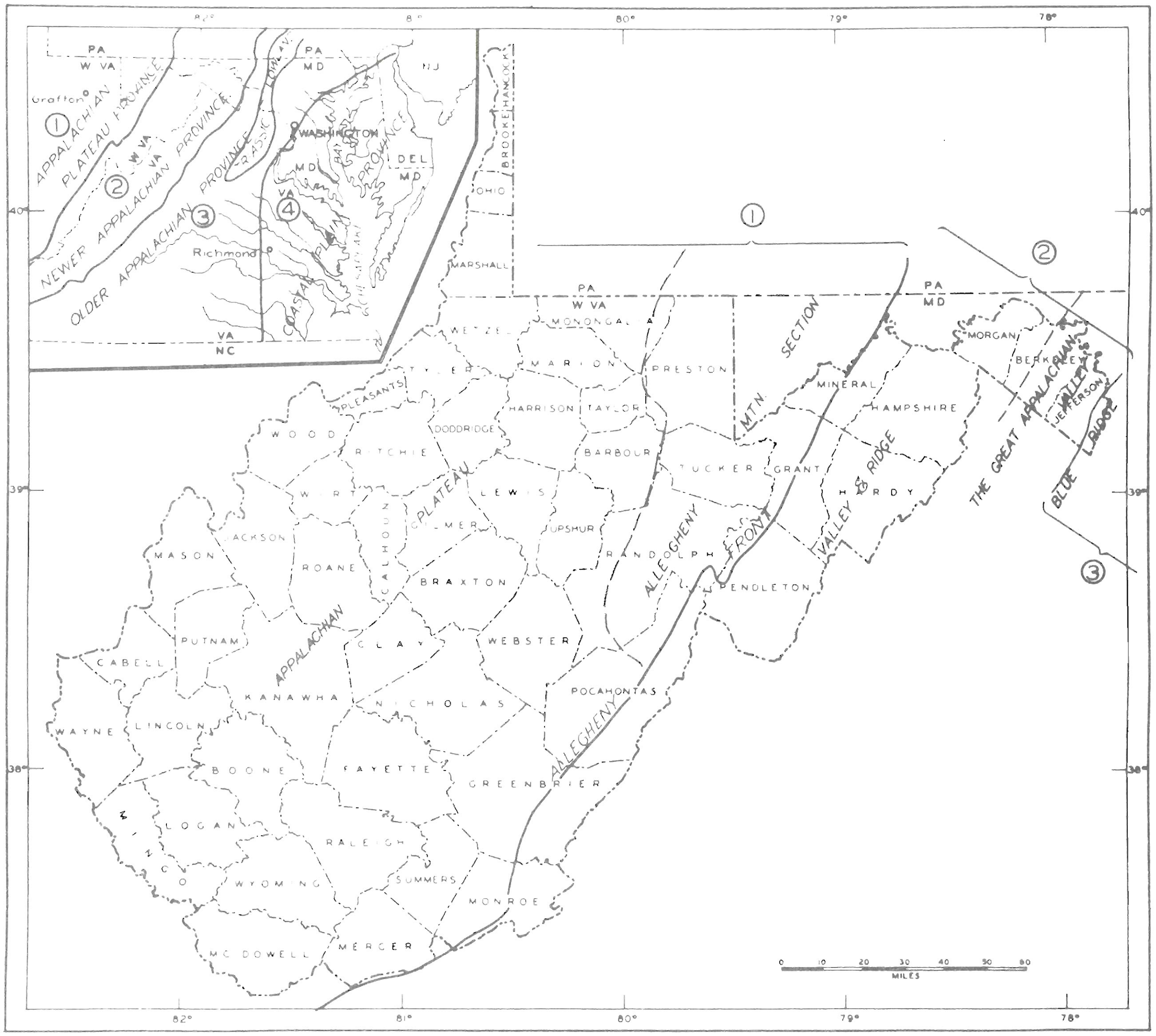


Figure 20. Map Showing Physiographic Provinces of West Virginia with Inset Map of Southern Part of Eastern U.S.

Mesozoic Era

At the close of the Paleozoic Era, the entire area that is now West Virginia, in fact the entire Appalachian region, had emerged to become a land area. There is no evidence that in the more than 200 million years since that time it has ever again been submerged beneath the sea. Thus ended, in the Appalachians, an almost continuous era of deposition of sediment that began more than 500 million years previously. As stated by Dunbar (1959, p. 244):

> . . . Since earliest Cambrian time the Appalachian Trough had subsided intermittently during every period, and had been the site of the most persistent interior seaways, trapping some 50,000 feet of strata. With the Permian came a change so profound that the region has never since been crossed by the sea!

Then, as stated by Udall (1964, p. 31):

> During much of the succeeding 200 million years (referring to the time subsequent to the Permian) West Virginia has been undergoing erosion. Several times the region has been worn down almost to a featureless plain, then broadly uplifted and reeroded. The linear features of the Ridge and Valley province are carved in tilted strata of unequal hardness, once deeply buried and now exhumed. The harder rocks form the rugged mountains that stand boldly above level river valleys formed in the softer rocks.

The Mesozoic Era began about 225 million years ago and lasted approximately 159 million years. It includes three periods: the Triassic, which lasted approximately 40 million years; the Jurassic, which lasted approximately 50 million years; and the Cretaceous, which lasted approximately 69 million years. The Mesozoic Era is commonly known as the "Age of Reptiles." The giant dinosaurs and pterosaurs that dominated the land and the ichthyosaurs and plesiosaurs that dominated the seas became extinct at the end of the era. Likewise, ammonites that flourished among marine invertebrates of the Mesozoic Era died out at the end of the era.

In West Virginia there are no known sedimentary rocks of Mesozoic age. To the east in the Piedmont Province of Virginia and Maryland, narrow basins, now highly faulted, contain predominantly nonmarine Triassic beds. Also, in the late Triassic or possibly Jurassic, there was considerable igneous activity resulting in many intrusive bodies, principally dikes of diabase and other basic rock. These cut the Triassic sediments and vast areas of surrounding older rocks. Several of these intrusives have been found in West Virginia, mostly in Pendleton County. These are the only Mesozoic rocks known to occur within the State.

Marking the end of the Mesozoic Era was the Laramide Orogeny. This mountain-building movement was active over several million years, causing great uplift and mountain-building in the western part of the United States and even in some of the Caribbean Islands. However, the effects of the orogeny are unimportant in the eastern part of our country.

Cenozoic Era

The Cenozoic Era began about 66 million years ago and extends to the present time. All but the last 2.5 million years of this era have been grouped into the Tertiary Period. This has in turn been divided into the Paleocene, Eocene, Oligocene, Miocene, and Pliocene Epochs. The last 2.5 million years of the earth's history is termed the Quaternary Period and has been divided into the Pleistocene and Recent (Holocene) Epochs.

Throughout the Cenozoic Era West Virginia has been a land area. So far as we know there has been no igneous activity. The only sediments are the recent alluvial deposits and a few lake deposits as described below. The alluvial deposits are mostly gravel, sand, and clay, deposited by and along the existing streams of today. Essentially, all of these were deposited during the more recent or Quaternary Period. During the Tertiary Period, a series of deposits was being laid down along the Atlantic Coast from Long Island to Florida. On the Gulf Coast such deposits locally extend inland as much as 300 miles. But West Virginia remained a land area throughout the period.

Having a profound effect upon the Appalachian region was the great period of glaciation of the Pleistocene Epoch. However, it must be emphasized that, contrary to public opinion, the glaciers themselves did not extend into West Virginia, although they did cover the area just north of the Northern Panhandle. The glaciers are important to our State because of some changes in the drainage pattern that caused the deposition of some important lake deposits in the Monongahela River basin. As stated by Clendening and others (1967, p. 1, 2):

> Before the advances of the continental ice sheets during the Pleistocene Epoch, the flow of the Monongahela River was northward to the ancestral St. Lawrence River system. This exit to the sea was dammed in western Pennsylvania as a result of continental glaciation, and an extensive lake was formed which occupied the river valley from just north of Beaver Falls, Pennsylvania, to some miles south of Weston, West Virginia, a distance of over 100 miles. This glacial lake is referred to as Lake Monongahela, the presence of which is reflected by extensive terrace deposits flanking the present Monongahela River valley. The terrace deposits represent the materials deposited in the lake during the time of its existence.

Another important Cenozoic alluvial deposit lies along the bed of the ancient Teays River which flowed westward from Charleston through Milton, Huntington, Ashland (Kentucky), and Chillicothe (Ohio) northward to the ancient St. Lawrence drainage (Rhodehamel and Carlston, 1963, p. 258). Figure 21 shows drainage of early Cenozoic time superimposed upon present drainage. In early Cenozoic time, drainage of the present Ohio River north of New Martinsville was northward to the St. Lawrence and the principal drainage of the remainder of West Virginia was northwestward along the old Teays River. Contrasted with this is the present Ohio River drainage (Figure 21).

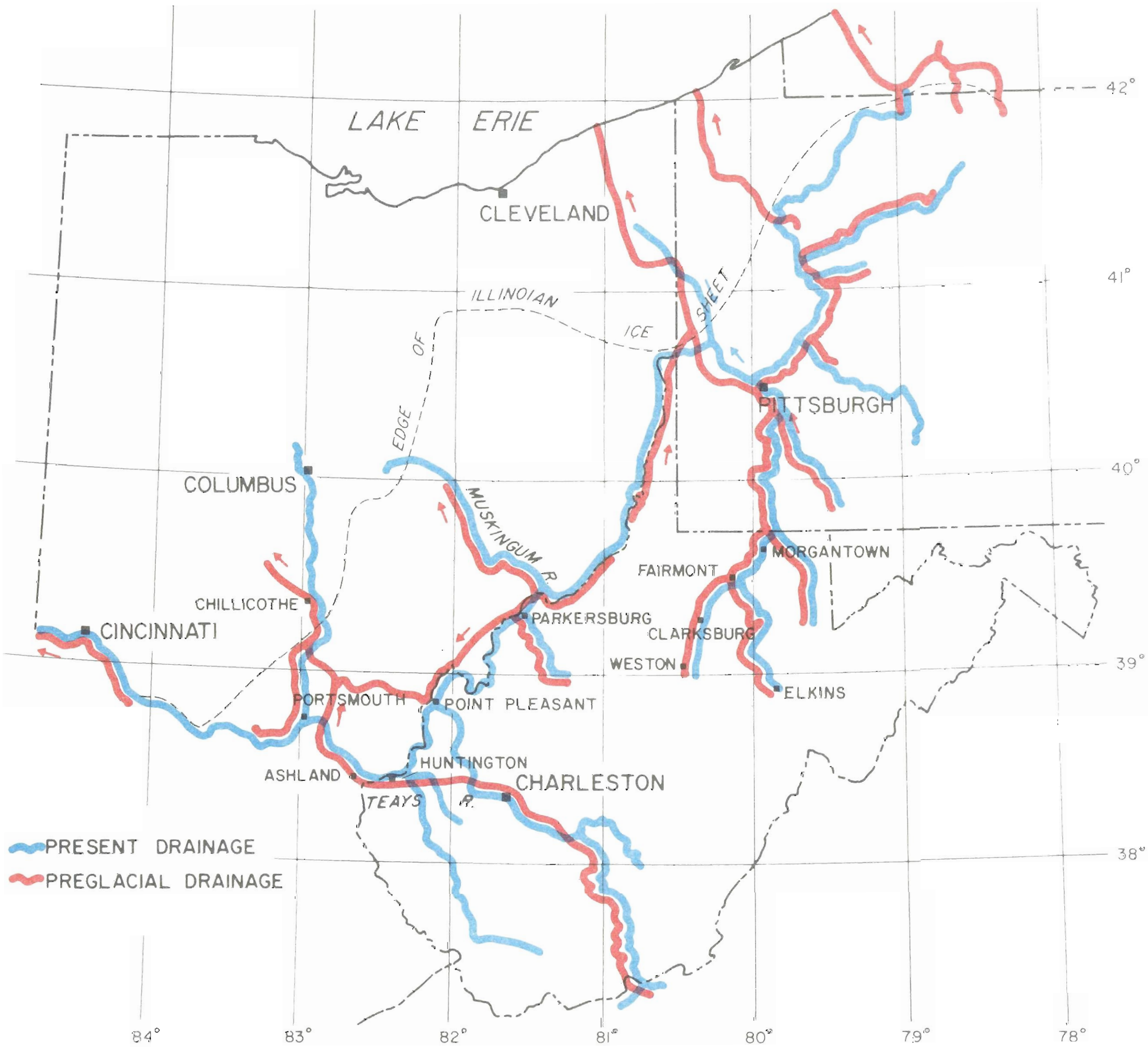


Figure 21. Pre-Glacial Drainage Contrasted with Present Drainage in Parts of West Virginia, Ohio, and Pennsylvania. (From various sources.)

Summary

Prior to one billion years ago the geologic history of West Virginia is obscure. Sometime between about 1,100 and 800 million years ago, lava was deposited in the extreme eastern part of the State forming our oldest exposed rock, the Catoctin Greenstone. Later, perhaps about 800 million years ago, a narrow trough began to form in extreme eastern West Virginia. An arm of the sea entered and sediments accumulated. As time went on, this sea transgressed westward. By the end of Cambrian time, about 300 million years later, this shallow sea covered essentially all of West Virginia. Marine deposition took place throughout most of this and the succeeding Ordovician Period. During this total interval of about 370 million years, most of the rocks exposed in Jefferson and eastern Berkeley Counties and in scattered areas southwestward along the Virginia boundary were deposited (Figure 3). Rocks of the same age are found in abundance in the deep wells throughout the State.

The Taconic Orogeny near the end of Ordovician time formed a high mountainous area east of West Virginia. These highlands formed the main source of sediments for the succeeding Silurian Period and part of the Devonian Period. Both clastics and carbonates were deposited in a mixed marine and nonmarine environment, with clastics predominating in the eastern part of the State. Evaporites were deposited in northern West Virginia in Late Silurian time.

During Middle and Late Devonian time the Acadian Orogeny, with the main uplift to the northeast, resulted in a further source for the predominantly clastic marine deposits of these epochs. However, near the end of Devonian time the sea was rapidly retreating westward and the continental red beds of the Hampshire Formation were being deposited over most of the State.

The sea made one more important intrusion into West Virginia during Middle Mississippian time, approximately 330 million years ago, resulting in the deposition of the Greenbrier Formation, predominantly limestone, the last marine deposit of significance in the State.

At the close of Mississippian time, about 310 million years ago, West Virginia was essentially a land area, subject to erosion. Early in the succeeding Pennsylvanian Period the area dropped to near sea level and for more than 50 million years continued to sink at about the same rate that deposition was taking place. Only occasionally and for very short periods of time did the area fall below sea level. Swamp conditions prevailed, resulting in the deposition of thousands of feet of nonmarine sandstone and shale and the many important coal seams that we know today.

Sometime during the Permian Period, roughly 270 to 225 million years ago, the Appalachian Orogeny began. West Virginia was uplifted, important deposition of sediments ceased, and erosion began taking place. Much folding and thrust faulting occurred, especially in the eastern part of the State. This orogeny played a major part in the formation of the Appalachian Mountains as we know them today. Never again has the sea invaded West Virginia.

So far as is known no sedimentary rocks were deposited in West Virginia during the Mesozoic Era, which extended from 225 to 66 million years ago. During the early part of the era, considerable igneous activity took place in neighboring states to the east, and a few dikes of diabase and other basic rock extended into Pendleton and surrounding counties.

Late in the Cenozoic Era, in fact extending to less than 100,000 years ago, glaciers covered the northern part of the North American continent, extending almost to the Northern Panhandle of West Virginia, but not into the State. Prior to the advance of these ice sheets, drainage of the Monongahela River was northward to the St. Lawrence River system. The ice sheet caused damming and a lake extended as far south as Weston. Important lake deposits, predominantly clay, were thus laid down in the Monongahcla River basin. Drainage was diverted westward into the Ohio River system. Divergence of the New River system that formerly drained northwestward caused the deposition of similar deposits in the old Teays River channel between Charleston and Huntington. Except for recent alluvial deposits, there are no other known Cenozoic rocks.

The oldest evidences of life found in West Virginia occur in rocks about 600 million years old, in the Antietam Formation of Lower Cambrian age. However, in this formation they are abundant and of forms that had already developed through a substantial part of all evolution that has taken place during the history of the earth. Evidences of life in other parts of the earth are found in rocks at least 3 billion years old. Fossils are found in increasing abundance and increasing stages of evolutional development in rocks of all ages since earliest Cambrian time.

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