THE GEOLOGIC STORY OF KENTUCKY

Preston McGrain

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Front Cover

Natural Bridge (of Kentucky) is the focal point for Natural Bridge State Park. Deep, steep-sided stream valleys and very narrow ridges capped with resistant sandstones characterize the terrain in which most of the natural bridges in Kentucky occur. No area in the eastern United States contains more natural sandstone bridges and arches than the region along and near the Cumberland Escarpment in eastern Kentucky. Kentucky Department of the Arts photograph.

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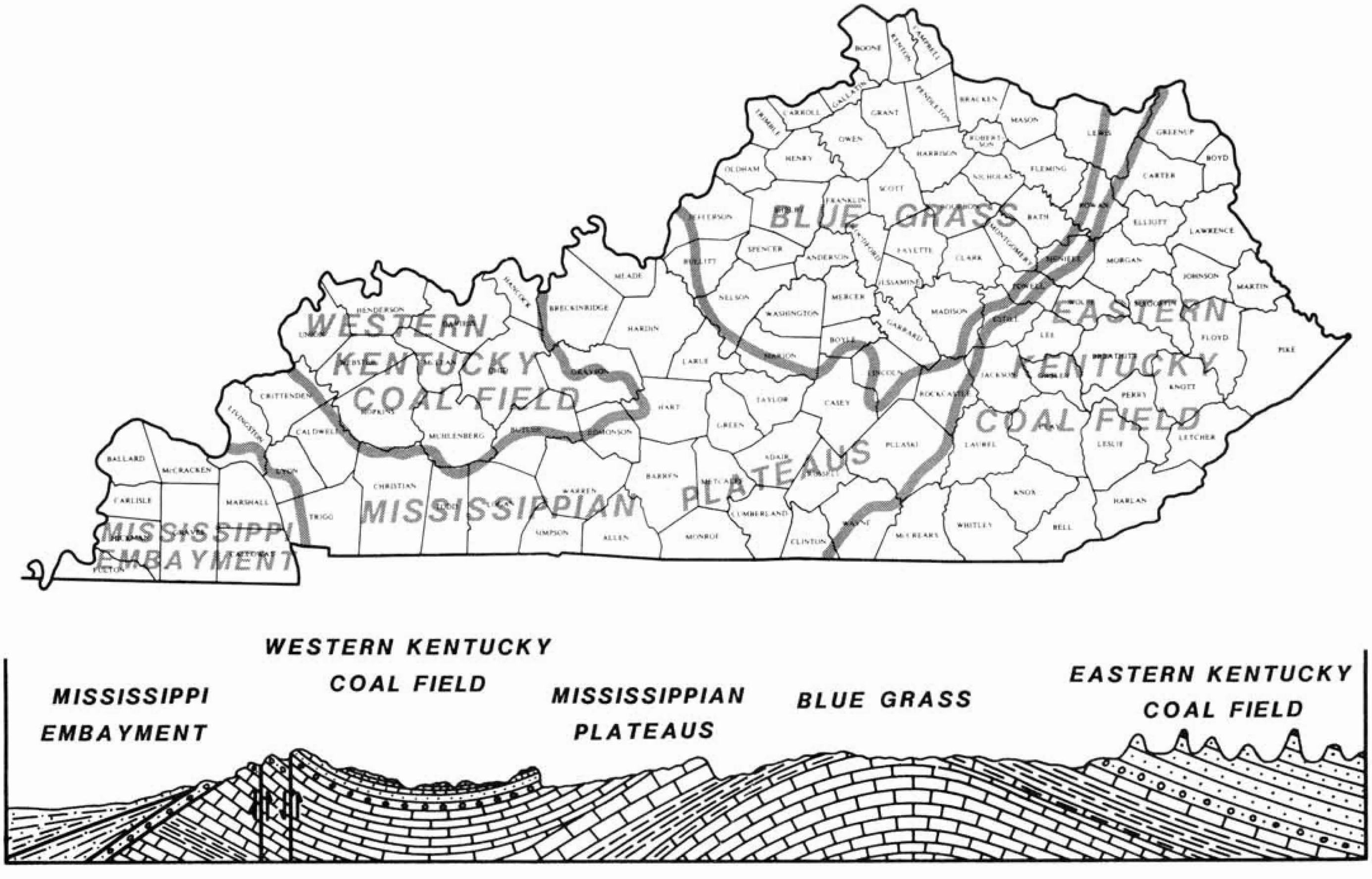

Generalized physiographic map of Kentucky with cross section.

THE GEOLOGIC STORY OF KENTUCKY

Preston McGrain

INTRODUCTION

From the Breaks of the Sandy to the bluffs of the Mississippi, Kentucky has a diverse geology, strikingly beautiful landscapes, an array of surface and underground natural scenic features, abundant water resources, and rich mineral wealth. Although better known for its thoroughbred race horses and tobacco and distilling industries, Kentucky has much to offer both the nature lover and student of natural science. Interesting pages of the Earth's history are revealed in the majestic mountains, rocky gorges, cascading waterfalls, picturesque caverns, broad valleys, fertile plains, and quiet glens.

Natural Bridge State Resort Park and Red River Gorge Geological Area are in a region unrivaled in the eastern United States for the number of natural sandstone arches and bridges. Cumberland Falls is one of the largest waterfalls in the Southeast. Mammoth Cave National Park contains the longest mapped cave system in the United States. And the Jackson Purchase region was once part of a much larger Gulf of Mexico.

A knowledge of geology guides the geologist in his search for needed fuels and minerals, assists the engineer in his design and construction of structures to improve our environment, helps the agriculturist interpret soil conditions, and aids the tourist in understanding the State's natural features. One cannot cross Kentucky, either east to west or north to south, without noticing changes in rock types in roadcuts and hillsides. From Lexington to Paducah one would traverse four major geologic regions and could observe rocks of eight major geologic periods. For a person who understands the geologic features, an excursion across Kentucky can be more than a sightseeing tour. The spectacle of changing landscapes becomes an adventure into the geologic mystery of the past and the scenic beauty of the present.

The geologic story of the rocks now exposed in Kentucky began approximately half a billion years ago when the area was covered by a great body of water. Most of the surface rock formations are sedimentary, and they are generally layered like a cake. Granites and metamorphic rocks are deeply buried. There is no evidence of volcanoes. There are only a few instances where deep-seated igneous rocks have been pushed to the surface. There have been frequent changes in sea levels over Kentucky, which are reflected in types of rock and nature of animal and plant life associated with them. Various muds, sands, shell fragments, and lime oozes accumulated on ocean bottoms much as they are today. Mud became clay and shale. Loose sand and silt became sandstone and siltstone. Gravels became conglom-

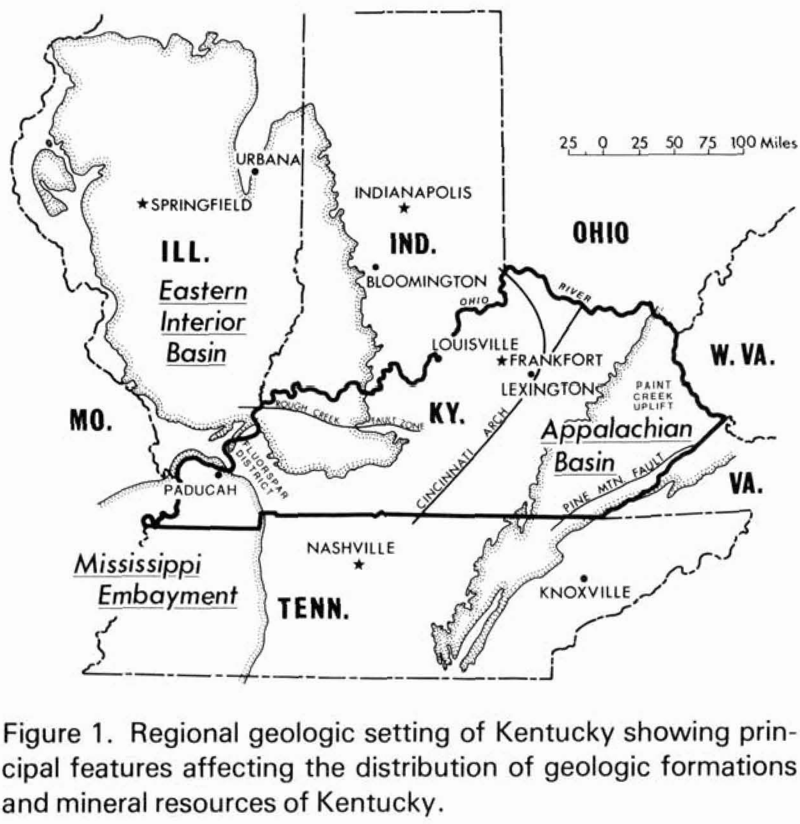

Figure 1. Regional geologic setting of Kentucky showing principal features affecting the distribution of geologic formations and mineral resources of Kentucky.

erates. Shells, shell fragments, lime oozes, and chemical precipitates became limestone.

Geologic factors affecting the distribution of rock formations and natural landscape features in Kentucky include the Cincinnati Arch, regional dip of rock layers into the Appalachian and Eastern Interior (Illinois) Basins, the Mississippi Embayment, complex faulting in and near the Western Kentucky Fluorspar District, Pine Mountain overthrust fault, and the Rough Creek Fault System (Fig. 1).

The oldest rocks exposed at the surface of the ground in Kentucky are hard limestones of Middle Ordovician age (Fig. 2). They are found along the Kentucky River gorge in central Kentucky between Boonesboro and Frankfort. Older rocks

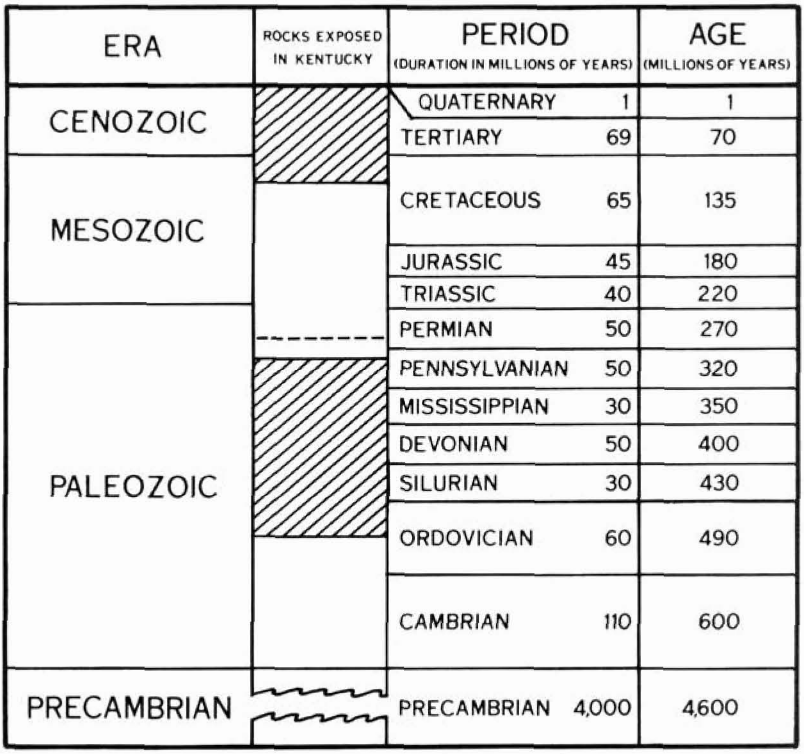

Figure 2. Geologic time chart showing the ages of rocks exposed in Kentucky.

are present in the subsurface but can be seen only in drill cuttings and cores taken from oil and gas drilling and mineral exploration. Later in Ordovician time the seas became relatively shallow, as indicated by the amount of mud (shale) in the sediments. When the waters were clear and warm, a profusion of animal life developed, particularly brachiopods and bryozoa. These are the rich fossil beds which have attracted amateur and professional paleontologists to the stream beds, rocky hillsides, and roadcuts of the Outer Blue Grass.

Silurian seas were commonly warm and clear, although the presence of some shale beds suggests that muddy conditions prevailed at times. Locally, numerous corals and brachiopods can be found in the Silurian limestones and dolomites (Fig. 3). During the Silurian Period, gentle folding began creating a major upwarp, or arching, of the rock strata, which extends from the Cincinnati, Ohio, area, through the central Blue Grass region, southeastward across the State toward Nashville, Tennessee. This upwarping raised part of the land above sea level and temporarily separated two major geological basins.

Upwarping of the Cincinnati Arch continued during the first part of the Devonian Period as evidenced by the absence of outcrops of rocks of Early Devonian age in central Kentucky. The Cincinnati Arch has been a significant feature in the determination of rock-outcrop pattern and regional topography in the State. Limestone formations of Devonian age are thin in Kentucky but may contain brachiopods, crinoids, and corals. Before the end of Devonian time, the sea floor became covered with an organic black muck. This muck is now a hard black shale (an oil shale) which is one of the most distinctive of all geological formations in Kentucky. It is easily recognized by its black color and thin, hard, brittle layers. Fossil remains of the earliest known trees have been found in this formation (Fig. 4).

Black shale continued to be deposited briefly during the Mississippian Period but soon gave way to a great influx of muds, silts, and sands brought in by rivers and streams from uplands many miles to the northeast and deposited as a great delta. Peculiar markings on some slabs of siltstone are indica-

Figure 3. Block of Middle Silurian dolomite with casts and molds of the brachiopod *Pentamerus.* This is a guide, or index, fossil for these rocks. Bernheim Forest photograph.

tions of water currents and sea-bottom life (Fig. 5). When Mississippian seas cleared, great thicknesses of limestone were deposited in the warm, shallow waters. Blastoids, brachiopods, bryozoa, corals, and crinoids were common forms during that geologic time period (Fig. 6). The seas receded briefly at the end of the Mississippian Period, as indicated by the uneven, eroded surface on which subsequent Pennsylvanian sediments were deposited.

Figure 4. Portion of a fossil tree in Devonian black shale. It has been identified as *Callixylon newberryi,* a form considered as probably the oldest fossil tree known—approximately 350 million years old. Bernheim Forest photograph.

During the Pennsylvanian Period parts of Kentucky were covered intermittently by shallow seas. Climate was warm, and extensive forests grew in great coastal swamps at the edge of the water. Marine waters advanced and receded many times. Pennsylvanian rocks are both marine and nonmarine, with the latter predominating. Grasses, reeds, and trees grew in these luxuriant forests. Vegetation of all sorts fell into the water and was buried under blankets of deltaic clays, silts, and sands (Figs. 7 and 8). Clay sealed the vegetation from oxygen, preventing decay. The weight of sediments over long geologic time compressed vegetation into coal. The process was repeated many times, thus accounting for the numerous coal beds in Kentucky's two coal fields.

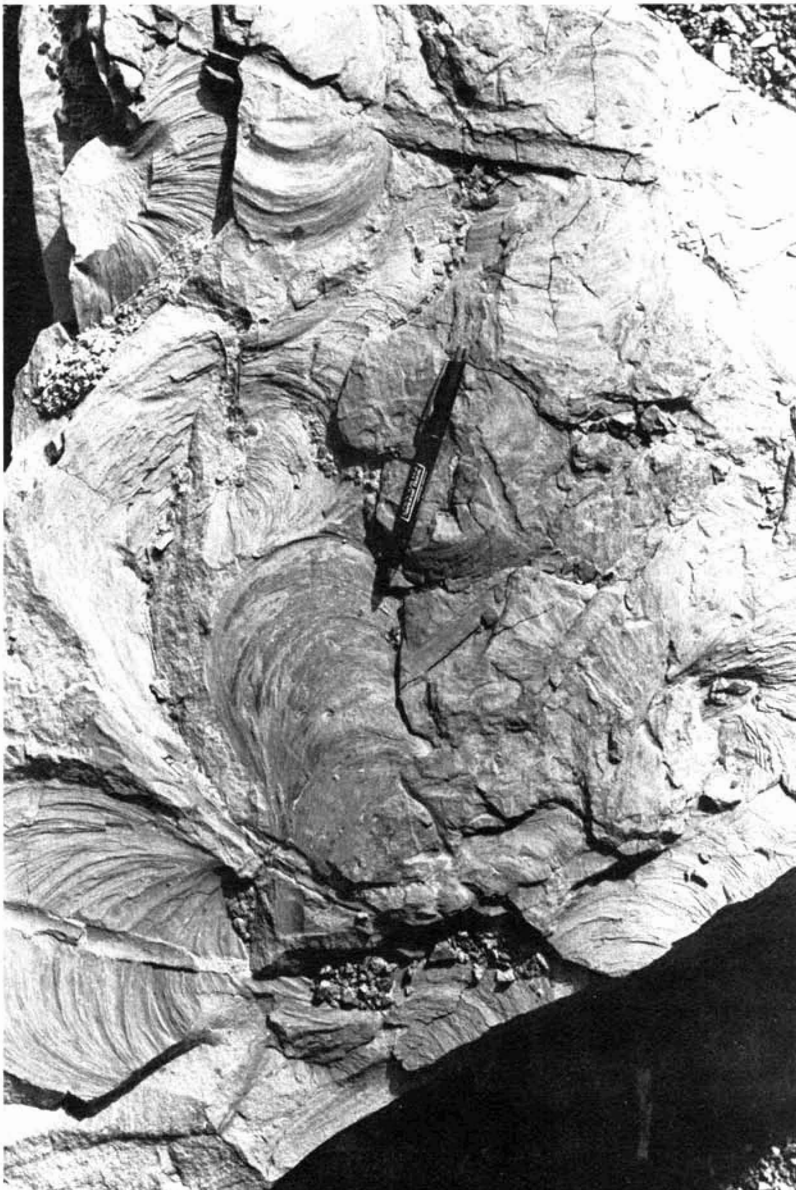

Figure 5. Tube-like and fan-shaped markings on slabs of silt-stone record activities of sea-bottom life in Early Mississippian time.

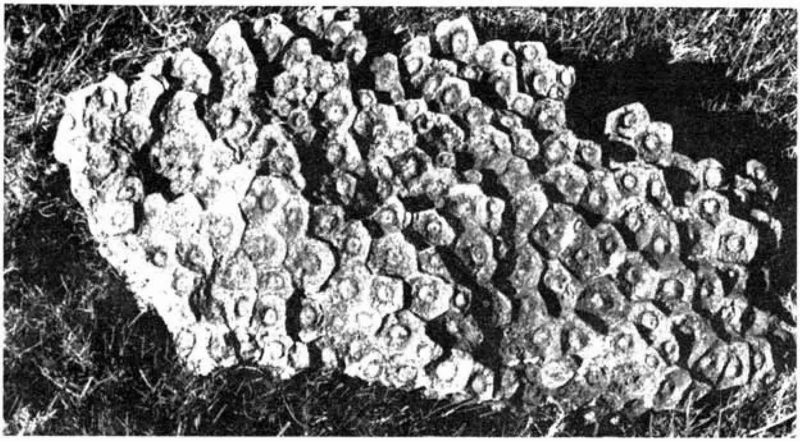

Figure 6. Petrified coral *Lithostrotionella* from the St. Louis Limestone of Mississippian age. This is a guide, or index, fossil for these rocks and is commonly found in limestones of Middle Mississippian age in many parts of the eastern United States.

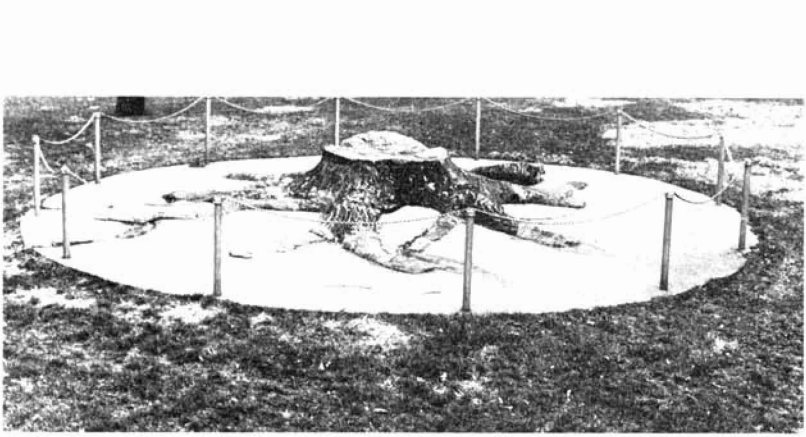

Figure 7. A fossil tree stump from the Eastern Kentucky Coal Field records evidence of plant life during the Pennsylvanian Period. The Pennsylvanian Period is characterized as having a relatively warm, moist climate which supported abundant vegetation such as trees, reeds, and ferns in a swampy terrain. This relic of a coal-age forest is now displayed on the University of Kentucky campus. University of Kentucky photograph.

Figure 8. Carbonized ferns of Pennsylvanian age in coal field rocks of eastern Kentucky. Photograph by J. R. Jennings.

Fossils from a drill-hole sample suggest that rocks of Permian age might be present in a small fault block in western Kentucky. This may indicate that Permian rocks, too, were widespread in Kentucky, but have been removed by later erosion. The Permian Period is further represented by the small igneous dikes in the Western Kentucky Fluorspar District and the small igneous plugs and dikes in Elliott County in eastern Kentucky.

A series of uplifts followed the Paleozoic Era in Kentucky. Seas receded and the land became dry for a long period of time. Much of Kentucky's landscape is a product of erosion which began at that time.

During the latter part of the Cretaceous Period, the Gulf of Mexico inundated much of the southern United States. A long bay extended northward from the Gulf, covering all of the Jackson Purchase and adjacent portions of the Mississippian Plateaus with sands, clays, and gravels. These geological deposits are a marked contrast to the underlying hard Paleozoic rocks because to this day most of the Cretaceous sediments remain unconsolidated and soft.

Deposition of marine and fresh- to brackish-water sediments continued in the Jackson Purchase area during Tertiary time. Distribution of deposits indicates that the area was near the northern limit of the Gulf embayment (also called Mississippi Embayment). Portions of the embayment must have been swampy because thin beds of lignite and carbonaceous clays occur in the western half of the eight-county Jackson Purchase area.

Glaciation played only a minor role in the geologic history of Kentucky as compared to our sister states to the north because the southern margin of the continental ice sheet rarely crossed the Ohio River. It did, however, affect the course of the Ohio Valley upstream from Cincinnati and at Louisville, and glacial meltwaters filled the valley with deposits of sand and gravel. The ice sheet or floodwaters from the melting glacier temporarily obstructed the flow of some northward-flowing streams such as Licking, Kentucky, Salt, and Green Rivers, causing local drainage modifications and leaving remnants of slack-water or lake-bottom sediments various distances upstream.

Kentucky's natural regions, scenic geologic features, and fossil-fuel, mineral, and ground-water resources are directly related to the underlying rock strata (Figs. 9 and 10). The land-surface features largely reflect the kinds of rock which lie beneath them and the effects of weathering and erosion upon these rocks. After layers of sediment were deposited, the area we know as Kentucky began to be modified by geological processes. Weathering and erosion of surface rocks and deformation by folding and faulting of many strata altered the landscape. Most of the areas underlain by sandstones are either hilly or mountainous because sandstones tend to resist weathering and erosion more than other Kentucky rocks. Caves, sinkholes, sinking creeks, large springs, and other features associated with underground drainage are found in the limestone terranes.

Stream erosion has been the predominant geological force sculpturing and modifying the Kentucky landscape since the close of the Paleozoic Era. Younger rocks were eroded from the crest of the Cincinnati Arch, leaving older Ordovician rocks exposed at the surface of the Blue Grass region. Away from the Blue Grass, the rocks are progressively younger. The softer or weaker rocks eroded faster than harder, more resistant ones. Thus, we see escarpments such as Muldraugh Hill (knobs area), Dripping Springs Escarpment at the outer edge of the sinkhole plain, and the escarpments at the edges of the eastern and western coal fields.

Kentucky is characterized by many miles of streams and a lack of many natural lakes. The Ohio River forms 664 miles of Kentucky's northern boundary. Other major rivers which border or cross Kentucky include Big Sandy, Cumberland, Green, Kentucky, Licking, Mississippi, and Tennessee. Segments of some of the streams, such as portions of Cumberland and Rockcastle Rivers, are exceedingly scenic and picturesque, and have been designated "wild rivers" for the purpose of maintaining their beauty and primitive character (Fig. 11). Despite the lack of natural lakes, Kentucky has many man-made impoundments, several of which have been the focal points for development of major parks and recreation areas. Each of the reservoirs is distinctive because of the role of local rock strata and topography.

Springs are a conspicuous part of the Kentucky landscape and have been a contributor to the early development of the State. They provided focal points for watering places, camping grounds, rural homesteads, villages, and industrial development. When mineral waters were popular in the late 1800's and early 1900's for medicinal purposes, health resorts and hotels were established at many locations.

Elevations in Kentucky range from a low of 260 feet on the Mississippi River where it leaves Fulton County in the western extremity of the State to 4,145 feet at a peak on Black Mountain in Harlan County near the Kentucky-Virginia border.

Higher elevations occur in the southern part of the Eastern Kentucky Coal Field. Bell, Harlan, Letcher, and Pike Counties have elevations greater than 3,000 feet. Only Harlan County contains elevations greater than 4,000 feet. Eight counties—Clay, Floyd, Knott, Leslie, McCreary, Perry, and Whitley—have elevations of more than 2,000 feet.

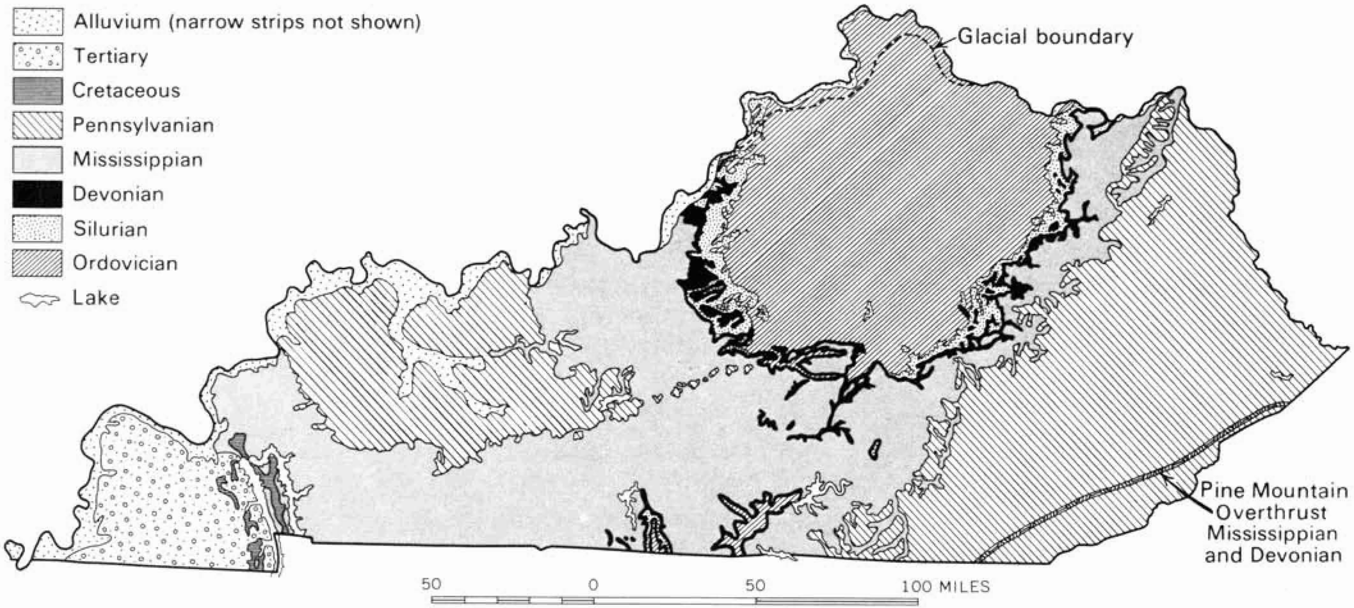

Figure 9. Generalized geologic map of Kentucky showing the distribution of rocks of various ages. The Ordovician rocks, which are exposed in the Blue Grass region, are the oldest. They dip gently to the southeast, south, and west from Lexington; successively younger rocks are encountered on the surface of the ground as one proceeds in those directions. Thus, at Madisonville or Pikeville one would have to drill a hole 5,000 to 6,000 feet to reach the same rock formations exposed in the Kentucky River gorge.

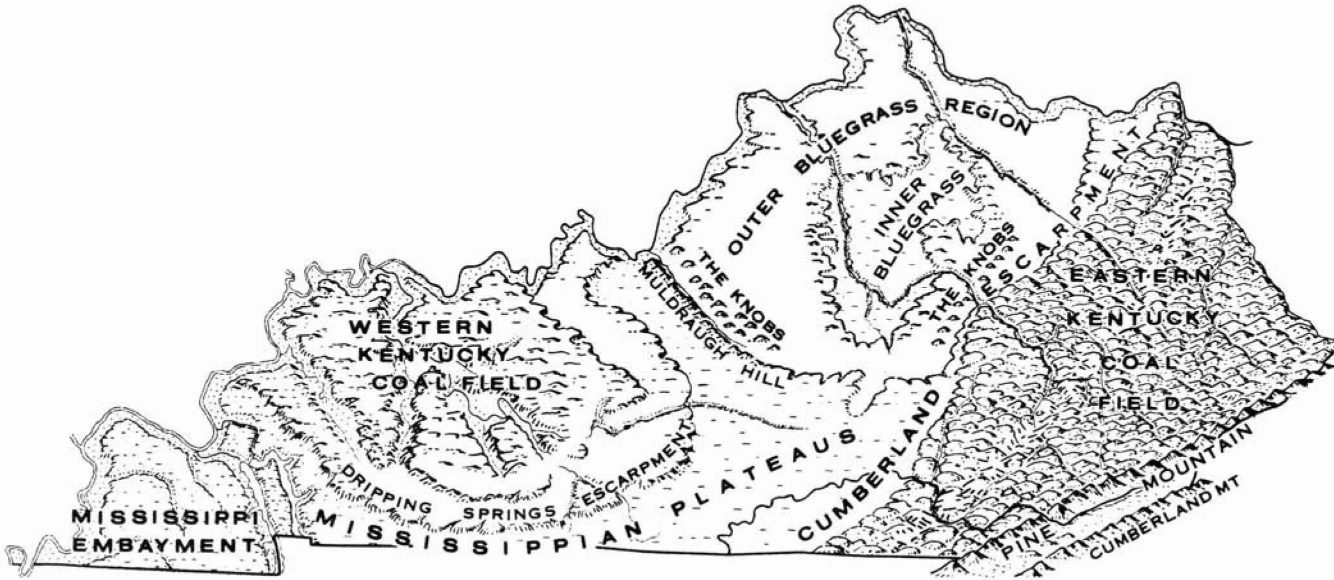

Figure 10. Physiographic map of Kentucky showing the major geographic and geologic areas of the State. The vast majority of rocks present at the surface in Kentucky are shales, sandstones, and limestones, each of which reacts differently to weathering and erosion and produces different landscapes. Note the similarity in pattern between the physiographic map and the geologic map.

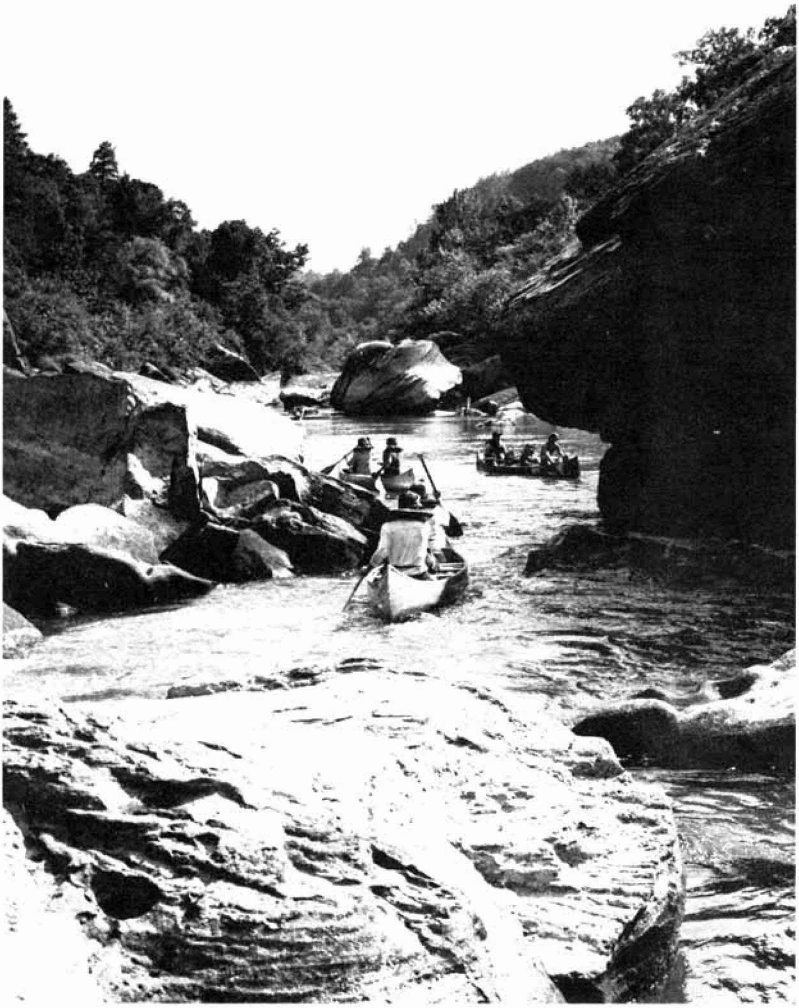

Figure 11. Great fallen blocks of sandstone almost choke portions of Cumberland River, Red River, Rockcastle River, Russell Fork of Big Sandy River, and other eastern Kentucky streams. Elephantine in size and shape, often appearing from a distance like backs of great animals partly submerged in the stream, they help generate the "white water" so sought by venturesome canoeists. Kentucky Office of Tourism Development photograph.

Green River Knob, at 1,789 feet in southern Casey County, is the highest point in Kentucky west of the Eastern Kentucky Coal Field. No county west of Allen, Barren, Hart, Hardin, and Meade Counties has elevations as great as 1,000 feet. And in the Jackson Purchase region, only Calloway County has elevations greater than 600 feet. If sea level were to rise 500 feet, as it undoubtedly did several times in the geologic past, most of the Jackson Purchase would be inundated and Louisville would be a seaport (Fig. 12)!

One cannot travel across Kentucky without recognizing the fact that minerals are a significant facet of the Kentucky scene. Fossil fuels and other minerals are very important to the economy of Kentucky, providing an income of $3 to $4 billion annually. While it is frequently not considered a major mineral-producing state, Kentucky ranks about fifth in the United States in value of minerals produced. Kentucky is the largest producer of bituminous coal in the United States, ranks second in the production of ball clay (a high-grade chinaware clay), was for many years the second largest producer of fluorspar, and ranks eighth in tonnage of crushed limestone produced. Fossil fuels and other mineral resources are widely distributed in Kentucky, being produced in approx-

Figure 12. Many Kentucky streams have carved deep valleys to relatively low elevations. If, for some reason, sea level rose 500 feet, many valleys would be flooded, much of the Jackson Purchase would be inundated, and Louisville would be a seaport.

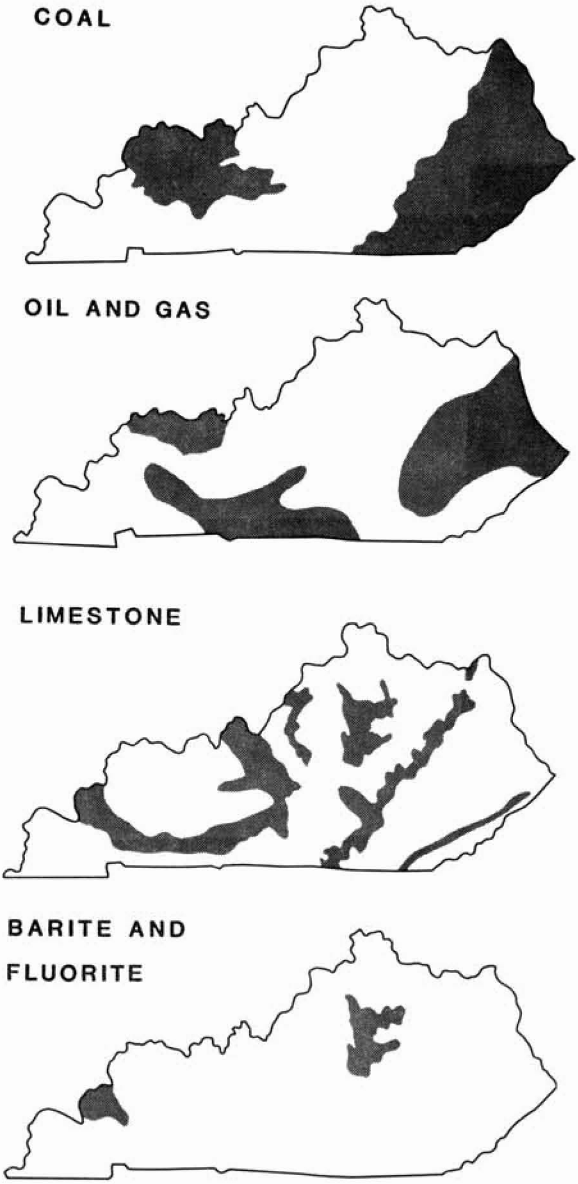

Figure 13. Kentucky contains several important fuel and non-fuel mineral resources. Individual mineral commodities are irregularly distributed and range widely in geologic age.

imately 100 of Kentucky's 120 counties (Fig. 13). Coal is produced in 44 counties, petroleum in 59 counties, and limestone in 65 counties. Other mineral commodities include natural gas, clay, shale, sand, gravel, and sandstone. In recent years, production has included rock asphalt and minerals of barium, lead, and zinc.

OHIO RIVER VALLEY

The historic and picturesque valley of the Ohio River follows a meandering route for 664 miles along the northern and western borders of the Commonwealth (Fig. 14). Generally, it is not considered a physiographic region or area, but because of its geologic and topographic features and unique geologic history it is described here as a regional entity.

Figure 14. The historic and picturesque valley of the Ohio River follows a meandering route for 664 miles along the northern and western borders of Kentucky. The river is not only a major source of surface water supplies but also serves as an interstate route for shipping great tonnages of bulk materials. Kentucky Office of Tourism Development photograph.

The general course of the present valley was determined by glacial activity. The preglacial Ohio was a much smaller stream, having its headwaters somewhere between Milton, in northern Trimble County, and Cincinnati, and the drainages of the ancestral Kentucky and Licking Rivers flowed northward to the ancient Teays River, a major preglacial drainage system in central Ohio. Advancing ice sheets blocked the northward-flowing streams with rock debris and diverted their flow to new courses near the margins of the glaciers. Floods of waters from melting ice carved a deep channel for the Ohio and later filled it to a depth of more than 100 feet with sand, gravel, and clay (Fig. 15). Bedrock is rarely seen except where the river flows against the valley walls or at the Falls of the Ohio River at Louisville. The Falls of the Ohio River is the only place along the entire river from its beginning at Pittsburgh, Pennsylvania, to its mouth at Wickliffe, Kentucky,

Figure 15. Glacial outwash sand and gravel in the valley of the Ohio River. The deposits are composed of igneous and metamorphic rocks from Canada and sedimentary rocks from Kentucky and neighboring states. These sands and gravels serve a dual purpose. They are an important source of construction raw materials for communities along the river and provide an important aquifer for cool, good-quality water for municipal, industrial, and domestic use.

where bedrock is exposed across the bottom of the present river channel.

The width of the valley ranges from about 1/2 mile to 10 miles. Variations in width are due to hardness or softness of rock along the valley walls, the differences in geologic age of different portions of the valley, and results of drainage changes. At some places in the valley, the buried channel divides around islands of bedrock. An example of this is Bon Harbor Hills west of Owensboro, where a hill of Pennsylvanian sandstone and shale rises 150 feet above the valley flats that surround it. Ben Hawes State Park is located in this area.

General Butler State Park is situated on an isolated bedrock hill (Late Ordovician limestones and shales) near the junction of the Ohio and Kentucky Rivers (Fig. 16). This island-like land mass, which rises more than 250 feet above the surrounding flood plain, is obviously the result of shifting stream channels, but there is no unanimity of opinion on the precise geologic history. Some geologists believe that the upland area is the result of the Kentucky River shifting its position, whereas others interpret it as a meander core developed when the route of the Ohio River was modified due to glacial action.

Large quantities of water are stored in the porous sands and gravels beneath the valley floor. In many of the counties through which the Ohio flows, this is the only source of large supplies of cool, good-quality underground water for municipal and industrial use. Similarly, the outwash and alluvial sands and gravels are Kentucky's second-most important sources of aggregates for construction purposes. Today the Ohio River itself is not only a major source of surface water supplies but also serves as an interstate route for shipping great tonnages of bulk materials.

Falls of the Ohio River

Probably nowhere in Kentucky have geologic and modern history come together as dramatically as at the Falls of the Ohio River at Louisville. The falls is at McAlpine Dam between Louisville, Kentucky, and Jeffersonville and Clarksville,

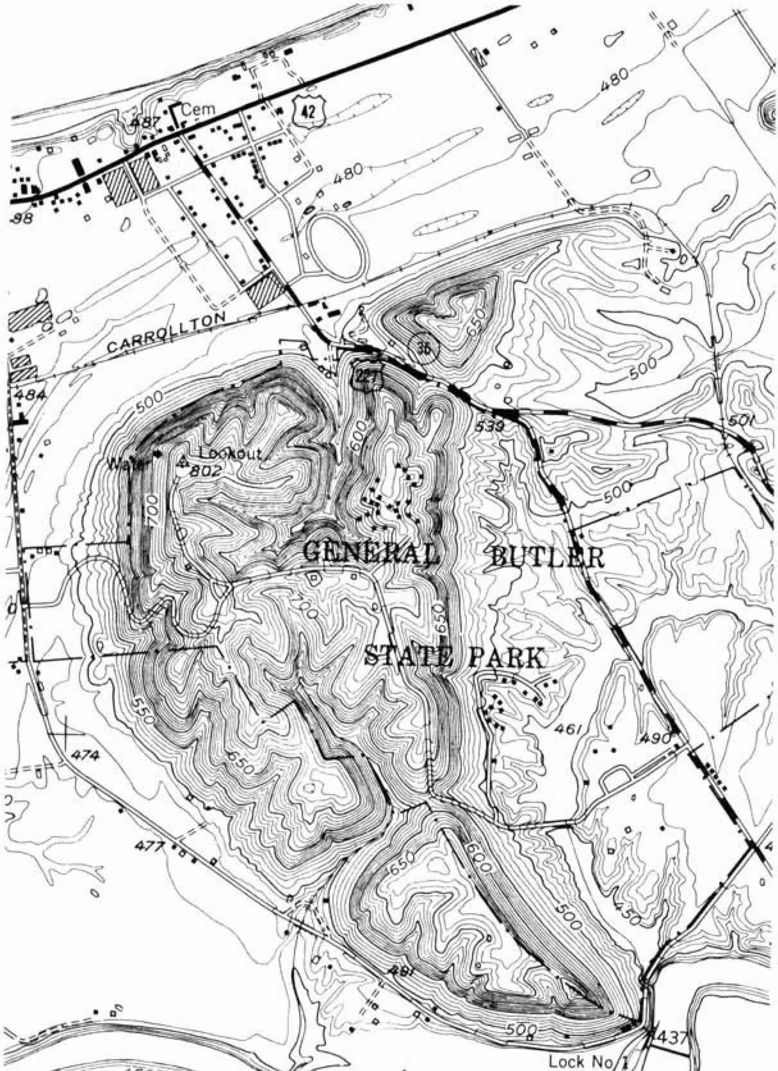

Figure 16. Portion of the Carrollton Quadrangle topographic map, near the junction of the Ohio and Kentucky Rivers, showing the meander core on which General Butler State Park is located. This bedrock hill has been cut off from the adjacent upland as a result of shifting stream channels.

Indiana. It is essentially within the Commonwealth of Kentucky because the State boundary was established at the north bank of the Ohio River in 1792, but access to the falls is now almost exclusively from the Indiana shore.

The Falls of the Ohio occupies an important place in the early history of the midwestern United States. It was the only natural obstruction along the 981-mile route of the Ohio which prevented navigation, and most shipping down the river was forced to portage at the falls. The first white settlement at the falls was reportedly established in the 1770's. Many travelers remained in the vicinity and later established Louisville, which was to become Kentucky's largest city.

Before the construction of the McAlpine locks and dam (a navigation structure), the falls consisted of a series of rapids, falling 26 feet in 2 miles over resistant limestone ledges of Devonian and Silurian ages. They are of additional interest because some of the rock layers are coral-reef limestones that contain thousands of fossils, representing life in ancient seas hundreds of millions of years ago. Warm, shallow marine waters, teeming with a luxuriant growth of corals and other marine organisms, produced the broad coral banks that are exposed in the bed of the river today.

The presence of coral beds at the Falls of the Ohio River has been known for many years, and it has been a major fossil-collecting locality for both scientists and laymen alike. Nowhere else are fossils of Devonian age so well exposed and preserved in such profusion. It has been estimated that approximately 75 professional reports have been written by scientists to describe more than 600 species of fossils in various rock strata exposed at the falls. Today there are attempts to preserve these fossil assemblages as a unique geologic site.

The Falls of the Ohio owes its history, in part, to the time when continental glaciers covered much of the north-central United States. Flood waters from the melting glaciers filled portions of the old channel of the Ohio River with sand, gravel, and clay, forcing the river to seek an alternate route across a buried bedrock ridge. The older preglacial route of the Ohio River remains filled and is buried under what is now downtown Louisville (Figs. 17 and 18).

Figure 17. Sketch of present and ancient channels of the Ohio River in the vicinity of Louisville. Flood waters, from melting glaciers, filled portions of the ancient channel with sand, gravel, and clay, forcing the river to seek an alternate route across a buried bedrock ridge known today as the Falls of the Ohio. The older preglacial route remains filled and is buried under what is now downtown Louisville.

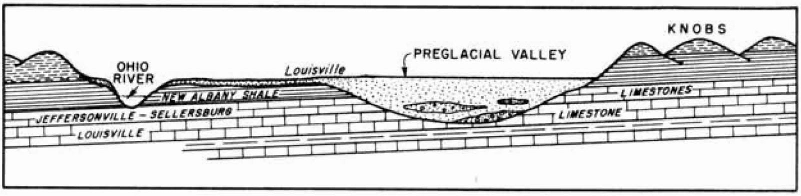

Figure 18. North-south geologic section through the Louisville area showing the relationship between the present and ancient valleys of the Ohio River. Adapted from McFarlan, 1958, p. 135.

EASTERN KENTUCKY COAL FIELD

The rugged beauty of the sandstone-capped, forested, mountainous terrain (Fig. 19) of the Eastern Kentucky Coal Field contrasts strikingly with the pastoral countryside of the nearby Blue Grass region. This is part of the great Appalachian Basin, or the Cumberland Plateau of some writers. It is the larger of Kentucky's two coal fields, covering approximately 11,000 square miles. Kentucky is the largest producer of bituminous coal in the United States. The Eastern Kentucky Coal Field produces tens of millions of tons of coal annually from thousands of mines in dozens of separate coal beds (Fig. 20). This is high-quality bituminous coal, in demand for coke for steel production, for chemicals, for the making of manufactured gas, and burning in plants for the generation of electricity. More than 3 billion tons of coal have been produced from this field.

Eastern Kentucky once supported a small iron industry. Principal producing areas were the Hanging Fork and Red River districts. The remains of several furnaces can be found between Greenup and Estill Counties (Fig 21). Buffalo Furnace at the entrance of Greenbo Lake State Park is an example. The low-grade iron ore occurred in thin beds or as small nodules in Pennsylvanian and Mississippian rocks, and the fuel was charcoal made from local timber.

The edge of the Cumberland Plateau (Eastern Kentucky Coal Field) is bounded by a westward-facing escarpment or cuesta that rises several hundred feet above the adjacent lowland. It contains some of the most scenic areas in Kentucky.

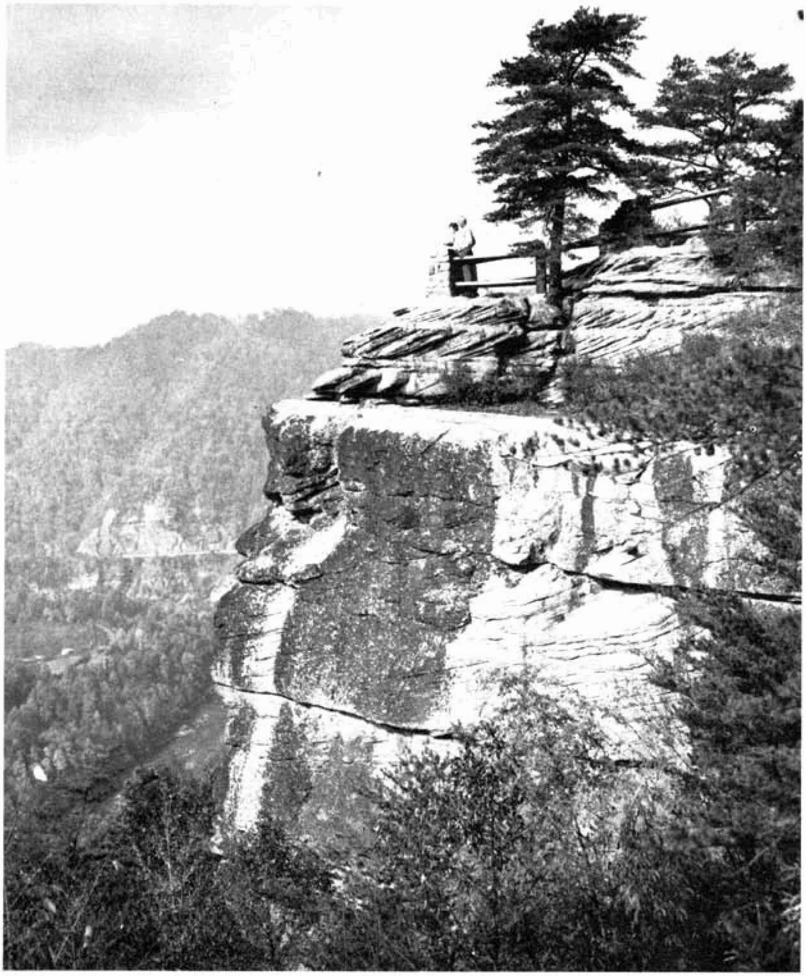

Figure 19. Cliff of Pennsylvanian sandstone 1,000 feet above Russell Fork of Big Sandy River. This rock-rimmed canyon, which crosses the north end of Pine Mountain, has been called "Breaks of the Sandy" or merely "Breaks." Kentucky Office of Tourism Development photograph.

Massive, cliff-forming sandstones of Early Pennsylvanian age which cap the escarpment and upland are resistant to erosion and produce rugged, picturesque landscape features. Precipitous cliffs, craggy pinnacles, rocky gorges, rock shelters,

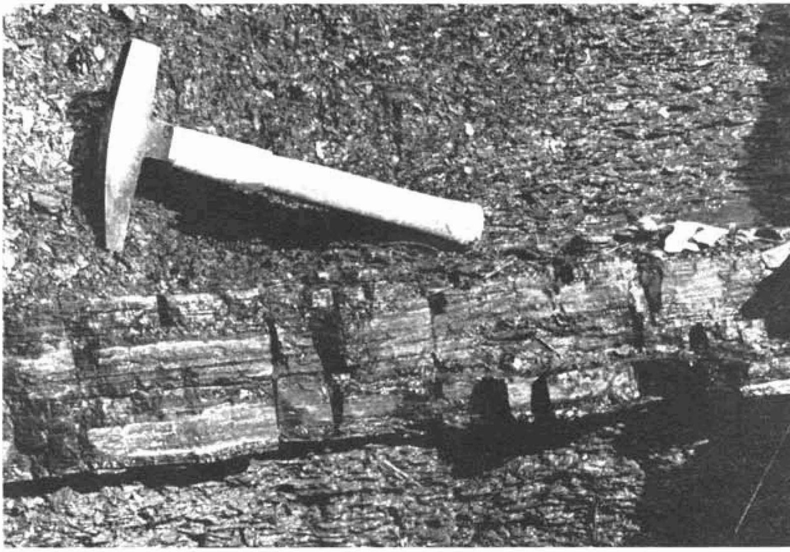

Figure 20. Coal is Kentucky's number one mineral commodity. Kentucky has two major coal fields and is the largest producer of bituminous coal in the Nation, producing 150 million tons from approximately 2,600 mines in 1980.

natural bridges, cascading waterfalls, and other natural features abound there. Towering walls of conglomeratic sandstone hem in the narrow drainage valleys with massive ledges and overhanging cliffs. Weathering and erosion have created fascinating etched and pitted patterns in some of the rock (Fig. 22). Limestone ledges underlie the sandstones and are the locale of caves, springs, and sinking creeks. Within a few miles to the east, the limestones and cliff-forming sandstones occur beneath the surface due to regional dip. This northeastward-trending belt contains Cumberland Falls, numerous natural stone bridges and arches, and Daniel Boone National Forest with its Red River Gorge Geological Area.

The interior of the Eastern Kentucky Coal Field contains the highest elevations and areas of greatest local relief in the State. The region is completely dissected by stream erosion and is a maze of irregular hills, ridges, and mountains. Ridge after ridge occurs in disorienting repetition. Very little flat

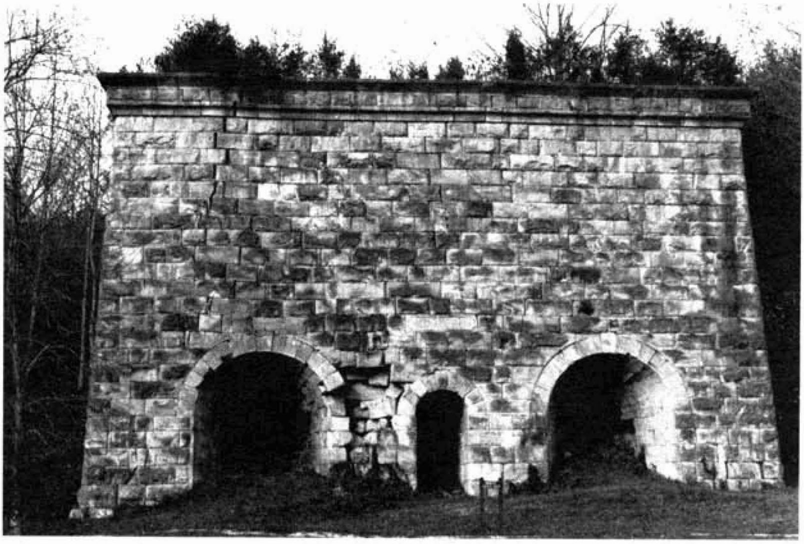

Figure 21. Remains of an old iron furnace at Fitchburg in Estill County. Being far removed from iron furnaces and foundries of the northern states, Kentucky residents in the mid-1800's constructed a number of iron furnaces utilizing the irregular, discontinuous, thin, low-grade local ore deposits. Local deposits of limestone were used as a flux, and the hardwood forests were sources of timber for charcoal. This furnace is unique in Kentucky in that it was a double- or two-stack furnace; most others had only one opening at the top to receive ore, flux, and fuel. Other furnaces were located as far east as Boyd County and as far west as Crittenden and Trigg Counties.

land exists, either in the valleys or on ridge tops. Streams flow in narrow, steep-sided, V-shaped valleys. Almost an equal amount of area is occupied by mountains and valleys. Pine Mountain, a high, single mountain ridge more than 100 miles long, and Cumberland Gap, a gateway through rugged Cumberland Mountain, are features of great geologic and historic interest (Fig. 23). Several State parks have been developed within the scenic mountain terrain of eastern Kentucky.

Cumberland Falls

Cumberland Falls has been a tourist attraction for more

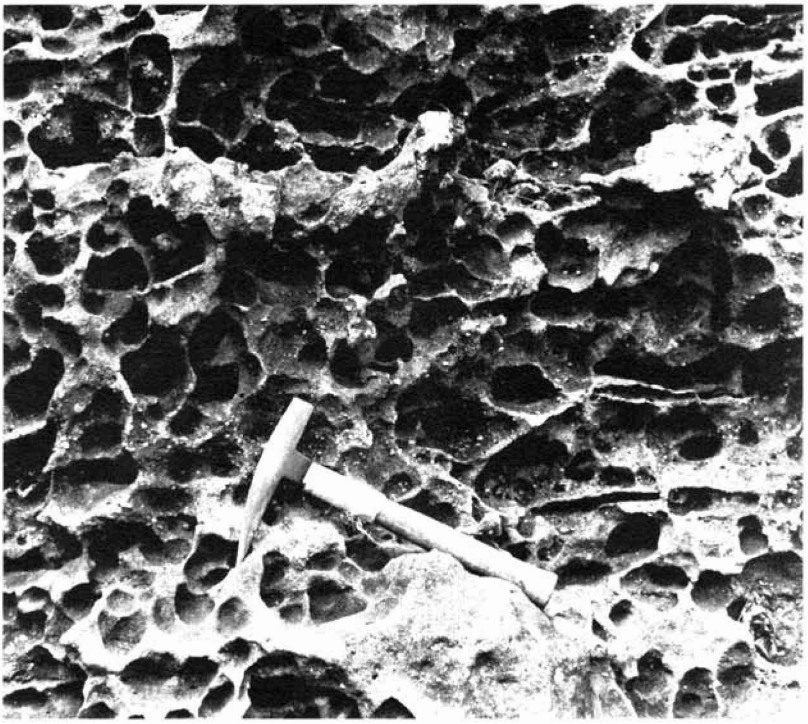

Figure 22. Honeycomb or "bee-rock" weathering, a common feature of massive sandstone formations in Kentucky. These intricate patterns are caused by differential weathering due to irregular distribution of cement in the stone.

than a century. It became a State park in the 1920's when private monies were donated to purchase the land to prevent industrialization of this beautiful site.

Cumberland Falls State Park is located in the southwestern part of the Eastern Kentucky Coal Field. The park area is a plateau-like region, characterized by a nearly level to undulating upper land surface dissected by deep, narrow, steep-sided valleys. Cumberland River and tributary streams have cut valleys several hundred feet below the upland, but the region, when viewed from the top of the hills, appears as a series of many narrow, nearly flat-topped ridges, each having the same general elevation. Within the immediate area of the

Figure 23. Cumberland Gap, a remnant of an ancient stream channel, was a gateway through the Cumberland Mountain barrier for early settlers more than 200 years ago, and today is an important route for north-south motor vehicle traffic. From the Pinnacle, a prominent lookout in the foreground, one may look down into Middlesboro, 1,300 feet below, and into parts of Tennessee and Virginia. Kentucky Office of Tourism Development photograph.

park, elevations range from less than 740 feet above sea level in the gorge below the falls to more than 1,300 feet on the highest hills, knobs, and ridges. Near the western edge of the Cumberland Plateau, elevations of more than 1,400 feet have been recorded.

The geologic story of Cumberland Falls is a story of water in action. Running water, carrying rock debris, is a powerful erosion agent. It wears away its bed and its walls. Soft or weak rocks wear away faster than strong ones, and waterfalls or rapids develop where the stream flows from a strong rock onto a weak rock. Cumberland Falls was produced by millions of gallons of water in the Cumberland River plunging over a ledge of massive, resistant sandstone (Fig. 24). It is reported to be one of the largest waterfalls in the eastern United States south of Niagara Falls. The drop from the lowest lip of the falls to the river below is 55 feet. The top ledge of the falls, from which water plunges when the river is at a high stage, is 10 feet or more higher, making a total drop in certain seasons of more than 65 feet. Cumberland River drains more than 1,900 square miles of mountain terrain above Cumberland Falls. Published records indicate variations in stream flow from a minimum of 4 cubic feet (30 gallons) per second to a maximum of 59,600 cubic feet (445,800 gallons) per second. Cumberland Falls has not always been in its present location

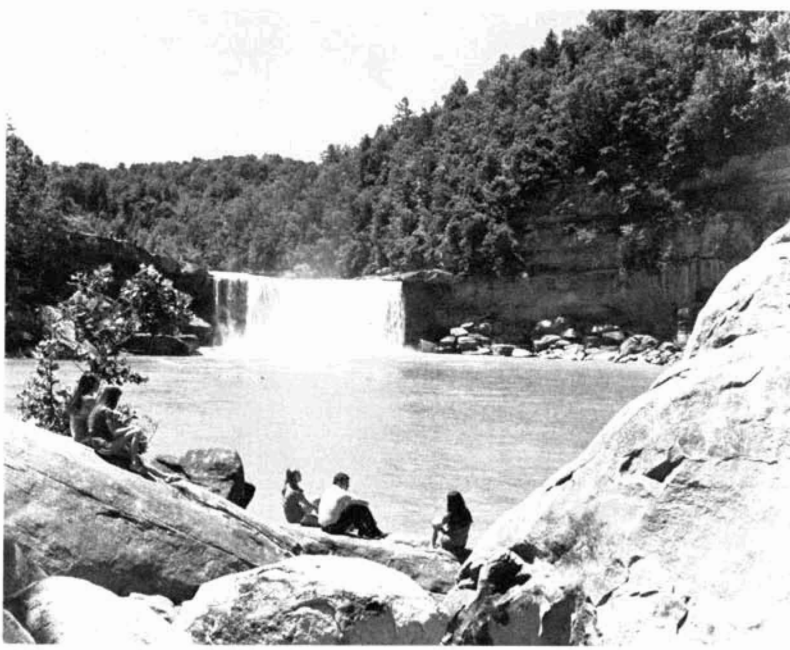

Figure 24. Cumberland Falls, situated near the edge of the scenic Cumberland Escarpment, is a major tourist attraction. At the falls, which reportedly is one of the largest in the southeast, thousands of gallons of water pour over a ledge of resistant sandstone each second into a plunge basin 55 feet below. Kentucky Office of Tourism Development photograph.

nor can it reasonably be expected to remain unchanged in the future. It is thought to have originated on the Cumberland Escarpment near Burnside and retreated upstream approximately 45 miles to its present position.

Development of Cumberland Falls is typical of cataracts formed by an escarpment in a relatively horizontal river bed consisting of a hard rock capping softer rock. In this case, the upper ledge is a hard, well-cemented, conglomeratic sandstone overlying a less resistant sandstone. Natural conditions wear away the softer sandstone. Falling water erodes it. Blowing spray alternately wets and dries the stone, stimulating weathering action. And in the winter, alternate freezing and thawing and ice plucking split sandstone from exposed ledges under the cap rock. Continued weathering and erosion leave the cap rock unsupported and unable to bear its own weight. Eventually the harder rock breaks at the lip and the falls retreats farther upstream. Breakage is usually along preexisting fractures called joints. Because the most prominent joints are roughly parallel to the valley instead of the brink of Cumberland Falls, most important rockfalls of recent times appear to be along the walls of the gorge rather than at the lip of the falls itself.

One of the highly publicized features associated with Cumberland Falls is the "moonbow." Visible only on bright moonlit nights, the phenomenon is reportedly quite rare. As water plunges over the falls a mist rises from the basin below and slowly floats down the gorge. Bright moonlight falling on the mist produces an effect similar to a rainbow. The colors, however, are not as vivid. At low stages of flow, the stream may not yield sufficient mist to produce a "bow." When a breeze is blowing upstream at the falls, it lifts the mist, giving the moisture a better opportunity to be intersected by light rays. Relatively unpublicized is the rainbow which is frequently visible at the foot of Cumberland Falls during the morning. Again, the amount of light and water and direction of wind affect the size, shape, and brilliance of the rainbow. On a bright, sunny morning the rainbow arched against the foaming cataract produces a very colorful scene that will be long remembered.

Pine Mountain

Pine Mountain, located within the Eastern Kentucky Coal Field in southeastern Kentucky, is one of the most outstanding landscape features in the Commonwealth (Fig. 25). Unlike many peaks which carry the term "mountain," Pine Mountain is a magnificent ridge that extends approximately 125 miles from near Jellico, Tennessee, on the southwest to Elkhorn City, Kentucky, on the northeast. The crest of Pine Mountain rises gradually from the southwest to northeast, with elevations ranging from less than 2,200 feet in western Bell County to more than 3,200 feet in southern Letcher County. It is not the highest mountain in eastern Kentucky, but with its spine-

Figure 25. Pine Mountain at Pineville. Chained Rock, a prominent sandstone pinnacle and local landmark in Pine Mountain State Park, is perched about 1,000 feet above the city. Cumberland River, which breaches Pine Mountain at this point, is one of only three present-day streams cutting through the 125-mile-long mountain ridge. Kentucky Office of Tourism Development photograph.

like crest, majestic cliffs, wooded coves, and assemblage of diverse rock formations, it is a strikingly attractive scenic feature.

Geologically, Pine Mountain is a long, nearly even-topped, erosion fault scarp, the steep face of which faces the northwest. It is part of a four-sided block of the earth's crust, approximately 125 miles long and 25 miles wide, known as the Cumberland overthrust block. The Cumberland overthrust block is a trough-shaped body which mountain-building forces within the earth pushed laterally for a distance of about 6 miles from the southeast. These crustal movements are thought to have taken place near the close of Paleozoic time, some 230 million years ago. Pine Mountain, a long monoclinal ridge, forms an upturned rim of the trough-shaped overthrust block. Its steep northwest face, overlooking the Cumberland Plateau, is capped by resistant basal conglomeratic sandstone of the Pennsylvanian System, known as the Lee Formation. Underlying the sandstone is the same general sequence of limestones, siltstones, and shales that occurs beneath correlative rocks along the eastern edge of the Eastern Kentucky Coal Field.

Pine Mountain is a striking contrast to the adjacent Cumberland Plateau. The linear character of its crest, the abrupt outer northwest-facing escarpment, and its gentler southeastern (back) slope with great dipping rock slabs and irregular boulders present a remarkably uniform picture throughout its entire length and set it apart from the maze of less rugged irregular hills and sinuous streams of the plateau (Fig. 26).

A majority of the great rock formations on Pine Mountain are accented by the array of native plants and trees. In the springtime the mountains are decorated with blooming redbud, rhododendron, and mountain laurel. In the autumn the multicolored leaves of the hardwoods make the woodlands appear to be ablaze. Three State parks (Pine Mountain, Kingdom Come, and Breaks Interstate), a community park at Jenkins, and the picturesque and scenic Little Shepherd Trail are developed on Pine Mountain.

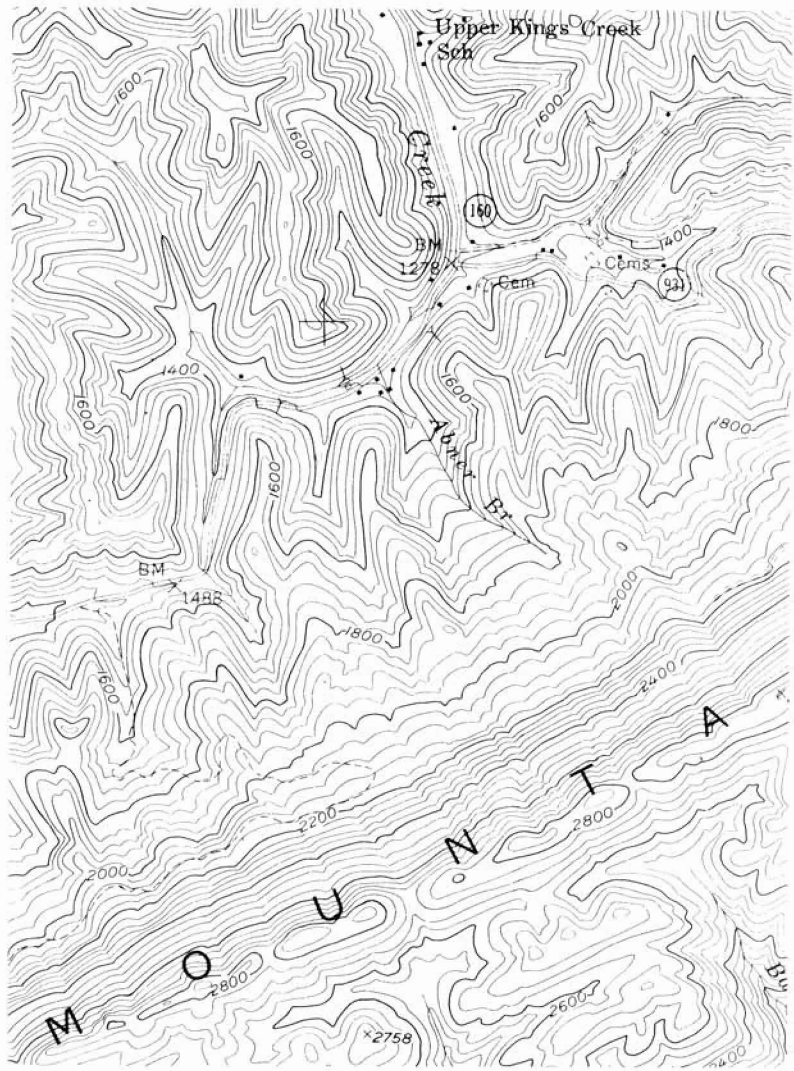

Figure 26. Portion of the Roxana Quadrangle topographic map showing the contrasting linear character of Pine Mountain and the adjacent irregular maze of ridges of the Cumberland Plateau. Three State parks (Pine Mountain, Kingdom Come, and Breaks Interstate), a community park at Jenkins, and the picturesque and scenic Little Shepherd Trail are developed in the Pine Mountain area so that people can enjoy this mountain region.

Red River Gorge Geological Area

The Red River Gorge Geological Area, surrounding the middle section of the Red River at the edge of the Cumberland Plateau, is a unique landscape containing more than 40 natural sandstone arches or bridges having a variety of sizes and shapes. The area covers more than 26,000 acres in the Daniel Boone National Forest and is administered by the U. S. Forest Service for year-round public use and enjoyment and protection of its watersheds, wildlife, unique natural formations, and primitive character. More than 40 miles of scenic drives and trails lead visitors to the many picturesque features, overlooks, and picnic and camping areas.

Although the gorge is only about 25 miles long, it contains a variety of scenic geologic features. In addition to the natural stone arches and bridges, the area abounds in precipitous cliffs, laurel-fringed rock walls, rocky ravines, small waterfalls, rockhouses, chimney rocks, and other formations. Numerous upland lookouts afford spectacular views of different parts of the gorge. Ridge-top elevations are generally 1,100 to 1,200 feet; the Red River flows in a rocky channel 400 to 450 feet below.

The oldest rocks exposed in the gorge are shales and siltstones of Early Mississippian age. They are found on the floor and lower sides of the valley. Marine limestones occur above these rocks. Although not as thick, they are considered to be geologically equivalent to the limestone formations in which Mammoth Cave is formed. Caves and springs are associated with this limestone in the Red River area but they are neither as large nor as numerous as those in south-central Kentucky.

The upland is capped with rocks of Pennsylvanian age. Sandstones and sandstone conglomerates predominate. These formations are part of an ancient delta system in which rivers flowing from the east deposited sediments that were later cemented into hard rock. They are part of the coal-field rocks, as indicated by the presence of plant fossils and coaly materials in some of the deposits. At one time the sediments were much thicker, but erosion has removed most of them down to the resistant sandstone ledges, leaving an almost flat upper landscape surface on some of the ridges.

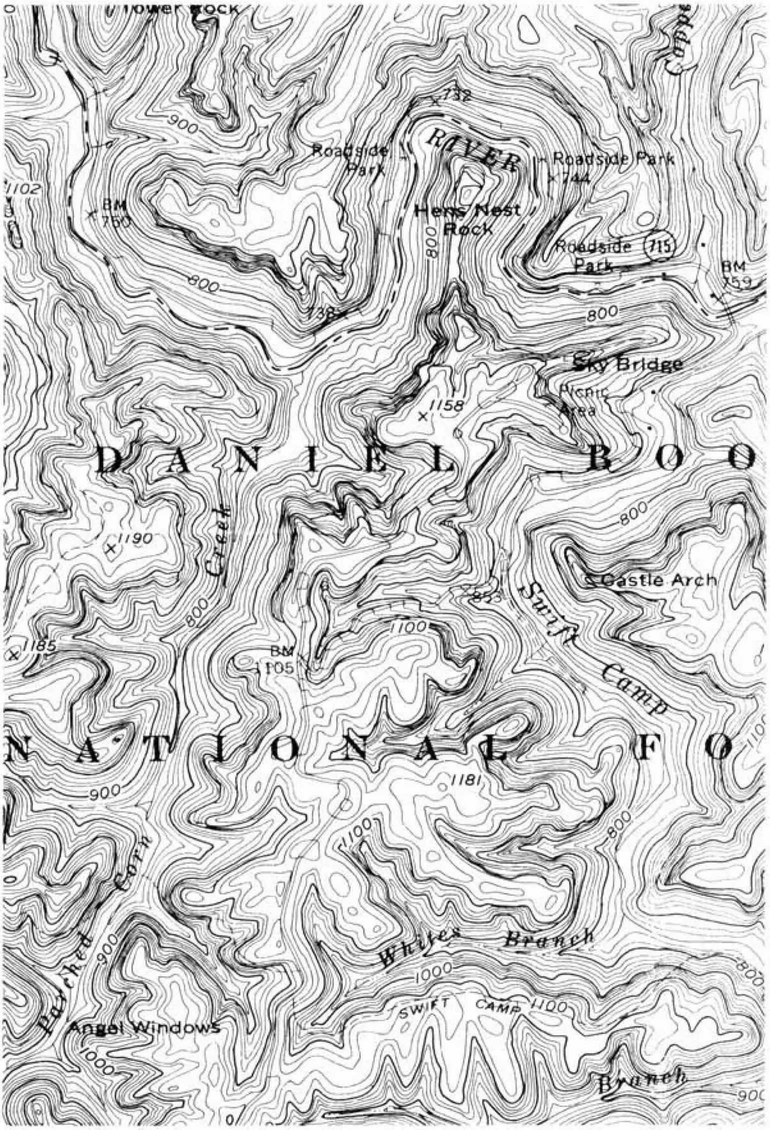

Figure 27. Portion of Pomeroyton Quadrangle topographic map showing Red River gorge and representative terrain in which natural bridges occur. Conglomeratic sandstones of Pennsylvanian age cap the narrow ridges.

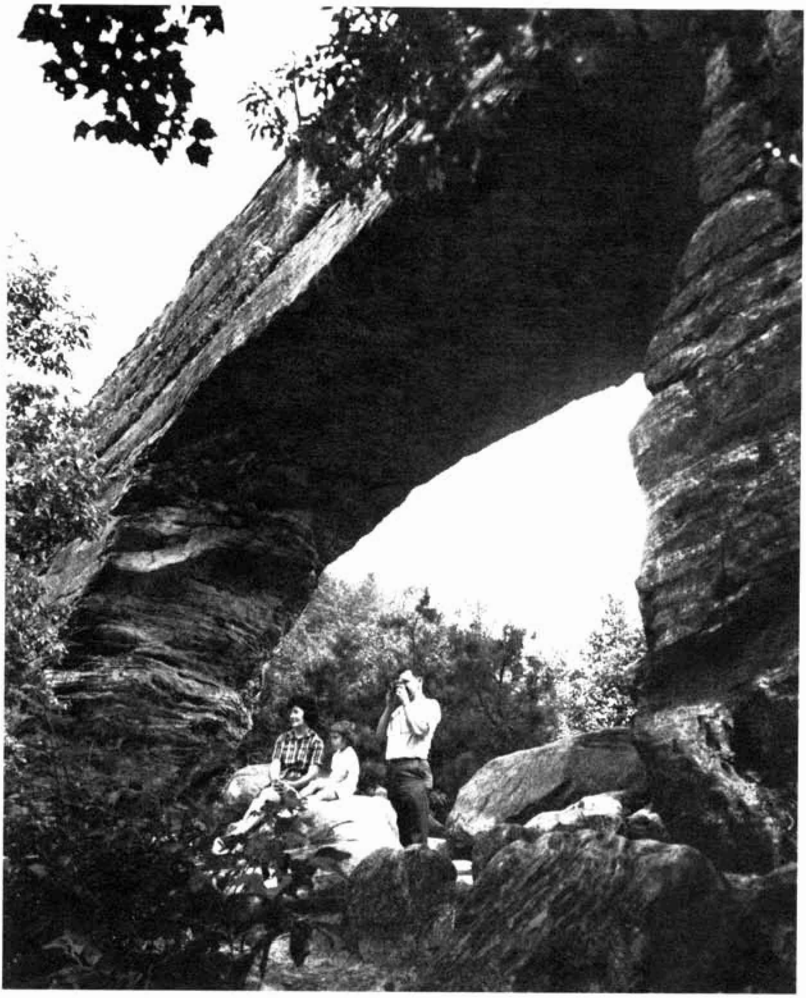

Figure 28. Natural Bridge (of Kentucky) is a natural sandstone arch, approximately 65 feet high, and 80 feet long, developed on a very narrow drainage divide in Natural Bridge State Park. The nearly vertical sides of the bridge are associated with joint fractures. Kentucky Office of Tourism Development photograph.

Stream erosion cut narrow valleys into and, eventually, through the sandstone, producing a seemingly haphazard maze of narrow ridges and valleys. Because of its hardness and chemical characteristics, the sandstone was relatively resistant to weathering and erosion. Consequently, the valleys are narrow and steep-sided. With time many tributary streams developed, producing a very rugged terrain of deep valleys and narrow ridges (Fig. 27). The presence of very narrow ridges capped with resistant sandstone is the principal condition for the formation of natural bridges in this area. Differential weathering of the sandstone cliffs, where for one reason or another some rocks are softer or weaker than adjacent layers, produces a shallow sandstone cave or rock shelter. Continued weathering with increase in depth, either from one side or oc-

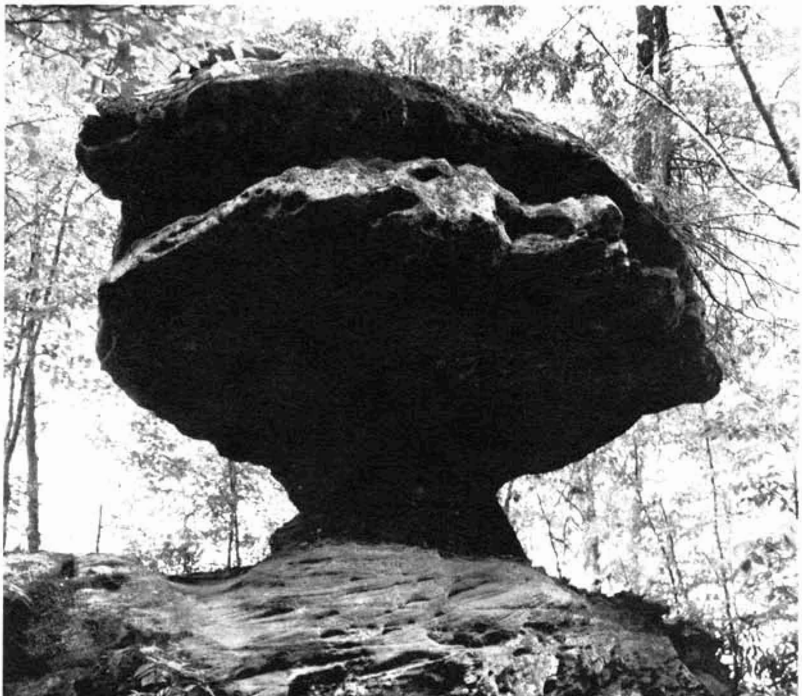

Figure 29. Balanced Rock, an erosion remnant in Natural Bridge State Park, is a product of differential erosion of massive sandstone. Kentucky Office of Tourism Development photograph.

casionally from opposite sides of a very narrow sandstone ridge, will form an opening through the rocks. As the process continues, the opening becomes larger, resulting in a natural sandstone arch or bridge.

Sandstone arches are also formed where a deepening rock shelter intersects an open joint fracture, separating it from the main body of the sandstone cliff. Other natural bridges, such as the sandstone Rock Bridge on Swift Camp Creek and the limestone Smoky Bridge in Carter Caves State Park, were formed by the underground diversion of a stream behind small waterfalls.

Nearby Natural Bridge State Park contains one of the best known of the natural bridges in Kentucky (Fig. 28) as well as rock houses, pinnacles, precipitous cliffs, and other interesting rock formations (Fig. 29).

BLUE GRASS REGION

Although to many the term "Blue Grass region" is synonymous with the whole of Kentucky, geologically it is restricted to the north-central part of the State. In its broadest sense it includes the contiguous outcrop area of rocks of Ordovician, Silurian, and Devonian ages. The Blue Grass region, in turn, is divided into two areas—Inner Blue Grass and Outer Blue Grass.

The Inner Blue Grass contains the oldest rocks exposed in Kentucky, which were raised to their present position by uplift along the Cincinnati Arch. They are dominantly thick-bedded limestones of Middle Ordovician age. This is the famous horse-farm country of Kentucky (Fig. 30). It is characterized by gently rolling terrain and a thick, fertile residual soil. Some of the limestone strata are phosphatic, and weathering of these rocks has enhanced the fertility of the soil. The gently rolling surface is modified by some karst development such as sinkholes, sinking streams, and springs, as is the case in most limestone terrains in humid climates. Although the sinkholes and caves are not as numerous or large as in the Mississippian Plateaus of the Mammoth Cave area, some springs were the sites of some of the early settlements such as Georgetown, Harrodsburg, and Lexington.

Figure 30. The Inner Blue Grass region is sometimes considered to be synonymous with "horse-farm country." Thick-bedded limestones of Middle Ordovician age underlie the thick, fertile residual soil and gently rolling terrain. Some of the limestone strata are phosphatic, and weathering of these rocks has enhanced the fertility of the soil. Kentucky Office of Tourism Development photograph.

A marked contrast to the gently rolling, fence-lined farmland is the rugged terrain along the deep, meandering valley of the Kentucky River that crosses the Inner Blue Grass region. Thick limestone formations form picturesque palisades along the gorge-like valley and some of its tributaries (Figs. 31 and 32). Entrenched approximately 400 feet below the level of the central Kentucky limestone plain, the valley is the beauty spot of the Blue Grass.

The palisades are found primarily between Frankfort, the State capital, and Boonesboro (location of Fort Boonesboro State Park), and are largely restricted to the outcrop of the High Bridge Group of carbonate rocks (Middle Ordovician). More resistant to erosion than other rocks in central Ken-

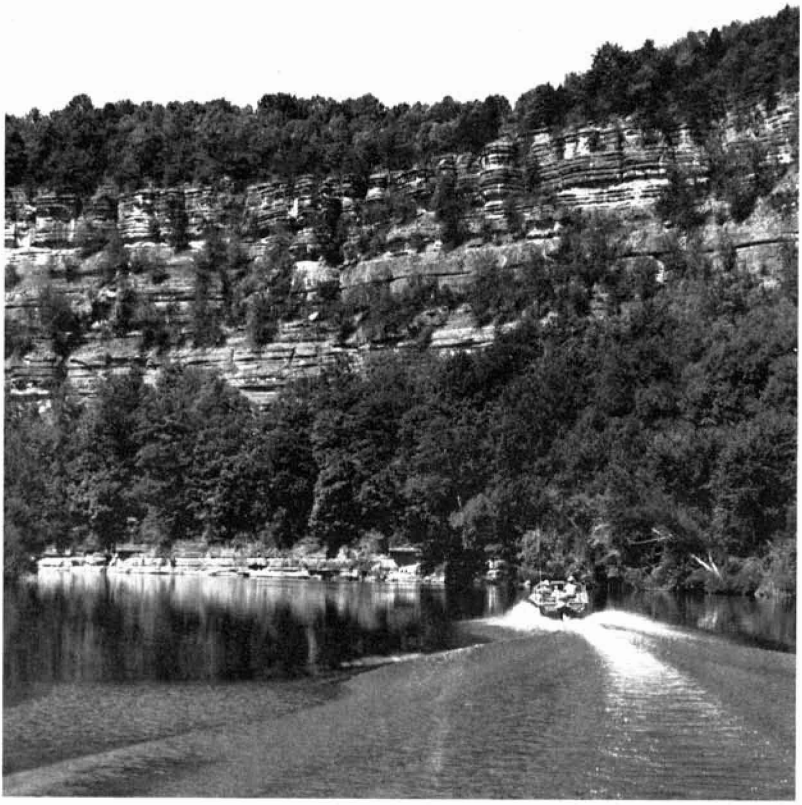

Figure 31. The deeply entrenched, meandering valley of the Kentucky River presents a marked contrast to the adjacent gently rolling, fence-lined pasture lands of the Inner Blue Grass. Thick limestone formations of Middle Ordovician age, the oldest rocks exposed at the surface in Kentucky, form picturesque palisades along the gorge-like valley. Kentucky Office of Tourism Development photograph.

tucky, the limestones and dolomites in the High Bridge Group are responsible for development of the rugged topography of the gorge. The palisades are not continuous. The meandering Kentucky River Valley crosses the Kentucky River Fault System several times, and fault displacement has taken rocks of the High Bridge Group below drainage level at several locali-

Figure 32. Candlestick Rock (also called "Chimney Rock") is a landmark in the Pollys Bend area of the Kentucky River near Camp Nelson. This isolated column is a product of differential erosion of the adjacent limestone cliff which forms part of the Kentucky River palisades. Photograph from McFarlan, 1958, p. 113.

ties. In these areas vertical cliffs give way to more gentle slopes, and the valley is widened at the expense of softer and weaker rocks. The gorge is crossed by Interstate Highway 75 and U. S. Highways 25, 27, 62, and 68.

Rock formations are progressively younger as one leaves the Inner Blue Grass region. Gentle inclination of the strata caused by regional dip carries the older rocks beneath the surface, and younger ones appear. The rocks exposed at the surface at Lexington are several thousand feet deep at Madisonville and Pikeville.

Rocks in the Outer Blue Grass are also Ordovician in age, but they are Late Ordovician and differ markedly in lithology from Inner Blue Grass rocks. Many of the formations contain interbedded shales and limestones. Consequently they are softer and less resistant to erosion. Stream erosion has cut a multitude of valleys. Hills and steep slopes predominate the landscape, and little flat land is present. This part of the Outer Blue Grass region has sometimes been called the Eden Shale belt. In the Louisville and Bardstown areas, the topography developed on the carbonate rocks of Silurian and Devonian ages appears similar to parts of the Blue Grass region and frequently is included with it. However, the terrain has fewer hills and more flat land, and is classified as a local physiographic entity by some earth scientists. Here, again, the geology of the area affected local topographic development. A conspicuous spring zone occurs at the base of some of the Silurian dolomites, and some of these springs were focal points of early distilleries in this part of Kentucky. The Falls of the Ohio River with its unique and famous coral beds is situated at the outer edge of this region.

The outer edges of the Blue Grass region are characteristically lowlands with little relief, being developed on shales of Mississippian and Devonian ages. The outcrop area of Kentucky's oil-shale deposits is in this part of the State (Fig. 33). These black shales, which form one of the most easily recognized rock units in Kentucky, are of additional geologic interest because they are the reservoir and source rocks for much of the natural gas produced from the Big Sandy Gas Field in eastern Kentucky.

Figure 33. The black Devonian-age shale is one of the most distinctive of all the geologic formations in Kentucky. The shale contains an organic material called kerogen, which gives the shale its black color on fresh, unweathered surfaces. When the fresh shale is heated it gives off a gas which is similar to natural gas, and an oil which is not much different from conventional crude oil. The shale is considered a potential future source of energy raw materials.

Big Bone Lick State Park

Big Bone Lick State Park, situated in the rolling hills of the Outer Blue Grass region of northern Kentucky, is one of the most unusual in Kentucky's park system. The park bears the name of and includes the locality known as Big Bone Lick, a swampy area surrounding some small salt-sulfur springs. Resort hotels during the 1800's reportedly did a flourishing business as people came to the area to drink and bathe in the mineral waters for medicinal purposes, but the locality has become famous as a fossil locality for bones of prehistoric animals.

Big Bone Lick is credited with being the first widely known collecting locality for vertebrate fossils in North America, being the source of materials which provided the foundations of the science of vertebrate paleontology in the New World. Reportedly, the area had been visited by Indians for game and for salt from the mineral springs. The first known white visitors were French military explorers in 1739; a small collection of mastodon teeth and bones was made and shipped to France. A portion of that collection is said to be still preserved in a museum in Paris, France.

Numerous collections have been made since 1739, largely removing all surface evidence of ancient animals. English scientists visited the site, and Benjamin Franklin and noted historians wrote about it, arousing the interest of scholars and statesmen alike in the history of ancient life. One of the most notable investigations was ordered by President Thomas Jefferson in 1807, which may have been the first organized paleontological expedition in North America. The most comprehensive investigation of the local geology and fossil assemblages was conducted between 1962 and 1966 by a team of scientists from the U. S. Geological Survey and the University of Nebraska, supported in part by the Kentucky Department of Parks. Meticulous excavations, in two terrace-fill deposits of Wisconsin and Holocene geologic ages, revealed a great variety of bones ranging from domesticated farm animals to modern buffalo and deer to long-extinct species of mastodon, mammoth, giant ground sloth, musk ox, and large bison (Fig. 34). Representative skeletons of the ancient land animals can be seen in the small museum in the park.

The bone-bearing deposits at Big Bone Lick are associated with geological events during and subsequent to the Wisconsin glacial age. Fossils of prehistoric great land mammals have been found occasionally in clay, sand, and gravel deposits along and near the Ohio River Valley, but nowhere have they been reported in such numbers as at Big Bone Lick. Differing theories have been offered to explain this concentration. Earliest investigators assumed that the animals, both modern and ancient, were attracted by the salts in the mineral springs and became mired in the bog that surrounded the springs. However, excavations have indicated that the fossil remains of the mammals were concentrated in a zone of calcareous, gravelly, and sandy silt, suggesting

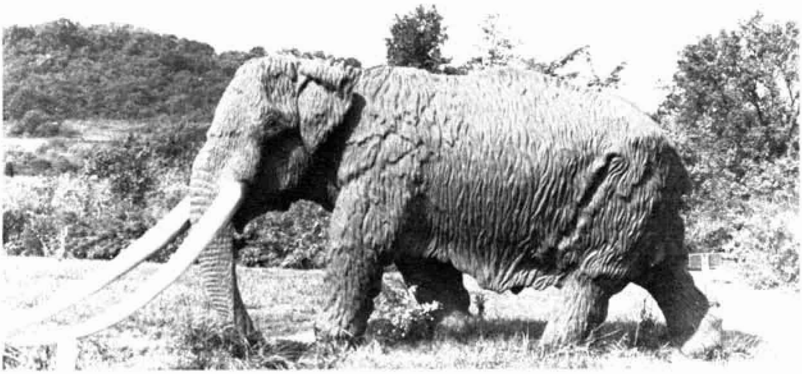

Figure 34. Replica of a mastodon, that once inhabited northern Kentucky, in Big Bone Lick State Park. Big Bone Lick is credited with being the first widely known collecting locality for vertebrate fossils in North America. Representative skeletons of this and other ancient land animals can be seen in the small museum in the park.

stream transportation of the bones. The presence of bones of modern buffalo (bison) and deer might be attributable to miring in the soft bog sediments. Researchers concluded that 7 to 8 feet of silt has been deposited in the valley of Big Bone Creek since the early part of the nineteenth century, thus further accounting for the fact that the fossils are obscured except in man-made excavations.

Waters that fed the sulfur-saline springs have been regarded as deep seated, rising approximately 900 feet from the St. Peter Sandstone (Ordovician) or other zones near the same depth, but this has not been confirmed positively.

MISSISSIPPIAN PLATEAUS

The Mississippian Plateaus region of Kentucky contains a diversity of landscapes and geologic features. The picturesque knobs country, extensive sinkhole plains, the famous Kentucky cave country, wooded escarpments, and sandstone-capped plateaus are found here. The region includes a broad arcuate belt around the Western Kentucky Coal Field, extends eastward around the southern edge of the Outer Blue

Grass, and occupies a relatively narrow belt parallel to the western edge of the Eastern Kentucky Coal Field.

A horseshoe-shaped belt of ridges and hundreds of more or less isolated, rounded, and conical hills borders the Blue Grass region on the west, south, and east. This forested upland area has been referred to as "The Knobs" or merely "Knobs" and constitutes a picturesque and scenic segment of Kentucky's landscape (Figs. 35 and 36).

In its typical development, the Knobs area is a narrow belt of hill country characterized by partially or completely isolated monadnocks in the form of rounded hills and conical knobs capped by resistant layers of rock. These knobs often stand out as prominent landmarks. Behind the Knobs is a cuesta or escarpment capped with resistant limestone. In south-central and west-central Kentucky the escarpment is re-

Figure 35. Knobs topography at Cave Run Lake in Rowan County. The rounded and conical hills, or knobs, are erosion remnants which have been detached from the Mississippian Plateaus by normal stream erosion. Collectively, they form a scenic horseshoe-shaped belt around the perimeter of the Blue Grass region. Kentucky Office of Tourism Development photograph.

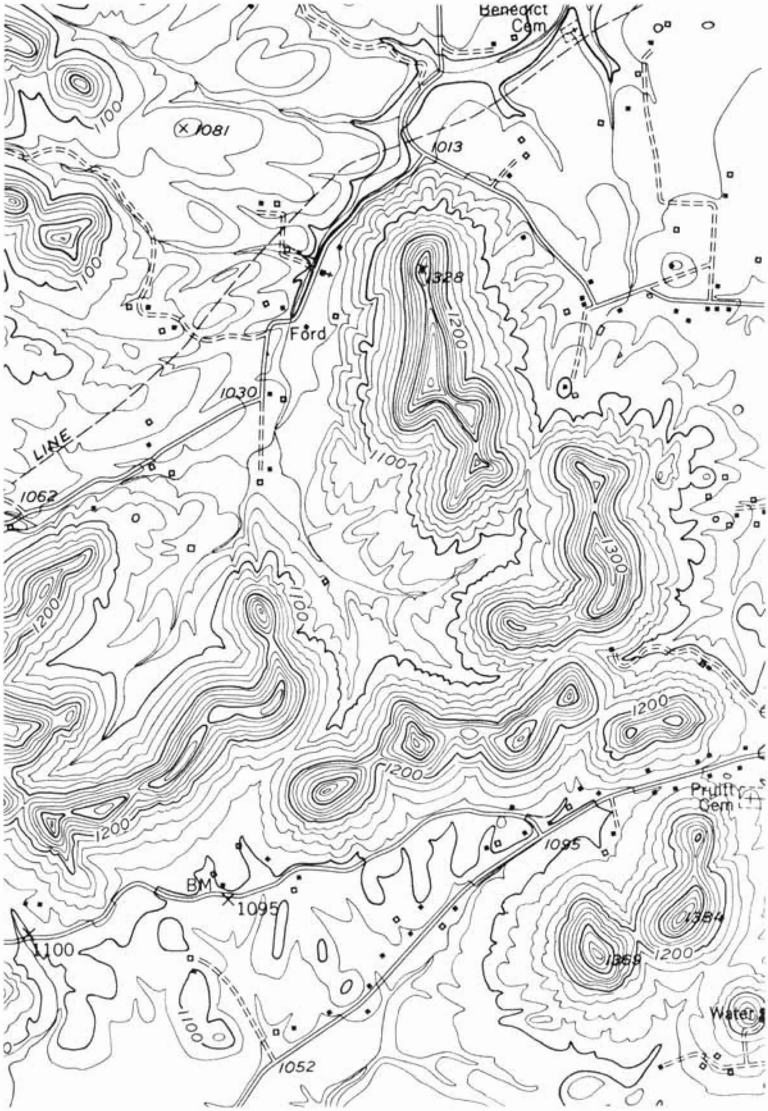

Figure 36. Portion of the Junction City Quadrangle topographic map showing knobs terrain in Lincoln County. Lobate and hummocky topography, expressed by the crinkled pattern of the contour lines at or near the bases of the isolated hills and ridges, is an indication of unstable slopes and the slumping of shaly formations.

ferred to as Muldraugh Hill. Along part of the eastern area, the Mississippian rocks are so thin that this escarpment appears to merge with the Cumberland Escarpment.

The hard ledges of limestone at the top of Muldraugh Hill serve as a caprock to retard surface erosion and protect the underlying softer shales and siltstones. The Knobs are erosion remnants which have been detached from the main upland by stream erosion (Fig. 37). When they first become cut off or isolated, they are flat-topped hills or ridges. Further erosion removes the resistant cap and they take on a conical form. These cone-shaped peaks constitute some of the most striking topographic features of the region. Bernheim Forest, a privately endowed 100,000-acre woodland, upland game sanctuary and natural science and horticulture educational area about 25 miles south of Louisville, is an excellent locality to view and enjoy the Knobs region. The southern Knobs area is well known for its geode-collecting localities.

The Mississippian Plateaus region, particularly in the western half of the State, contains two distinct areas. The eastern and southern parts of the region consist of a limestone plain characterized by tens of thousands of sinkholes, mysterious sinking streams, streamless valleys, large springs, and interesting caverns. (The term "karst" is commonly used to designate this type of terrain.) This is the "Sinkhole Plain" or "Pennyroyal Plateau" of some writers (Figs. 38 and 39). A second, higher plateau lies to the west and north and is separated from the limestone-surfaced sinkhole plain by the Dripping Springs Escarpment, a sandstone-capped cuesta which faces the lower limestone area. The higher plateau (Mammoth Cave Plateau) is a dissected upland of moderate relief, underlain by sandstones, shales, and limestones. Near the Dripping Springs Escarpment the sides and bottoms of the valleys are in limestones and are the locale of many large caves. Isolated sandstone-capped hills, rising above the sinkhole plain, are erosion remnants of the Dripping Springs Escarpment. They have been called "knobs" but should not be confused with the belt of knobs along Muldraugh Hill.

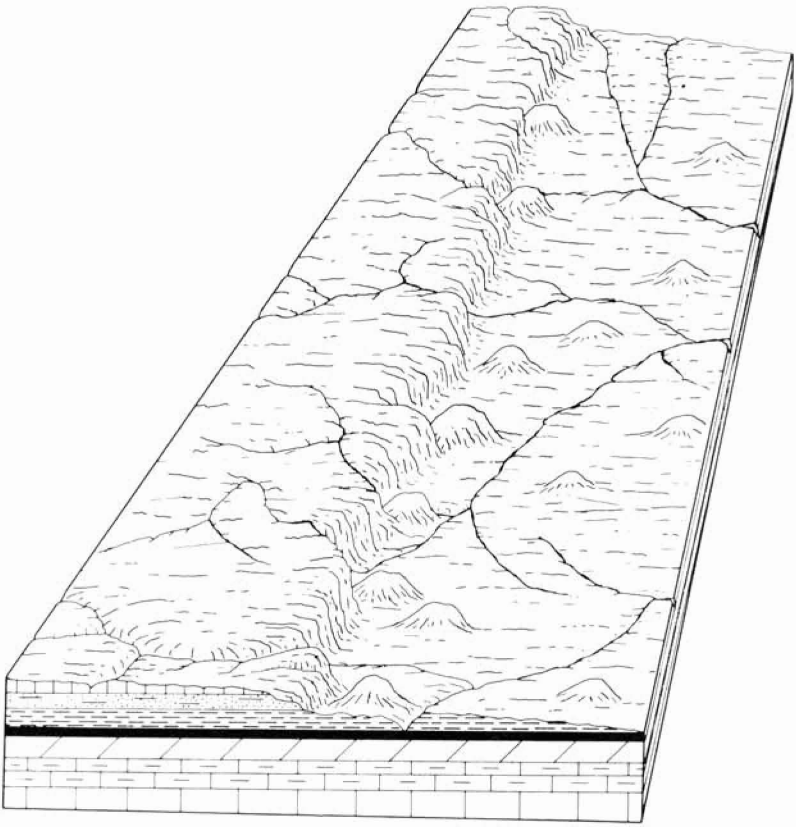

Figure 37. Diagram of Muldraugh Hill and development of the Knobs area (adapted from McFarlan, 1958, p. 37). Muldraugh Hill is a cuesta, or escarpment, capped with Middle Mississippian limestones, facing the Blue Grass region. The Knobs are erosion remnants of the upland area after the front of the escarpment has been carved by stream erosion. When first cut away from the escarpment, the hill areas may be flat-topped, but as the resistant cap is removed and softer shales and siltstones are exposed to weathering processes the hills take the shape of cones.

Mammoth Cave Area

This is the region in which Mammoth Cave National Park is located (Fig. 40). It is classic in geologic literature because probably no part of the United States rivals this area for the

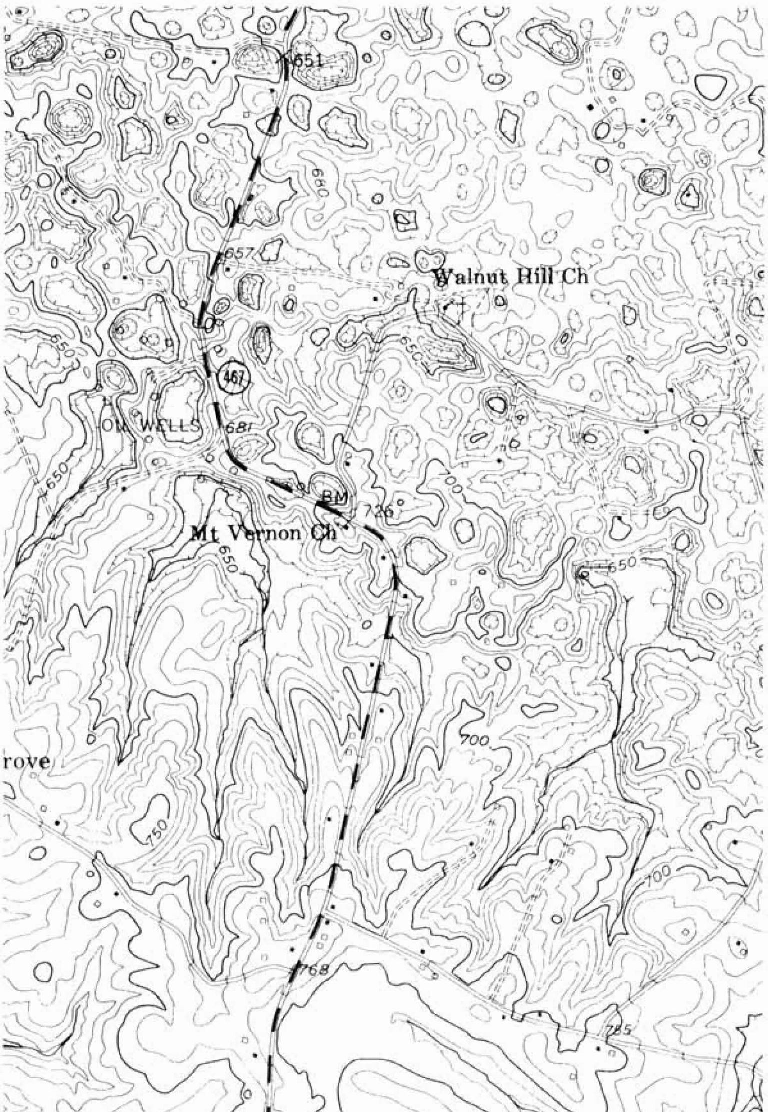

Figure 38. Portion of the Park City Quadrangle topographic map showing sinking creeks and sinkholes which are typical of the karst topography developed on the limestone plain near Mammoth Cave.

Figure 39. Aerial view of the Pennyroyal Plateau (sinkhole plain), Dripping Springs Escarpment, and sandstone-capped Mammoth Cave Plateau west of Park City. Normal surface streams are absent in large parts of this karst area, and drainage is through underground routes in cavernous limestones. Photograph by W. Ray Scott.

number of well-known large and spectacular caverns and associated underground solution features. The Mammoth Cave-Flint Ridge Cave System in Mammoth Cave National Park has more than 200 miles of measured and charted passageways, more than any other cave in the world.

A limestone cavern in its simplest form is an underground drainage route—one of nature's storm sewers. It has been made almost entirely by water, diverted from surface to underground routes, which dissolved and removed the calcium carbonate from the thick limestone formations. The phenomenon of solution is a complex matter, depending upon the interplay of many factors. Calcium carbonate, the principal constituent of limestone, is only slightly soluble in pure water, but it is chemically eroded when water containing organic or inorganic acid comes in contact with it. Humid re-

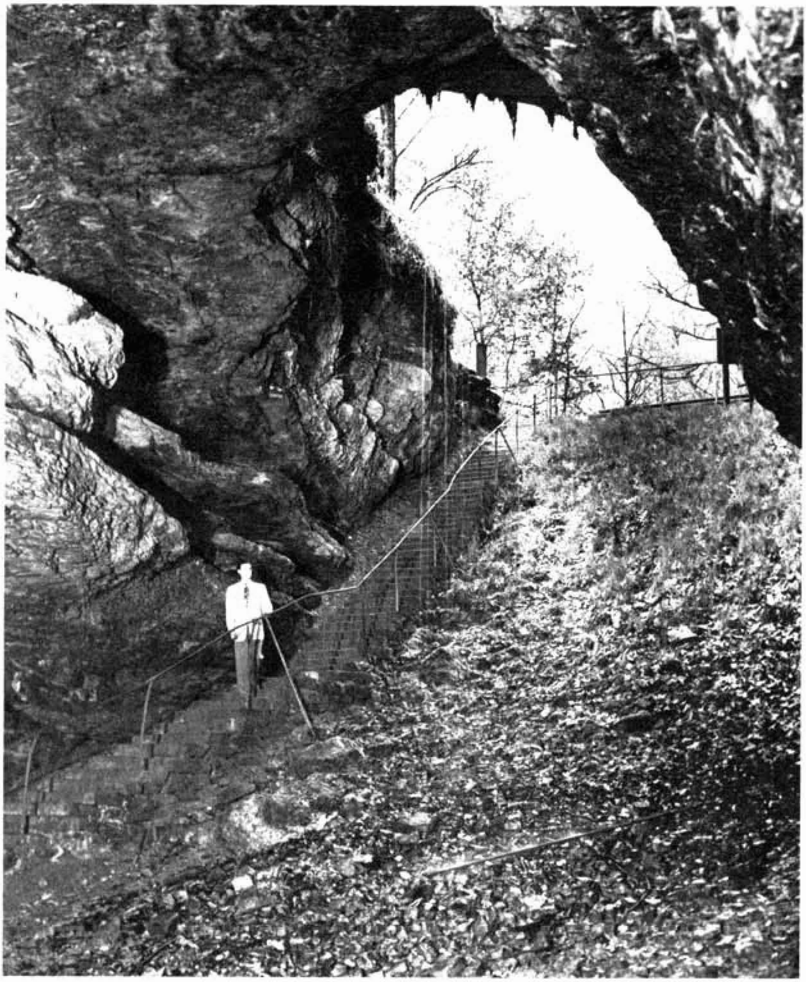

Figure 40. The natural or historic entrance to Mammoth Cave. Since 1816, when the cave was first opened to the public, hundreds of thousands of people have passed through this cavernous opening to view the wonders of this outstanding scenic geologic attraction. National Parks Concessions, Inc., photograph.

gions having moderate to heavy rainfall, such as is present in the Mammoth Cave area, provide good conditions for solution of limestone rocks. Much of the permeability of limestone is developed by circulation of water into and through vertical and horizontal fractures (Fig. 41). These openings in

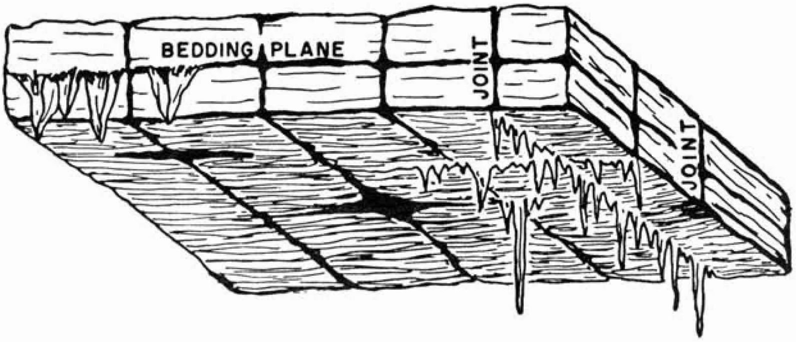

Figure 41. Horizontal and vertical fractures, called bedding planes and joints, in limestone strata provide access routes for surface waters to penetrate the rock layers, thus bringing about the solution of the limestone and subsequent deposition of decorative formations (after Lobeck, 1929, Fig. 26). Cave passageways and dripstone formations in Kentucky caves are commonly associated with these fractures.

the rock provide access routes for surface waters to penetrate the limestone formations and thus bring about solution and erosion of the rock, enlarging the openings many times. For the formation of larger cavern passageways, the topography of an area must be such as to allow free flow or circulation of water. The deeply entrenched valley of Green River, situated at a lower elevation and downdip from the sinkhole plain, allowed precipitation and other surface waters on the sinkhole plain to move freely underground, and then migrate by gravity and hydrostatic flow to outlets along Green River Valley (Fig. 42). The gentle gradient of the slightly tilted rocks initially helped to direct the movement of underground waters toward Green River, the level of which was lower than the sinkhole plain. As Green River cut its valley deeper, the water table was lowered, exposing cave passages to the air. As storm waters flowing through these passages continued to enlarge and deepen them, both through solution and erosion, dip of

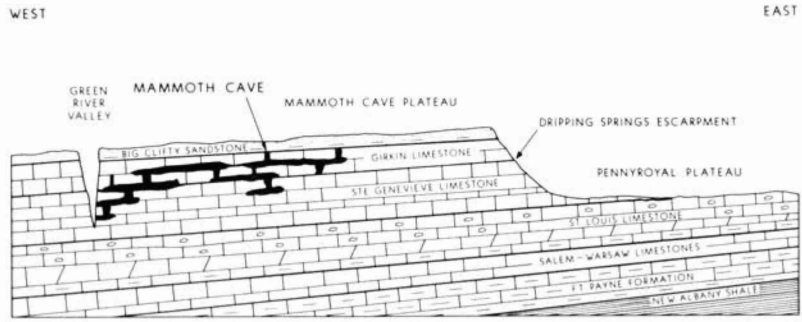

Figure 42. Generalized geologic cross section of the Mammoth Cave area. The highlands above the sinkhole plain (Pennyroyal Plateau), separated from it by the Dripping Springs Escarpment, are protected from rapid erosion by a resistant sandstone formation.

the rock became less important. After the underground waters were diverted by nature to lower levels, some of the cave passageways became relatively dry, and the slow process of deposition of dripstone (cave travertine or cave onyx) and gypsum began, adding a variety of features to ceilings, floors, and walls of underground openings which enhance the beauty and interest of the caverns (Figs. 43 and 44).

Decorative formations are not found in all caves or in all parts of the same cave. If rocks overlying the cave passages contain shales or other impermeable strata, water may be prevented from dripping or seeping into the air-filled passages, and no stalactites, stalagmites, or other dripstone will form.

The Mammoth Cave National Park area, with its vast and seemingly endless miles of grand subterranean avenues and spectacular arrays of decorative formations, leaves most visitors filled with astonishment and wonder. As the visitor attempts to absorb and digest all that he has seen, he may be asking himself, "Why is it here and not somewhere else?" An oversimplified answer is that this region contains the essential ingredients for the formation of large limestone caves. Briefly, the geological factors are:

1. Thick sequence of relatively pure, bedded and jointed limestone, without insoluble interbeds. The solubility of the limestone is a prime reason for the presence of the

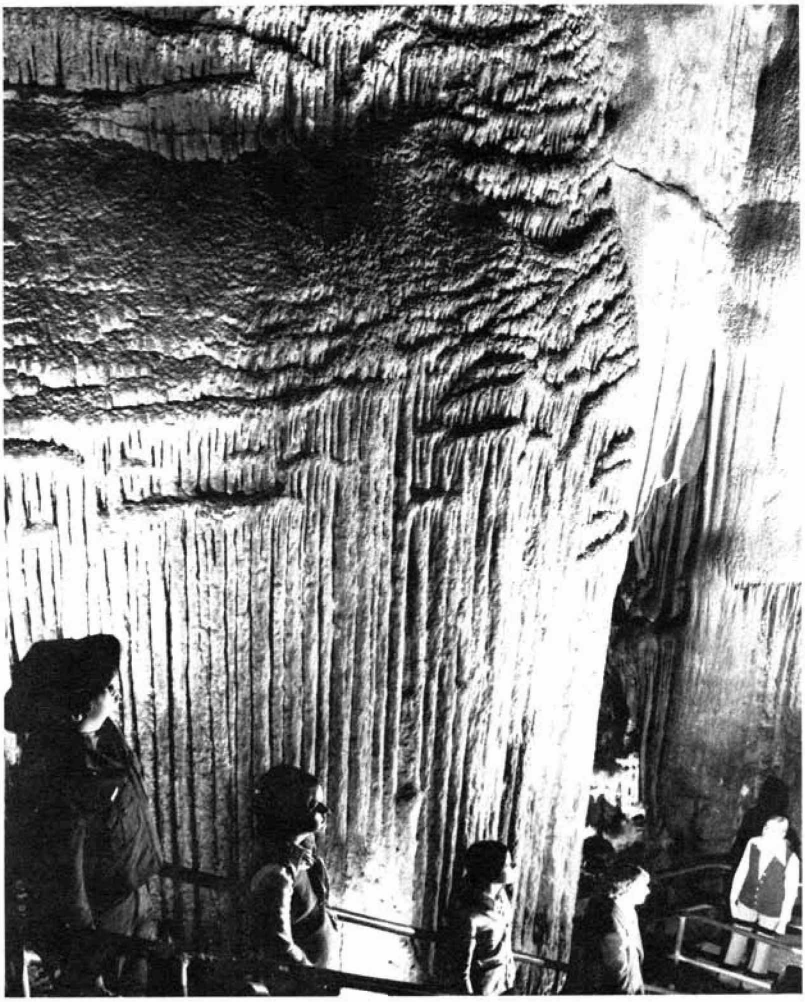

Figure 43. Frozen Niagara, one of the most spectacular and popular natural features of Mammoth Cave, is a dripstone formation formed by the slow deposition of calcium carbonate from water dripping or flowing down the cave walls and over collapsed blocks of limestone. It is 75 feet high and 50 feet wide. National Parks Concessions, Inc., photograph.

caves. Bedding planes and joint fractures are focal points for the initial penetration and concentration of percolating ground water. In aggregate, St. Louis, Ste.

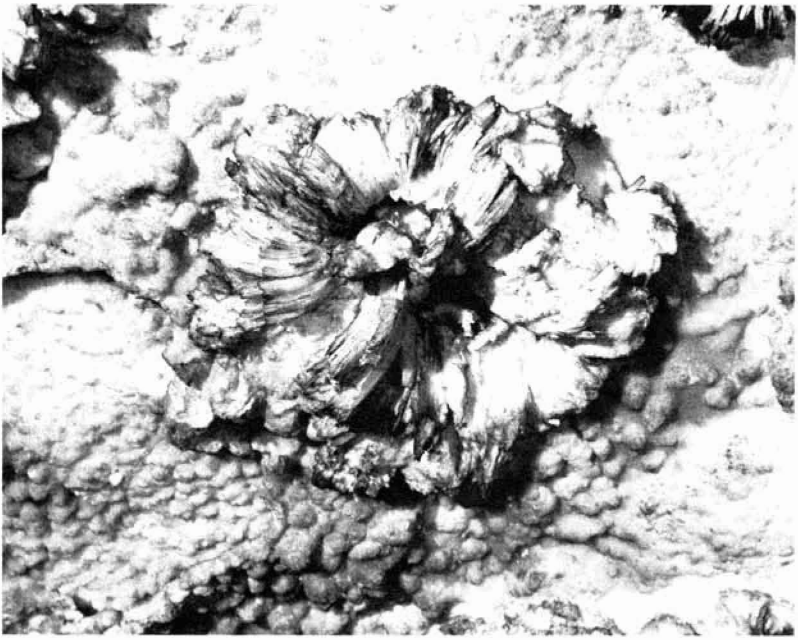

Figure 44. Delicate gypsum formations are found only in the drier parts of Mammoth Cave, where slow seepage of calcium sulfate-bearing water evaporates in open pores of limestone in a cave ceiling or wall, producing gypsum crystals. Continued growth may form crusts, balls, or blisters, and gypsum "flowers." National Parks Concessions, Inc., photograph.

Genevieve, and Girkin Formations contain an essentially uninterrupted sequence of 400 feet or more of carbonate rock. The purest ledges are found in the Girkin and Ste. Genevieve, the formations in which most of the explored and all of the commercialized avenues of Mammoth Cave are developed. To the north and west, sandstone and shale beds interrupt the limestone sequence above the Ste. Genevieve, restricting the downward movement of water and limiting the size and number of caves.

2. Adequate supply of water to generate solution activity. This is a humid region, receiving an average of 45 to 50 inches of rainfall annually. In addition, there is geological evidence to suggest that probably two ancient

streams (Tertiary and pre-Pennsylvanian in ages) once crossed this part of south-central Kentucky, further concentrating great quantities of water in the area and allowing for a longer period of solution activity, thus localizing cavern development.

3. Topography or elevation of rocks above the water table. The Pennyroyal Plateau (sinkhole plain) and the Mammoth Cave Plateau are perched 200 to 400 feet above the principal water table, allowing free and active circulation of waters which fall on soluble limestone rocks. In Mammoth Cave National Park, the principal water-table level is controlled by Green River, which has carved a deep valley and flows through the park at an elevation of 422 feet.
4. Structural setting or attitude of the rocks. In the Mammoth Cave area the layers of limestone are not flat but dip gently to the northwest, being inclined toward the deeply entrenched valley of Green River. Underground waters, concentrated along the bedding planes, will move naturally by gravity and hydrostatic flow in the direction of this stream, selectively dissolving the rock and establishing localized zones of flow.

Regional dip causes the Ste. Genevieve Limestone to go below drainage (level of Green River) in the vicinity of Turnhole Bend, and the Girkin Limestone goes below drainage near the mouth of Nolin River; thus, the opportunity of free circulation and movement of underground waters in the formations is significantly decreased west of these points. Consequently, that portion of the Mammoth Cave Plateau west of the mouth of Nolin River should not be expected to contain caverns of the magnitude and the magnificence of the Mammoth Cave system, even though there is a well-developed sinkhole plain to the south.

In addition to world-famous Mammoth Cave, there are also a number of privately owned commercialized caves in the south-central Kentucky area. And in northeastern Kentucky, Carter Caves State Resort Park is centered around a group of small but interesting and picturesque caves and natural, scenic geologic features which occur in rocks of correlative geologic ages (Figs. 45 and 46). From Carter Caves the

Figure 45. This narrow, steep-walled passage in X Cave at Carter Caves State Park was formed by solution along a vertical fracture in soluble limestone. The limestones in which this and other caves in the eastern Kentucky region were formed are correlative in part with those of the Mammoth Cave area. Kentucky Office of Tourism Development photograph.

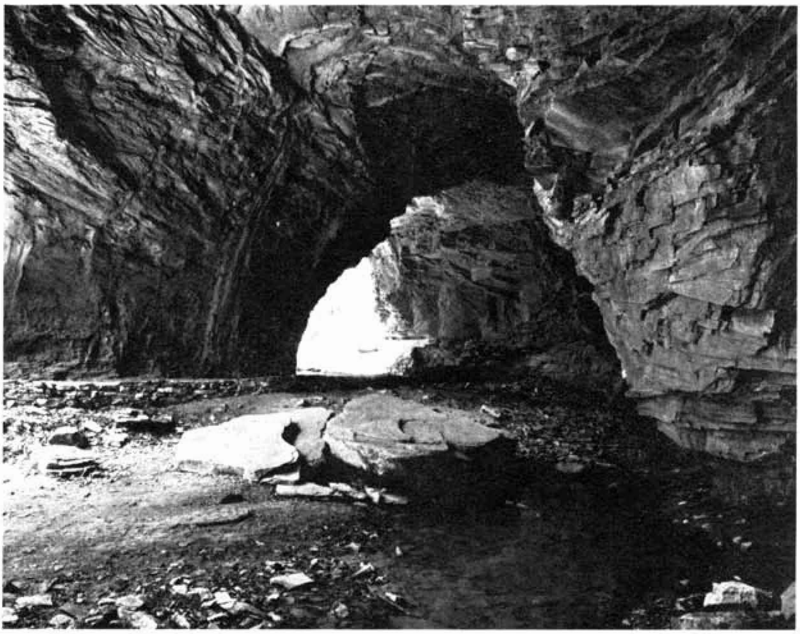

Figure 46. This natural limestone arch or bridge, 150 feet long, 60 feet wide, and 40 feet high, spans Cave Branch in Carter Caves State Park. It was made by the normal process of cave formation involving solution, erosion by underground stream, and collapse of part of the roof-rock. This bridge was probably part of Bat Cave, located a short distance upstream; complete collapse of the thin-bedded limestone roof severed the connecting passages. Kentucky Office of Tourism Development photograph.

karst landscape can be traced southwestward past Somerset to Clinton and Wayne Counties.

The Western Kentucky Fluorspar District is situated in the extreme western part of the Mississippian Plateaus. This complexly faulted, mineralized area has been an important mining district for many years and has made Kentucky the second largest producer of fluorspar (fluorite) in the United States. The ore occurs mainly as vein deposits along faults. Minerals of zinc (locally the principal mine product), lead, barium, cadmium, germanium, and silver have been recovered as by-products of fluorspar mining. Host rocks for the fluorspar ore are primarily Mississippian-age limestones.

Rocks in the Mississippian Plateaus region are of further economic significance because almost 70 percent of the construction stone produced in Kentucky comes from limestone deposits of Mississippian age (Fig. 47).

Figure 47. The Governor's Mansion in Frankfort, official residence of the Commonwealth's first family, is faced with limestone which was quarried near Bowling Green. Kentucky Office of Tourism Development photograph.

Lake Cumberland, a flood-control, power, and recreation facility formed by Wolf Creek Dam on the Cumberland River near Jamestown, extends across a portion of the Mississippian Plateaus to the outer edge of the Eastern Kentucky Coal Field. At the lake's highest level, waters are impounded upstream to the foot of Cumberland Falls. Crinoid- and geode-bearing Mississippian-age strata are commonly exposed along the rocky shores of the lower section of the lake (Fig. 48). Lake Cumber-

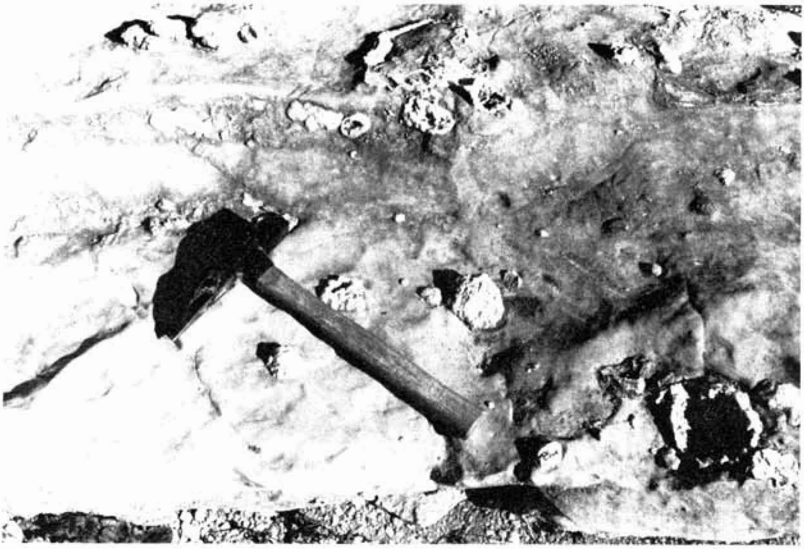

Figure 48. Geode-bearing Mississippian-age limestone on the shore of Lake Cumberland in south-central Kentucky. Geodes, which are hard, globular bodies of silica, are much sought by collectors for the variety of minerals they contain. In Kentucky, they are most common around Muldraugh Hill and the Knobs area.

land State Park, situated approximately 13 river miles upstream from Wolf Creek Dam, overlooks the lake for which it is named.

Rock House (Creelsboro) Natural Bridge, a magnificent arch or tunnel in limestone of Late Ordovician age, is located on the north side of the Cumberland River approximately 11 river miles downstream from Wolf Creek Dam, on a very narrow ridge between Cumberland River and Jim Creek. Erosion by both streams created the narrow drainage divide, allowing waters from Jim Creek to seep through bedding planes and joint fractures. Solution activity enlarged the openings to cavernous size, causing the flow of Jim Creek to be diverted from its normal channel to the Cumberland River through an underground route. Subsequent weathering and erosion resulted in further enlargement, creating a span about 75 feet wide and 40 feet high.

Rough River Lake, another man-made flood-control and recreation reservoir, is also located in the Mississippian Plateaus region, and is the site of Rough River State Park. The lake and park are located in the outcrop area of Late Mississippian sandstones, shales, and limestones about 5 miles east of the Western Kentucky Coal Field. Low bluffs of Big Clifty Sandstone, the same sandstone formation that caps the Dripping Springs Escarpment in the vicinity of Mammoth Cave, rim the lake in the vicinity of the park lodge.

WESTERN KENTUCKY COAL FIELD

The Western Kentucky Coal Field, which is characterized by its Pennsylvanian-age strata, is one of two major coal fields in the State. The western Kentucky field is part of the larger Eastern Interior Basin, a structural depression which includes parts of southern Illinois and southwestern Indiana. The terrain is rolling to hilly, but the topography is much less rugged and the elevations much lower than the eastern Kentucky counterpart. Discontinuous sandstone ridges and cliffs mark the edge of a cuesta that overlooks the Mississippian Plateaus and approximately marks the coal-field boundary. Sandstone-capped outliers, bold, precipitous cliffs, and narrow, rocky valleys along the perimeter of the region constitute the most scenic natural features (Fig. 49). Typical sandstone bluffs are present in and near Lake Malone and Pennyrile Forest State Parks, and along the Ohio River near Hawesville. Natural sandstone arches or bridges are present near Lake Malone State Park, near Apex in northern Christian County, and near Joy in northwestern Livingston County.

Lake Malone, a man-made reservoir, and Lake Malone State Park are situated near the junction of Muhlenberg, Logan, and Todd Counties, in a little-publicized, scenic portion of the Western Kentucky Coal Field. Small by comparison with many of the State's impoundments, the lake is almost continuously lined with nearly vertical bluffs of massive, conglomeratic, basal Pennsylvanian sandstone; some of the rock faces along the narrow, twisting arms of the lake rise 100 feet or more above the water's surface. Precipitous cliffs, rock shelters, small waterfalls, and a small natural sandstone

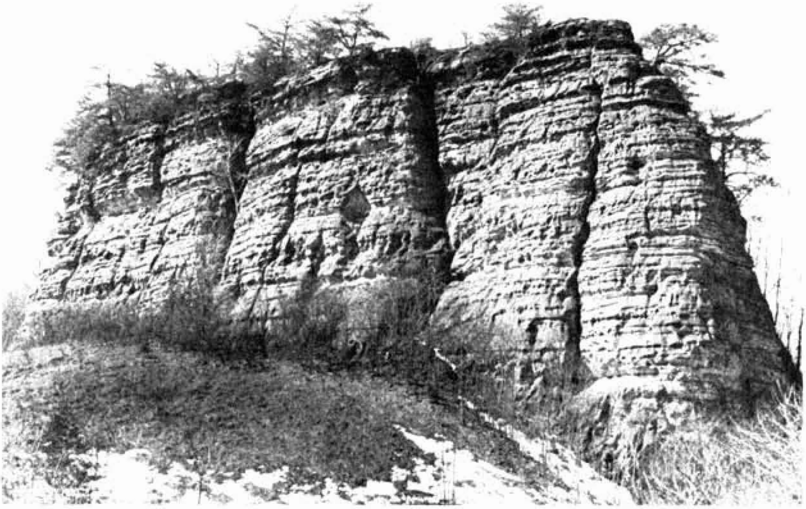

Figure 49. Sand Knob, near Rough River State Park, is an isolated hill capped with more than 100 feet of massive conglomeratic sandstone of Early Pennsylvanian age. This outlier is situated approximately 5 miles east of the main area of Pennsylvanian outcrop, indicating that the Western Kentucky Coal Field was once considerably larger than it is now.

arch—features commonly found along the Cumberland Escarpment of eastern Kentucky—are present at Lake Malone.

The distribution of Carboniferous (Pennsylvanian and Mississippian) rock formations in Kentucky warrants the inference that the Eastern and Western Kentucky Coal Fields were once connected.

In the interior of the Western Kentucky Coal Field, the topography is more subdued than along the outer limits where massive sandstones are common. The region is drained by the Ohio, Green, and Tradewater Rivers and their tributaries. Stream gradients are low, and broad, silt-filled valleys are common. Some swampy areas are present. During Pleistocene time the floods of glacial meltwaters pouring down the Ohio River and filling its channel with rock debris caused some tributary valleys to be ponded and filled with slack-water alluvium. This condition reached many miles up some of the streams and produced broad valley flats that look too large for the streams that occupy them.

Southeast of Livermore, in southern McLean County, Green River flows through a narrow neck of upland, creating an island-like land mass to the west from what had been part of a great meander bend of Green River. The diversion of Green River through the former channel of Elk Creek may have been induced by floodwaters of the meandering Green River, or ponding and alluviation associated with Pleistocene glaciation, or a combination of both. A community which occupies a part of the low hills within the abandoned meander is appropriately named "Island."

The Rough Creek Fault System is an important geological feature of the region. Bisecting the coal field, it extends from the Ohio River west of Morganfield to eastern Grayson County. The fault system is a zone of ancient faulting, ranging from less than 1 to more than 5 miles in width, with displacements of 300 feet or more. It has played a major role in the exploration and development activities for oil and gas, coal, and limestone in this part of Kentucky.

Like the Appalachian area to the east, the Western Kentucky Coal Field has a long history of bituminous coal production. Although it does not contain as many individual coal beds as the eastern field, several are widespread and easily mined by surface methods, and the land can be restored into new forests and agriculturally productive land more easily. More than 1.5 billion tons of coal have been produced from this field. Western Kentucky coals generally have higher ash and sulfur contents than eastern Kentucky coals; most of the production is used by electric utilities.

Hundreds of small oil and gas pools lie hidden beneath the surface of this region. Most of the production has come from sandstones and limestones of Mississippian age.

Discontinuous deposits of bitumen-bearing Upper Mississippian and Lower Pennsylvanian sandstones (natural rock asphalt or tar sands) are present along the eastern and southeastern edge of the coal field (Fig. 50). These occurrences are unique in that no other part of the perimeter of the Eastern Interior Basin contains deposits of comparable number or size.

Figure 50. Bitumen-impregnated sandstones (also called natural rock asphalt and tar sands) are present in Late Mississippian and Early Pennsylvanian age rocks near the southeastern edge of the Western Kentucky Coal Field. They have been used for paving purposes but also have potential as an alternate source of energy raw materials.

Used primarily in the past as a road-surfacing material, these tar sands are considered to be a potential future source of energy raw material.

MISSISSIPPI EMBAYMENT

The Mississippi Embayment region includes the eight-county Jackson Purchase area and adjacent portions of Trigg, Lyon, and Livingston Counties. It is the principal region of outcrop of Cretaceous and Tertiary rocks in Kentucky. These deposits consist of unconsolidated sands, gravels, and clays as contrasted with the adjacent hard Paleozoic limestones and cherts. This portion of Kentucky is near the northern extremity of the Mississippi Embayment, a broad, southward-plunging synclinal trough that once opened into the Gulf of Mexico. Cretaceous and Tertiary sediments dip gently toward the axis of the trough which roughly parallels the present Mississippi River.

Topographically, most of the area is a gently rolling plain of low hills and flat-topped, gravel-capped ridges. Local relief, except near Kentucky and Barkley Lakes and along the Mississippi River bluffs, is generally less than 100 feet. The lowest elevation in the State, 260 feet, is found here. Bottom lands adjacent to the Mississippi River range from 290 to 330 feet above sea level. They are marked by north-south oriented lakes, ponds, sloughs, chutes, and swamps, all former routes of the Mississippi in normal or flood-flow conditions. An impressive view of the Mississippi River is afforded by the lookout at Columbus-Belmont Battlefield State Park (Fig. 51).

The area bordering the Mississippi River is currently tectonically active and has been the site of earthquake tremors. The center of the New Madrid earthquake of 1811-1812, one of the most violent earthquakes that has taken place in modern time in the eastern United States, was located near this area. Reelfoot Lake, one of the subsidence features associated with the New Madrid earthquake, reached the southern border of Kentucky.

Gravels are the most conspicuous of the unconsolidated sediments, and occur as two distinct geologic formations. One is light gray to off white (Fig. 52); the other has a distinctive brown or red-brown color due to limonite (hydrous iron oxide) coating. Both gravel formations are nonmarine and owe their origin to disintegration of chert-bearing Devonian and Mississippian carbonate rocks. They have been used extensively in the past for fill and secondary roads, but they do not meet most current specifications for cement-concrete aggregate.

Figure 51. View of the Mississippi River from Columbus-Belmont Battlefield State Park in northwestern Hickman County. The bluff, which is more than 100 feet above the river, is capped with brown chert gravels and thick deposits of windblown silts. Kentucky Office of Tourism Development photograph.

Locally, Paleozoic rocks are exposed in the bottoms and walls of the stream valleys on the eastern and northeastern borders of the embayment area. The oldest rocks are Devonian chert, limestone, and shale, found in narrow fault blocks on Barkley Lake near Kuttawa and north of Aurora on Kentucky Lake. Elsewhere the indurated rocks are predominantly Mississippian limestones and cherts. Mississippian limestones have been quarried on the eastern and northern borders of the area for construction stone, riprap, and agricultural limestone. In many places the limestone has been leached and partly replaced by chert.

The embayment region of western Kentucky is characterized by numerous clay deposits (Fig. 53). The best known are

Figure 52. Light-colored chert gravels of Cretaceous age near the eastern edge of the Mississippi Embayment area of western Kentucky. These well-rounded, water-worn pebbles and gravels were derived primarily from rocks of Mississippian and Devonian ages.

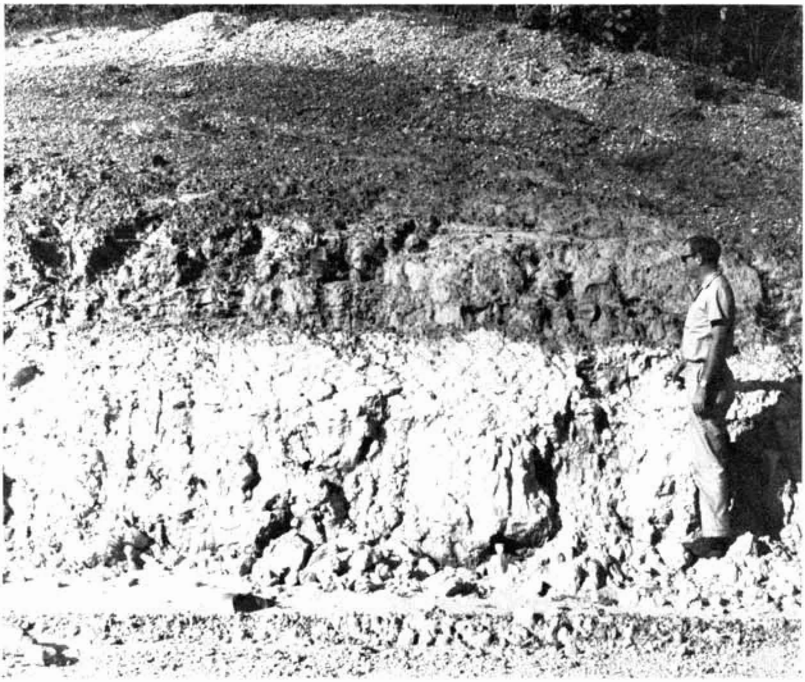

Figure 53. Deposit of light-burning clay of Eocene age in western Calloway County. The Mississippi Embayment area of western Kentucky contains numerous clay deposits which have potential in the chinaware, pottery, structural clay products, and absorbent industries. This region is the second-largest producer of ball clay in the United States.

the ball clays which are used in the manufacture of whiteware, sanitary ware, artware, enameling, and many other products. This part of Kentucky is the second largest producer of ball clay in the United States. Other clays have firing properties which would qualify them for use in pottery, structural clay, and absorbent industries. In some places thin beds of lignite are associated with the clays.

Kentucky Lake, a man-made, multipurpose reservoir for flood control, navigation, power, and recreation, has the largest flood-storage capacity in the Tennessee Valley Authority system (Fig. 54). Barkley Lake, an impoundment on Cumberland River, is east of and roughly parallel to Kentucky

Figure 54. Kentucky Dam, on the Tennessee River in western Kentucky, impounds waters to form Kentucky Lake, the largest in the Tennessee Valley Authority system. The dam and lake are used for flood control, navigation, power generation, and recreation. Kentucky Office of Tourism Development photograph.

Lake. Three State parks have been developed in the vicinity of the two lakes. A canal, 2 miles upstream from Barkley Dam, connects Barkley Lake with Kentucky Lake for navigation and to permit operating the two flood-control reservoirs as a unit. Beginning at the canal and extending southward into Tennessee is a narrow ridge of land approximately 40 miles long that separates the two lakes. The Tennessee Valley Authority has developed this area of woodland, open fields, and irregular shoreline into an outdoor recreation and conservation area. Appropriately, it has been named "Land Between the Lakes." It is in the transition area between the Mississippian Plateaus and the Mississippi Embayment. The hills and ridges adjacent to both lakes are capped with Cretaceous and Tertiary gravels and sands, but lower in the valley walls and near the shores of the lakes hard ledges of Paleozoic limestone and chert are present. Surface rocks at the two dams are mainly clays, gravels, and sands, but the foundations of the dams rest upon indurated limestones of Mississippian age.

Of both geologic and historic interest in this part of Kentucky are the evidences of a once-active iron industry. Near the community of Suwanee, northeast of Barkley Dam, is the site of a furnace built by William Kelly in 1851, where he reportedly discovered a method of making steel that is now known as the Bessemer process. The furnace, fueled by charcoal, operated until 1857. The ruins of several other old iron furnaces have been found in the Land Between The Lakes. Center Iron Furnace is located in the Conservation Education Center. The iron ore, which was dug from small pits in nearby hills, appears to be bog ore formed in the basal Cretaceous sediments on the post-Mississippian erosion surface. The deposits appear to be too small and of too low grade to meet present-day industry requirements. At one time during the 1800's Kentucky ranked third in the Nation in production of iron but declined rapidly due to larger, richer, and more economical sources in other states.

Ground water is an important resource in the Mississippi Embayment. Aquifers in Cretaceous and Eocene sands, the alluvium of the Ohio and Mississippi Rivers, and the buried Paleozoic limestones are capable of producing large quantities of good-quality water for industrial and public needs.

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