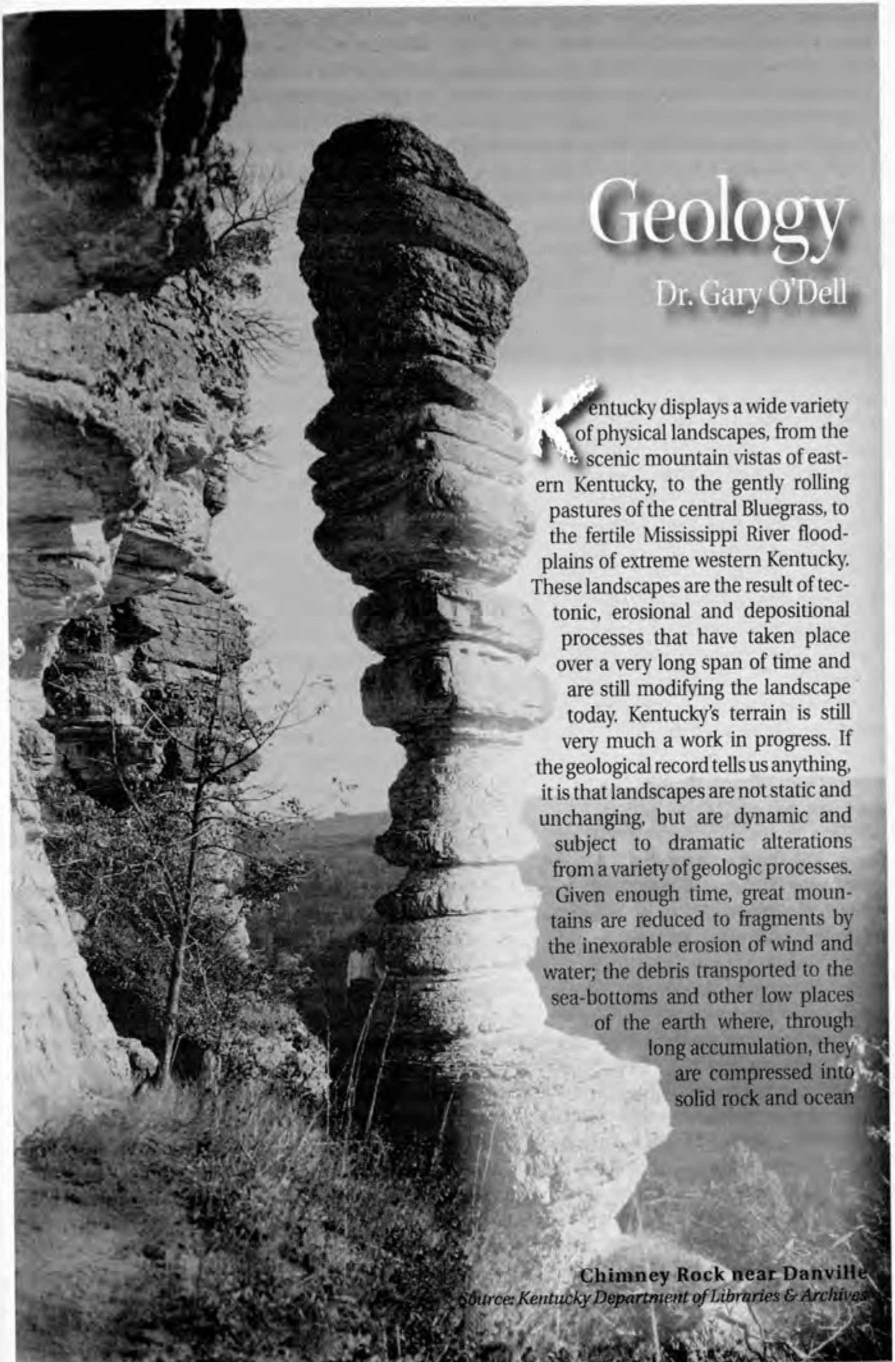

Geology

Dr. Gary O'Dell

Kentucky displays a wide variety of physical landscapes, from the scenic mountain vistas of eastern Kentucky, to the gently rolling pastures of the central Bluegrass, to the fertile Mississippi River floodplains of extreme western Kentucky. These landscapes are the result of tectonic, erosional and depositional processes that have taken place over a very long span of time and are still modifying the landscape today. Kentucky's terrain is still very much a work in progress. If the geological record tells us anything, it is that landscapes are not static and unchanging, but are dynamic and subject to dramatic alterations from a variety of geologic processes. Given enough time, great mountains are reduced to fragments by the inexorable erosion of wind and water; the debris transported to the sea-bottoms and other low places of the earth where, through long accumulation, they are compressed into solid rock and ocean

Chimney Rock near Danville
Source: Kentucky Department of Libraries & Archives

floors are uplifted by the ponderous but irresistible movements of colliding crustal plates. Thus it has continued throughout the history of our planet, a continuous cycle of conflict between the processes that build land and those that wear it away. Mountains become dust and the dust becomes the stuff of new mountains.

The shaping of Kentucky's landscape is a story written in the rocks for those who can interpret the geological text. Each layer is a page in the ancient history of the land. The rocks of the surface speak of more recent events; beneath these are tales more deeply buried in place and in time, miles beneath the surface and representing a span of years greater than our comprehension. To understand the forces and processes that produced modern-day Kentucky we must peel away the layers of time and bedrock to recreate landscapes of hundreds of millions of years ago, when the world was a very different place. Kentucky's geologic history is part of a drama played out on a grand scale, a story of continents slowly colliding to form giant supercontinents and of those same giant land masses rupturing and splitting apart, even as great oceans were created and destroyed.

Red River Gorge
Source: Sid Webb

Centered around Hudson Bay in Canada is a region of ancient granitic igneous rock, the nucleus or craton, of the original continent of North America known as the Canadian Shield. Some of the rocks of the Shield have been dated to more than four billion years in age. The North American continent grew around the Canadian Shield by the gradual process of accretion as other, and usually smaller, land masses were carried into contact with the craton by the movement of crustal plates and often became permanent additions to the continent. Around the margin of the core area, more extensive to the south and west, is the relatively stable region known as the platform, which, while submerged, accumulated massive sediment deposits eroded from the craton. Kentucky is positioned on the platform of the southeastern margin of the Canadian Shield.

From approximately 1.3 to 1.0 billion years ago, during Precambrian time, this core region was located along the equator and the eastern edge was in the process of colliding with a continental block. The collision, which took place over several hundred million years, led to the formation of a supercontinent called Rodinia (homeland) by geologists and a massive mountain-building event known as the Grenville Orogeny. The western edge of the collision zone, the Grenville Front, traverses central Kentucky, but is today buried beneath thousands of feet of sedimentary rock. Rodinia remained stable for a long period of time, and the Himalaya-scale mountain ranges generated during the orogeny were leveled by erosion near sea level. About 700 million years ago, Rodinia began to split ("rift") apart in the vicinity of the previous suture zone, and a new ocean, the Iapetus, separated the parts of the former supercontinent.

At the beginning of the Paleozoic Era, more than a half billion years before the present, the crustal plates containing the continents of North America, Europe, and Africa were again on a collision course. The Iapetus Ocean, the predecessor of the modern Atlantic, was shrinking as the floor of the ocean plunged beneath the eastern coastal margin of North America in a process known as subduction. Along the subduction boundary, as the subducting plate melted and magma rose to the surface, lines of volcanic islands were produced.

As the continental masses converged, these island arcs and wedges of crustal material were compressed between them in several major episodes of mountain-building. During the later Paleozoic, beginning in the Pennsylvanian Period about 310 million years ago, a full contact collision began to occur that lasted for nearly 60 million years and created the supercontinent of Pangea. This supercontinent persisted for about 100 million years and then began to split apart during the Triassic Period of the Mesozoic Era. The rift that developed to separate the continents was the origin of the present-day Atlantic Ocean, which is still widening today as the crustal plates move farther apart.

Each of the major mountain-building episodes of the Paleozoic produced major deformations and disruptions of the crust. These earlier mountain ranges, uplifted by plate collisions, and ancestral to the modern Appalachian Mountains, no longer exist, having been long-since leveled by erosion. The by-products of their disintegration were deposited as broad sheets of sediment in adjacent ocean areas.

During most of the Paleozoic Era, which spanned nearly 300 million years, the region that is now Kentucky was covered by a shallow sea and only intermittently exposed. Much of the bedrock that is today at or near the land surface was deposited as sediments in this marine environment and was compressed and transformed to solid rock by the accumulating weight of overlying material. Because of their origin as marine deposits, the sedimentary bedrocks of Kentucky occur in layers that are more-or-less horizontal, except where they have been disturbed. Features associated with Precambrian tectonic events, such as the Grenville Front, lie deeply buried beneath thousands of feet of sedimentary rocks. Reactivation of several of these lines of structural weakness in later eras resulted in fracturing of the sedimentary cover to produce fault zones, some of which are active today.

Rocks such as sandstone and shale originated as particulate (clastic) sediments received from eroding highland areas eastward. The extensive limestone strata of Kentucky were also deposited during the Paleozoic, not as transported sediments, but as a calcium-rich ooze consisting largely of the remains of organisms who extracted calcium from seawater to make their hard body parts. The type of sedimentary rock being deposited at any given time largely depended upon the nature of the rock being eroded from adjacent highlands, prevailing environmental conditions and the configuration of land and sea. Deposition of clastic sediments dominated some eras and carbonates (limestone, dolomite) during others.

This has produced a stratigraphic sequence for Kentucky in which the lowermost Precambrian and early Paleozoic sedimentary rocks are of clastic origin, then a period of carbonate deposition followed by more sandstones and shales, then a thick sequence of carbonates in the middle to late Paleozoic, and, closing the era, a thick layer of sandstones and other clastics. Embedded within the late Paleozoic rocks are seams of bituminous coal, derived from massive accumulations of organic matter in vast lowland swamps that represented the explosion of plant and animal life on land at this time.

Natural Bridge State Park
Source: Sid Webb

The proto-Appalachian ranges that were uplifted by continental collisions during the Paleozoic were reduced to a flat, eroded plain in North America by the end of the Mesozoic. Regional uplift during the Cenozoic Era brought the Paleozoic marine sedimentary rocks of the interior to the surface, exposing them to weathering and erosion. The uplift rejuvenated regional streams and rivers, which began to cut deeply into the plateau surface formed by sedimentary rock. Differential rates of weathering, according to the nature of the bedrock, developed a new mountainous topography influenced by ancient mountain roots, preserving the geologic structures of rocks folded and overthrust during previous orogenies. These are our present-day Appalachian Mountains of North America.

Although we might like to think of our Appalachian Mountains as uniquely American, in the geologic sense they are quite international. With the breakup of the Pangean supercontinent, the ancestral Appalachians were divided among three continents, so that the largest remnant is today in North America, another section comprises the Atlas Mountains of Africa, and a third piece forms the Pyrenees that separate France and Spain.

In eastern Kentucky, the Appalachian Mountains tend to be more erosional than tectonic in origin, because the platform area was the marine dumping ground for Paleozoic sediments which accumulated in horizontal layers. Unlike the overthrust and folded mountains farther east, the Kentucky mountains are erosional remnants left by the carving of deep valleys into these horizontal rock strata rather than the product of an orogeny.

During the post-Grenville episodes of slow-motion tectonic violence, Kentucky's location on the cratonic platform was far enough to the west of the collision zone that the sedimentary rocks of the region were generally spared major distortions and faulting, except in the extreme southeast corner. Instead, the tectonic events that built mountains in the east produced a series of gradually diminishing accordian pleats or waves in the bedrock of the continent westward away from the collision zone.

In Kentucky, this flexing of the bedrock produced a slight structural upwarp, known as the Cincinnati Arch, flanked by downwarps to the east and west, known as the Appalachian Basin and the Illinois Basin, respectively. The axis of the Arch runs diagonally through the state from Ohio through Tennessee, and is one of the defining features of Kentucky's overall geology. The concept involved may be somewhat confusing to the non-geologist. The upward flex of the Arch is primarily expressed in the bedrock rather than the topography. Millions of years of erosion concurrent with and subsequent to the uplifts have leveled the surface, cutting across the rock layers and planing away the convexity. The structure of the Arch is revealed at the surface only by a very subtle upward bulge in the center as a consequence of exposed strata that have been more resistant to erosion than layers higher in the sequence.

Pine Mountain Thrust Fault in the Pound Gap road cut near Jenkins, Letcher County
Source: Steve Greb, KY Geological Survey

The Arch has two major domes: one centered nearly under Lexington called the Jessamine Dome, and another near Nashville. Because of the upward bulge of the rock structure and subsequent erosion, the oldest rocks in the state are exposed in the center of the Jessamine Dome (in the gorge of the Kentucky River) and become progressively younger as one travels outward in any direction. The surface geology of Kentucky resembles a vast bull's eye target comprised of concentric rings of bedrock of similar age. Driving across Kentucky is like traveling through time, with tens of millions of years of bedrock time passing for every hour on the road.

The oldest rocks at the center of the planed-down dome are limestones, formed in shallow tropical seas that dominated the region 500 million years ago during the Ordovician Period. Surrounding this Ordovician core are younger rock belts of Silurian and Devonian age. During this geologic time period, less carbonate and a greater amount of silt and mud was deposited from eroding mountains to the east, so that shales and siltstones are dominant. Moving still further out from the central region, the traveler again enters a zone representing carbonate deposition; limestones deposited during the Mississippian Period, and, at last, Pennsylvanian sandstones with their seams of coal.

The basins to either side of the Arch served as reservoirs for sediment accumulation, and the tremendous weight of these sediments augmented the tectonic downwarp to depress these areas still farther into the crust. The Ordovician strata that are exposed at the center of the Cincinnati Arch lie buried beneath more than 3,000 feet of sedimentary rock in the Appalachian Basin to the east and more than 4,000 feet of rock in the Illinois Basin to the west. Both sides of the Illinois Basin are present in Kentucky, so that the pattern of bedrock at the surface forms a series of roughly concentric circles similar to the pattern exhibited by the Jessamine Dome. On the Dome, however, the rocks become older toward the center, whereas on the Basin the youngest rocks are toward the center. Only the western side of the Appalachian Basin is present in Kentucky, so that rock strata in the state continue dipping downward toward the east. During the later Paleozoic Era, the eastern coastline of the Appalachian Basin was dominated by numerous river deltas and wetlands, formed of riverborne sediments eroded from the ancestral Appalachians in the east. These were the coal swamps of the Pennsylvanian and Permian periods, in which organic matter accumulated and was eventually transformed to bituminous coal.

Because of the Cenozoic uplift, the region was no longer underwater and accumulation of marine sediments ceased across most of the area that is now Kentucky. Deposition was replaced by erosion, and much of the uppermost Paleozoic bedrock was worn away to form the present day surface landscape. In far western Kentucky, however, beginning in the late Mesozoic, gradual subsidence along an ancient rift zone combined with higher sea levels than at present allowed the ocean to invade the land mass along a broad corridor. Known as the Mississippi Embayment, this longitudinal dent in the southern margin of the continent stretches from southern Louisiana to Illinois. Since the Cretaceous Period, thousands of feet of marine sediments eroded from the adjacent land areas accumulated in this depositional trough. As sea levels subsequently dropped and the ocean retreated from the embayment, particularly during the last 2 million years as a consequence of Quaternary glaciation, the Mississippi River became established in this location.

The multiple episodes of recent Ice Age continental glaciation of the Quaternary Period had other significant effects in Kentucky, although the landscape was directly impacted by ice sheets only in northern Kentucky. The direct effects of glaciation exist as a thin strip of till, outwash, and lacustrine (glacial lake) deposits along the Ohio River from Kenton County to Oldham County. These deposits reach a thickness of several hundred feet. Glacial outwash deposits mixed with alluvium are found further westward along the river to the embayment area, which served as an outlet for a tremendous outpouring of meltwaters during periods of glacial retreat. Deposits of wind-blown silt and fine sand (loess) as much as 70 feet thick occur mixed with glacial deposits in some locations, and as a thin layer in much of western Kentucky. The presence of massive ice sheets covering the lands bordering Kentucky to the north blocked existing rivers and caused a reorganization of regional drainage. The major rivers of Kentucky, including the Kentucky, Licking and Green, were forced to find shorter pathways to the sea. The reduction in the overall length of these rivers increased the gradient, or steepness of the flow path, so that the streams began downcutting their channels. Consequently, rivers in Kentucky were entrenched, and the residual alluvium of former flood plains exists in numerous locations as high-level terrace deposits above the present-day river courses.

In summary, during virtually the entire 300 million year span of the Paleozoic, the region that includes present-day Kentucky was under water – a depositional environment. Sediments eroded from land areas to the east, north, and west accumulated in this low area and were compacted and cemented to form thick layers of sedimentary rock. These initially flat-lying rock strata were several times disturbed by tectonic events to the east, producing an alternating series of upwarps and downwarps that are today visible in the rock structure. The region was uplifted during the Cenozoic and has remained dry land to the present day, so that no further accumulation of marine sediments occurred except in the area of the Mississippi Embayment to the extreme west. As a result, Kentucky was transformed from a region of deposition to an erosional environment, and about 2,000 feet of accumulated sedimentary rock were subsequently worn away to produce the modern landscape.

Fault Lines & Earthquakes

Dr. Gary O'Dell

An earthquake is generated as the result of a sudden movement along a fault. Stress builds up along a fracture in the earth's crust until slippage occurs, releasing energy in the form of seismic waves. These waves radiate outward through the earth from the point of origin, or focus; the location on the surface directly above the focus is known as the epicenter. Generally, the longer movement along the fault is hindered, allowing stress to build, the greater will be the displacement along the fault and the associated severity of the quake. There are hundreds of earthquakes around the globe every day, most of which are so slight that the vibrations cannot be detected except by sensitive instruments.

Most earthquakes take place near the boundaries of tectonic plates, but approximately one in ten is an intraplate quake, located far from an active plate margin. The New Madrid Seismic Zone (NMSZ), is such a region, and is situated above a failed rift zone. This zone trends approximately SW-NE from northeast Arkansas, through southeast Missouri, western Tennessee, and western Kentucky to southern Illinois, but is deeply buried beneath thousands of feet of Mississippi River alluvial deposits. About 750 million years ago, when the supercontinent Rodinia began to break apart, the rupture that began in the location now occupied by the NMSZ ceased before a split could take place. The rifting process produced a zone of weakness here that has persisted to the present day and is known as the Reelfoot Rift, located in the most northerly part of the Mississippi Embayment. Most of the fault systems in Kentucky appear to be related to failed rift zones that developed in the late Precambrian, associated with the breakup of the Rodinia supercontinent.

During the Mesozoic breakup of Pangaea, stretching of the crust reactivated the long-dormant faults of the Reelfoot Rift, which were subsequently covered by many thousands of feet of sediments as a consequence of the downwarping of the Mississippi Embayment later in the Mesozoic. Some geologists have lately come to believe that the most recent episodes of continental glaciation – the "Ice Ages" – have also played a role in stimulating seismic activity along the NMSZ. The tremendous weight of the ice sheets, thousands of feet in thickness, that periodically covered much of the North American continent during the last two million years actually depressed the earth's crust. After the glaciers melted, most recently about 10,000 years ago, the crust slowly rebounded upward toward its original position and is still recovering today.

There are several other fault systems located within Kentucky or nearby that appear to be related to the New Madrid Seismic Zone, although these are far less active. Although the NMSZ lies buried in the Mississippi River floodplain and is detected through seismic activity, other faults can often be traced along surface exposures. The fault complex known as the Fluorspar District emerges from the covering sediments of the Mississippi Embayment in western Kentucky. These faults are aligned with the NMSZ but have exhibited very little recent seismicity. The District was once of economic significance to Kentucky as a source of certain vein minerals of hydrothermal origin, including fluorite and galena, which were deposited along the fault pathways

East of the Fluorspar District is the Rough Creek Graben, which appears to be an extension of the Reelfoot Rift. The graben is a section of the crust that has been displaced gradually downward between two east-west trending faults, the Rough Creek Fault System to the north and the Pennyrile

> **y'know what...?**
>
> ACTIVE FAULT ZONES POTENTIALLY AFFECTING KENTUCKY:
>
> - New Madrid Fault System
> - Wabash Valley Fault System
> - Eastern Tennessee Fault System
> - Unmapped fault system responsible for 1980 Sharpsburg quake

Fault System southward. The Rough Creek system traverses the central part of the Western Kentucky Coal Field, and the Pennyrile system is located near the southern edge of the Coal Field. These fault systems are relatively inactive, although the monitoring system established in the vicinity of the NMSZ has recorded a number of minor earthquakes here, too small to be detected by human senses.

The Wabash Valley Fault System, located in southeastern Illinois and southwestern Indiana, has experienced at least five earthquakes from magnitude 5.0 to 5.8 during the last 100 years, and geologic evidence indicates an event of at least magnitude 7.0 took place here within the last 5,000 years. Although the seismic zone associated with this fault system lies mainly outside Kentucky, earthquakes generated here have been felt in Kentucky and have sometimes caused minor damage. The Wabash system of faults overlies what appears to be a failed rift zone that is probably associated with the same tectonic stresses that produced the Reelfoot Rift, although faulting is not directly continuous across the Rough Creek Graben from the NMSZ to the Wabash Valley Fault System.

Midway between the New Madrid and the Eastern Tennessee fault systems is the Lexington Fault System. This system, inactive today, is a zone of ancient faulting that traverses the Bluegrass region of central Kentucky from southwest to northeast, passing through eastern Lexington, and is aligned with the much older Grenville Front zone of structural weakness. Tectonic events during the Paleozoic that developed the Cincinnati Arch upwarp produced faulting associated with the line of the Grenville Front. The Lexington Fault system parallels the Arch along the eastern flank.

Several fault zones which are roughly parallel with the Eastern Tennessee Fault System extend eastward from the Lexington Fault System. The major structural feature associated with these faults is the Rome Trough, bounded to the north by the Kentucky River Fault System and to the south by the Rockcastle River- Warfield Fault System, with the Irvine-Paint Creek Fault System running parallel between these. The Irvine-Paint Creek faulting can be traced at the surface through much of central and eastern Kentucky, but much of the Kentucky River Fault System and all of the Rockcastle River-Warfield fault zone lies buried. The Rome Trough may be associated with a Precambrian failed rift, although most of the subsidence

STRONGEST EARTHQUAKES IN THE CONTIGUOUS UNITED STATES (EXCLUDES ALASKA)

Location	Date	Time UTC	Magnitude
1. New Madrid, Missouri	1811 Dec 16	08:15	8.1
2. New Madrid, Missouri	1812 Feb 07	09:45	~8
3. Fort Tejon, California	1857 Jan 09	16:24	7.9
4. New Madrid, Missouri	1812 Jan 23	15:00	7.8
5. Imperial Valley, California	1892 Feb 24	07:20	7.8
6. San Francisco, California	1906 Apr 18	13:12	7.8
7. Owens Valley, California	1872 Mar 26	10:30	7.6
8. N Cascades, Washington	1872 Dec 15	05:40	7.3
9. California - Oregon Coast	1873 Nov 23	05:00	7.3
10. Charleston, South Carolina	1886 Sep 01	02:51	7.3
11. West of Eureka, California	1922 Jan 31	13:17	7.3
12. Kern County, California	1952 Jul 21	11:52	7.3
13. Hebgen Lake, Montana	1959 Aug 18	06:37	7.3
14. Landers, California	1992 Jun 28	11:57	7.3

Source: US Geological Survey

occurred during the Cambrian Period. There also appears to be something of an association with the Rough Creek Graben. The Rough Creek Graben and the Rome Trough (a graben-like structure) are approximately aligned west-to-east. The Rome Trough extends eastward through West Virginia into Pennsylvania, but has not been traced west of the Lexington Fault System. Displacement within the Rough Creek Graben is downward to the north, opposite from the Rome Trough which exhibits downward to the south displacement. The fault systems associated with the Rome Trough have been reactivated numerous times since the Cambrian, although none have been active during historic times.

The most dramatic fault zone in Kentucky is the Pine Mountain Thrust Fault in the southeastern part of the state, and differs considerably from the types of faults noted previously. Displacement along a thrust fault (also called an overthrust fault) is primarily horizontal, rather than vertical, as is the case for faults such as those associated with the Rough Creek Graben or Rome Trough, where one side of a fault block drops down relative to the other. Thrust faults are the result of compressional forces so extreme as to cause one section of the rock strata, thousands of feet in thickness, to be pushed up and over another. The Pine Mountain fault originated about 275 million years ago during the late Paleozoic as one of a series of overlapping fault blocks generated by the collision of land masses that formed the Pangaea supercontinent. The total horizontal displacement along the fault, which extends through Virginia into Tennessee, ranges from 4 to 11 miles, and created a ridge more than 100 miles long known as Pine Mountain. A number of small earthquakes have occurred along this fault during historic times, including a January 19, 1976, event that registered magnitude 4.0 and was felt in five states.

A previously unknown and therefore unmapped fault system was responsible for the strongest earthquake ever to originate within Kentucky during historic times, which occurred on July 27, 1980. The 5.2 magnitude quake, centered near Sharpsburg in Bath County, was felt in 15 states and in Ontario, Canada. Property damage amounted to more than $3 million. The most severely affected community was Maysville, located on the Ohio River about 30 miles north of the epicenter, where 37 commercial structures and 269 homes were damaged. This quake may possibly have been associated with the Kentucky River Fault System, which is not too very far from the apparent epicenter.

Breaks Interstate Park
Source: Sid Webb

There is an additional category of rather exotic small-scale, very localized fracture systems which do not represent an earthquake hazard. In years past, before their origin and nature was well understood, these were referred to as "cryptovolcanic" or "cryptoexplosive" structures. These terms are still found on topographic maps and in older geological publications, but they may be more properly referred to as "astroblemes." Recent theorization holds that these are not of tectonic origin but from the impact of extraterrestrial objects such as large meteors or cometary fragments. Traveling at speeds measured in miles per second, such bodies shatter the rock strata upon impact in a roughly circular pattern and may bring up rocks from deep underground that rebound into a central uplift structure within the crater. At such sites, rocks are often found that have been metamorphosed, transformed and partially melted by the tremendous heat and pressure of an impact.

Three such possible astrobleme structures are known in Kentucky: Jeptha Knob in Shelby County, a site in Woodford County near Versailles, and the Middlesboro Impact Structure in southeastern Kentucky near the Virginia border, within which the city of Middlesboro is situated. The Middlesboro structure, the largest, is about 4 miles in diameter and was produced by a body estimated to be about 1,600 feet in diameter. As all of these impacts occurred long ago, time and weather have eroded the former craters so that only the core of the central uplift area remains. The Jeptha Knob is the most easily viewed of these structures, a low hill clearly visible from Interstate 64 between Frankfort and Shelbyville, to the north of the highway.