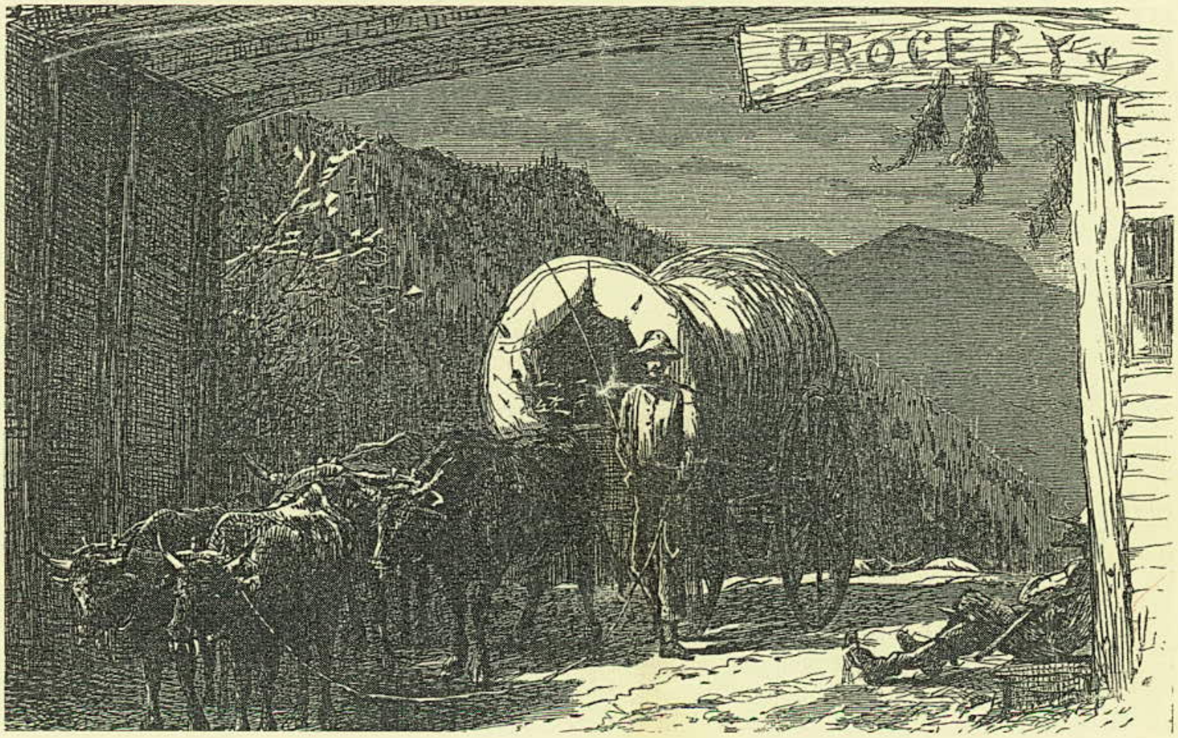
Geologic Impacts on the History and Development of Middlesboro, Kentucky



Kentucky Society of Professional Geologists
Annual Field Conference
September 18–20, 2003

Designation of Middlesboro as Distinguished Geologic Site 3

KENTUCKY KSPG SOCIETY OF PROFESSIONAL GEOLOGISTS

Published by the Kentucky Society of Professional Geologists
2003

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Kentucky Society of Professional Geologists
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Nomination and Designation

The Middlesboro Basin and Cumberland Gap area is a compelling example of the key role geology plays in the development of society. Tom Shattuck (Bell County Historical Society) originally nominated the area for Distinguished Geologic Site status because of the unique origin of the Middlesboro Basin and the historical and economic significance of Cumberland Gap. Recent research by Keith Milam has confirmed the presence of numerous impact features associated with the Middlesboro Basin, which alone would make this site worthy of being a Distinguished Geologic Site. The proximity to Cumberland Gap and the critical transportation and settlement history associated with this dramatic geologic feature only add to the educational and scientific value of the area. Thousands of Kentucky's early settlers crossed the gap on foot and on horseback to start new lives in the young Commonwealth. Coal mining and late 19th-century iron production contribute to the overall importance of the area in demonstrating the profound importance geology can have upon the history, culture, economy, transportation, and land use of our Commonwealth. Strong community interest and support ensures continued support for educating the public about the significance of this area.

The Kentucky Society of Professional Geologists, under the leadership of Greg Cornett (president, 2003) and David Jackson (president, 2002) has accepted the nomination of Middlesboro and Cumberland Gap as Distinguished Geologic Site 3.

William M. Andrews Jr.
Distinguished Geologic Sites Committee Chairman

Endorsement

Kentucky has a rich heritage that includes world-class geologic features. Certain of these features have attracted scientific attention from around the globe. Some of the geologic features are used as examples in science text books and some as "best in class" examples for geology for the world.

Many Kentuckians who pass these features, some on a daily basis, do not know how valued they are in the world of science and geology. Therefore, the designation of Distinguished Geologic Sites helps education and conservation efforts in the state, brings pride to local citizens, and adds new destinations for tourists coming to Kentucky.

The Middlesboro–Cumberland Gap area Distinguished Geologic Site is a world-class example of the interactions of geology and human history. As the 12th State Geologist of Kentucky, I encourage and support this designation.

James C. Cobb
State Geologist and Director, Kentucky Geological Survey

Welcome

Kenneth W. Kuehn and Keith A. Milam, Field Trip Leaders

Welcome to the Kentucky Society of Professional Geologists' 2003 Annual Field Conference. This year we honor Middlesboro, Ky., as the third in our ongoing series of Distinguished Geologic Sites. Our conference will be multifaceted, emphasizing the role of geology in the growth and development of the region. From its early settlement through the Cumberland Gap, to Alexander Arthur's 19th-century dream of creating an industrial giant based on coal and iron resources, to its present-day transportation- and tourism-based economy, the history of Middlesboro has been shaped by geology. We will discuss the regional geologic setting and examine in detail the evidence that leads geologists to conclude the town grew up in an ancient meteorite impact structure. We will walk the old pioneer trail and pass beneath it through the engineering marvel known as the Cumberland Gap Tunnel. Our final stop will be the airport to visit the *Glacier Girl,* a World War II fighter plane recovered from within the Greenland ice cap in 1992. Now completely restored, this remarkable plane took its first flight in 60 years in October 2002. It is a fitting metaphor for Middlesboro itself, for it too is ready to soar again and meet the demands of the new economy in the 21st century.

Acknowledgments

The guidebook authors wish to acknowledge the outstanding work of Margaret Luther Smath, who compiled this field guide and served as editor. The KSPG Executive Committee provided advice, guidance, and assistance throughout the planning process. William M. "Drew" Andrews served as chair of the KSPG Distinguished Geologic Site Committee and made arrangements for the formal presentation and sponsorships. The Kentucky Geological Survey contributed logistical support. Special thanks are due the Business and Professional Women's Club of Middlesboro (Martha Burke, president), the City of Middlesboro (Ben Hickman, mayor; Pat Welch, city council member), the Bell County Tourism Commission (Judy Barton, executive director), the Bell County Historical Society (Jerry Browning, president), and the Bell County Chamber of Commerce (Nioma Lawson, executive director). Thanks also to Bisceglia Auction Company, Middlesboro Country Club, Middlesboro Coca-Cola Bottling, Middlesboro Kiwanis Club, *Middlesboro Daily News,* and the Avenue Cafe. Thank you, all!

Cover Art: This sketch appeared as part of the article entitled "Cumberland Gap," by F.G. de Fontaine in *Appletons' Journal of Literature, Science and Art,* v. VII, no. 155, March 16, 1872.

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Historical Overview

Settlement History of the Cumberland Gap Region

Katie Algeo

From Trail to Turnpike

The Cumberland Gap has long been a place between, a point in passage from southeast to upper Midwest, from east to west, and back again. The alignment of the Cumberland Gap with the Narrows, a water gap through the Pine Mountains, creates a natural passageway through this part of the Appalachian Mountains. Migrating animals, including bison and elk, created a path that Native Americans incorporated into an extensive network of trails used for hunting, trading, migrating, and waging war. The trail through the Cumberland Gap became known as the Warrior's Path and connected Cherokee territory in the mountains of North Carolina and Tennessee with Shawnee lands in the Ohio Valley (Fig. 1). Neither group had permanent settlements in the vicinity of the gap, but both used the region for hunting and seasonal camps. A mound near Pineville, probably an outpost of the Mississippian mound building culture, provides evidence of earlier Native American occupation.

Initially, the Euro-Americans who passed through the gap were not much interested in the rugged uplands, but in what lay beyond them: the fertile lands of the Bluegrass, Nashville Basin, and beyond. By the mid-18th century, the rising tide of immigration and the need for new land to replace that depleted by extensive tobacco cultivation and poor agricultural practices created a land hunger that pushed the frontier westward. A few people, such as Kentucky's famed long hunters, crossed the Appalachians on their own, but early mass migration was facilitated by land companies. These companies, usually chartered by politically connected members of the Eastern social elite, received grants for vast tracts of western lands from colonial representatives of the British crown. They sent explorers west to identify promising locations for colonies, entered the claims, then organized parties of settlers. It was in just such a role that Thomas Walker of the Loyal Land Company of Virginia, which had been awarded 800,000 acres, traversed the Cumberland Gap with a small party of explorers in 1750.

Walker is often credited with being the first Euro-American through the gap (see Levey and Greenhall, 1983, p. 210), but his journal records evidence of prior passages. Upon reaching the gap, he noted "Laurel Trees marked with crosses, others blazed and several figures on them" (Rust, 1950, p. 16). As he crossed the Gap, he added his name to a beech (Walker *in* Rust, 1950, p. 17). Almost a century earlier, in 1673, an Indian trader by the name of Gabriel Arthur is known to have passed through the gap. Arthur had been living with the Cherokee for some time when a raiding party he was part of was captured by the Shawnee. Arthur was released a year later and set upon the Warrior's Path, which took him through the gap to Cherokee territory, from where he made his way back east (Burns, 2000, p. 16). What Walker did do was keep a meticulous record of his journey through the Cumberlands, noting landforms, the character of the land, and the quantity of game, details essential for selecting the location of a new colony and mapping a route for settlers.

Walker is also credited with naming a river he found beyond the gap after William Augustus, Duke of Cumberland, second son of King George II, and leader of victorious forces at the 1746 Battle of Culloden that defeated Bonnie Prince Charlie and secured England for the House of Hanover. Walker referred to the gap in his journal as Cave Gap, but the name of the river was eventually

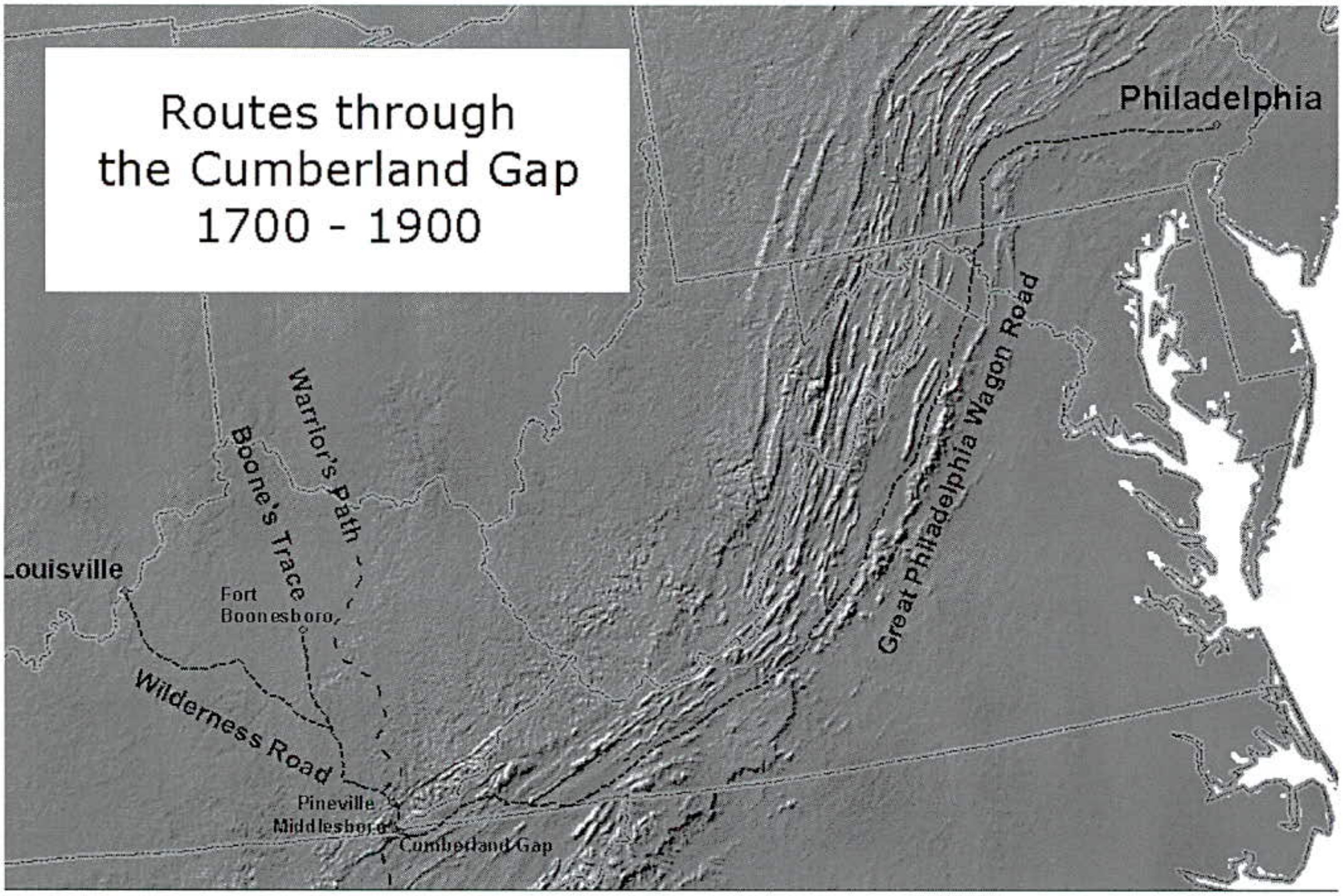

Figure 1. Routes through the Cumberland Gap, 1700–1900.

transferred to the gap. The cave at the gap has had several names, but is now known as Cudjo's Cave after a mid-19th century novel by James Townsend Towbridge that relates the story of an escaped slave named Cudjo who hid in the cave.

Daniel Boone was in the employ of another land company, the Transylvania Company, when he crossed the gap in 1775 with a party of 30 men to clear a trail that would open land claimed by the company to settlers. Boone and his men followed the Warrior's Path as far as Flat Lick, then blazed a trail through mixed upland forest to a spot south of the Kentucky River where they built Fort Boonesboro (Fig. 1). The company had recently negotiated a "land for beads" deal with several Cherokee chiefs—in exchange for a quantity of trade goods, the Cherokee would relinquish all claim to some 20 million acres of land between the Cumberland and Ohio Rivers. The terms of the 1763 Treaty of Paris that ended the French and Indian War prohibited both British settlement beyond the Appalachian Mountains and private treaties with Native Americans, however. Since the Cherokees did not enjoy exclusive access to the Transylvania purchase and did not have settlements there, in effect the company illegally bought land that could not legally be settled from people that did not have the right to sell it. As was the case with much U.S. settlement, legalities were manufactured after the fact.

Boone's Trace soon became part of the Wilderness Road, the main route for settlement, not just of the Transylvania colony, which lasted a mere 3 years, but for much of the western frontier of Kentucky and Tennessee. Migration across the Appalachians began in earnest in the late 18th century as pressure for land mounted. Those moving west included veterans of the French and Indian and Revolutionary Wars (who were given land grants rather than money for their military service), indentured servants who had either finished their term of service or who were fleeing bondage for the anonymity and promise of the frontier, and Eastern planters and sons of planters seeking new ground to replace that worn out by continuous tobacco cultivation and poor agricultural methods. Thousands annually climbed the steep narrow trail over the Cumberland Gap, which, prior to 1800, saw more settlers enter Kentucky than the rival immigration route, the Ohio River (Harrison and Klotter, 1997, p. 49). The Cumberland Gap was used not only by settlers coming from the southern colonies, but also by many departing New England along the Philadelphia Wagon Road, which led through western Maryland and the Great Valley of Virginia to connect with the Wilderness Road (Fig. 1).

The section of the Wilderness Road that crossed the gap remained primitive for several decades. Upon reaching the Cumberlands, many of those traveling by wagon found they had to abandon bulkier pieces of furniture that pack horses could not carry through the gap (Harrison and Klotter, 1997, p. 13). The Virginia Assembly (Kentucky was then part of Virginia) passed legislation in 1779 authorizing improvements to the Wilderness Road, development that Kentucky continued upon achieving statehood in 1792. Four years later, after the road was widened and fords improved, the Wilderness Road was finally passable by wagons. The State funded further improvements by turning the Wilderness Road into Kentucky's first toll road. The first toll gate was erected in 1797 at "the Narrows," the gap through Pine Mountain. In 1830 it was moved a short distance to the ford over the Cumberland River, where it remained until 1865. A community grew up around the toll gate and ford. Originally called Cumberland Ford, the town has been known as Pineville since the early 1800's.

Even as settlers streamed through the Cumberland Gap, the Wilderness Road became just as important for traffic in the opposite direction, although much of that was of the four-legged variety. Hogs and cattle were driven south from Kentucky through the Cumberland Gap as early as 1792 to markets in Virginia and North Carolina, and by the mid-19th century, drovers annually took 50,000 hogs alone over the gap (Hudson, 1994, p. 87). Such livestock was an important addition to the food supply of the plantation South, which concentrated on producing nonfood cash crops such as cotton and tobacco and was, therefore, far from self-sufficient in food stuffs. Kentucky was also an important source of horses and mules to serve as work stock on Southern farms in the days before agricultural mechanization.

The Pittsburgh of the Cumberlands

Middlesboro, Ky., experienced a dramatically different development trajectory from Pineville, although the two shared remarkably similar situations. Both places were located on the north side of a gap through a wall of mountains that was otherwise difficult to cross, and both sat astride the same major immigration route to the interior of the North American continent. Pineville grew steadily, first as a market town for the surrounding farm communities, and, after the creation of Bell County in 1867, as a county seat. Middlesboro didn't exist until 1885, and then was built, virtually overnight, as a planned industrial center. Prior to that time, a mere handful of families farmed the Yellow Creek Valley where Middlesboro would be platted, and settlement was dispersed. The nearby Hensley Settlement, now unoccupied but preserved by the National Park Service, portrays the largely self-sufficient lifestyle typical of much of the region before its bucolic tranquility was indelibly altered by the vision of Alexander Allen Arthur.

Arthur first visited the region as a timber scout for the Knoxville-based Scottish-Carolina Timber Company (DeRossett, 1988, p. 44). He brought with him industrial experience from years working in the Scottish steel and mining sectors, so when he found the area was rich in coal, iron ore, and timber, he realized it had all the ingredients for a major industrial center except one—transportation to export raw materials or manufactured product. He tried to interest the Richmond and Danville Railroad, for whom he sometimes acted as agent, in building a line to and through the Cumberland Gap (Caudill, 1984). When the railroad declined, he used his social connections among the scions of wealthy American industrialists to garner capital to develop the region himself. After further fund-raising in Britain, Ameri-

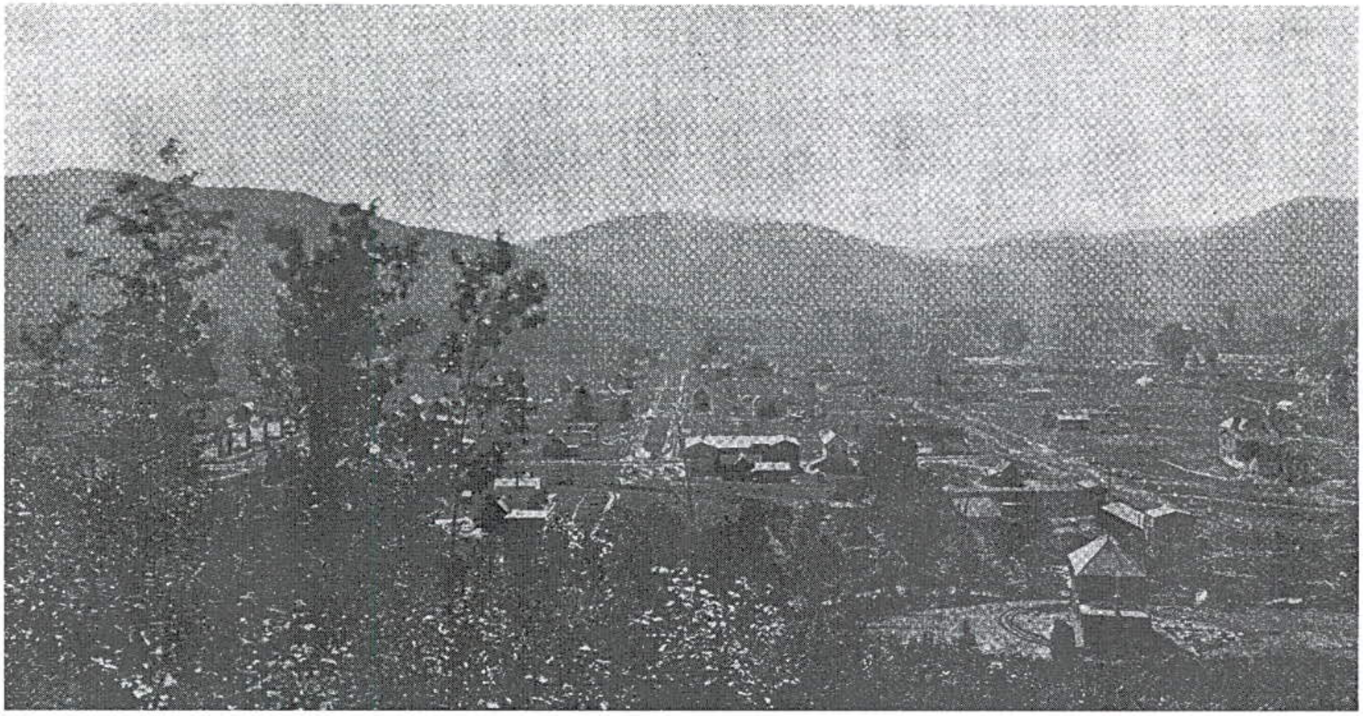

Figure 2. Middlesboro street grid circa 1890 (from *Louisville Courier-Journal,* 1890, p. 41).

can Associates Limited was incorporated. This investment company planned to create a steel manufacturing center and build enough infrastructure to attract other manufacturing ventures and generate profit through real estate sales.

Middlesboro became a boom town. It was platted on a grid and surveyed with wide streets bearing English names such as Exeter, Dorchester, and Gloucester (Fig. 2). Middlesboro itself was named for Middlesborough[1], England, in the center of the English iron district. The population of Arthur's town burgeoned from 50 in May 1889 to 6,200 in August 1889 and 10,000 by the end of that year (*Louisville Courier-Journal,* 1890, p. 58; Simon, 1939, p. 227). Workers were brought in en masse to create a labor force, craftsmen and specialists were imported as needed, and businessmen flocked to what seemed to be an economic wellspring. Although workers were initially accommodated in tents, houses were erected quickly, but with attention to quality. Tenant housing was of solid construction, and owner-occupied houses were elegant multistory stone and brick Victorians (Caudill, 1984). Middlesboro had the look, not of a contingent and temporary boom town, but of a solid and prosperous community.

Economic development was rapid. By 1890 the Watts Steel and Iron Company, with two blast furnaces, a steel mill, and a brick factory, was Middlesboro's largest industrial concern. Other manufactories included a tannery, a brewery, and an ice house, and numerous mining and timbering concerns were getting under way. Arthur's corporation had bought up mineral and timber rights to tens of thousands of acres on both sides of the gap and leased them to others to develop. The retail and service sectors of the new town flourished (Fig. 3), with 80 stores and businesses, 16 hotels, four banks, and a casino operating by 1890 (DeRossett, 1988, p. 8). Residential lots in the town changed ownership rapidly, and speculation drove up prices far beyond what was usual in American towns of the day (Caudill, 1984).

Those in charge of development paid attention to social and cultural institutions as well. By 1890 the town had a city hall and courthouse, newspaper, library, opera house, and hospital (DeRossett, 1988, p. 78). Middlesboro even had one of the first golf courses in the United States, a game

[1] Middlesboro, Kentucky, originally used the English spelling "Middlesborough," but later simplified the spelling.

Figure 3. Cumberland Avenue, Middlesboro, Ky., 1890 (from *Louisville Courier-Journal*, 1890, p. 18).

newly imported from Scotland. The British cultural veneer reflected the source of much of the money that allowed Middlesboro to be built, but more significantly, the stately touches represented "cultural capital," indicators of class, wealth, and power that were designed to attract people who had money to invest in the nascent town.

Development of Middlesboro spawned several other settlements. The town of Cumberland Gap, which consisted of a few log cabins in 1886, expanded greatly to house railroad workers when the Knoxville, Cumberland Gap, and Louisville Railroad built a tunnel through the Cumberland Mountains in 1889 (Manning, 1993, p. 34). Arthur planned and laid out Harrogate, Tenn., as "an extension of a small English town with English manor houses, English servants and mansions set among the rolling lands and quiet countryside" (DeRossett, 1988, p. 78). The captains of industry for whom it was intended could no doubt better enjoy the mountain air and scenery on the south side of the Cumberland Mountains, away from the logging, mining, and manufacturing activity that generated their wealth. The Four Seasons Hotel, a lavish resort built overlooking the town, opened in 1892. With mineral baths, a golf course, and a ballroom, it was part sanitarium and part country club. Its grounds are now the site of Lincoln Memorial University. The small town of Arthur, Tenn., a few miles southwest, is named for Alexander Arthur.

Middlesboro's boom turned to bust following three financial disasters in the early 1890's, two of which roiled the British and American banking industries. In 1890, Baring Brothers, the London bank that was both a heavy investor in Arthur's project and the conduit for much other British investment in Middlesboro, went bankrupt, causing a chain of bankruptcies among Arthur's other investors. British investment in Middlesboro halted. A fire in the spring of 1890 destroyed much of the downtown business district, leaving many businesses and the town itself bankrupt. Arthur's American Associates extended loans to help many of the businesses rebuild, but in doing so, committed capital sorely needed to finish development projects. Then, in 1893, a financial panic closed many American banks, and credit from American sources dried up. American Associates had many projects under way, but few were yet generating much revenue, and the company was heavily in debt. The railroad tunnel to Middlesboro was finished, but the rail line was not yet completed, slowing coal and timber operations. Even more problematic, the high-quality iron ore that Arthur had assayed on his initial visit turned out to be limited in quantity, and the bulk of the ore failed to meet commercial standards. Almost as quickly as the town arose, a downward economic spiral resulted in layoffs, store closings, failure of all four town banks, abandonment of buildings, and a 50 percent population loss (Simon, 1939, p. 277).

Coal mining eventually restored a measure of prosperity to Middlesboro, and, during the 20th century, the town's fortunes generally followed the coal market. Increased demand for coal during World War I, for instance, brought profits to mine owners, and the labor shortage allowed mine workers to command higher wages. Middlesboro area miners, however, took part in the labor unrest and fights for unionization that were common throughout the eastern Kentucky coal fields.

Road Building and Road Removal

The desire for improved transportation sparked dreams of engineering marvels at the Cumberland Gap as early as 1836, when Robert Baker, Kentucky's chief engineer, suggested diverting the Cumberland River through a canal and tunnel dug through the mountain (Manning, 1993, p. 39). James Lane Allen, Kentucky writer and noted commentator on Appalachia, lampooned the condition of the road over the gap in his essay "Mountain Passes of the Cumberland," published in *Harper's New Monthly Magazine* in September 1890 (p. 565):

> They are said to have been notorious for profanity, those who came into Kentucky from this side [through the Gap]. Naturally. Many were infidels—there are roads that make a man lose faith.... Perhaps one of the provocations to homicide among the mountain people should be reckoned this road.

The USDA's Office of Public Roads chose the Cumberland Gap for one of its "object lesson roads," projects scattered around the country that demonstrated improved road-building techniques in the hope that states and municipalities, upon experiencing the benefits of hard-surfaced roads, would adopt the recommended construction practices. In 1908, 2½ mi of macadamized road using crushed and compacted limestone was constructed over the gap, creating an all-weather road that made Middlesboro more accessible to commercial traffic. The following year the road was designated part of the Dixie Highway, an early transnational road that connected Michigan and Florida and facilitated the growth of automobile tourism. In the 1920's, with the inauguration of the national highway system, the Wilderness Road became U.S. 25E (north of the gap) and U.S. 58 (south of the gap).

Within three decades, the National Park Service had formulated a plan to remove the asphalt road and replace it with a dirt track. The removal of the highway over the gap and the restoration of the Wilderness Road to its condition circa 1800 was part of the charter of the Cumberland Gap National Historical Park, created in 1955 (National Park Service, 2003). The goal was not regression, but historic preservation and finding a way to use landscape to help visitors see and understand, in a visceral and memorable way, an important movement in American history, the settlement of the West through the Cumberland Gap.

U.S. 25E was to be rerouted through a new tunnel. Funds did not become available until the 1970's, however, and construction did not begin until the 1990's. Completed in 1996, the twin-bore tunnel separates north- and southbound traffic and lowers the grade of the highway, improving safety for travelers over what had been dubbed "Massacre Mountain" (U.S. Department of Transportation, 2003). Bulldozers scraped away the asphalt of the former U.S. 25E, and planners studied old maps, photographs, and the landscape itself to determine the original route of the Wilderness Road and restore it as nearly as possible. In this small way, at least, history repeats itself.

Civil War History of the Cumberland Gap

William M. Andrews Jr.

Cumberland Gap has served as a key transportation route through Cumberland Mountain for over 250 years. During the American Civil War (1861–1865), the gap served as a strategic goal for both armies, offering the Confederate armies access to Kentucky's rich Bluegrass area and providing Union armies with access to East Tennessee and southwestern Virginia.

The gap was the eastern anchor of the original Confederate defensive line established across southern Kentucky in the late summer of 1861 (Fig. 4). A series of Union victories at Middle Creek, Mill Springs, and Fort Donelson had unhinged most of the line in early 1862, but Union forces were not able to capture Cumberland Gap until the summer of 1862. Union General George Morgan moved a relatively small force from Pineville over treacherous mountain paths to outflank the rebels and capture the gap from the Tennessee side. When crossing the mountains, the Federals had to haul their artillery over the mountains by hand, with 400 men or more dragging each gun over the rocky slopes. The Federals under Morgan held the gap until the late summer of 1862, when Kirby-Smith's invasion of central Kentucky (culminating in the battles at Richmond and Perryville, Ky.) cut off their supply lines and forced them to retreat through eastern Kentucky to safety along the Ohio River. The Confederate armies occupied the gap following the Battle of Perryville until Federal forces again recaptured the position in September 1863. Federal forces held Cumberland Gap until the end of the war, using it as an avenue of supply and attack to support operations and raids in East Tennessee and southwest Virginia.

Earthworks built by both armies are still visible within Cumberland Gap National Historic Park. Fortifications and gun emplacements constructed by the Confederates face dominantly northward toward Middlesboro, whereas the Union positions primarily face southeast into Tennessee and Virginia.

Figure 4. Civil War–era photograph of Cumberland Gap, looking from the present-day location of the Ramada Inn toward Kentucky.

Role of Geology in Economic Development at Middlesboro

Geologic Overview of Middlesboro and Cumberland Gap

Kenneth W. Kuehn, Keith A. Milam, and William M. Andrews Jr.

The city of Middlesboro is located in southeastern Kentucky, west of the Cumberland Gap, near the junction of the Kentucky, Tennessee, and Virginia state lines. It lies in a circular, alluviated, geomorphic basin approximately 3 mi in diameter that represents the largest expanse of level land in Bell county. Figure 5 is a shaded relief map of the area indicating the Middlesboro Basin (MB) as well as the positions of Cumberland Mountain (CM) to the southeast and Pine Mountain (PM) to the northwest. Geologically, the Middlesboro Basin is interpreted as an "astrobleme," or ancient impact structure (Englund and Roen, 1962). Englund (1964) and Englund and others (1964) first mapped this structure, depicting a series of concentric, arcuate faults and juxtaposed, intensely deformed strata within the basin. The Middlesboro Basin is superimposed on the renowned Pine Mountain Thrust Sheet, one of the classic structures of the Appalachian Mountains, shown diagrammatically in Figure 6.

Strata exposed in the Middlesboro area range from the Late Devonian Chattanooga Shale through the Mississippian Grainger, Newman, and Pennington Formations to the Pennsylvanian Lee and Breathitt Formations. The Devonian-Mississippian section is exposed along the leading (northwest) edge of the thrust sheet at Pine Mountain and partially along Cumberland Mountain to the east. The sequence consists of lower clastics, shallow-water ramp carbonates, and finally the tidal clastics and paleosols that impart distinctive red and green hues to the Pennington Formation. The nature of the Mississippian-Pennsylvanian systemic boundary is controversial; discussion centers on the conformity or disconformity of the Pennington/Lee contact across the region.

The units of primary concern for this field trip are the Lower Pennsylvanian Lee Formation and the Lower to Middle Pennsylvanian Breathitt Formation. The Lee Formation (whose type area is along the Cumberland Mountain outcrop belt in nearby Lee County, Va.) consists of mixed clastics with occasional limestones and coals. Most prominent are its sandstone and conglomeratic facies that were deposited in fluvial and marginal marine settings. In general, these thick, pebbly to conglomeratic sandstone units dominate the lower part of the Pennsylvanian section, making the Lee easily identifiable. The overlying Breathitt Formation consists of mixed clastics, but generally lacks the conglomeratic sandstones typical of the Lee. A few thick and widespread marine units serve as stratigraphic markers; otherwise, the dominant lithologies tend to be vertically cyclical and laterally discontinuous. The Breathitt also contains most of the region's economic coal beds, and is appreciated for its abundance of plant fossils. The marine units also offer a variety of interesting fossils, including ammonoids and shark teeth.

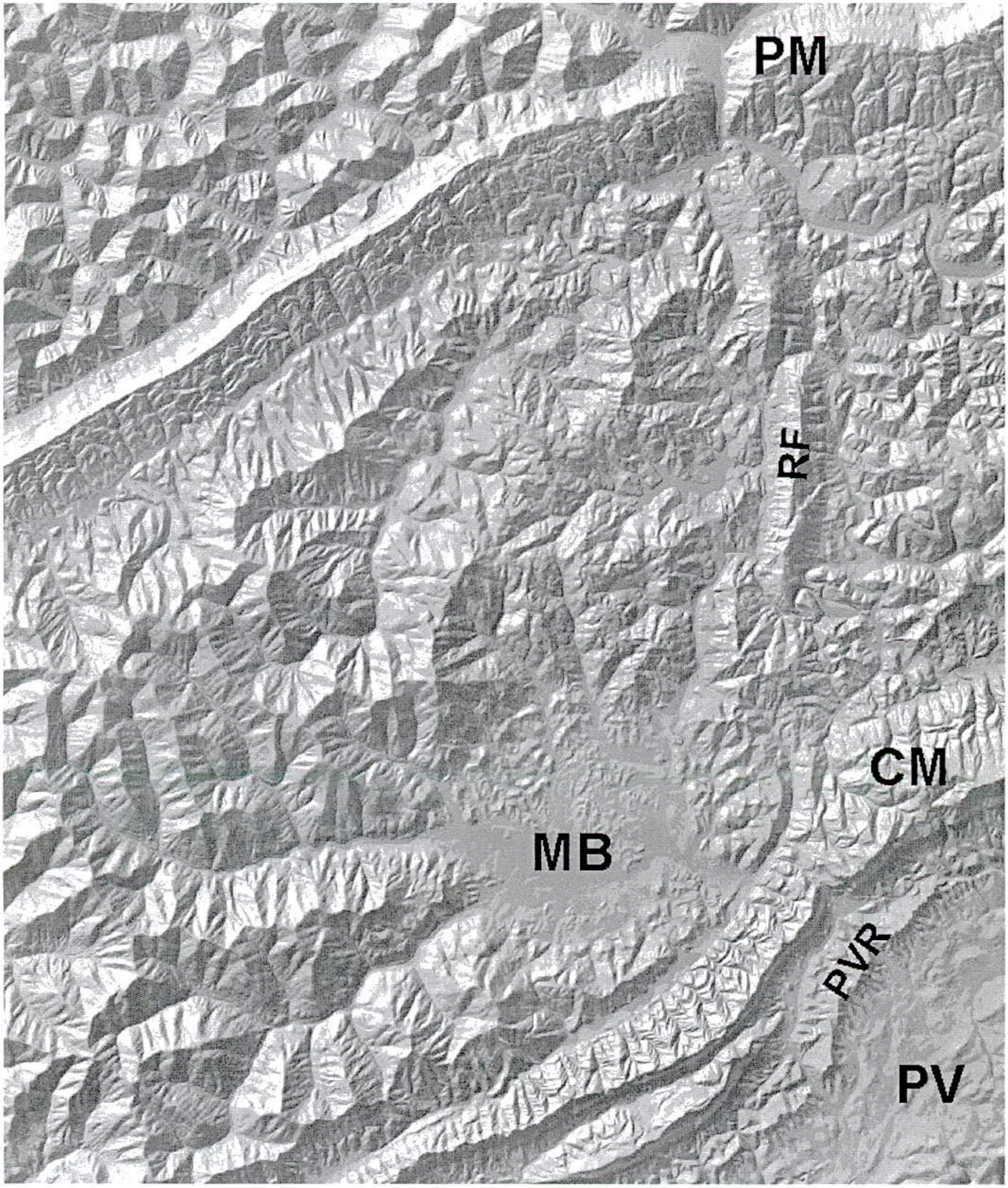

Figure 5. Shaded-relief map of the field trip region. MB: Middlesboro Basin, CM: Cumberland Mountain, PV: Powell Valley, PM: Pine Mountain (near Pineville), RF: Rocky Face, PVR: Poor Valley Ridge.

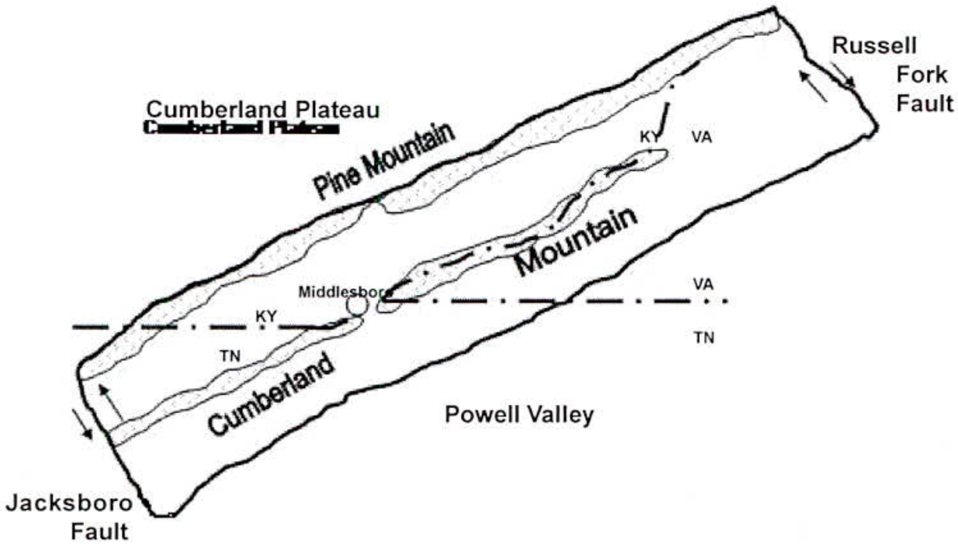

Figure 6. Prominent features of the Pine Mountain Thrust Sheet and the location of the Middlesboro impact structure (modified from McGrain, 1975).

Chesnut (1992) established a new stratigraphic framework for the Pennsylvanian System in eastern Kentucky. This nomenclature is used on the digitally vectorized geologic quadrangles (DVGQ's) now being produced by the Kentucky Geological Survey. Most notably, the Lee Formation was abandoned and the Breathitt Formation was elevated to the Breathitt Group, comprising eight formations. The four lower formations, previously members of the Lee Formation, are the Warren Point, Sewanee, Bee Rock, and Corbin Sandstones. The Corbin Formation interfingers laterally with the Grundy Formation. Overlying the Grundy are the major coal producers: the Pikeville, Hyden, Four Corners, and Princess Formations. Figure 7 compares the nomenclature adopted for the U.S. Geological Survey–Kentucky Geological Survey geologic mapping project of the 1960's and 1970's to that developed by Chesnut (1992). Some map symbols have been added to the figure to aid in interpreting the stratigraphic relations shown in Figure 8.

The geologic map in Figure 8 was compiled from parts of the Middlesboro North, Middlesboro South, and Kayjay 7.5-minute DVGQ's. The circular Middlesboro impact structure is labeled, as is the Pine Mountain Thrust, which transects the northwest corner of the map. The mountain's west-facing scarp slope exposes the Upper Devonian and the various Mississippian units (Mv). Trending parallel to Pine Mountain in the southeast corner of the map is part of Cumberland Mountain and the Cumberland Gap. Both mountains expose near their crests the prominent lower Breathitt sandstones (Pss). Between them lies a second-order structure called the Middlesboro Syncline that preserves younger formations within the Breathitt Group (Pg through Pfc). The Middlesboro Syncline is divided into two blocks by the north-trending Rocky Face Fault. This fault is exposed on Cumberland Mountain and is likely responsible for Cumberland Gap having formed there as a result of ancient stream erosion. To the north, the gap in Pine Mountain at Pineville, Ky., was cut by the Cumberland River and also owes its existence to the Rocky Face Fault. Both sides of the fault are believed to have thrust northward, the eastern block advancing differentially, causing a predominantly left-lateral strike separation. The component of dip separation indicates a "down to the west" motion. The fractures associated with this fault system enabled deeper erosion of the mountains through the resistant Pennsylvanian sandstones, creating the gaps.

The geometry among the regional structures is shown clearly in Figure 9, which is modified from Mitra (1988). The Pine Mountain Thrust Sheet is a large (125 x 25 mi) northeast–southwest-trending overthrust block that is bounded by faults on all four sides. It is considered to be the westernmost structure of the southern Appalachian Valley and Ridge Province. The northwestern leading edge of the sheet is the Pine Mountain Thrust; the southeastern trailing edge (Virginia and Tennessee) is the Hunter Valley Fault. The Jacksboro Wrench Fault in northern Tennessee defines the southwestern end of the block and indicates about 11 mi of movement. The Russell Fork Wrench Fault on the northeastern end (Kentucky and Virginia) indicates about 4 mi of westward movement. The thrust sheet was detached and moved northwest-

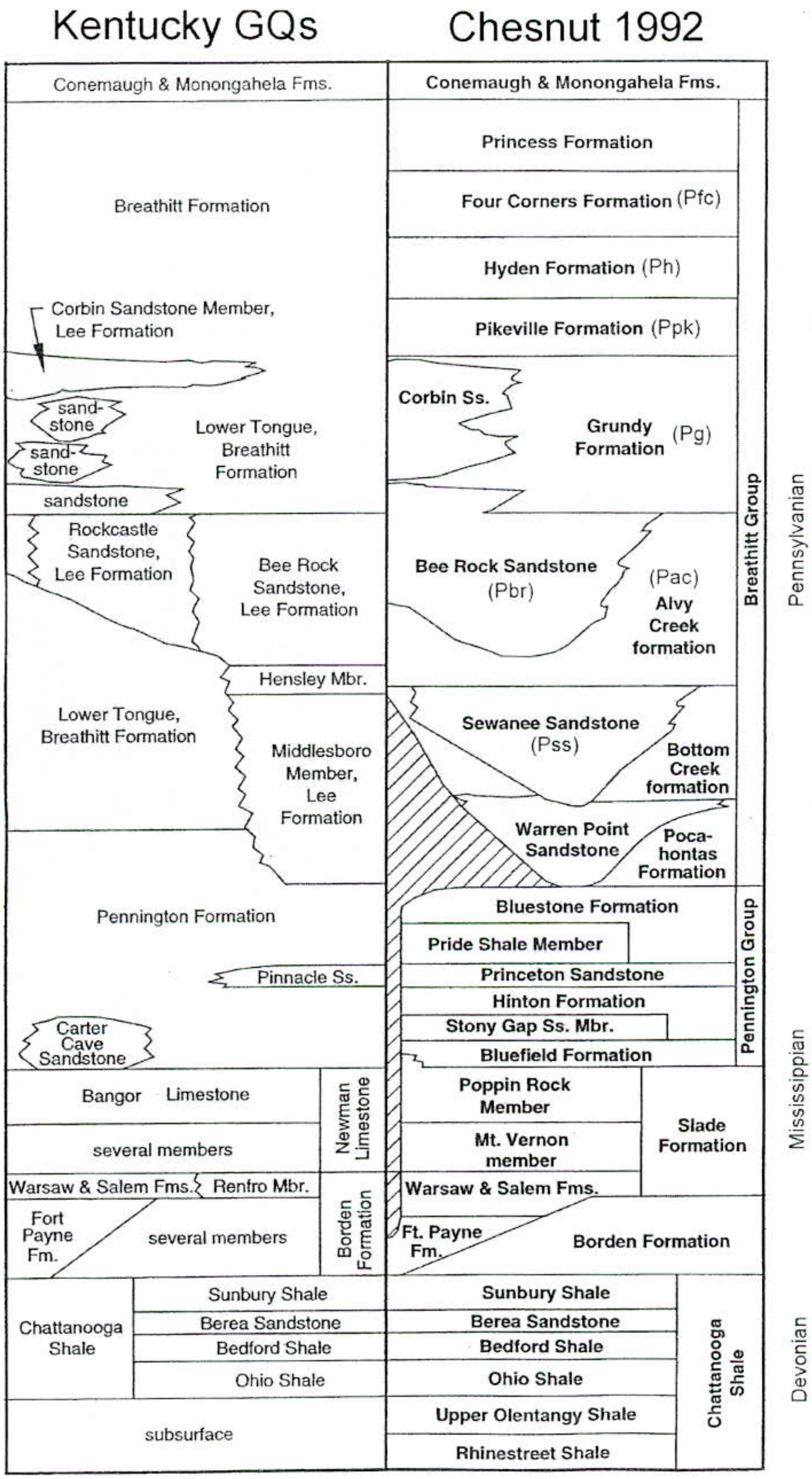

Figure 7. Correlation between two systems of stratigraphic nomenclature in use for eastern Kentucky (after Chesnut, 1992).

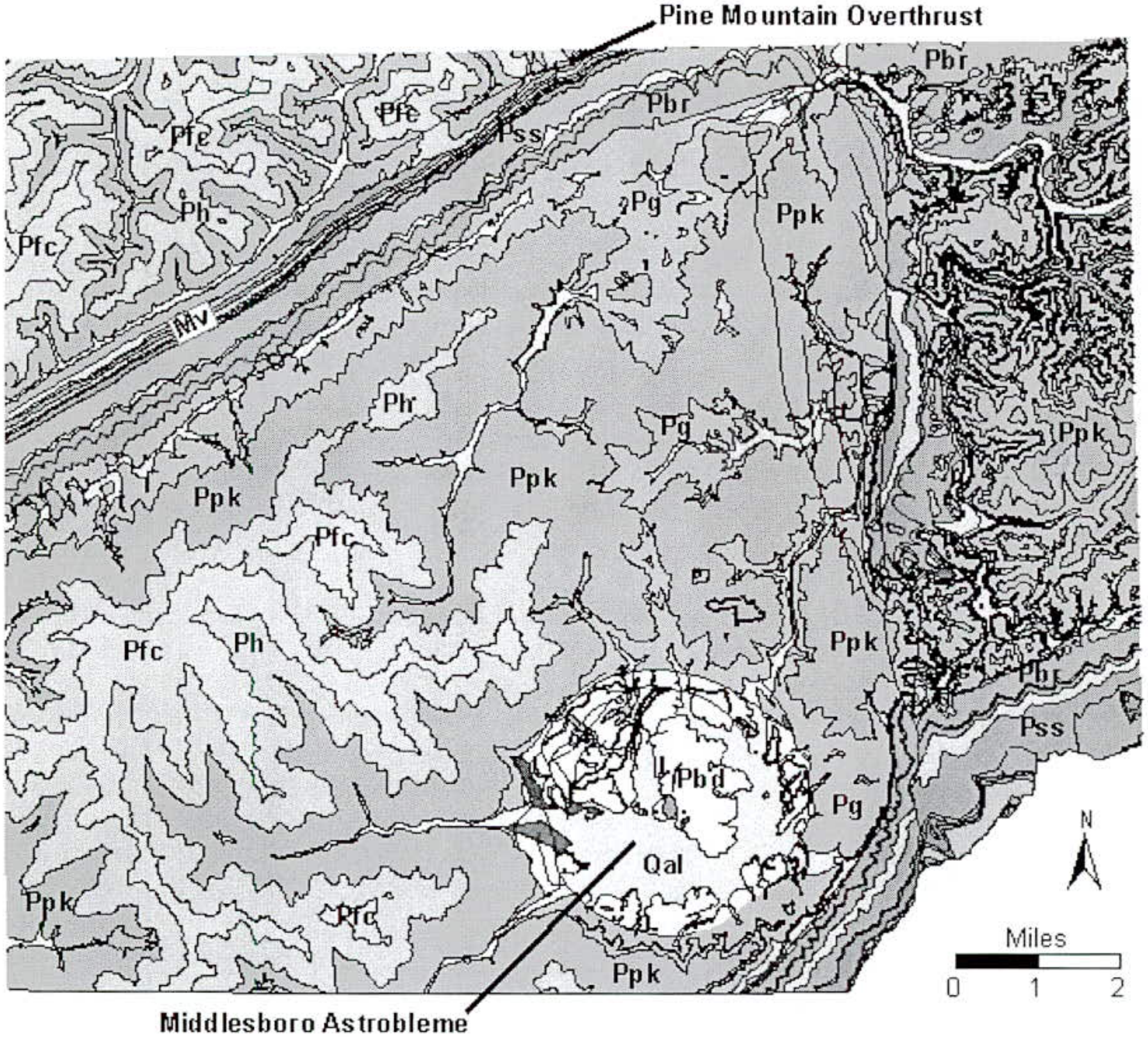

Figure 8. Geologic map of Middlesboro, Ky., and surrounding area, compiled from DVGQ's.

ward across the foreland by lateral compressive forces during the late Paleozoic assembly of the North American, European, and African continents to form the supercontinent of Pangaea. This collision, known as the Alleghanian Orogeny, was the final stage in forming the Appalachian Mountains.

The mechanism of ramp folding was introduced by Rich (1934) to explain structures of the Pine Mountain Thrust Sheet. He proposed that the thrust surface developed horizontally in the least competent units until frictional resistance became too great. Then, the fault would shear upward across bedding, forming a ramp, and continue until a weaker unit higher in the section was encountered. According to this mechanism, the growth in fold amplitude results from the duplication of strata along the ramp and the detachment surface beyond, because of differential movement within the hanging-wall block. In general, the major horizontal detachments developed in the shales of the Rome Formation (Middle Cambrian) and again in the Chattanooga Shale (Upper Devonian). Where these faults ramped upward, large folds such as the Middlesboro Syncline and Powell Valley Anticline (southeast of Cumberland Mountain) were formed. This vertically repeated sequence of horizontal detachments and steep ramps developed within the sedimentary cover rocks is today referred to as "thin-skinned" tectonics, and the concept once spurred a flurry of oil and gas exploration in the southern Appalachians (Harris and Milici, 1977).

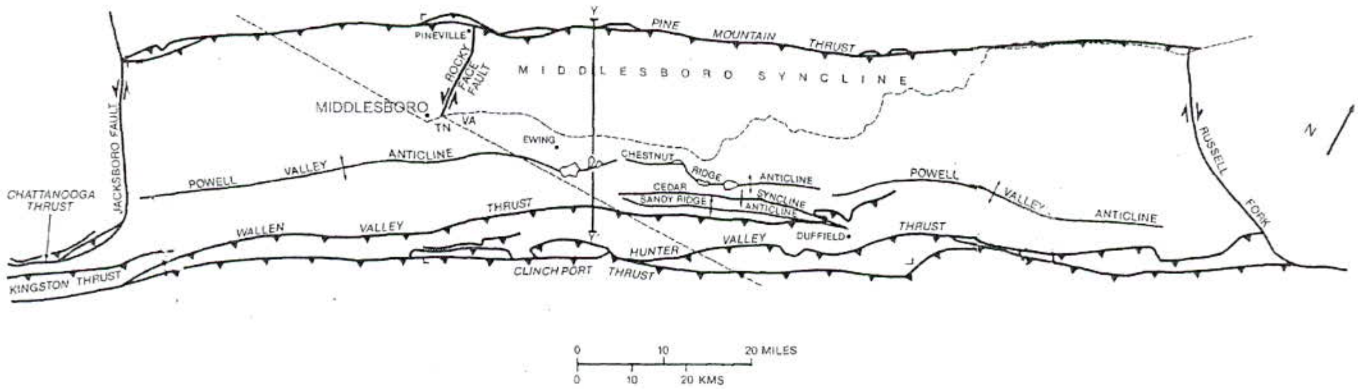

Figure 9. Major structures of the Pine Mountain Thrust Sheet (after Mitra, 1988).

Mitra (1988) was able to define three distinctive styles of deformation within the Pine Mountain Thrust Sheet by combining seismic data with surface and borehole geology. One of his centrally located, geologic cross sections (taken through y–y′ in Figure 9) is shown as Figure 10. It depicts the Powell Valley Anticline having formed as a result of stacking on a series of imbricate thrusts. Cumberland Mountain itself is located on the west limb of the Powell Valley Anticline, and its strata dip westward. Miles to the west, the strata exposed on Pine Mountain dip eastward. Thus, these two parallel, linear mountains comprise the opposing limbs of the Middlesboro Syncline. Figure 11 is a generalized northwest–southeast cross section depicting the major structures in this discussion. Additional discussions of the structures within the Pine Mountain Thrust Sheet are found in Hauser and others (1957), Mitra (1988) and Moshier and Dean's (1989) guidebook.

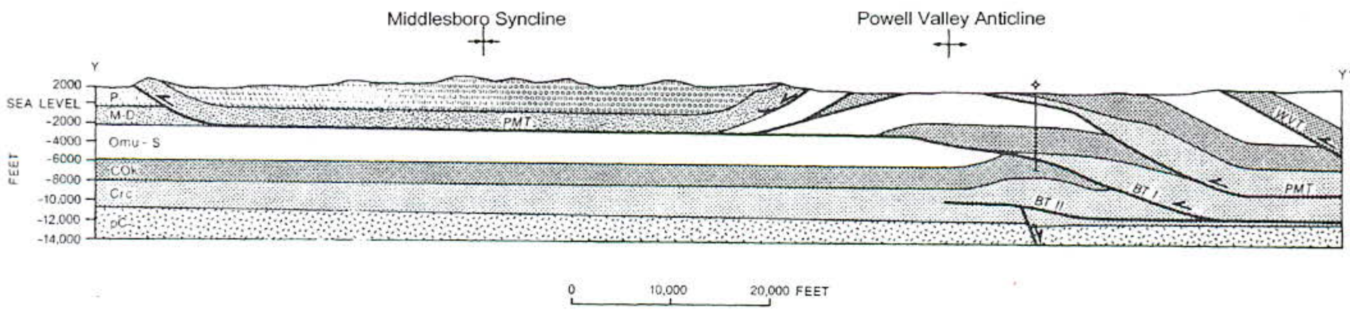

Figure 10. Geologic cross section through the central region of the Pine Mountain Thrust Sheet (after Mitra, 1988).

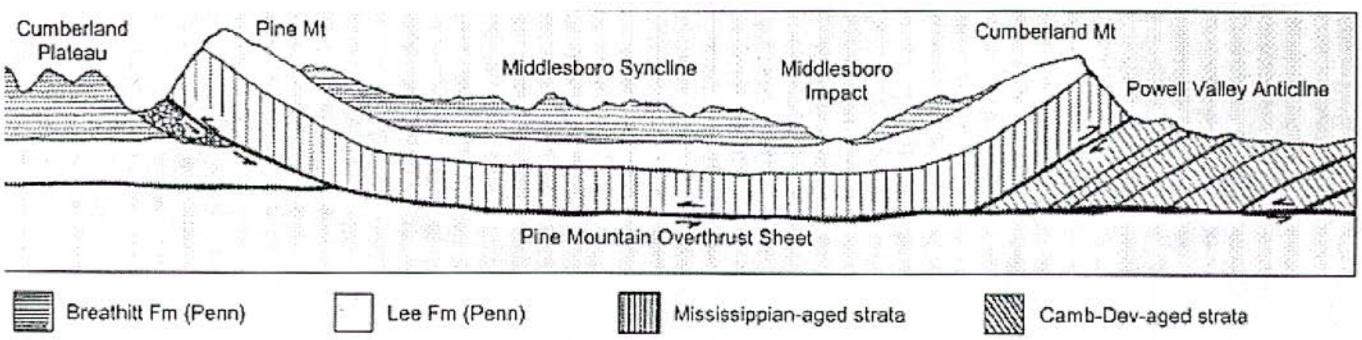

Figure 11. Generalized (not to scale) northwest–southeast cross section through the field trip area, showing prominent structural features between the Cumberland Plateau and Powell Valley.

Iron History of the Middlesboro Region

William M. Andrews Jr.

One of the historical features of interest in the Cumberland Gap National Historic Park is the sandstone chimney of an abandoned iron furnace located on the edge of the town of Cumberland Gap, Tenn. The Cumberland Gap furnace was a cold-blast charcoal-fueled iron furnace supporting a massive ironworks complex known as Newlee Iron Works. All that remains is the stone chimney of the iron furnace itself (Fig. 12). The Iron Furnace at Cumberland Gap was constructed in 1819 of local sandstone; John G. Newlee acquired the facility sometime between 1845 and 1850. The iron complex bore his name until abandonment in the late 19th century.

The furnace used local timber—converted to charcoal—for fuel, and used local limestone as flux for the iron-smelting process. A water wheel drove a bellows, forcing cool air (i.e., "cold blast") into the furnace during the smelting process. The iron ore for the furnace was obtained from the uppermost of three crinoidal oolitic hematite beds in the Silurian Rockwood Formation, which crops out in the nearby Poor Valley Ridge. Silurian iron ores were also exploited in the Bath County iron furnaces (using the "Rose Run beds") in central Kentucky. Comparably aged ores also were found and used in Pennsylvania, New York, Tennessee, and Wisconsin, and recognized through much of the eastern United States.

The furnace complex was destroyed by Confederate forces in 1862. Reconstruction began soon after the Civil War ended. Production at the facility continued at least into the mid-1880's.

For more information, see Moore (1884), or consult the National Park Service.

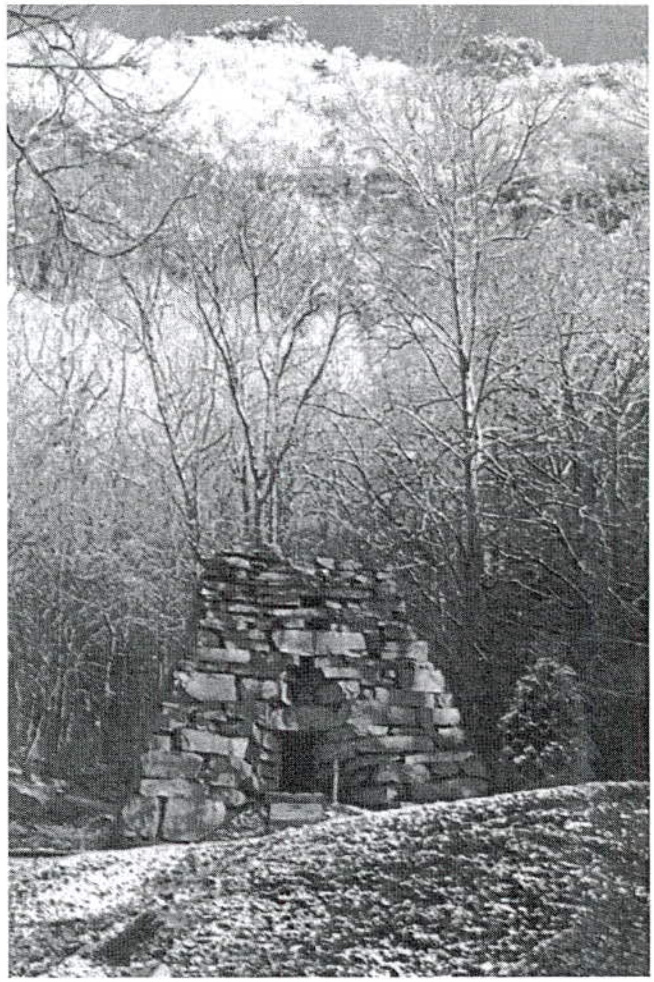

Figure 12. The stone chimney of the iron furnace at Cumberland Gap.

Mining and Construction Obstacles in the Middlesboro Basin, Kentucky

Stephen F. Greb

Introduction

Mining history

The Middlesboro Basin is located in Bell County, in southeastern Kentucky. The rocks rimming the basin are Early Pennsylvanian in age and contain many coal beds. These coal beds have been mined for the last 100 years, often with considerable difficulty because of the basin's unique geology.

Middlesboro was created as a mining town. Alexander Arthur, a Canadian developer, discovered iron ore (sedimentary hematite) and coal in prospects within the Middlesboro Basin in 1885. With capital from England, he bought up thousands of acres in the Middlesboro area in the hopes of mining iron and coal, and harvesting timber. Between 1890 and 1898 the Watts Steel and Iron Company built blast furnaces, brick works, and steel mills in Middlesboro. The plan was to make coke from the coal, and use the local iron ore to make steel (Kentucky Historical Society, 2002). Between 1900 and 1910 there were 18 coal camps, as many as eight operating at the same time. Most of these camps were short lived, however. By 1930, 27 coal camps had come and gone from the Middlesboro area (Kentucky Coal Education, 2002).

Unfortunately, (1) there was not much iron in the surrounding hillsides, (2) modern iron-smelting methods were replacing the old charcoal furnace–pig iron methods as the town was getting started, and (3) a large area of any coal that would have been in the basin was intensely brecciated, fractured, and folded because of the unique geology of the Middlesboro area.

Coal mining has occurred on the slopes around Middlesboro (outside of the breccia zone) and in the hills beyond Middlesboro. Mining was by underground drift, surface area (mountaintop), and surface contour–bench methods. The most recent mining was a contour surface operation on the south side of the basin, which operated during the late 1990's and mined the Hance through Harlan coals. This mine has since been reclaimed, and probably represents the last major mining within the ring fault area. The only area that has not been extensively mined within the ring area (and is not overlain by roads or buildings) is near Fern Lake, and the lake's watershed has been protected since 1996. Fern Lake was made part of Cumberland Gap National Park in 2001.

Local geology

Coals that occur at the surface in the Middlesboro Basin, in ascending order, are the Splitseam, Mason, Mason rider, Hance (Bennett's Fork) zone, Phoebe, Path Fork zone, and Harlan (Mingo). The Cumberland Gap and Tunnel coals crop out on the northwest slope of Cumberland Mountain. All of these coals have been mined in the Middlesboro area, but only the coals below the Hance zone occur inside the arcuate fault ring, within the Middlesboro Basin proper. Of these, the Hance coal has been the most heavily mined, and is mostly mined out (Englund, 1964).

Mapping of the Middlesboro North (Englund and others, 1964; Rice and Ping, 1989), Middlesboro South (Englund, 1964), and Kayjay and Fork Ridge (Rice and Maughan, 1978) quadrangles showed that the circular basin is rimmed by a complex system of arcuate faults, with overall down-to-the-center displacement. Most of the faults noted during mapping were near-vertical normal faults, although subsequent studies have also noted thrust and reverse faults (see Greb and Chesnut, 1998). Within the inner ring faults, bedrock strata are highly fractured and brecciated. A rebound structure of older, Early Pennsylvanian quartzarenites occurs toward the center of Middlesboro. These geomorphic features in combination with shatter cones and shocked quartz grains have been used to interpret a bolide impact origin for the Middlesboro Basin (Englund and Roen, 1962; Dietz, 1966; Greb and Chesnut, 1998; Milam, 1998; Milam and Kuehn, 1999). Rather than a crater, the present basin represents faulting and fractured rock that was far beneath the crater.

Coal Mining in an Impact Structure

The coal mining in the Middlesboro Basin represents *the only occurrence of coal mining within an impact structure in the world.* As can be imagined, mining in and around an impact structure is problematic, at best. Faulting, fracturing, folding, and brecciation inward from the outer rim faults greatly complicate local stratigraphy and coal geology. Recent mining on the southern rim of the basin not only documents the problems associated with mining in highly deformed strata, but also has provided exposure to faults that may help to corroborate some aspects of an impact-origin theory for the Middlesboro Basin.

Major obstacles to mining around Middlesboro are changes in bed dip and offset along faults of different scale, orientation, and throw. Figure 13 shows the type of bed dip changes encountered during mining within the ring faults on the south side of Middlesboro. The floor of the excavation is on the base of a coal in the Hance zone. The photograph shows the bench rolling over in the middle and then dipping steeply into the hillside toward the outer ring fault. Large faults truncate beds, effectively blocking continued surface contour mining on benches that encounter the faults. The major ring faults are arcuate around the basin. At least two ring faults were mapped on the north, east, and west sides of the basin during previous geologic mapping (Englund and others, 1964; Rice and Maughan, 1978; Rice and Ping, 1989). On the south side of the basin, only a single fault was mapped. During recent mining on the south side of the basin, the second outer ring fault was encountered. As shown in Figure 13, the steep dip of the bed into the hillside was probably caused by the outer ring fault.

Between the arcuate ring faults are numerous splinter faults of varying scales and orientations. Figure 14 shows coal dip increasing to nearly 40° from the horizontal before being offset by a large fault that splinters from the outer ring fault. Figure 15 shows two faults offsetting the Hance coal by 4 to 5 m. These are splinter faults within the ring system. The coal was surface mined on the upper bench (left side of the photo), and then mining dropped down to the lower bench (right side of the photo) on the other side of the faults. Kinks, drags, and folds are common along these faults. In fact, various kinks and folds occur along even the smallest offset faults. Figures 16A–B are small faults noted on the haul road. They occur between splinter faults. Overall offset on these smaller faults may be a few meters to less than a meter. The different scales of complex faulting, folding, and fracturing requires a

Figure 13. Surface mine pit on southwest side of the Middlesboro Basin. The coal rolled over steeply into the hillside.

highly adaptive mine plan.

Although most of the mapped faults in the basin exhibit normal, down-toward-Middlesboro displacement (Englund, 1964), reverse faults also occur. During mining, a reverse fault was encountered within the outer rim. Figure 16 is a photomosaic of a bench in a contour surface mine at the level of the Hance rider coal bed (Cr). The rider coal is offset 15 m along a high-angle reverse fault and sheer zone, which suggests movement away from Middlesboro. At least five normal faults were reported across a distance of approximately 100 m. Each offset was accompanied by 2 to 4 m of normal displacement, toward Middlesboro. Miners started at the toe of the slope, hit rock (fault trace), stepped up to coal and continued mining (bulldozing), hit rock, stepped up, etc.

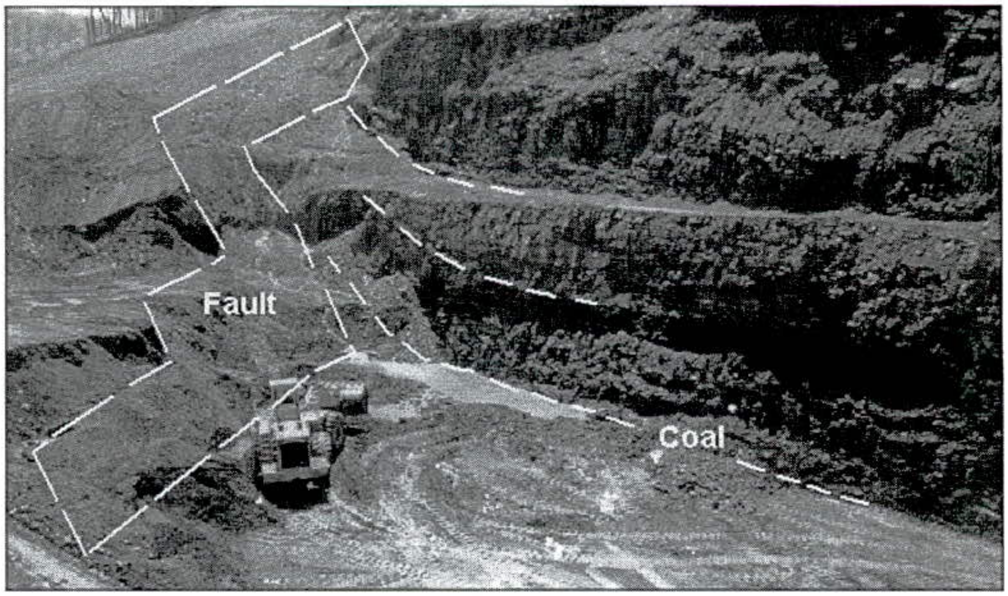

Figure 14. Fault plane intersected on south side of the Middlesboro Basin during surface mining. Small dashed lines in highwall are traces of bedding to show inclination of bedding along fault.

Figure 15. A pair of splinter faults encountered on surface mine bench.

Figure 16. Photomosaic showing highwall along outer ring fault on south side of Middlesboro. The rider coal (white dashes) is offset along a reverse fault, and then a series of normal faults offset the coal down toward Middlesboro.

The high-angle reverse fault indicates local thrusting to the south, away from Middlesboro, and opposite the orientation of stress fields from Cumberland Mountain. In terms of an impact origin, reverse movement would be expected during the excavation and compressional stage of the impact, or during the collapse stage when the overheightened uplift collapsed. The succession of normal faults inward from the outer reverse fault indicates subsequent normal movement on the hanging wall; these faults are interpreted to have formed in response to relaxation, during the collapse phase of the impact. Evidence for compression followed by extension is consistent with the types of movement expected from a bolide impact.

Another obstacle to mining and construction in the Middlesboro Basin is the intense fracturing of the bedrock and brecciation inward from the inner ring fault. On the slopes around Middlesboro, soils are significantly thicker than in surrounding areas, because fracturing has allowed for deeper infiltration and deeper weathering (as can be seen in the upper parts of Figures 17A–B). Weathered profiles in excess of 5 m were encountered on the south side of the basin during recent mining. The deep weathering and fractured nature of the bedrock make exploration drilling difficult. Numerous drill rigs have reported that caving and loss of tools are common. At one point during mining on the south side of the basin, the coal was reported to have became so brecciated on the northern side of the contour bench (toward Middlesboro) that it was like slurry. Whether this

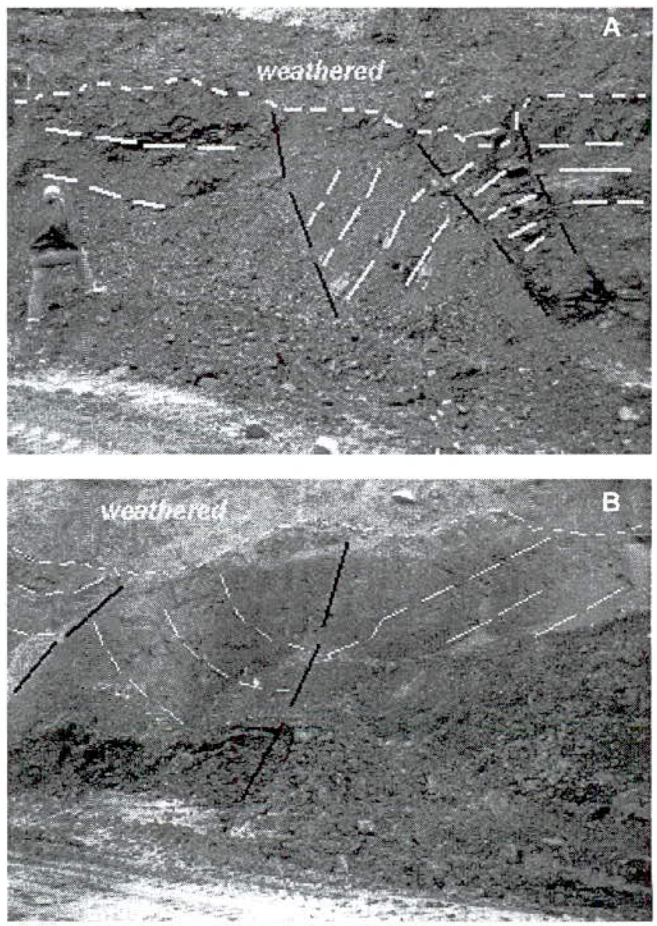

Figure 17. Small faults overlain by thick weathered sediment and soil. John Kiefer for scale in (A).

was because of the physical brecciation near the inner ring fault, deeper weathering on the slopes around Middlesboro, or a combination of the two is uncertain.

Deep infiltration and weathering, increased bed dip, and abrupt changes in lithology have also resulted in numerous large slumps within the basin. Slope movements along the rebound structure have resulted in damage to roads and property (Fig. 18). Slope instability occurs between the porous quartz-rich sandstones that form the rebound structure, and the brecciated shales and silts on the rebound structure's slopes. Slope movements have also caused road and property damage on the concentric slopes around Middlesboro. Most of the hillsides around Middlesboro (within the ring structure) are classified as soil and rock susceptible to sliding (Outerbridge, 1982a, b). In fact, in limited outcrop, determining whether listric-normal structures and small faults are related to past slope failure of the existing slopes or to movement caused by the impact origin of the Middlesboro structure can be problematic. To what extent slope instability in the outer ring area is related to the Middlesboro structure is difficult to assess, because slope instability is not uncommon in this part of the Appalachians.

Conclusions

1. Middlesboro is the only place in the world where coal is mined within an impact structure!
2. Coal mining has exposed faults in the Middlesboro Basin that exhibit outward thrust, followed by inward normal displacement, which would be expected in an impact structure. The reverse movement is opposite the orientation of Appalachian thrusting.
3. Complex deformation, which greatly affects local mining and construction, includes various fault scales and orientations, offset coals, rapid lateral changes in coal dip (dips, rolls, folds, kinks), steep bed dips, fracturing, intense brecciation, and highly weathered slopes.
4. Perhaps someday lessons learned from mining in and around this impact structure may help in planning future mining on cratered asteroids, satellites (the Moon), or even planets (Mars).

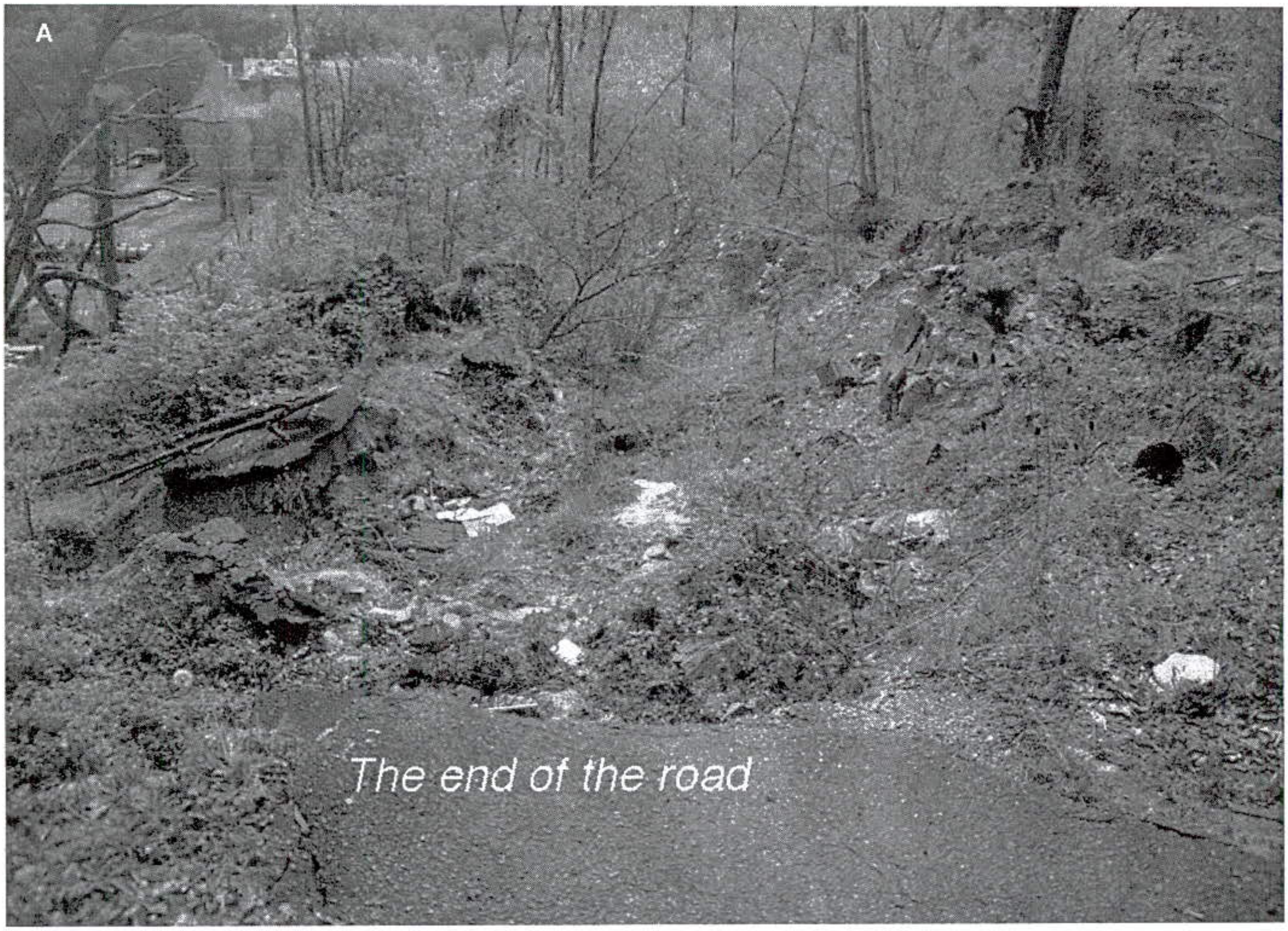

Figure 18. A road (A) and building (B) damaged by slump off of the rebound structure.

An Introduction to Impact Cratering

Keith A. Milam

Overview

Impact cratering is a significant process that has been responsible for modifying planetary surfaces in the solar system. Until recently, impact cratering had received little scientific attention, and many researchers doubted its importance. During the 1960's, research into nuclear explosions, travel to the Moon in the Apollo Program, and work with suspected terrestrial impact craters revealed impact cratering to be a prominent modifying force in the solar system. Today, impact craters have been identified on virtually every solid solar system surface. Examples are shown in Figure 19.

Here on Earth, approximately 150 impact craters have been discovered on land (Fig. 20); approximately the same number is suspected on the ocean floor. Within the Kentucky-Tennessee region, three confirmed impact craters have been identified. Middlesboro (Fig. 21) is the only confirmed impact crater in the state of Kentucky, whereas the Flynn Creek (Roddy, 1968) and Wells Creek (Stearns and others, 1968; Wilson and Stearns, 1968) structures have been identified in Tennessee. Two other suspected impact structures, Jeptha Knob (Seeger, 1968; Seeger and others, 1985, 1988a, b; Cressman, 1981) and Versailles (Seeger, 1972), in the state of Kentucky (Koeberl and Anderson, 1996), have also been reported.

In order to meaningfully understand the Middlesboro impact structure, a brief introduction to the process and results of impact cratering is warranted. More detailed discussions of concepts reviewed here can be found in Melosh (1989) and French (1998).

The Impact Process

Impact craters are circular or elongate topographic depressions that result from the collision or near collision of a projectile with a planetary surface (such as Earth). Projectiles include meteoroids, asteroids, or comets, which impact at velocities between 5 and 40 km/s. During impact, a tremendous amount of kinetic energy is transferred to the target body, the amount of which is dependent upon projectile mass and speed and the target body's gravitational acceleration. This energy instantaneously produces extremely high pressures and temperatures that deform and sometimes melt target material.

The impact-cratering process is generally divided into three stages: compression/collision, ejection/excavation, and post-impact modification. The compression stage involves the initial penetration or explosion of the projectile with the target. Following collision, a bowl-shaped depression called the transient crater is excavated (Fig. 22). Some of the excavated material is ejected into the atmosphere, while the remainder falls back into the crater or lands adjacent to the rim. During the ejection stage, rim material is thrust up, out, and away from the center of impact; some strata overturn to form an "ejecta flap." Seconds, minutes, hours, and even days following impact, during the modification stage (Fig. 22), the transient crater rim collapses along arcuate normal faults, enlarging the crater to its final diameter. On Earth (and other planets with atmospheres) weathering and erosion serve to modify and obliterate the crater form following impact. Hence, Earth appears to have a lower crater density than other bodies, such as the Moon or Mercury.

Types of Impact Craters

The types of craters that result from the impact process can be classified as simple, complex, oblique, or multi-ring basins. Simple craters are bowl-shaped in cross section, with strata dipping away from the center of impact (Fig. 23). A well-known example of this is Meteor (or Barringer) Crater in Arizona (Fig. 24). Complex craters are larger and have a core of uplifted material, generally flat floor, and a crater rim that has been modified by crater wall collapse (Fig. 22). Middlesboro (Fig. 21) and Tycho Crater on the Moon (Fig. 25) are examples of complex craters. The transition in size from simple to complex craters usually occurs

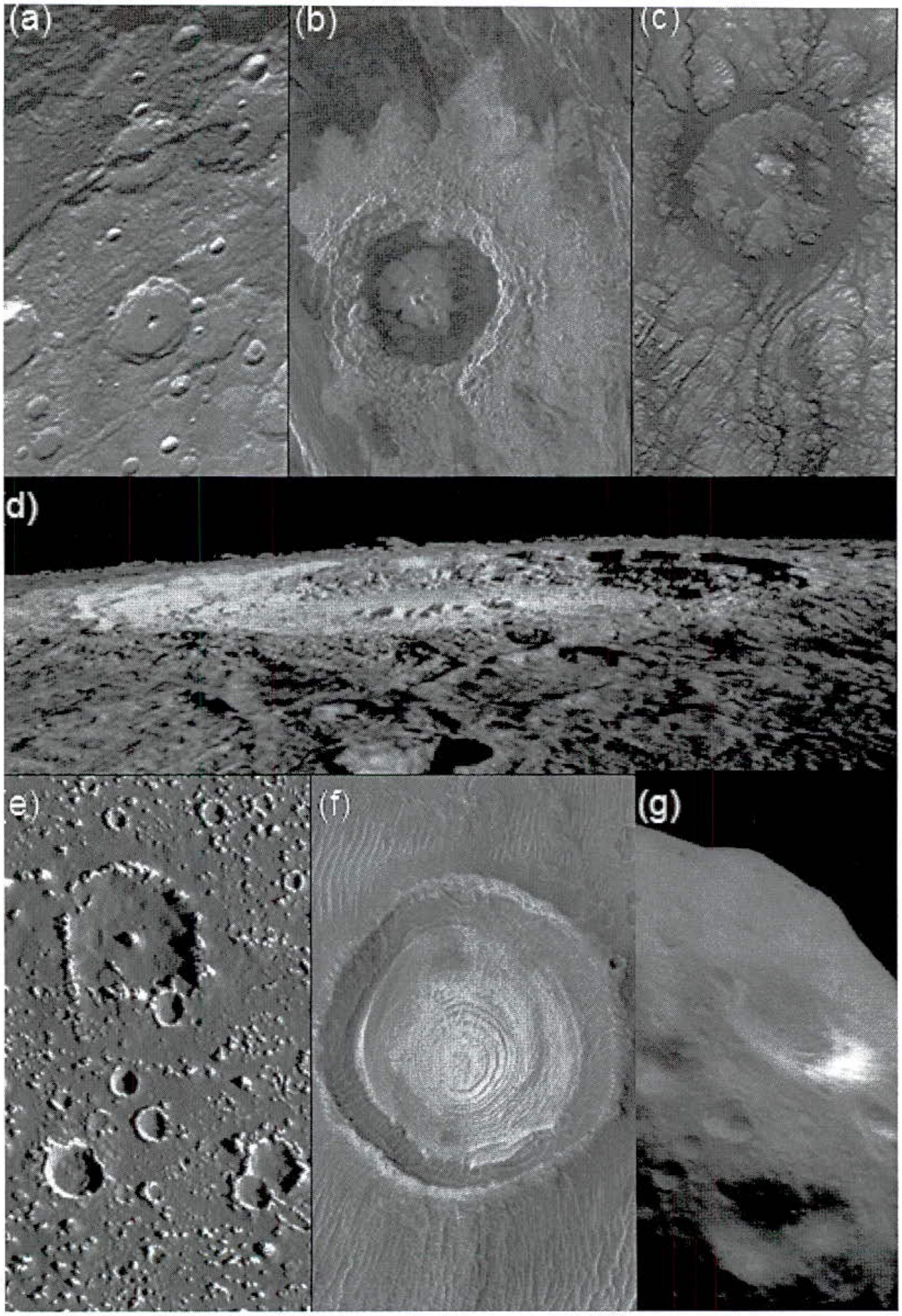

Figure 19. Examples of impact craters in the solar system: (a) Mariner 10 view of cratered landscape on Mercury (NASA), (b) Magellan radar view of Dickinson Crater on Venus (NASA/JPL), (c) Manicouagan Crater from Space Shuttle SRTM mission (NASA), (d) oblique view of Copernicus Crater on the Moon (NASA/USGS), (e) Mars Orbiter Camera view of Shiparelli Crater and its interior sedimentary deposits, Mars (NASA/MSSS), and (f) NEAR-Shoemaker view of craters on Eros asteroid (NASA/JHU-APL).

Figure 20. Global view of known impact craters (compiled by R. Grieve, Geological Survey of Canada).

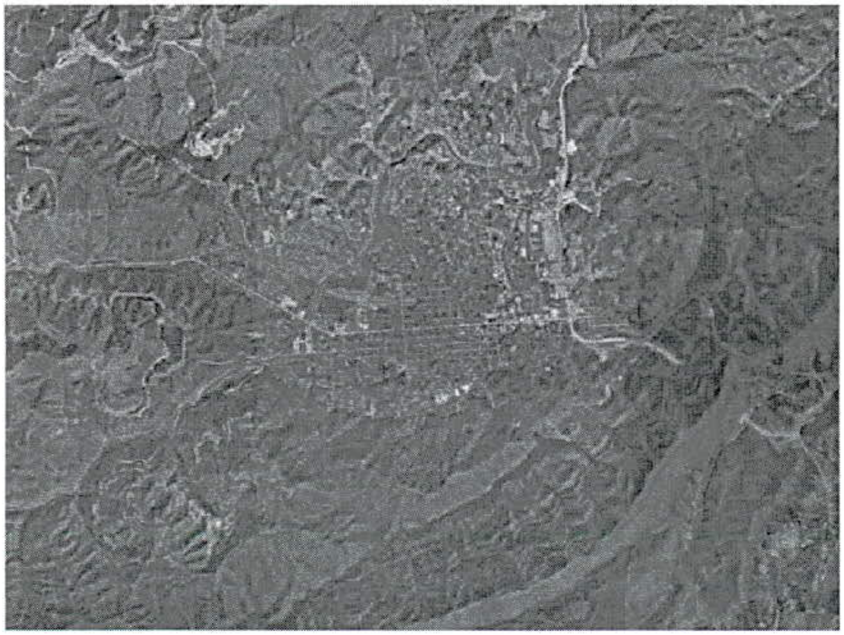

Figure 21. Aerial view of the Middlesboro impact structure (5 km diameter; courtesy of U.S. Geological Survey).

at 4 km and 2 km for impacts into terrestrial crystalline and sedimentary rocks, respectively. This transition is dependent upon the mass and velocity of the incoming projectile and the gravitational acceleration of the target body. Projectiles impacting at angles greater than 30° produce oblique-shaped impact craters (Fig. 26). Oblique impacts commonly produce asymmetrical distributions of crater ejecta (Pierazzo and Melosh, 2000). Multi-ring basins generally occur at even larger diameters (hundreds of kilometers in diameter) and are characterized by multiple, concentric uplifted rings and grabens, giving them a "bull's-eye" appearance. A prominent example on the Moon is the 930-km-diameter Mare Orientale (Fig. 27).

Evidence for Impact

Telescopic views of the Moon, Mars, and other planetary bodies reveal worlds scarred by impact cratering since the early beginnings of the solar system. The majority of impacts occurred early (less than 3.8 Ga) in solar system history, during a period known as the Early Bombardment, but continue into modern times. Examples of recent impact activity include the Tunguska event in Siberia in 1908 and the 1994 impact of comet Shoemaker-Levy 9 into Jupiter (Fig. 28). On planets with dynamic atmospheres and hydrospheres, such as the Earth (and even Mars), craters have been degraded or obliterated altogether with the passage of time. On Earth, impact structures have been modified by burial, erosion, or vegetative cover. As a result, original crater forms can be difficult to observe in the field. This, coupled with the fact that the projectile itself is often destroyed or vaporized during the impact event, leads to difficulties in identifying terrestrial impact craters. A process known as shock metamorphism does provide a means of identifying heavily eroded impacts, or astroblemes, however. Shock metamorphism of preexisting material, or target rock, during the compression stage leaves behind evidence of impact long after the original crater has been removed.

Energy released at the point of impact produces a rapidly propagating shock wave that deforms material as it progresses through target rock. This shock metamorphism occurs at pressures and temperatures above those typical for crustal rocks (Stöffler, 1971) and results in features unique to the impact process. Resulting shock fabrics are dependent upon peak pressures and temperatures reached during impact and the physical properties of target material.

Numerous studies of nonporous, crystalline rock have made possible the recognition of several stages of shock metamorphism (Table 1). At

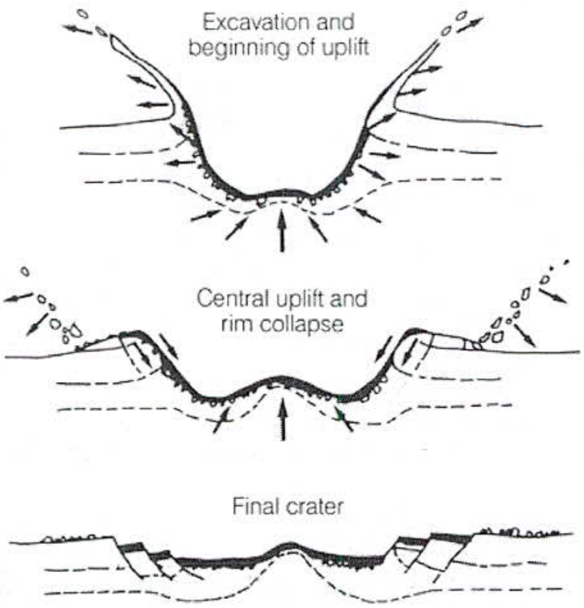

Figure 22. The excavation and modification stages of the impact cratering process, shown with a complex crater (from Melosh, 1989). The top two diagrams illustrate the excavation stage, whereas the lower one shows the crater during the modification stage.

Figure 24. Aerial view of Meteor (or Barringer) Crater in Arizona (Dave Roddy, USGS).

pressures less than 2 GPa (gigapascals), fracturing and brecciation of target rock occurs. Such effects can also result from endogenic processes. Between 2 and 30 GPa, conical striations known as shatter cones are often produced in finer-grained rocks (Fig. 29). At pressure ranges between 5 and 45 GPa, planar fractures and parallel striations called planar deformation features result. Planar deformation features are common in quartz and feldspar, and can be distinguished from similar features found in tectonically deformed grains, by their specific crystallographic orientations. Between 15 and 50 GPa, high-pressure polymorphs of minerals, such as quartz and olivine, are formed. If pressures of 25 to 40 GPa are reached, solid-state transformation of minerals can occur, producing amorphous phases or diaplectic glass. Partial melting of some minerals begins between 35 and 60 GPa, and complete melting occurs at more than 60 GPa. At even higher pressures, greater than 100 GPa, rock is completely vaporized. Thus, the identification of specific shock metamorphic features can

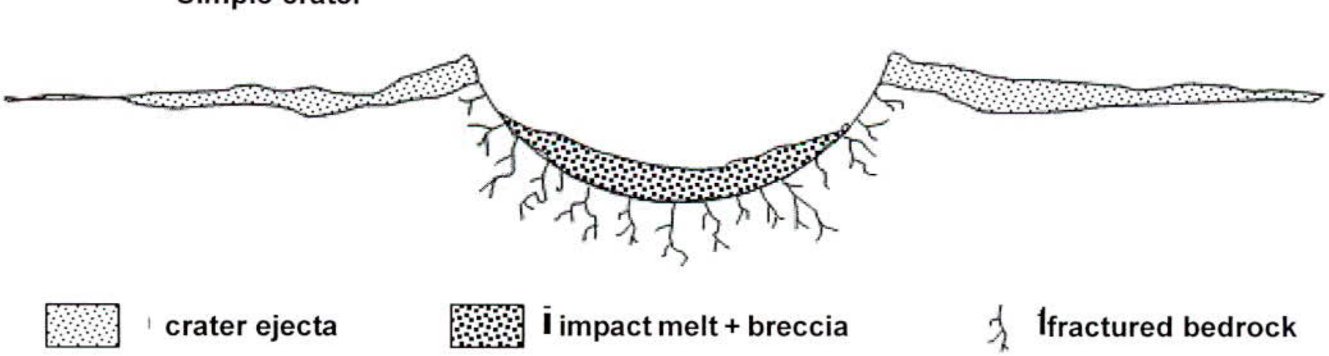

Figure 23. Idealized cross section of a simple impact crater.

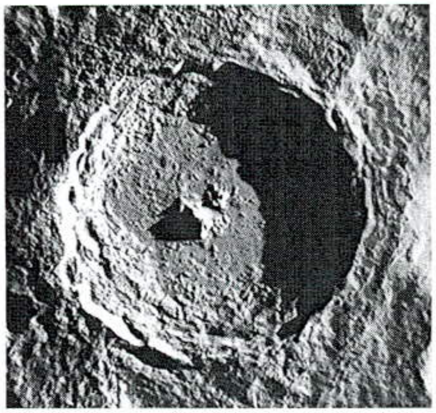

Figure 25. Lunar Orbiter photo of Tycho Crater on the Moon (NASA).

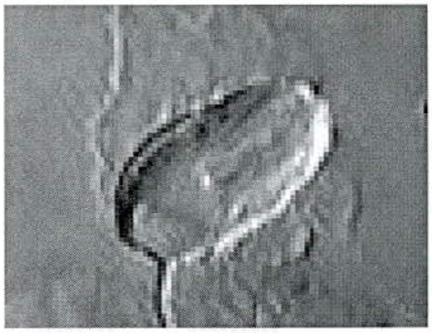

Figure 26. Viking image of unnamed oblique crater (34 x 18 km) near Ceraunius Tholus, Mars (NASA).

Figure 27. Lunar Orbiter image LO-IV-187M of Mare Orientale on the Moon from Lunar (NASA). The diameter of the multi-ring basin is 930 km.

lead to confirmation of suspected impact sites and provide important information about parameters of the impact event.

Importance of Impact Research

Impact research has become important to planetary geology and the examination of the geologic and biologic records on Earth and other planets.

Researchers have shown that some mass extinctions in the geologic record may have resulted from major impact events, such as the one that occurred at the end of the Cretaceous (Alvarez and others, 1980). Whether or not the effects (atmospheric vaporization and dust, global wildfires, tsunamis, significant CO_2 release, etc.) of impact lead to biologic extinctions is still the subject of much debate (see Joachimski and Buggish, 2000; Kaiho and others, 2001; Ward and others, 2001). An increased understanding of pre-global impact ecosystems and post-impact recovery is important in understanding modern-day ecosystems and how they can or cannot recover from such environmental stresses. Additional discovery of impact indicators in the geologic record can also provide a better estimate of impact cratering rates over Earth's history and lead to a better understanding of when the next event might occur.

Impact craters are also ideal locations for preserving the geologic record of a planet. On Earth and Mars, craters have served as depositional basins for sediment, which in turn can preserve evidence of climatic records and potential biotic activity. Some impact craters have held ponded water or lakes (Figs. 19c, 30), which are prime sites for preservation of biomarkers. On Mars, one possible crater-paleolake, Gusev Crater, is the targeted landing site (Milam and others, in press) for the first of the Mars Exploration Rovers.

Figure 28. Hubble Space Telescope image of Jupiter on July 18, 1994, 45 minutes after the impact of fragment G of Comet Shoemaker-Levy 9. Impact point is at the center right of the image (NASA).

Figure 29. Shatter cones from the Beaverhead, Montana, impact structure (Peter Fiske).

Table 1. Shock metamorphic features. Data from Alexopoulos and others (1988), Chao (1967), French and Short (1968), Koeberl (1994), Stöffler (1968, 1971, 1974, 1984), von Engelhardt and Stöffler (1968), Sharpton and Grieve (1990), Stöffler and Langenhorst (1994).

Shock pressure range (GPa)	Shock metamorphic features
< 2	Fracturing and brecciation of target rocks
2–30	Shatter cones
5–45	Planar fractures & planar deformation features
15–50	High-pressure polymorphs
25-40	Diaplectic glass
35–60	Partial melting
> 60	Complete melting
> 100	Complete vaporization

Figure 30. THEMIS daytime infrared photomosaic of Gusev Crater (160 km), a suspected paleolake, on Mars. From Milam and others (in press). Individual images courtesy of NASA/JPL/ASU.

Field Guide to the Middlesboro Impact Structure and Beyond

Keith A. Milam and Kenneth W. Kuehn

Day 1: Friday, September 19, 2003

The Middlesboro Impact Structure

History of Middlesboro. Middlesboro Basin has long held both historic and scientific significance for this part of the southern Appalachians. Initially, it served as a stopover for settlers migrating from the east through the Cumberland Gap. Middlesboro's lowland topography provided abundant water for immigrants, but was also notorious for its wetland quagmires that hindered settlers traveling along the Wilderness Road.

Prior to the late 19th century, Middlesboro consisted of scattered dwellings and trading posts along the Wilderness Road. The 1890's brought the extraction of coal reserves from local Pennsylvanian strata, which, in turn, led to a booming local economy. With the addition of English investment and the influx of new workers, the town of Middlesboro was established in 1889 by local coal baron Alexander Arthur and named after Middlesborough, England. Middlesboro's economic boom continued until the crash of 1893 and a major fire destroyed part of the town. After a slow rebound, Middlesboro recovered and still maintains its mining-based economy.

Early Scientific Investigations. Before the turn of the 20th century, geologists began to take interest in the southern Appalachians and the conspicuous Middlesboro Basin. N.S. Shaler of Harvard University conducted the first geologic survey of the region and simultaneously ran a geologic field school for students from 1875 to 1880 (Kincaid, 1999). Other early investigations examined possible origins for Middlesboro Basin. Ashley (1904) and Ashley and Glenn (1906) discovered strata in the basin that were "greatly disturbed by folding and faulting" and a broad, flat, alluviated basin (Ashley and Glenn, 1906). Both researchers attributed the disturbed strata to "stresses that produced the formation of the Appalachian province." Development of the basin occurred as a result of the erosion of weakened strata and subsequent ponding within the basin. In 1933, John L. Rich agreed with Ashley and Glenn's conclusions, adding that Middlesboro resulted from the collapse of a small dome, followed by gravitational settling and ponding.

Later geologic mapping of the area led to a different interpretation for the Middlesboro Basin. Englund and Roen (1962) interpreted it to be the site of an ancient impact. They cited the presence of a circular basin, intensely deformed rock, normal faulting with circular trends around the basin, overturned beds, "shattered" quartz grains, and a central core of uplifted material as evidence of impact. Such observations were consistent with an impact model for Middlesboro, but did not confirm an impact origin.

Confirmation came in 1966, when Robert Dietz discovered shatter cones (Fig. 31) around the central uplift area and later petrographic analyses of sandstone specimens led to the identification of shocked quartz (Bunch, 1968; Carter, 1968). Later examination of shocked conglomeratic sandstones from the center of impact found additional shocked quartz and extensive microfaulting that may have resulted from central uplift formation (Milam and Kuehn, 2002). Additional magnetic and gravity surveys (Seeger, 1970, 1974; Steinemann, 1980) have further supported an impact origin.

Although these early studies have identified Middlesboro as an impact crater, detailed mapping and petrologic analyses have yet to reveal the true mechanics and morphology of this impact.

Part I: Regional Geology

Begin at the Cumberland Gap National Historical Park Visitor Center along U.S. 25E south of Middlesboro (Fig. 32). Hours are 8:00 A.M.–5:00 P.M. daily year-

round, except December 25 and January 1. This stop provides water and restroom facilities.

Stop 1. Cumberland Gap National Historical Park Visitor Center. Our trip begins with a visit to the Cumberland Gap National Historical Park Visitor Center. The visitor center houses cultural and natural history exhibits from the Cumberland Gap area. The center provides a historical and cultural context for the remainder of an otherwise scientific trip.

The geology of this region and the human saga have been intertwined for thousands of years. Northeast–southwest-trending mountains, such as Cumberland Mountain and Pine Mountain, have influenced human settlement and commerce. Both Native Americans and early European-descent settlers crossed these mountains through natural wind or water "gaps." From 1790–1810, approximately 250,000 settlers from eastern states crossed through Cumberland Gap on their way to Kentucky and Tennessee. Cumberland Gap was also of strategic value for funneling supplies and troops to the North and South during the Civil War. The gap remained a primary transportation route until 1995, when the Cumberland Gap Tunnel, a 4,600-ft twin-bore tunnel, was opened. The tunnel was designed to better accommodate growing traffic along U.S. 25E in the Cumberland Gap area. It enters and exits Cumberland Mountain west of the gap. An important component of the tunnel project has been restoration of the landscape through Cumberland Gap by the National Park Service. Historical documentation was used to provide information about the gap's appearance circa 1790–1810. After removal of the abandoned U.S. 25E through the gap, fill material from the tunnel excavation was used to restore original topographic contours. Although such impressive engineering feats have improved traffic flow, natural gaps still serve as important transportation corridors through the southern Appalachians.

Take a right out of the parking lot and proceed east along Pinnacle Road for 3.6 mi (Fig. 32). This winding road is not suitable for trailers and large vehicles over 20 ft in length. A parking lot is available at the top. From the parking area, take the short hike to Pinnacle Overlook. During inclement weather, the overlook can be very windy.

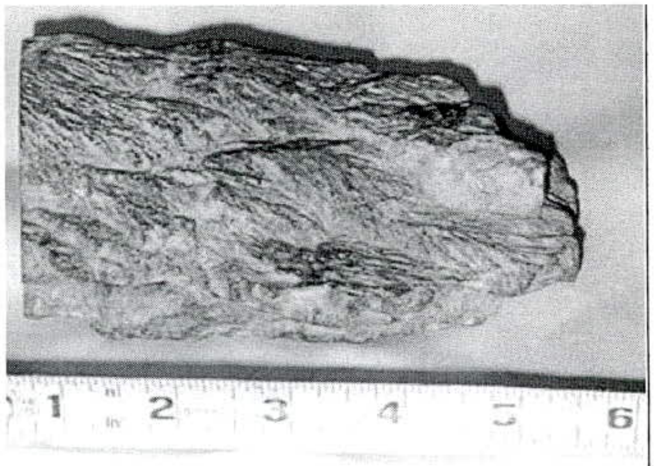

Figure 31. Shatter cones collected from the central uplift area of the Middlesboro impact structure.

Stop 2. Cumberland Mountain/Pinnacle Overlook. This stop in Virginia affords a breathtaking view of Cumberland Mountain, Powell Valley, and at least the southern half of the Middlesboro impact structure, depending upon the time of year and amount of foliage (Fig. 33).

Most natural features within view are a part of the Pine Mountain Thrust Sheet (also know as the Cumberland Overthrust Block), a large northeast–southwest-oriented thrust sheet extending through Kentucky, Tennessee, and Virginia.

Pinnacle Overlook is situated atop Cumberland Mountain, an exposed section of northwest-dipping, Devonian to Pennsylvanian rock. Cumberland Mountain forms the northwestern limb of the Powell Valley Anticline, whose axis of lower Paleozoic strata lies within the valley viewed to the southeast from the overlook.

A brief examination of strata at the overlook reveals graded and crossbedded conglomeratic sandstones of the Lee Formation (Fig. 34). These coarse-grained sandstones containing very well-rounded quartzite pebbles (up to 1.5-in.-diameter) were deposited during the Late Mississippian to Early Pennsylvanian Periods (Rice, 1984). Pennsylvanian *Calamites* fauna are present in this unit. You will see this prominent ridge-forming unit exposed again along Pine Mountain and anomalously within Middlesboro.

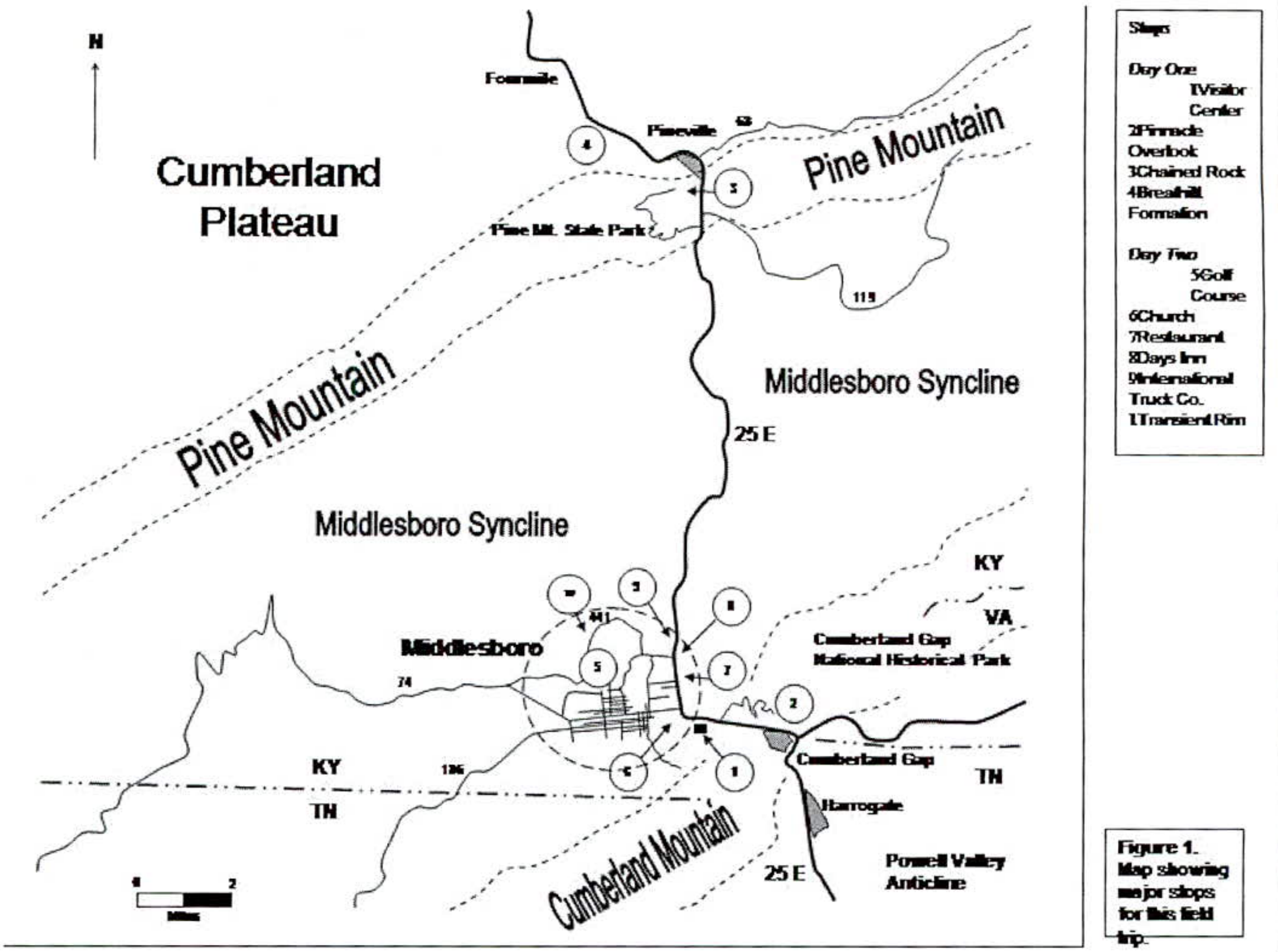

Figure 32. Major stops for day 1 of this field trip.

Middlesboro Basin lies to the northwest and holds the town of the same name (Fig. 33). The Middlesboro Basin is a circular, alluviated depression (with up to 2,000 feet of relief) containing intensely deformed rocks mostly of the Breathitt Formation. It is drained by Yellow Creek, which flows northward into the Cumberland River.

This anomalous structure, situated atop the Pine Mountain Thrust Sheet, led early researchers to hypothesize various formation mechanisms (see "Early Scientific Investigations," p. 30). More recent geologic mapping of the Middlesboro North (Englund and others, 1964), Middlesboro South (Englund, 1964), and Kayjay/Forkridge (Rice and Maughan, 1978) quadrangles led Englund and Roen to propose an impact origin for Middlesboro in 1962.

Surrounding Middlesboro and visible to the northwest lie the flat-lying strata of the Pennsylvanian Breathitt Formation. These units form a deeply incised plain around Middlesboro and within the Middlesboro Syncline.

Retrace the route down Cumberland Mountain along Pinnacle Road (Fig. 32). Go past the visitor center and follow the signs to U.S. 25E North. Take U.S. 25E north for 10.6 mi until reaching a turnoff on the left (west) for Pine Mountain State Resort Park. After 3.4 mi, enter Pine Mountain State Resort Park. Continue for 4.6 mi, following the signs to the Chained Rock Overlook parking lot. Hike the 0.5-mi trail to the Chained Rock Overlook. (Caution: This stop has very steep drop-offs and is very dangerous for climbing. There are no handrails.)

Figure 33. Westward view of the Middlesboro Basin from Cumberland Mountain, showing prominent landmarks. White dashed line demarcates the approximate outer boundaries of the modified Middlesboro impact.

Stop 3. Pine Mountain/Chained Rock Overlook. High atop Pine Mountain in Kentucky, you're now viewing the leading edge of the thrust sheet to the north (Fig. 35). Chained Rock Overlook (Fig. 36) is approximately 2,200 ft above sea level and 1,200 ft above the town of Pineville, Ky. Chained Rock gets its name from the large, yet-to-be-detached boulder chained to the mountain here. Local tradition has it that in the early 1900's residents from Pineville, concerned about the threat the boulder posed to the town, attached a 101-ft chain to the ominous rock, anchoring it to Pine Mountain. The chain (with 7-lb links) was purportedly carried to the mountaintop by four-mule teams in two trips. The chain seen today is a 1933 replacement of the original one. The effectiveness of this preventative measure is open to debate.

The gap visible just below and to the northeast (Fig. 35) was produced by the Cumberland River downcutting through Pine Mountain as uplift occurred. This is the only point in Kentucky where a modern-day stream breaches Pine Mountain along its entire length (McGrain, 1975).

The escarpment along the leading edge of the thrust sheet contains exposures of southwest-dipping Devonian to Pennsylvanian strata. Pine Mountain is capped here by the resistant, conglomeratic sandstones of the Lower Pennsylvanian Lee Formation, similar to those on Cumberland Mountain. Additional conglomeratic sandstone exposures just above the overlook provide a vantage point for viewing the entire structural setting from the Cumberland Plateau to Cumberland Mountain farther south.

Retrace your route, exiting Pine Mountain State Resort Park, and return to the intersection with U.S. 25E (Fig. 32). Take a left and continue north along U.S. 25E for 3 to 4 mi. Travel beyond Pineville. Pull off the highway at some spectacular exposures of the Breathitt Formation along mile marker 16. (Note: There is heavy traffic at this site, and extreme caution should be used when viewing this outcrop.)

Stop 4. North of Pineville. Horizontal strata of the Lower to Middle Pennsylvanian Breathitt Formation are exposed here in the Cumberland Plateau. Note the variety of lithofacies (sandstone, siltstone, shale, and coal) and the extent of their lateral continuity (Fig. 37). The Breathitt Formation lies immediately above the Lee Formation in the field trip area (Fig. 38). These strata represent deposition in marginal marine/terrestrial environments. It is important to get a sense of the nondeformed appearance of these units prior to entering Middlesboro, where similar units are heavily disturbed.

Part II: Middlesboro Impact Crater

From the Cumberland Gap National Historical Park Visitor Center, take a left out of the parking lot and follow the signs to U.S. 25E North to Middlesboro (Fig. 32). One-half mi after getting on U.S. 25E, just inside the city limits of Middlesboro, take a left at the first stoplight onto Cumberland Avenue. Continue for 1.3 mi, passing through the downtown area, until reaching 27th Avenue. Take a right (go north). Continue for seven blocks until reaching Circenster Avenue. Take a left (go west). At the next intersection, take a right (go

Figure 34. Crossbedded conglomeratic sandstone of the Lee Formation along Cumberland Mountain near Pinnacle Overlook, Cumberland Gap National Historical Park.

north) onto Haywood Road. Take the next left (west) into Middlesboro Country Club. Park in the parking lot next to the clubhouse. Hours are 10:00 A.M.–8:00 P.M. (winter), 9:00 A.M.–10:00 P.M. (summer), and 8:00 A.M.–10:00 P.M. weekends. (Note: Permission must be obtained from the manager prior to viewing exposures, and collecting is not allowed.).

Stop 5. Central Uplift/Middlesboro Golf Course. You are now standing at ground zero of the Middlesboro impact structure (Fig. 39). Englund and Roen (1962) first noted the presence of conglomeratic sandstones of the Lee Formation here (Fig. 40) and suggested that this area was a centrally uplifted core of material bounded by "steeply inclined normal faults" (yet to be confirmed), common in complex craters. They also noted that "shattered" quartz grains with "parallel arrangement of fractures" were present in the core conglomerates. Bunch (1968), Carter (1968), and Milam and Kuehn (2002) later identified shocked quartz containing planar deformation features in these rocks, providing confirmation of an impact origin for Middlesboro.

It was at this site that Robert Dietz (1966) noted the presence of "concave striations suggestive of shatter coning" in an outcrop at the northeastern end of the parking lot adjacent to the clubhouse (Fig. 40). Whether or not this is actually an outcrop is uncertain. This may only be a remnant boulder. A couple of hundred yards to the northwest, Dietz reported finding boulders that were "intensely shatter coned," however. These boulders are no longer there because of extensive landscaping, but additional samples of Lee conglomerate can be viewed in a cobble field approximately 100 feet north of the clubhouse. In 1999 we located a single sample of coarse-grained siltstone from Middlesboro containing approximately 10 shatter cones (Fig. 31), owned by Dr. Nicolas Rast (deceased) of the University of Kentucky (Milam and Kuehn, 1999). Additional rare shatter cones were found by Milam (Fig. 41) in 2002.

In 1999, new samples of Lee conglomerate were collected from the central uplift area and have undergone petrographic analysis (Milam and Kuehn, 2002). They show intense shattering and fracturing of the fine-grained conglomeratic sandstone, possible melt textures, sheared quartzite pebbles, planar fracturing, and planar deformation features. These textures are providing new insight into the impact cratering process and, specifically, central uplift formation (Milam and Kuehn, 2002). Additional field work has allowed us to further document and delineate other surface exposures of the Lee Formation (Fig. 42). Structural data from the crater rim, however, suggest that the bulk of the central uplift may actually be present farther to the northeast. Now that we've examined the center of the impact, let's look at some exposures along the rim areas.

Return to the parking lot and retrace your route back to Cumberland Avenue (Fig. 32). Take a left (heading east) onto Cumberland Avenue and travel for 1.2 mi and turn right (south) onto the last road on the right

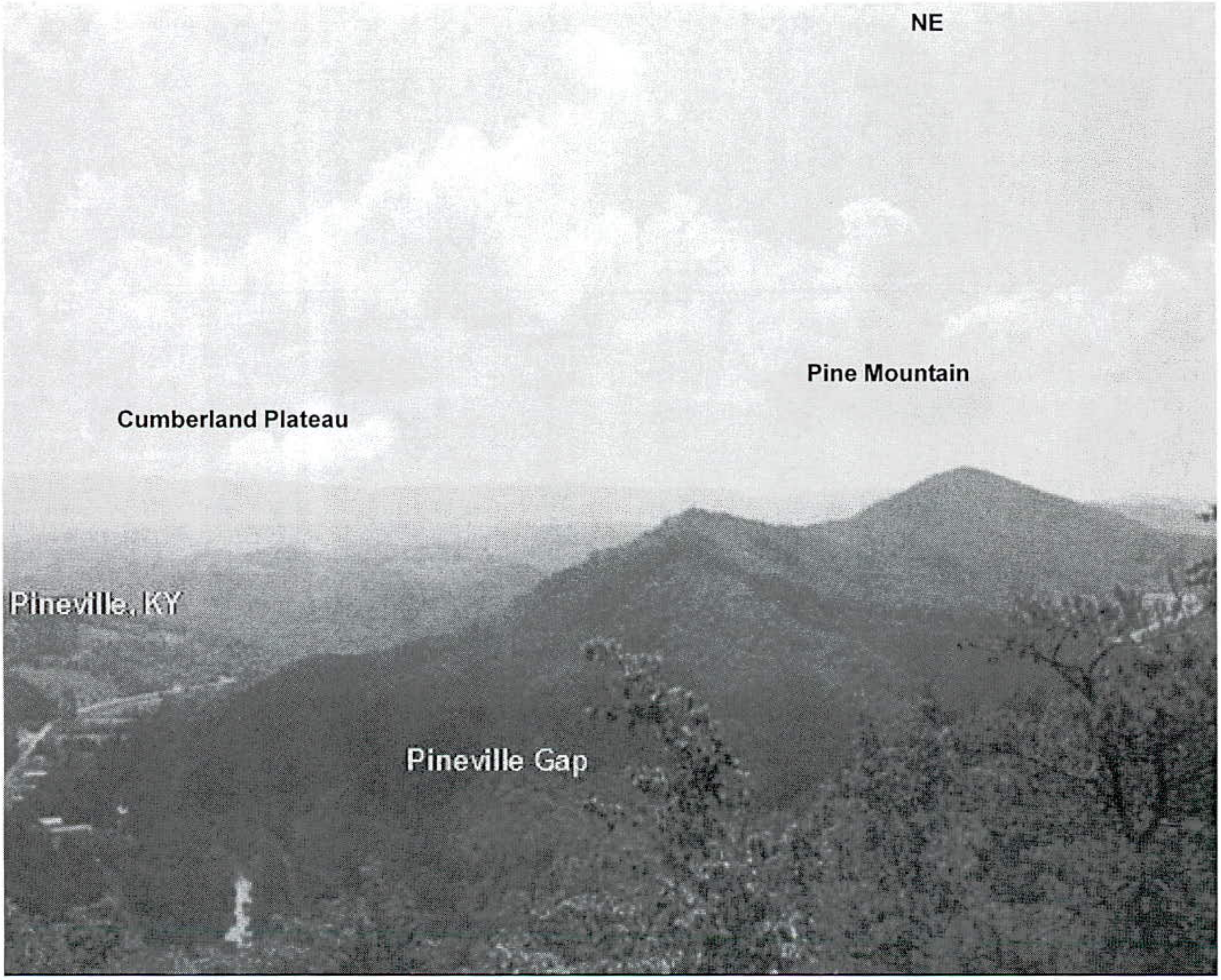

Figure 35. View of the leading edge of the Pine Mountain Thrust Sheet along Pine Mountain from Chained Rock Overlook. The Cumberland Plateau is visible along the horizon farther to the north.

before U.S. 25E. Continue for 0.1 mi to the parking lot of the Faith Missionary Baptist Church. Exposures are behind the church. This is a heavily weathered, sloping site that isn't easily visible from the parking lot. A better view can be obtained by cautiously climbing the slope. (Note: Permission must be obtained from the proper church officials before viewing this site.)

Stop 6. Transient Crater Rim/Faith Missionary Baptist Church. Now you're near the southeastern rim of the transient crater that was initially formed at Middlesboro (Fig. 43). This exposure preserves the ejection and modification stages of impact. At the top of the site you'll notice a series of primarily reverse faults (Fig. 44) in southwest-dipping sandstones, siltstones, and shales from the Lower Pennsylvanian Breathitt Formation, with interspersed normal faults. Bedding strikes to the northeast and dips to the southeast, away from the central uplift. Notice the drag folds associated with the reverse faults (Fig. 44). Approximately 10 ft farther down section you'll notice monoclinal folds oriented according to similar stress fields. Fault planes and fold axes have northeast strike and northwest dip orientations. The primary force that was placed on these strata appears to have come from northwest of this site, from the direction of the central uplift area.

This site thus preserves an instant in time during crater formation, when material was being

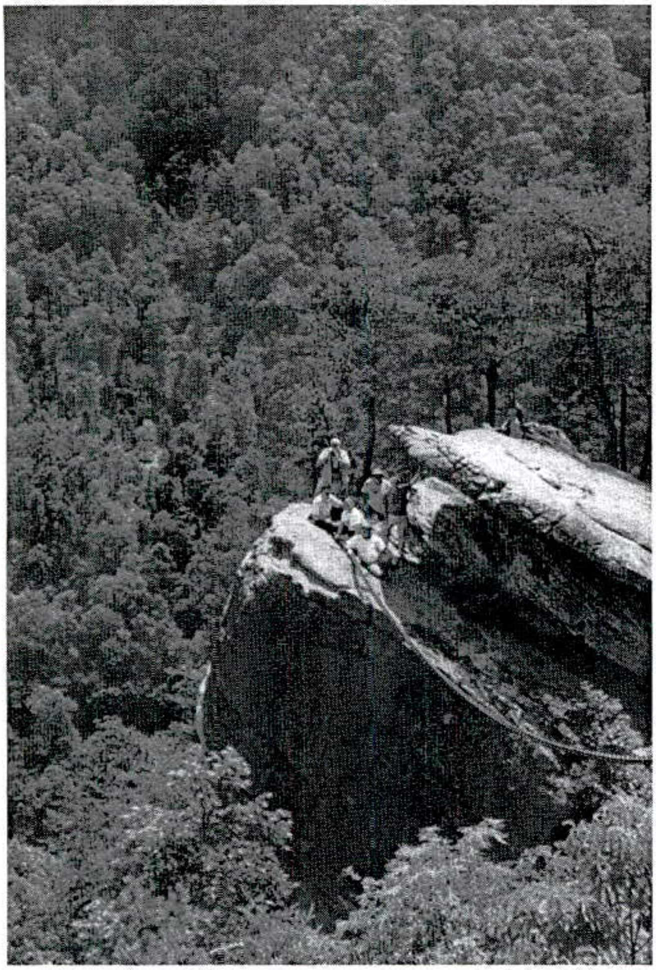

Figure 36. Chained Rock Overlook, Pine Mountain State Resort Park, looking northeast toward Pineville Gap. Notice the southeast-dipping strata of the Lee Formation.

thrown from the transient crater, and material near the rim was being pushed up, out, and away from the center of impact (Fig. 45). Some of the material was ejected, while the rest was thrust up along high-angle reverse faults (such as at this site). Following the ejection stage, large blocks of material then slumped back into the basin along arcuate normal faults. The hill containing this exposure may be one such block, but only future excavations to the south will determine this.

Retrace your route back to Cumberland Avenue (Fig. 32) and take a right (heading east). Turn left at the next stoplight and head north on U.S. 25E. Approximately 0.7 mi down the road on the right is an outcrop behind a restaurant (Lee's Famous Recipe). Park at the rear of the parking lot. Walk around behind the fence to view the outcrop (Note: Permission must be obtained from the restaurant manager before viewing this site.)

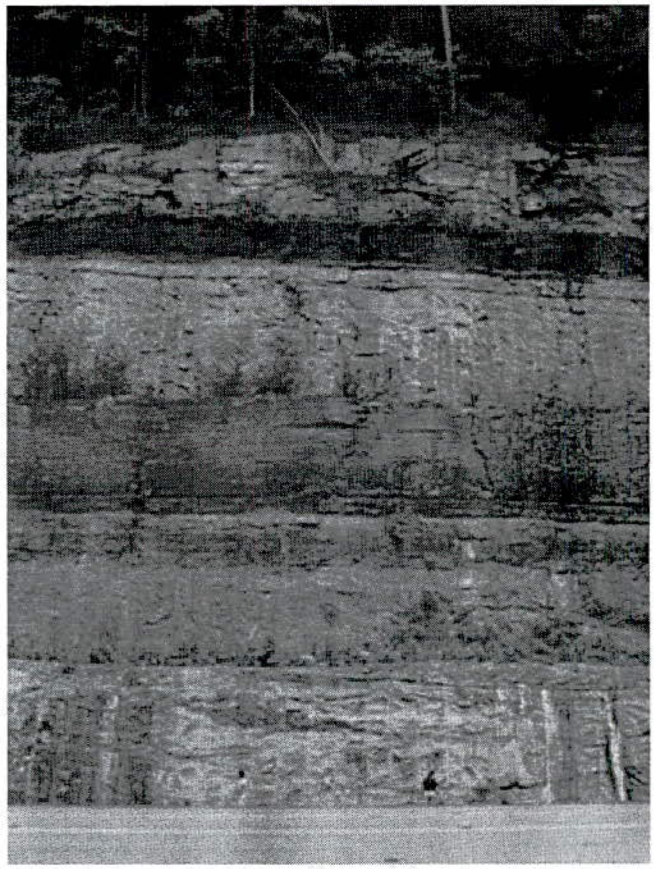

Figure 37. View of the flat-lying stratigraphy of the Breathitt Formation in the Cumberland Plateau, northwest of Pineville, Ky., at stop 4.

Stop 7. Lee's Famous Recipe. At this stop you'll view severely deformed shale, siltstone, sandstone, and coal of the Breathitt Formation (Fig. 46) that is relatively undisturbed as the exposure continues to the south. Several faults, small folds, and drag folds are present within this cut.

How this deformed block of material relates to the impact model isn't clear. Were these strata thrust from the east upon nearly horizontal strata (to the west) and we are viewing the leading edge of an arcuate fault along which a terrace block has collapsed during crater modification? Or is this a localized slump feature? Future examination of new exposures to the north and south may reveal the answer in time, but for now, you are the judge.

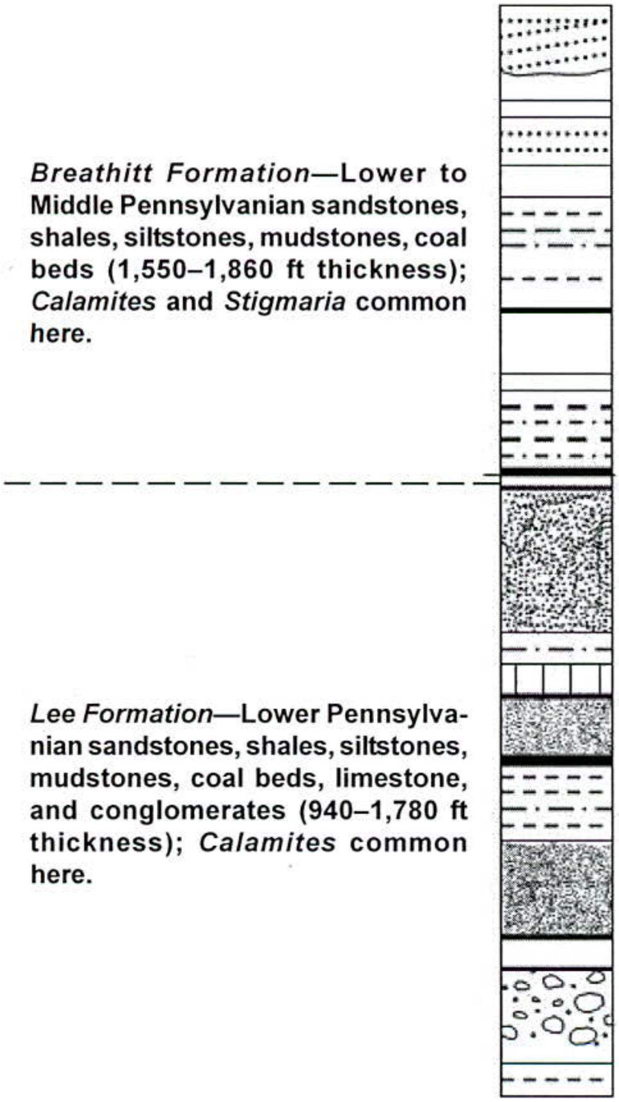

Figure 38. Generalized stratigraphy of Pennsylvanian strata (Lee and Breathitt Formations) in the field trip area.

Return to your vehicle and exit the parking lot by taking a right (heading north) onto U.S. 25E (Fig. 32). Drive for 0.8 mi and turn right into the parking lot of Days Inn. (Note: Exposures are behind a Hardee's restaurant, Days Inn motel, and Ryan's Steakhouse. Please obtain permission from each facility's manager before viewing the site.)

Stop 8. Modification Stage/Days Inn. The entire hillside is a footwall of Breathitt Formation that slumped along a normal fault to the east during the modification stage of impact (Fig. 47). Most of the material you're viewing consists of siltstones

Figure 39. View of the central uplift area, now the Middlesboro Country Club golf course; Cumberland Gap is visible in the background to the southeast.

Figure 40. Outcropping (or boulder?) of conglomeratic Lee Formation north of the clubhouse at Middlesboro Country Club golf course, displaying striations originally described by Robert Dietz (1966).

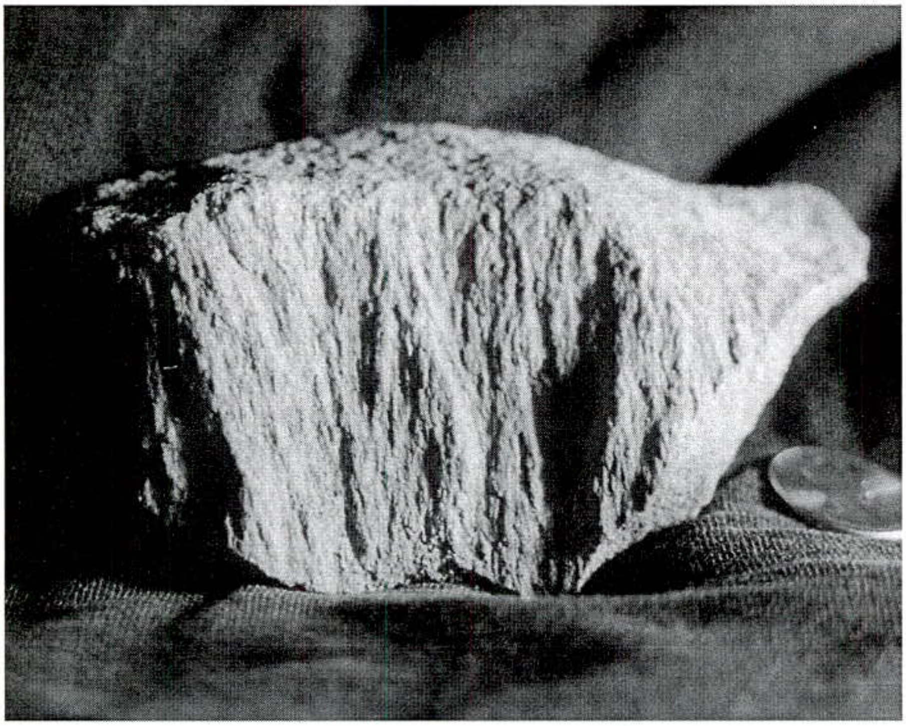

Figure 41. Shatter cones collected by Keith Milam in 2002.

and shales, heavy with carbonaceous plant fossils. These rock layers contain small channels of dark brown fluvial sands (as viewed on the upper, southern end of the outcrop). The top of the hill is capped by a thick, coarse-grained, crossbedded, fluvial sandstone unconformably overlying stringers of coal and associated underclays. Bedding here dips gently to the north and southwest.

One of the most noticeable features of this cut is its heavily fractured nature. The fractured strata here have resulted in environmental impacts in this urban area. At one time, the hillslope actually extended across present-day U.S. 25E. As you may notice, much of this hill has been cut away to accommodate the previously mentioned businesses on the eastern side of the highway. Because of the densely fractured nature of the strata and the orientation of the bedding, slumping, rock falls, and slides are quite common here. This situation has been alleviated somewhat by "stair-stepping" the slope of the outcrop to control minor sliding.

Return to your vehicle and take a right (heading north) out of the parking lot (Fig. 32). Continue through the stoplight, and 0.2 mi after the last stop, take a left at the International Truck Company Park into the parking lot. Exposures are behind the buildings. (Note: Permission must be obtained from the manager prior to viewing these cuts.)

Stop 9. Modified Crater Rim/International Truck Company. Nearly horizontal strata of the Breathitt Formation are preserved in the southern end of this cut. On the northern end, rocks are dipping away from the center of Middlesboro Basin (to the northeast). This site contains a zone of intense deformation. Many normal and reverse faults whose fault planes are perpendicular to the center of impact are preserved here (Fig. 48). Cataclasis along fault planes is common here. Reverse faults here appear to have resulted from the ejection stage of impact just outside the transient crater rim. Following impact, material collapsed back into the transient crater along normal faults. The identification of key marker beds at the southern end of this outcrop shows that the southernmost block has approximately 800 ft of vertical displacement.

Take a right (heading south) form the parking lot onto U.S. 25E (Fig. 32). Continue for 0.2 mi to the stoplight. Take a right (heading west) at the stoplight onto Ky. 441 (Hollywood Road). Continue on Ky. 441 for 0.2 mi, taking a right; continue for 0.4 mi and take a left on Belt Line Road. Travel approximately 1.5 to 2 mi (you should eventually see Yellow Creek Bypass [a stream] on your left) until you reach a small cut on the right (north) between Lick Fork and Stevenson Roads. Turn in to the right and park. (Note: This is private property, so permission should be obtained from the current landowner.)

Stop 10. Transient Crater Rim/Yellow Creek Bypass Site. This last stop for today also preserves the ejection stage of impact and lies along the transient crater rim. It displays deformed strata of the Breathitt Formation (Fig. 49). Shale, siltstone, sand-

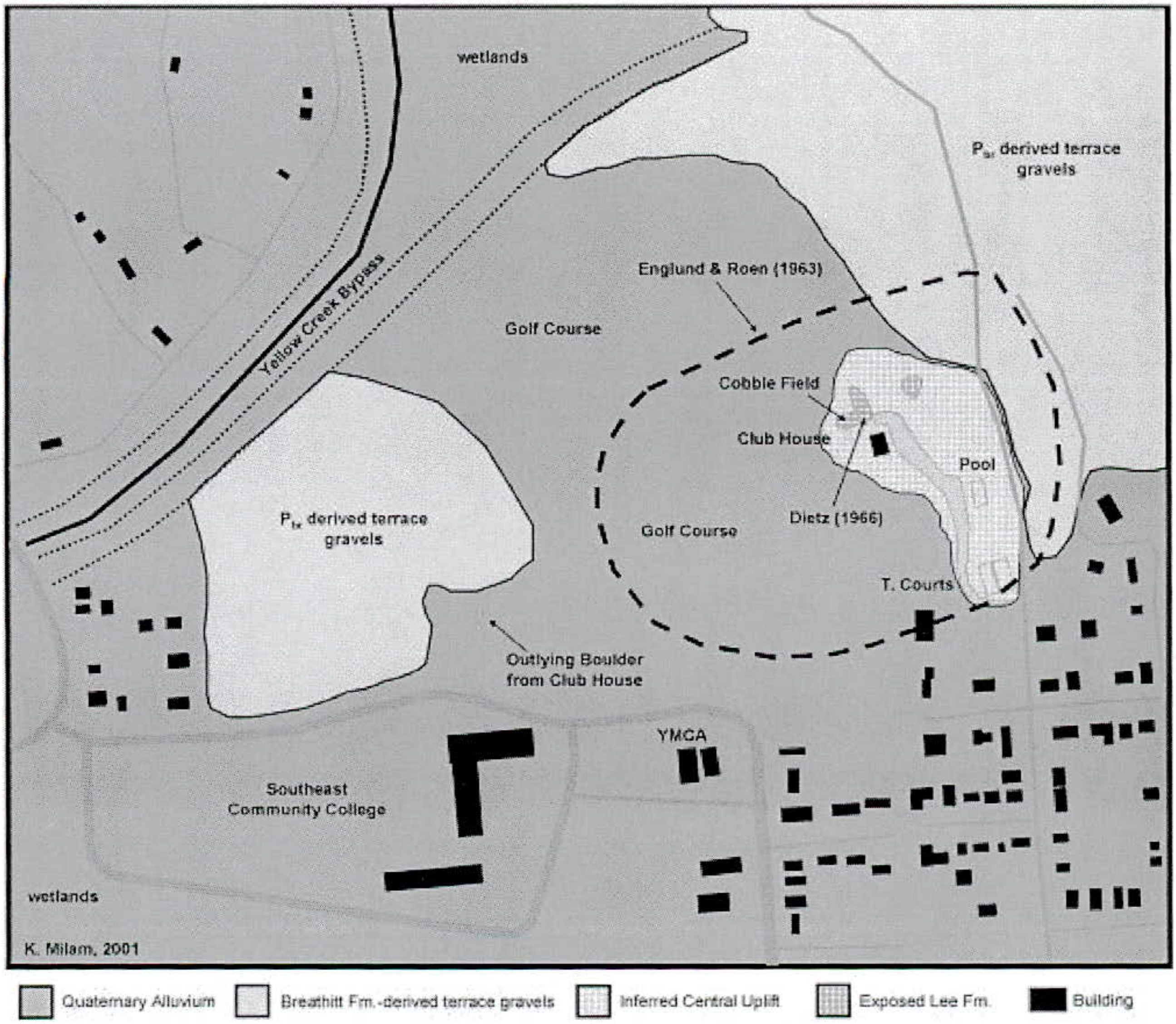

Figure 42. The inferred central-uplift location, showing exposures of the Lee Formation.

stone, and coal of the Breathitt Formation all strike 15 to 35° to the northeast and dip 44 to 68° to the northwest (generally away from the center of the impact).

The most interesting feature of this cut is the nearly overturned flap of shale, coal, and underclay. Similar structures have been noted in other impact structures. Overturned bedding in the form of an "ejecta flap" was first recognized at Barringer Meteor Crater, Arizona (Shoemaker, 1960) and has been shown to be a distinguishing feature of transient crater rims. This site may represent preservation of the lower half of an ejecta flap at Middlesboro, and allows us to confine the location of the transient cater in the northwest. During the impact ejection stage, this flap of material was nearly overturned and was followed by collapse of the crater rim (Fig. 50). During crater-wall collapse, the block of material shown moved along a normal listric fault, leading to rotation of bedding and thus the current orientation of strata in this exposure.

Afterword

There are several additional exposures within the Middlesboro impact crater that do not fall

Figure 43. Exposure of Breathitt Formation near the transient crater rim near Faith Missionary Baptist Church.

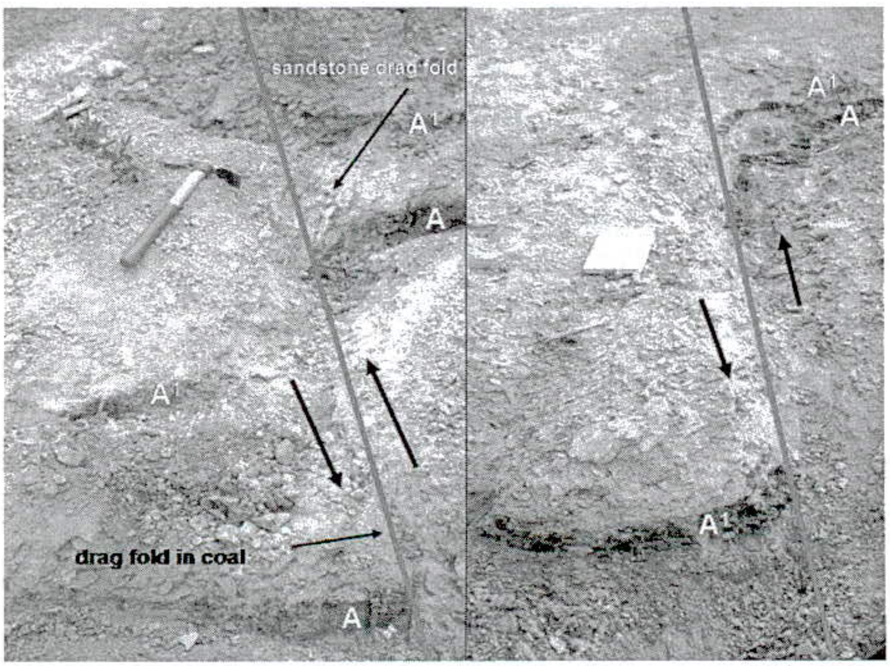

Figure 44. Examples of reverse faults and associated drag folds at stop 6.

within the scope of this field trip. New exposures are also created with continuing urban development in this basin. If you would like to see any of these additional exposures, take the time to drive around town now that you're more familiar with the area. Additional mysteries await the trained geologic eye at Middlesboro, Ky.

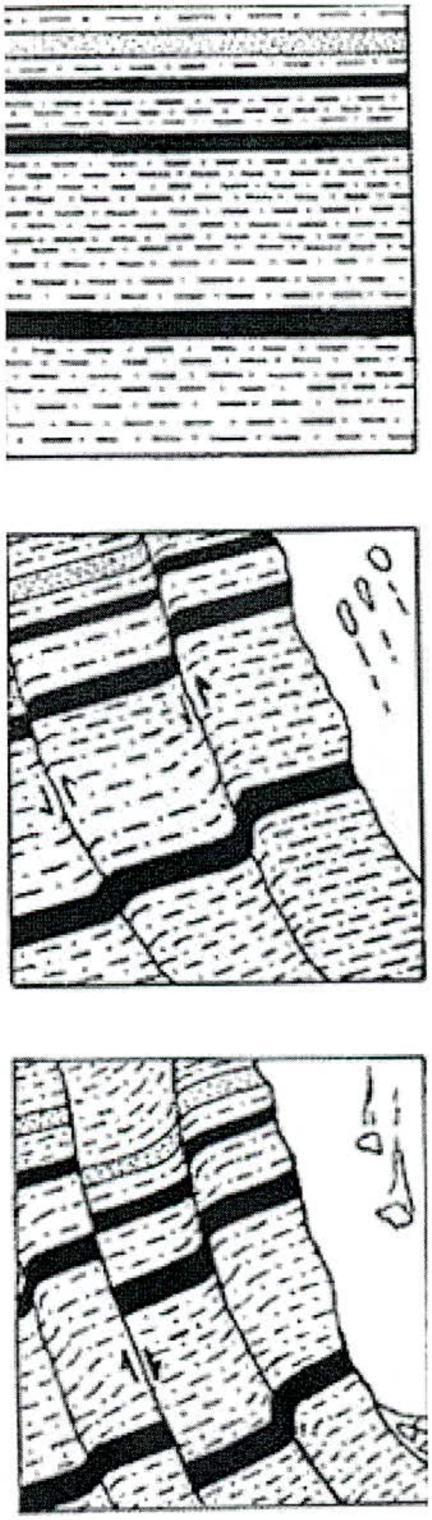

Figure 45. The formation of the transient crater rim and subsequent collapse near stop 6. (a) Preexisting stratigraphy. (b) Strata being faulted and folded during the ejection/excavation stage. (c) Collapse of the transient crater rim and fallback of ejecta during the modification stage of impact.

Figure 46. Exposure of highly disturbed Breathitt Formation behind the restaurant at stop 7.

Figure 47. Hillside exposures of highly fractured Breathitt Formation behind motel at stop 8.

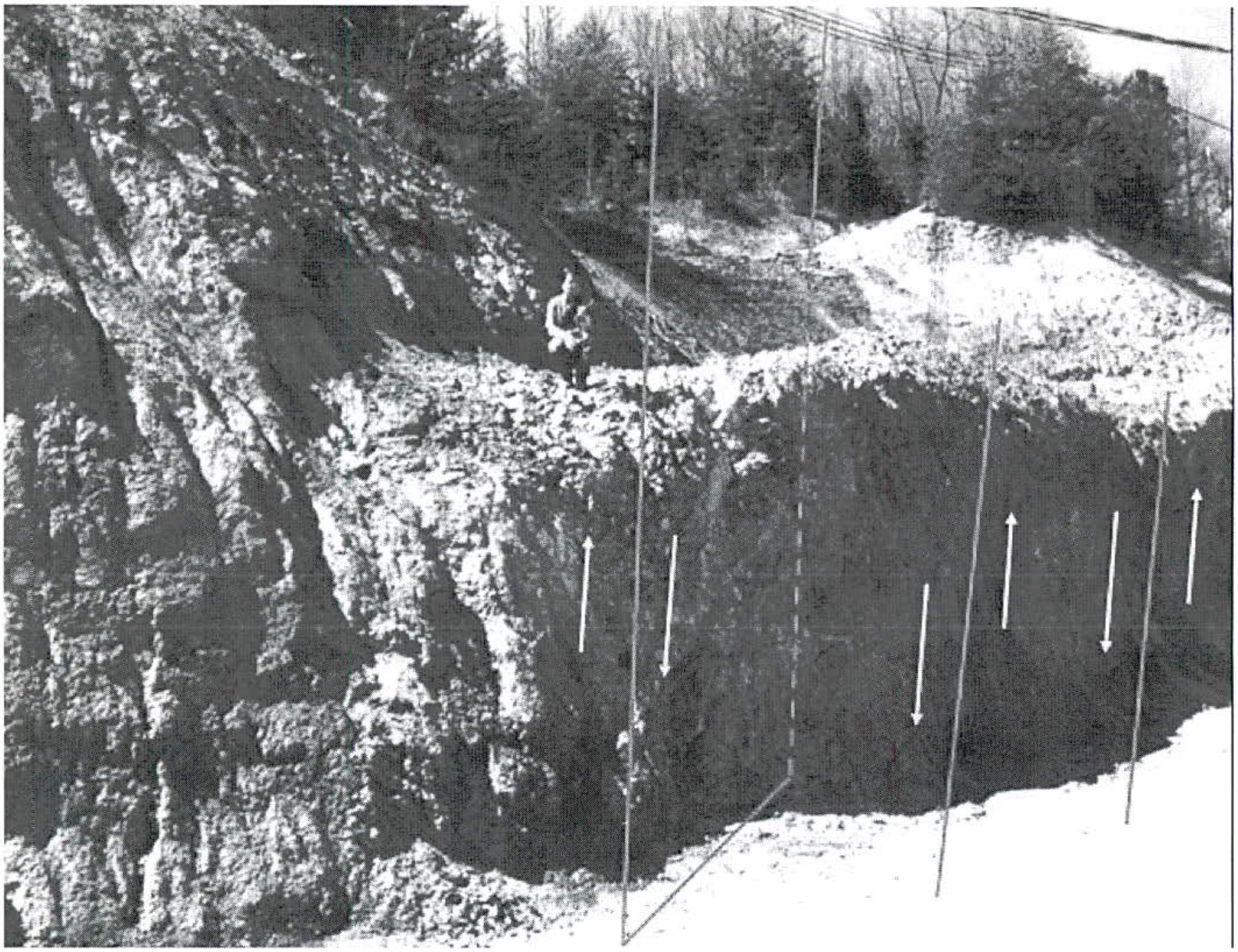

Figure 48. Extensive faulting behind stop 9.

Day 2: Saturday, September 20, 2003

Stop 1. Cumberland Gap Tunnel

In September 1989 our predecessor group, the Geological Society of Kentucky, also visited the Cumberland Gap Tunnel as part of its annual field conference (Moshier and Dean, 1989). At the time, all that existed of the now-operational twin-bore tunnel was a single 4,150-ft-long, 10-ft-diameter pilot bore. A walk through this pilot tunnel provided the participants an unprecedented "inside story" of the geology of Cumberland Mountain—that is to say, we observed a continuous, unweathered exposure of 2,750 ft of Middle Silurian to Lower Pennsylvanian stratigraphic section striking N45°E and dipping 40°W.

The completed Cumberland Gap Tunnel cost an estimated $280 million and was dedicated in October 1996. The twin tunnels are 30 ft high, 4,600 ft in length, and have two driving lanes. They are cross-connected by passages every 300 ft that are equipped with fire extinguishers and telephones for emergency use. Large, jet-powered fans circulate the air while sensors collect data on traffic movement and volume. These data, along with visual information supplied by video cameras, are monitored in the control room of the portal building on the Kentucky side of the tunnel. We will be given a tour of the control room and its Intelligent Transportation Systems (ITS) technologies.

More than 25,000 vehicles now pass through the twin portals on a daily basis. The annual operation and maintenance costs of the tunnel ex-

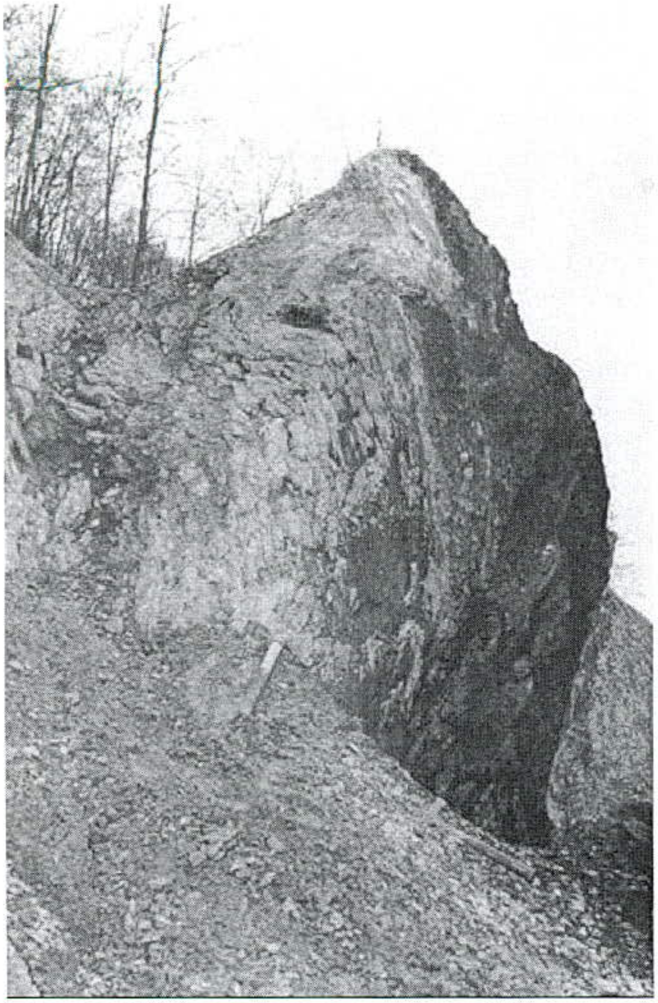

Figure 49. View of rotated and "upturned" coal, shale, and siltstone bedding of the Breathitt Formation near the transient crater rim at stop 10.

ceed $2 million and are shared by the states of Kentucky and Tennessee. In 2002, the Cumberland Gap Tunnel and the state's parkway system were cited as Kentucky's most significant transportation infrastructure development projects of the 20th century by the American Road and Transportation Builders Association.

In addition to providing a safer and more convenient passage, another goal of the tunnel project was to help preserve the historic Cumberland Gap. Opening the tunnel diverted traffic from a dangerous section of U.S. 25E and allowed the National Park Service to restore the old pioneer trail. Their restoration, which was completed in May 2002, removed asphalt, returned the land to its original contour, and replanted native vegetation. More

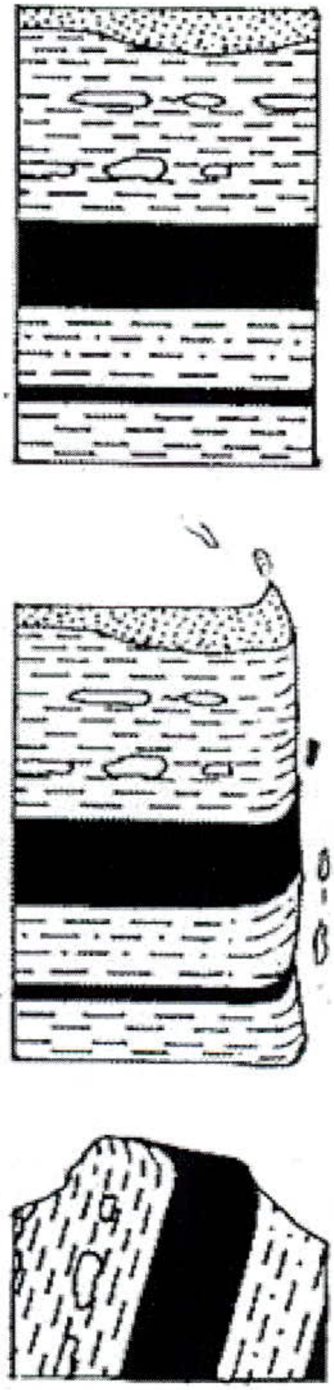

Figure 50. Schematic view of the "upturned flap" shown in Figure 51. (a) Preexisting stratigraphy. (b) Material being excavated along the transient crater rim during the ejection stage. (c) How post-impact modification has rotated strata as the transient crater rim has collapsed back in the basin along normal arcuate faults.

than 20,000 trees were planted along the old roadbed and adjacent areas.

Internet Resources:

- National Park Service: www.nps.gov/cuga/tunnel.htm and www.nps.gov/cuga/restore.htm
- Federal Highway Administration: www.efl.fhwa.dot.gov/projects/cumgap/cumbgap.htm

Stop 2. The Lost Squadron Museum

At our final stop of the day we will learn the improbable history of *Glacier Girl*, a Lockheed P-38 Lightning fighter plane from World War II. This airplane was actually recovered in 1992 from a depth of 268 ft within the Greenland ice cap! It then underwent a 10-year restoration process and took to the air again on October 26, 2002.

In World War II, the P-38 was the fastest fighter plane in the world, capable of speeds in excess of 400 mph, which earned it the nickname "Lightning." It was also very heavily armed and had a long cruising range. As part of Operation Bolero, the *Glacier Girl* was one of six P-38 fighters and two B-17 bombers on a mission to Europe until bad weather caused them to turn back and land on Greenland before their fuel ran out. That was July 15, 1942. The crews were rescued safely a few days later, but the airplanes were left behind and over the years became covered by ice and snow.

Between 1977 and 1992, a number of attempts were made to locate, reach, then salvage the airplanes, but all were unsuccessful. Finally, using a process called "cold mining," a special probe using circulated hot water slowly melted its way through the ice and reached the *Glacier Girl*. This truly remarkable story has been documented in a book, in an hour-long television program, and here in the Lost Squadron Museum, which is open to the public.

Internet Resource:

- thelostsquadron.com/museum.html

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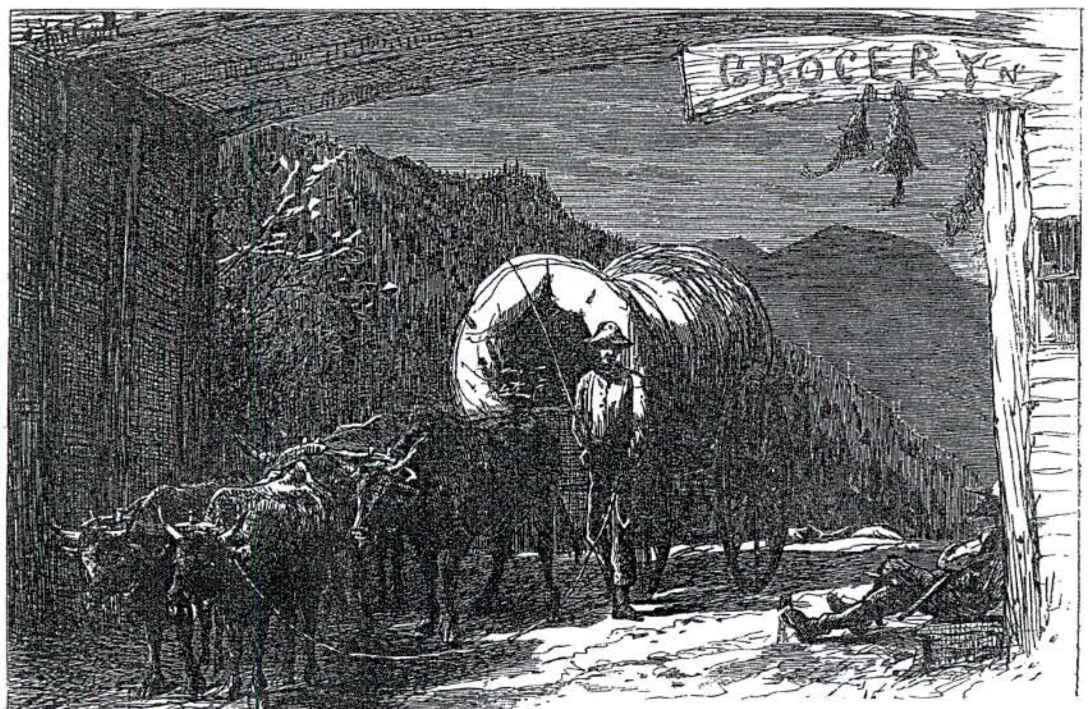
Appendix: Excerpts from *Appletons' Journal, 1872*

APPLETONS' JOURNAL
OF LITERATURE, SCIENCE, AND ART.

ENTERED, according to Act of Congress, in the year 1872, by D. APPLETON & Co., in the Office of the Librarian of Congress at Washington.

No. 155.—VOL. VII.] SATURDAY, MARCH 16, 1872. [PRICE TEN CENTS.

CUMBERLAND GAP.



A GLIMPSE OF KENTUCKY, FROM CUMBERLAND GAP.

THE tourist may be familiar with the fastnesses of Alpine scenery, the heights of Mont Blanc, the cone of Vesuvius, the bald summit of Washington, or the gigantic outlines of the Western cañons, and yet, memories and associations attached to all of these localities will be recalled by a visit to that region of America in which the Cumberland Mountains trend obliquely across the States of Kentucky and Tennessee; because, somewhere in the four thousand four hundred miles of territory occupied by these "everlasting hills," they present to the eye almost every variety of picturesque expression that elsewhere has excited wonder or admiration.

Great ridges—now roofed over with thickets of evergreen, now padded with moss and ferns, or, again, crowned with huge bowlders that seem to have been tumbled about in wild disorder by some convulsive spasm of the monster beneath—shoot suddenly upward, from two thousand to six thousand feet, and become, as it were, landmarks in the skies, that are visible at such distances as to appear like a part of the clouds. Here and there, a broad table-land, on which a city might be built, terminates abruptly in sharp escarpments and vertical sheets of rock, seamed and ragged, like the front of a stupendous fortress that has been raised by giant hands to protect the men of the mountains from the encroachments of the lowlanders. There are other rocks full of grand physiognomics; caves that might be the hiding-places of the winds; water-falls where the melody of the rills is never silent; glens and chasms; and forests so dense that a man might live and die in their recesses—

"The world forgetting, by the world forgot."

And so, in every conceivable shape that can appeal to the eye of poet, artist, or geologist, Nature has here piled up her changeless masonry of creation.

The "ridges" referred to are among the curiosities of the Cumberland region. Aside from the fact that they observe a species of parallelism to each other, they contain numerous "breaks," or depressions, which, in the peculiar configuration of the country, appear to the traveller who is at the foot of the mountain to be distant only a few hundred rods; yet he must frequently ride for miles through a labyrinth of hills, blind roads, and winding paths, before he can reach the entrance and pursue his journey.

The chief and most celebrated of these great fissures, or hall-ways, through the range, is known as "Cumberland Gap." The name "Cumberland," it may be observed parenthetically, was given to the mountains in honor of the Duke of Cumberland, a celebrated English prince and soldier. This gap is situated in East Tennessee, near the Kentucky border, about one hundred and fifty miles southeast from Lexington, and may be regarded as the only practical opening, for a distance of eighty miles, that deserves the name of a "gap." There are other places which are so called, but it is only for the reason that they are more easy of access than because of any actual depression in the mountain. At a place called "Rogers's Gap," for example, which is eighteen miles distant from Cumberland Gap, there is no gap whatever; but the road, taking advantage of a series of ridges on the northern side, and running diagonally on the southern side, is rendered passable by man and beast, and with great exertion may be travelled over by wagons.

The gap illustrated by Mr. Fenn is about six miles in length, but so narrow in many places that there is scarcely room for the roadway. It is five hundred feet in depth. The mountains on either side rise to an altitude of twelve hundred feet; and, when their precipitous faces have been scaled by the tourist, and he stands upon the summit, the view, beneath a cloudless sky, is one of the most beautiful in America. Southward, there stretch away the lovely valleys of Tennessee, carpeted in summer with every shade of green, and in autumn with every rainbow tint—the rolling surface resembling in the distance a vast plain, written all over with the handiwork of human enterprise; while, looking to the north, the vision is lost among a series of billowy-backed mountains, rising barrier-like to hide the luxuriant fields of Kentucky. "Across the country," is here a significant phrase; for the luckless traveller whose route lies in that direction must be prepared to encounter—

"wave on wave succeeding."

The gap delineated in the two accompanying sketches is a great highway between Southwestern Virginia and her sister States adjoining. Hence, during the late war, the position was early deemed important, and was occupied and strongly fortified by the Confederate Government. Cannon bristled from the neighboring heights, and a comparatively small force held the pass for many months, defending in that secluded mountain-recess the railroad-connections between Richmond, North Alabama, Mississippi, Nashville, and Memphis, on the integrity of which so much depended.

The approach to the range from the northeast side, after leaving Abingdon, Virginia, is over a rough, broken country; and the only compensation to the traveller, as he saunters along on horseback, is in the enjoyment of bits of scenery wherein rocks and running streams, mountain-ferries, quaint old-fashioned mills, farm-houses and cabins perched like birds among the clefts of hills, lovely perspectives, wild-flowers and waving grain, and a homely but hospitable people, combine in charming confusion to keep the attention ever on the alert.

The road through the gap, winding like a huge ribbon, to take advantage of every foot of rugged soil, up, down, and around the mountains, is but the enlarged war-trail of the ancient Cherokees and other tribes, who made incursions from one State to the other. You are following the path pursued by Boone and the early settlers of the West. Passing through the scenes of bloody ambuscades, legends, and traditions, it would seem almost a part of the romance of the place if now an Indian should suddenly break the reigning silence with a warwhoop, and its dying echoes be answered by the rifle-shot of a pioneer. In short, it is an old, old locality, covered with the rime of centuries, and but slightly changed by the progress of events.

Of residents in the gap, there are but few. One of these has been enterprising enough to establish, near an old bridge, which is shown in the picture, a grocery-store, and obtains his livelihood by trading in a small way with the teamsters of the passing trains, and exchanging whiskey, clothing, etc., for the produce of his neighbors. Similar establishments will be found at intervals of five, ten, or fifteen miles; sometimes they are half hidden from view in the coves, or "pockets," of the mountains. But they absorb much of the small "truck" that finds its way to market from this section. The commodities thus purchased and shipped in the mountain-wagons through the gap, *en route* to Baltimore and elsewhere, consist of dried apples, peaches, chestnuts, butter, lard, flax-seed, bacon, etc. Horse and mule trading is likewise carried on to a considerable extent; and sharp-witted, indeed, must be that man who can buy or sell more acutely than these self-same mountaineers, whose lives have been hammered out on the anvil in Nature's own workshop.

As a class, they are a large-bodied, large-hearted, large-handed people, rude in speech, brave in act, and honest in their friendships. They may know nothing of the conventionalities of society, but they will exhibit the "small, sweet courtesies of life"—as they understand them—with an *abandon* of generosity that makes one "feel at home." They may have but a single room in their cabin; yet you will be invited to enjoy the night's hospitality like one of the family, and may go to bed with "he, she, and it," on the family floor, with the manifestation of no more curiosity or concern, on the part of the individual members thereof, than if they had been born without eyes. And in the morning, after a "pull" at the "peach-and-honey" and a breakfast of hog and hominy, a long stride by your horse's side for three or four miles will tell you that the mountaineer knows how to "speed the parting guest," in his simple fashion, with a grace and hospitality that has come straight from the heart.

The road through a portion of the gap, and one of the caravans which are frequently *en route*, may be seen in one of the accompanying pictures; while in the other sketch is a view of a primitive, old mill, now almost in ruins, where grain is ground for the neighbors; but it is situated in a spot so picturesque that, if money could buy the beauty of Nature, long ago it would have been transplanted to become the site of a rural palace.

Whatever may be the peculiarities of the locality, social or otherwise, the time cannot be far distant when the whole of this wild region must yield to the march of improvement, and pour forth the treasures of mineralogical wealth now latent in its soil. Already, a railroad is in process of construction, that is destined to cut the backbone of Kentucky and Tennessee in twain, and open a new avenue of communication between the East and West; while geologists and engineers are "prospecting" among the mines.

Iron exists in abundance—a common variety being the red iron-ore, which soils the fingers, and is generally composed of small round and flat bodies, for which reason it is called "lenticular ore." Not unfrequently, fossils, shells, and a species of coral, are found in the mass, showing that at some period in the misty past the sea or its tributaries have swept through the heart of the continent. At some points in Cumberland Gap the iron is hard enough to be quarried out in blocks, and this band of metal has been traced one hundred and fifty miles. It is from twenty-four to thirty inches thick, and is of excellent quality. Coal is likewise found in this region, and, as far back as 1854, many thousands of bushels were transported through the gap. Nitre, alum, Epsom salts a cubic foot in volume, gypsum, sulphur, slate, marble, flagging-stones, are also products of the neighborhood, that only await the completion of railroads, the settlement of the country, and the magic wand of the immigrant, to add vastly to the prosperity of the State and people. And, when that period arrives, and the iron fingers have fulfilled their mission, a section of America will be opened, not merely rich to the geologist, capitalist, and artisan, but rich to the lover of all that is wild, beautiful, and picturesque in Nature—a field of wealth and romance that has been scarcely touched, of which little is known beyond local history, and which makes even a day's sojourn an episode of life wherein are merged the associations of a century.

F. G. DE FONTAINE.

CUMBERLAND GAP, FROM THE EAST.

See Page 281.