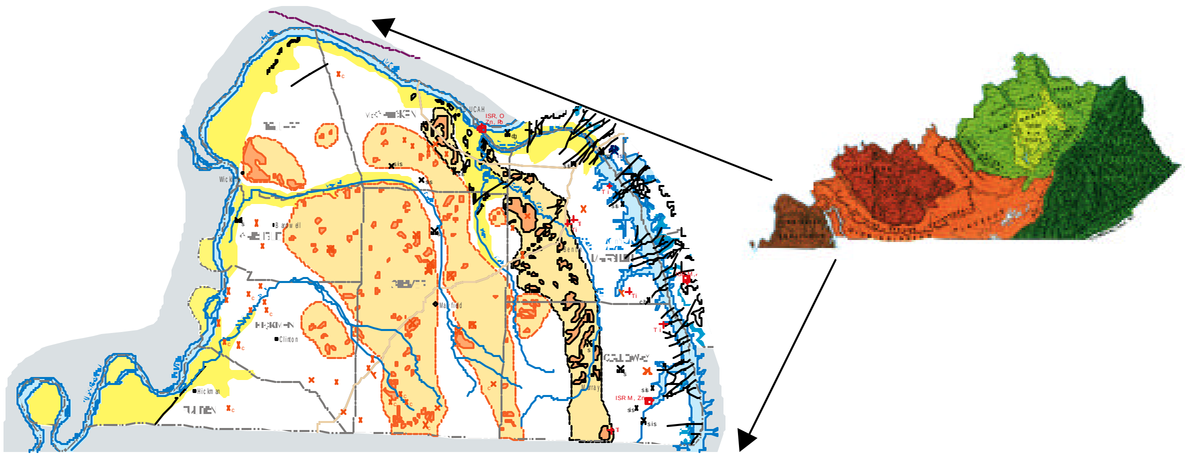
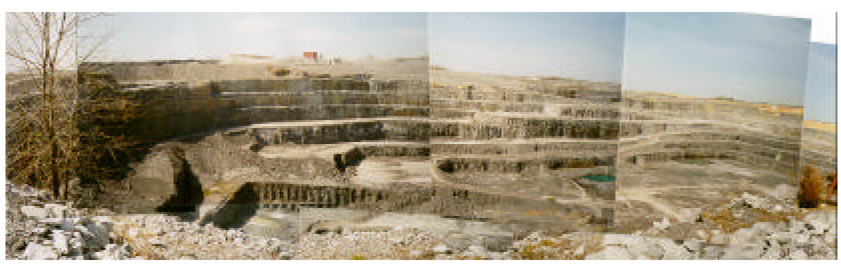
Economic and Engineering Geology of the Jackson Purchase Area, Kentucky





Year 2000 Annual Field Conference of the Kentucky Society of Professional Geologists

November 2-4, 2000

Economic and Engineering Geology of the Jackson Purchase Area, Kentucky

Compiled by
Richard A. Smath and Bart Davidson

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Cover images (clockwise from top left): Mineral resources map of Kentucky; (Anderson and Dever, 1998); physiographic map of Kentucky; Claiborne Formation overlain by continental deposits; Hickman landslide remediation project; Reed Quarry (Vulcan Materials Company).

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Dedication

The Kentucky Society of Professional Geologists would like to dedicate this field trip to the memory of four outstanding geologists who have recently passed away: Lloyd N. Baker, Robert McDowell, Wilds W. "Bill" Olive, and Harry Settle. Each of these men played an important role in helping to expand the base of geologic knowledge about the Jackson Purchase area.

Acknowledgments

A field trip of this magnitude cannot be accomplished without the help of numerous organizations and people. KSPG especially wishes to thank the following companies and people for their help in making this trip possible:

Old Hickory Clay Company: Steve Balkwill and Larry Kirk
Vulcan Materials Company (Reed Quarry): Terry Teitloff and Dale Driskill
Southern Heritage Tours (The Travel Company, Ltd.): Norma Holmes and Regina Walls
Days Inn, Mayfield, Kentucky
Kentucky Geological Survey: Jim Cobb, State Geologist and Director;
Meg Smath and Collie Rulo, guidebook production
Mary Lou Cordell: Caterer
Zakaria Lasemi (Illinois State Geological Survey): speaker at stop 7
Our Guidebook Contributors
Dr. Paul Edwin Potter (University of Cincinnati): banquet speaker
Dr. Bob Self (University of Tennessee–Martin): banquet speaker

Economic and Engineering Geology of the Jackson Purchase Area, Kentucky

Richard A. Smath[1] and Bart Davidson[1]
Compilers

Introduction

by Bart Davidson

Welcome to the Year 2000 Annual Field Trip of the Kentucky Society of Professional Geologists. The idea for this trip was conceived while Richard Smath and I were gathering data last year on non-coal mining operations to update the Survey's new mineral resources map. We had such a memorable time meeting the people and visiting the sites you will see on this trip that we suggested it to the KSPG Executive Committee early this year. The last KSPG trip to this area was in 1972, so a return visit has been long overdue!

President Andrew Jackson purchased this part of Kentucky from the Chickasaw Indians in 1818, and it was named the Jackson Purchase in his honor. The Purchase includes eight complete counties and parts of Trigg, Lyon, and Livingston Counties to the east. The geology of the area consists primarily of unconsolidated sands, gravels, clays, and cherts of Cretaceous and Tertiary age. These sediments dip gradually toward the axis of a synclinal trough called the Mississippi Embayment, which extends to the Gulf of Mexico, and is generally parallel to the course of the Mississippi River. The gravels are from two distinct formations (Tuscaloosa and Lafayette)—the first is light gray to white, and the second is brown to reddish brown because of its limonite coating. The source of these gravels continues to be debated, but is generally thought to be from cherts in Devonian or Mississippian carbonates (McGrain, 1983). They are used extensively for road aggregate and landscaping in the area.

Eocene clay deposits (Porters Creek) are also found in abundance in the Purchase, and are still regularly mined for ball clay. Lignite coal is sometimes associated with the clays, but is generally discarded as overburden. Mining operations for sand, gravel, and clay are active from April through November. In places, the Porters Creek Clay is intersected by near-vertical clastic dikes, thought to be the result of seismic activity. We will visit one location where these dikes are exposed on day 1 of the trip.

The topography of the area consists of gently rolling hills on a plain; relief is usually less than 100 ft. There are occasional flat-topped hills that are capped with resistant gravel beds.

Each of these geologic units will be described in greater detail in the following sections of the guidebook. The stop locations are indicated on the geologic map provided in Plate 1 (pocket). On day 1 of our trip, all stops will be in the Jackson Purchase "proper." Day 2 will consist of a tour of the Reed Quarry in Grand Rivers, situated at the northeastern tip of Kentucky Lake. Plate 2 (pocket) shows the Jackson Purchase portion of the mineral resources map of Kentucky (Anderson and Dever, 1998).

[1]Kentucky Geological Survey

General Geologic Setting of the Jackson Purchase

by Richard A. Smath and
Donald R. Chesnut Jr.[1]

A generalized time-expansion stratigraphic column of the units exposed in the Jackson Purchase Region is shown in Figure 1, and the regional geologic setting of the area is shown in Figure 2.

Paleozoic rocks crop out along the eastern edge of the Purchase area, but are buried to the west and southwest beneath unconsolidated Mesozoic and Cenozoic sediments. The Cambrian–Ordovician basin of sedimentation in western Tennessee is referred to as the Reelfoot Basin. The center of the Reelfoot Basin moved north into what is now the Jackson Purchase Region in Late Ordovician time when a thick section of sediments accumulated. This basin was later uplifted, forming the Pascola Arch, and pre-Late Cretaceous erosion exposed Cambrian beds at the center of the arch. Downwarping later submerged the Pascola Arch and allowed for the accumulation of Late Cretaceous and Cenozoic sediments in the present trough of the Mississippi Embayment. The axis of the trough coincides roughly with the present-day course of the Mississippi River, and plunges to the south. Regional dip (1° or less) of the Paleozoic rocks in the Jackson Purchase Region trends north into the Eastern Interior Basin, and away from the Ozark Uplift to the west and the now-buried Pascola Arch to the south.

The Mesozoic and Cenozoic sediments were deposited on Paleozoic bedrock of Ordovician age in the southwest to Mississippian age in the northeast. Eocene formations exposed in the Jackson Purchase strike parallel to the Mississippi Embayment axis and dip west to south toward the axis, which roughly coincides with the east valley wall of the Mississippi River Valley (Olive and Finch, 1969). Because there is little exposure of the strata and a lack of key horizons, dips are approximated. Olive and Finch (1969) suggested through correlation of surface and subsurface data that the regional dip of the unconformity at the base of the Eocene series is to the west and south at slightly more than 30 ft/mi. They also noted that some locally exposed Eocene strata have high-angle dips in directions other than the regional dip, which may be caused by slumping after deposition, or faulting. The most significant feature to note in Figure 1 is the unconformity between the underlying late and mid-Paleozoic strata and the overlying Late Cretaceous and younger sediments. The Cretaceous and Tertiary strata are as thick as 2,050 ft in the western part of the Jackson Purchase and thin to zero along the eastern margin of the Jackson Purchase (Olive, 1980). They are shown in three dimensions in Figure 3.

The Tuscaloosa Formation

The Tuscaloosa Formation (Late Cretaceous), from 0 to 180 ft thick, is composed of very coarse gravels of chert with sand, silt, and some clay. It is restricted to a belt along the eastern edge of the Jackson Purchase and the extreme western edge of the exposed Paleozoic rocks in Kentucky (McDowell and others, 1981). The Tuscaloosa Formation extends from its outcrop belt laterally about 3 or 4 mi downdip (southwest) into the subsurface, where it pinches out (Olive, 1980).

Chert gravels and cobbles in the Tuscaloosa Formation are largely derived from Devonian and some Mississippian strata. A concentration of such large grain size suggests a local source for cobbles. The belt-shaped occurrence of the Tuscaloosa Formation and the very coarse grain size suggest a fluvial environment, possibly braided, perhaps with attendant debris flows and alluvial fans. An overabundance of cobbles and gravels indicates proximity to an uplift area (Chesnut, 1998).

The McNairy Formation

The McNairy Formation (Late Cretaceous) contains sand, silt, clay, and some gravels (McDowell, 1986). Lignites have been described by Hower and others (1990), and were deposited in terrestrial environments. The vertical trace fossil *Ophimorpha* is locally common in some sands and indicates a shallow open marine to estuarine environment (Pollard and others, 1993). Evidence suggests that the McNairy Formation was deposited in a coastal setting with varying relative sea levels (Chesnut, 1998).

The Clayton Formation

A regional disconformity separates the Late Cretaceous McNairy Formation from the overlying Paleocene Clayton Formation, which also consists of sand, silt, and clay. Palynological methods have been used to separate the two similar units (Tschudy, 1970). Although an abundance of freshwater palynomorphs suggests a largely freshwater deltaic or lacustrine environment for part of the Clayton (Olive, 1980; McDowell, 1986), pale-

[1]Kentucky Geological Survey

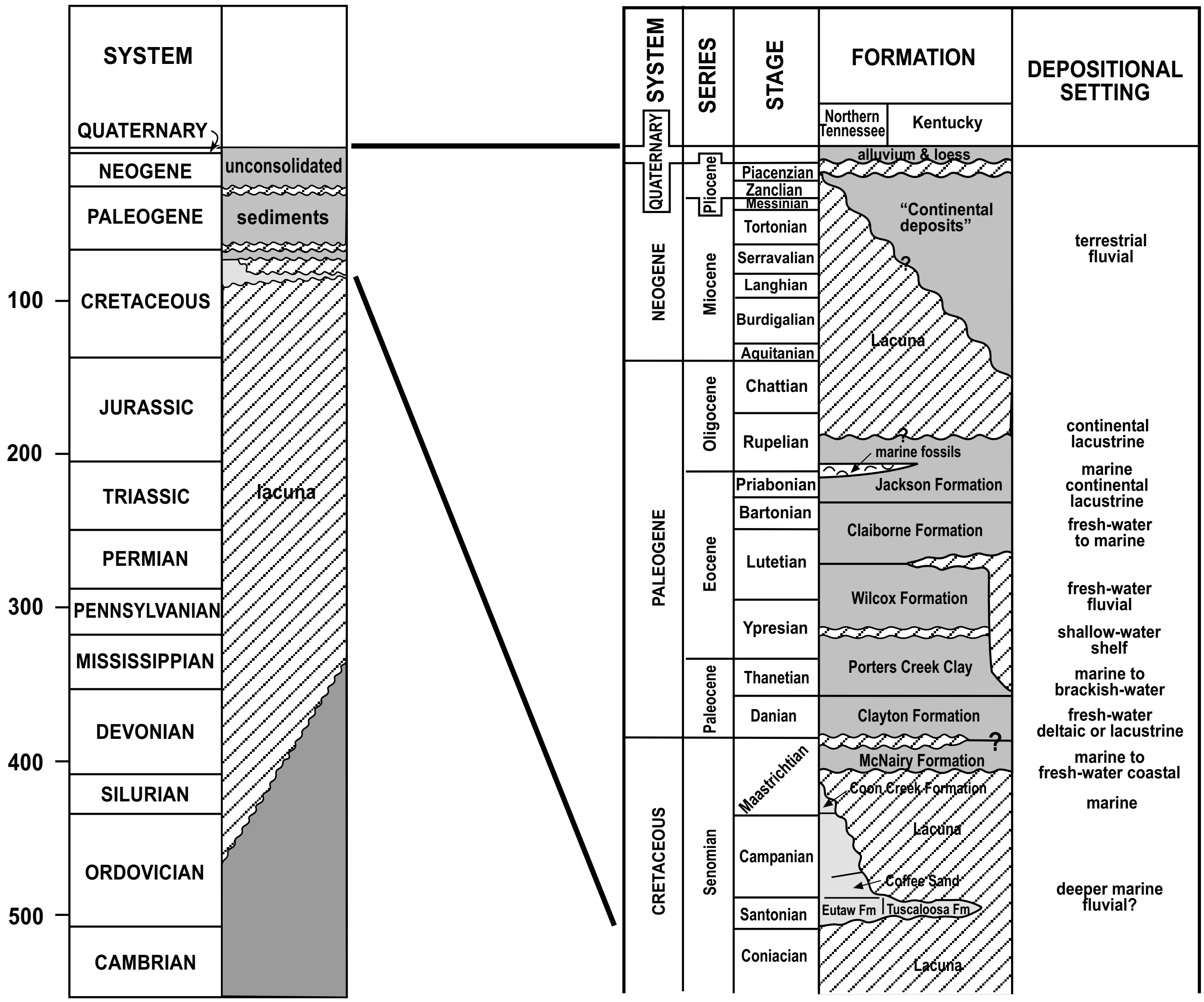

Figure 1. Time-expansion diagram of Jackson Purchase strata. Adapted from Harland and others (1989).

ontologic information indicates that marine conditions also existed (Reed and others, 1977).

The Porters Creek Clay

The Porters Creek Clay (Paleocene) is composed of sand, silt, and clay. Palynomorphs provide evidence for a marine environment, including shallow-water shelf to shallow epicontinental sea, with a possibly brackish-water, near-shore deltaic component in the northeast (Olive, 1980; McDowell, 1986). Oddly, the Porters Creek Clay yields little in the way of macrofossils; foraminifera, fish scales, and marine pelecypods and gastropods have been reported in McCracken County (Roberts, 1931).

The Wilcox Formation

The Wilcox Formation (early Eocene) consists mainly of thinly laminated, poorly sorted, intermixed sand, clay, and silt and attains a maximum thickness of 335 ft near the Mississippi Embayment axis. The clay is light gray to black with various shades of brown; it weathers to a dark yellowish brown to white and mottled pastel shades of red and orange. The clay is thin-bedded to massive and occurs as lenses from a few feet to a thousand feet or more across and as much as 30 ft thick. In the eastern part of the area, lenses of pisolitic clay 3 to 4 in. thick occur at the base in several places. Lignite deposits are also found (Cobb and Williams,

Figure 2. Regional geologic setting of Kentucky, including the Jackson Purchase Region.

1982; McDowell, 1986). Leaf imprints and comminuted lignite material are abundant at some horizons.

Much of the sand of the Wilcox Formation is fine, very clayey, micaceous, and white-specked; because of its appearance, it is commonly referred to as "sawdust sand" (Whitlatch, 1940, p. 233). Within the sawdust sand are white, curved, striated rods of kaolinite, 2 to 3 mm long, with well-formed transverse cleavage (Finch, 1964). The Wilcox Formation is extremely variable in thickness because of the irregular surface on which it was deposited, but largely because of the erosion preceding deposition of the overlying Claiborne Formation. In much of the outcrop area, Wilcox sediments filled stream valleys in the underlying Porters Creek Clay.

Palynomorph assemblages indicate a freshwater environment; the climate was probably subtropical and humid. Samples from northwest Calloway and northeast Graves Counties contain an abundance of varieties of conifer pollen and a relative scarcity of subtropical genera, suggesting a temperate or highland forest source (Olive, 1980). The configuration of the eroded surface on which the Wilcox Formation was deposited in updip areas suggests a drainage system of moderate- to high-gradient streams, probably tributary to a principal stream that flowed south along the Mississippi Embayment axis (Olive, 1980).

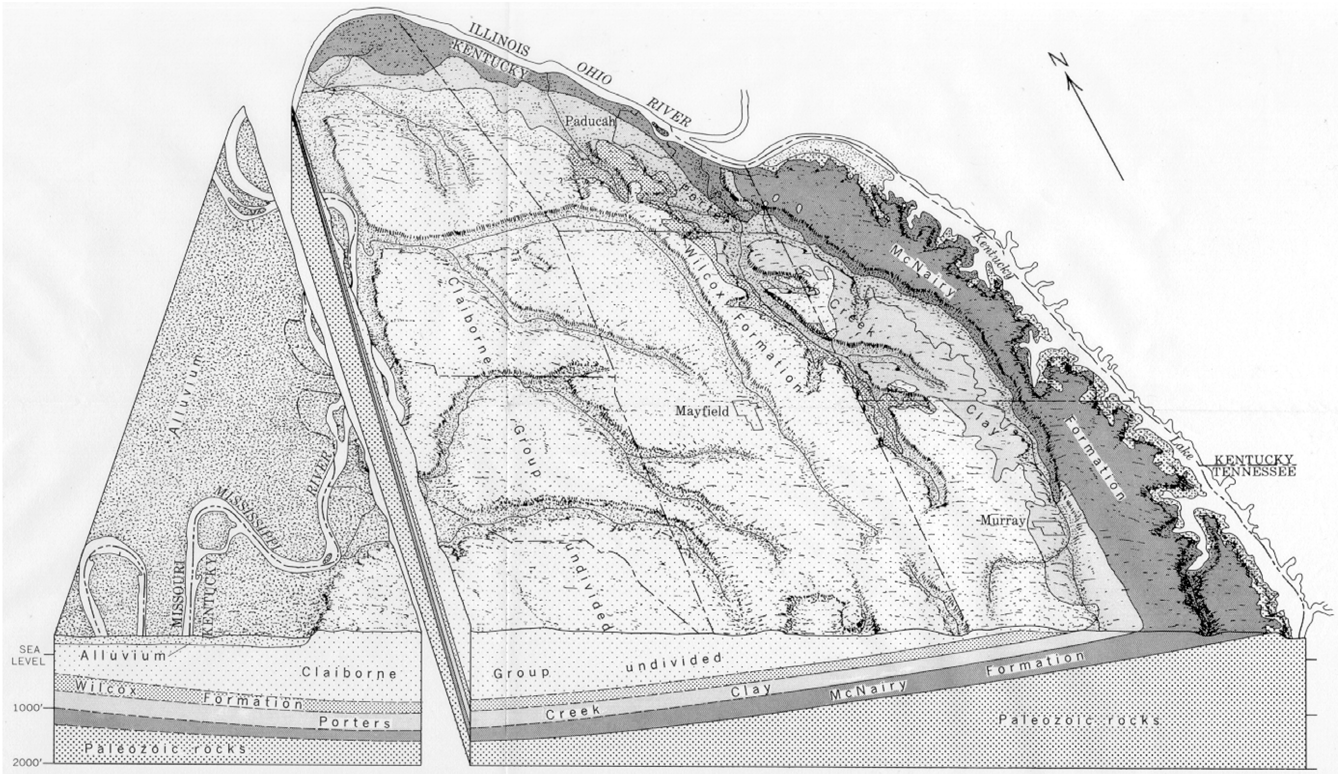

Figure 3. Block diagram showing generalized stratigraphy of the Jackson Purchase area. From Davis and others (1973).

The Claiborne Formation

The Claiborne Formation (Eocene) is the thickest unit of the Eocene sequence, attaining a maximum thickness of about 600 ft at the Mississippi Embayment axis. Most of the ball clay mined in the area is in the stratified layers of gravel, sand, clay, and minor deposits of lignite that make up the Eocene sediments of the Claiborne Formation. The sand is made up of angular to well-rounded, fine to medium and, in places, coarse to granular quartz, dark minerals, and locally muscovite (Olive and Finch, 1969). Crossbedding and cut-and-fill structures are common. Lenses of clay breccia and clay-ball (a chunk of clay released by erosion and rounded by stream action) conglomerate occur at various horizons throughout the unit (Olive and Finch, 1969). The clays are thin to thick bedded and massive. They occur in widely spaced lenses, and many are interstratified with argillaceous sand and silt, clean sand, and lignite. These lenses are as much as 18 to 40 ft thick, and average about 20 acres in size. They consist of three grades of clay, with organic material on top, pure clay in the middle, and siliceous clay at the bottom. The overburden on top of the clays is commonly sand, lignite, or gravel, and is between 25 and 80 ft thick.

Mineralogy of the clays consists predominantly of quartz and clay minerals. The clay minerals, in order of frequency of occurrence, are kaolinite, mixed-layer clay (made up of alternating layers of clay minerals or mica minerals such as chlorite or beidellite), illite, and montmorillonite.

Pollen assemblages from most localities indicate a freshwater deposition (Olive and Finch, 1969). Samples from the upper and lower parts of the formation indicate marine to brackish-water environments. Other evidence for a marine environment is glauconitic sand from one locality in southeastern Graves County (Olive and Finch, 1969). The climate during Claiborne deposition was warm and humid.

In updip areas, the Claiborne Formation rests on an unconformable surface of moderate relief that truncates the Wilcox Formation and Porters Creek Clay. This surface thins toward the axis of the embayment, as a result of erosion by streams that drained southward and westward from the embayment margins.

The Jackson Formation

The Jackson Formation (Eocene and late Oligocene?) is composed of sand, silt, and clay. The sand in the Jackson Formation is similar to the sand in the

Wilcox and Claiborne, but with a small amount of chert, which provides a means of distinguishing it from the Claiborne Formation. This makes it hard to distinguish from the cherty sand in local lenses and beds in the Continental Deposits of Pliocene(?) and Pleistocene age (Olive and Finch, 1969).

Jackson clay is dark to light gray, bluish gray, yellowish brown, and olive green. It is commonly sandy and micaceous and locally contains coaly plant material. It forms thin- to thick-bedded and lenticular clay deposits.

Samples taken from this unit show that palynomorph assemblages were deposited in a continental lacustrine environment. These samples were taken from sediments of late Eocene age and represent the youngest evidence of a marine environment in the Jackson Purchase Region (Olive and Finch, 1969). The climate during the late Eocene was subtropical to warm temperate. By Oligocene time, the sea had receded from the northern embayment region, and continental deposition prevailed.

Jackson Formation sequences consisting predominantly of clay and subordinately of silt are as much as 100 ft thick in areas bordering the Mississippi River in Fulton and southern Hickman Counties. These sequences thin and intergrade with sand northward and eastward. In updip areas, widely spaced lenses in the lower part of the formation resemble, in appearance and size, those of the underlying Claiborne Formation (Olive and Finch, 1969).

The Upper Eocene (and lower Oligocene?) consists of sand, silt, and clay. Lignite deposits occur locally (McDowell, 1986; Hower and others, 1990). Palynomorph assemblages of Eocene and Oligocene age are thought to have originated in a continental lacustrine environment. A few marine organisms have been found in the southwestern part of the area, however (Olive (1980).

Continental and Younger Deposits

Unconformably overlying the Jackson Formation are terrestrial deposits loosely termed "Continental Deposits" or Lafayette gravels (Olive, 1972). These largely fluvial deposits are of Miocene, Pliocene, and Pleistocene age. The overlying Quaternary sediments are alluvial, lacustrine, and loess deposits that drape over the older units throughout the Jackson Purchase (Chesnut, 1998). A more detailed description of the Lafayette gravels is given in the stop 1 section.

Day 1

Stop 1. The Old Hickory Clay Company Processing Plant, *by Richard A. Smath and Bart Davidson*

The Old Hickory Clay Company is one of four companies in the Jackson Purchase that mine ball clay. Figure 4 shows a view inside Old Hickory's clay-processing plant located in Hickory, just north of Mayfield on Kentucky Highway 1241. Ralph Scott founded the company in 1918. At that time, it was typical for one person to be involved in every phase of the business. Today Old Hickory is a corporation rather than a partnership, and the duties are divided between members of the Powell family. Clay is currently mined in Graves, Hickman, and Carlisle Counties. For more information, see the Old Hickory Clay Company Web site at www.oldhickory.com.

History of Clay Production. Clay has been mined in the Jackson Purchase Region commercially since its early settlement in the 1820's, and by the late 1800's clay was a major economic contributor to this region. During World War I, when imported clay from Europe had declined, the Jackson Purchase Region increased production to meet the demand. By the 1940's, clay from the Jackson Purchase Region and western Tennessee was supplying more than 80 percent of the ball clay consumed in the United States (Olive and Finch, 1969). Most of the ball clay comes from central and northern Graves County. All the clay pits are in the Eocene-age Claiborne Formation, with the exception of one that is in the Wilcox Formation, which is below the Claiborne Formation.

Today, ball clay refers to a kaolinitic clay (a common clay mineral of the kaolin group, $Al_2Si_2O_5(OH)_4$), up to 70 percent of which turns white after firing at 1,200°C in an oxygenated environment. Ball clay is virtually free of objectionable contaminants, is very plastic, and has a high "wet strength." Ball clays are uniform in their mineralogical makeup and are highly suitable for ceramics, sanitary wares, tile, sparkplug insulation, and as the heat shield for space vehicles.

Ball clay occurs in four areas: western Kentucky, western Tennessee, and Texas; Devon and Dorset, England; central Europe; and northern Thailand. Ball clays from northwestern Tennessee through southwestern Kentucky exhibit an array of physical and chemical properties. They also exhibit the highest diversity and quality.

Stop 2a. Clay Mining Operation (Old Hickory), *by Richard A. Smath*

A view of the Old Hickory Clay Company's Campbell pit is shown in Figure 5. Clay, sand, and gravel are currently being extracted from the pit, which is operational from April through November. The clay (from the Claiborne Formation) occurs at the base of the pit, and is overlain by Continental Deposits, which may include the Lafayette gravel. This gravel is separated, sorted, and stockpiled in the pit. A close-up view of Lafayette gravel is shown in Figure 6.

Production of Ball Clay. Once exploration has delineated economic deposits of clay, the mineral rights are secured by land purchase or mineral lease. Permits are then obtained to develop a mine at a chosen site, and a reclamation plan is submitted. Core drilling finalizes a mining plan, based on the information retrieved. Once the overburden is stripped, the area is inspected by the production manager and mining superintendent to ensure that the pit is ready for mining. Then the mining crew removes the clay according to the mining plan. As mining progresses, samples are always tested for quality control so that the clay can be stored according to its specific physical and chemical properties at the primary drying facility for several months and then later blended.

Processing of Ball Clays. Clay processing begins with receipt of an order. The production superintendent delineates the specific quantity of each type of clay used to produce the desired grade. The loader operator then selects the proper proportion from each specific pile of the stored clays and they are put into a mixing bin. The mix is shredded, which further blends the clays. The shredded clay is then conveyed to one of the following process stages:

1. Finished grade storage
2. Mechanical drying process
3. Air-floating process
4. Slurry process.

The clays are checked at each production stage for quality control, and all data are recorded and retained for each sample to study a number of control variables for process or material trends.

Stop 2b. Sand and Gravel Mining, *by Richard A. Smath*

When you travel across the Jackson Purchase, you see that many of the small side roads are topped with a distinctive brown to orange gravel. This aggregate consists of cherty gravel from the Continental Deposits (the Lafayette gravel) that are common throughout the area. This gravel is used for landscaping, paving, and home construction purposes. It is generally not suitable for use in concrete because of its high chert content, which can cause it to expand when wet. The sand separated from the gravel is used in making cement and concrete.

Stop 3. Clastic Dikes Near Symsonia, *by Todd Hendricks*[2]

In this area, the Porters Creek Clay is composed of three basic lithologic subunits. The basal unit, 20 to 40 ft thick, is composed of interbedded, partly glauconitic sandy clay and fine-grained, reddish-brown weathering sand. The middle unit is up to 120 ft thick, and is composed of light- to dark-gray, conchoidally fracturing, micaceous, montmorillonitic clay that weathers to chips and small blocks. The uppermost Porters Creek includes some 25 to 30 ft of interbedded, micaceous, dark-gray clay and silty, micaceous quartz sand.

The middle part of the Porters Creek is exposed in the stream bed south of the bridge. The clay is generally in the Porters Creek here and in adjacent areas of Marshall County (Olive, 1963; Olive and Davis, 1968). These dikes are composed of sand, silty sand, and micaceous sand that was liquefied and intruded into the Porters Creek during strong earthquakes in the area. They are medium gray, micaceous, and exhibit blocky weathering. Abundant vertical or nearly vertical clastic dikes are present, as shown in Figure 7.

Seismic liquefaction features like these dikes form when the constituent grains of water-saturated sediments are reorganized by earthquake shear waves into a more compact arrangement, thus increasing the fluid pore pressure. When the fluid pore pressure is greater than the confining pressure of the overlying sediment (usually along fractures or fissures in the fine-grained cap material), the sands flow into overlying sediments, forming dikes, and if vented onto the surface result in "sand blows." Many of these sand blows are evident in aerial photographs.

Several different types of clastic dikes are present in the stream bed. Some of the dikes are composed of medium- to dark-gray, micaceous sand that is more resistant to erosion than the Porters Creek Clay. These dikes form ledges and small waterfalls in the creek. Other dikes are composed nearly entirely of muscovite mica flakes.

One sandstone dike is approximately 16 in. wide in the stream bed, widens into a sandstone sill some 8 ft or more in width and 4 ft in height in the stream bank, and then narrows upward into a dike approximately 1 ft in width. Slickensides are present along the margins of some intrusions, as well as in the clay adjacent to the features.

These liquefaction features formed following the deposition and dewatering of the Porters Creek Clay and are therefore post-Paleocene in age, but the exact timing of the emplacement of these features is not certain. More study is required to determine the mechanism and timing of the emplacement of these intrusions, and to determine if more than one generation of intrusions is present.

The formation of liquefaction features like these requires the presence of water-saturated liquefiable sediment (typically sand or silt), an overlying thin, fine-grained, relatively impermeable cap, and cyclic shear stress from strong earthquakes. The threshold magnitude of earthquakes inducing liquefaction is about **M** 5.5 (Obermeier, 1996a, b, 1998), which is sufficient to cause damage to many man-made structures. Therefore, the mere presence of liquefaction features is evidence of strong earthquakes, and with careful study, the timing of these events may be ascertained.

Because strong earthquakes occur so infrequently in western Kentucky, the recognition and study of liquefaction features such as these provide an opportunity to determine the location and timing of prehistoric strong (**M** > 5.5) earthquakes. Such knowledge is imperative to a proper evaluation of earthquake hazards in the area.

Stop 4. Landslide Remediation Project, Hickman, Ky., *by John D. Kiefer*[2]

From December 1811 through March 1812, in the vicinity of the town of New Madrid, Mo., one of the greatest series of earthquakes in recorded history occurred. Jared Brooks, who lived in Louisville, Ky., over 200 miles away, recorded 1,874 earthquakes during that period. Three of these earthquakes were in the range of magnitude 8.0 or greater. The town of Hickman, Ky., lies less than 25 mi across the Mississippi River from New Madrid. Although Hickman was not yet founded, its problems had already begun. This great series of earthquakes caused numerous landslides in the area, many of them along the bluffs of the Mississippi River. One of these very large landslides was on the bluff at

[1]Kentucky Division of Waste Management
[2]Kentucky Geological Survey

Figure 4. View inside the Old Hickory Clay Company processing plant.

Figure 5. View of Old Hickory Clay Company Campbell Pit.

Figure 6. Close-up view of Lafayette gravel.

Figure 7. View of clastic dike in Porters Creek Clay near Symsonia.

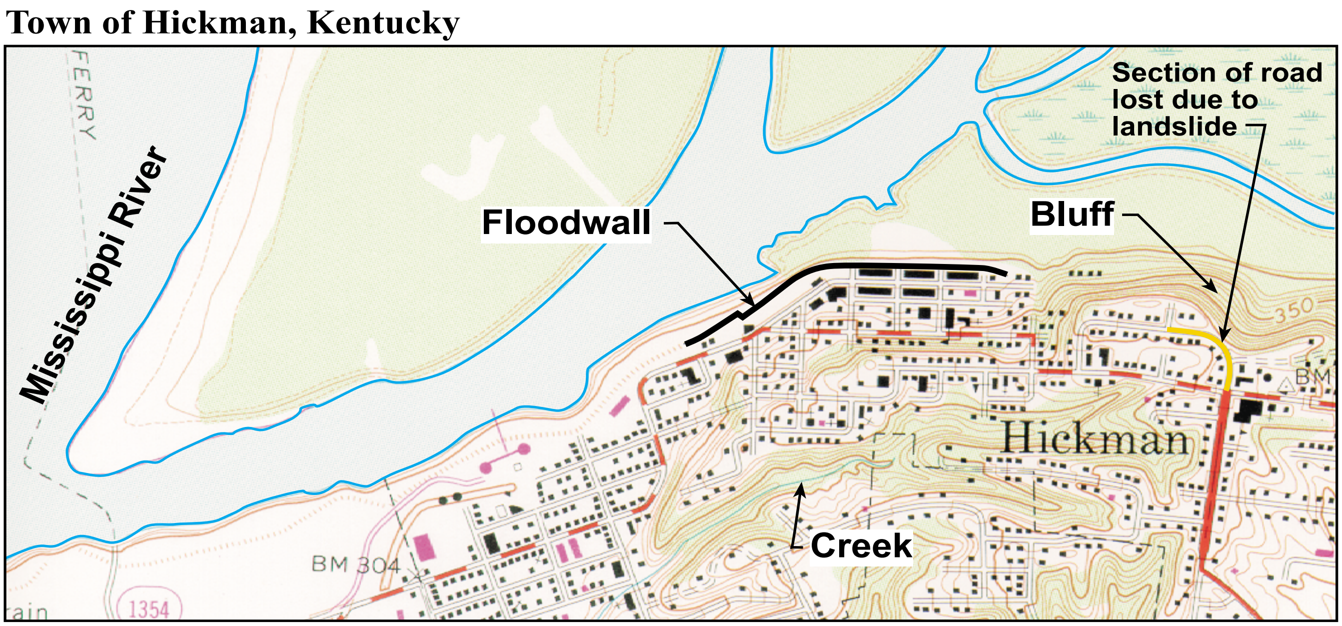

Figure 8. Map showing location of Hickman landslide area.

Figure 9. Panoramic view of Hickman landslide remediation.

the site that would ultimately become Hickman. The location of this bluff is shown in Figure 8, and a panoramic view of the landslide is shown in Figure 9.

Hickman, the county seat of Fulton County, was founded as Mills Point, on the banks of the Mississippi, in 1819. The name was changed to Hickman, the maiden name of the wife of G.W.L. Marr, who once owned the town site, in 1937. River trade made Hickman a thriving town, but Hickman's status as a port lessened as a result of sediment accumulation along the Kentucky side of the river, which made navigation to get to the town very difficult. Dredging along the river by the U.S. Army Corps of Engineers has helped to ensure that Hickman maintains a permanent harbor, but it may also contribute to instability, because material in the harbor that helps to buttress the hillside must frequently be removed to maintain adequate depth.

The Kentucky Geological Survey became involved in the Hickman situation on August 6, 1986, through an interesting chain of events. A geologist at the U.S. Geological Survey in Reston, Va., found a message on his phone that said, "The streets and sidewalks of Hickman, Ky., are cracking up and someone ought to know about it." Since the person receiving the call knew nothing about Hickman, he asked someone at the USGS to call the Kentucky Geological Survey, and it turned out that no one at the Kentucky Geological Survey knew anything about it either. A call to the Kentucky Division of Disaster and Emergency Services (DES) shed no light on the situation, but a subsequent call to the regional DES office brought information. It seems that merchants opening their stores on the north side of Main Street in Hickman were greeted by falling bricks and plaster, broken water pipes, and large cracks in the floors and walls. Downtown Hickman was truly on the move, and the results were unforeseen and certainly undesirable.

It all started in July of 1986, when the Corps of Engineers was beginning a project to improve the flood defenses of downtown Hickman. The project called for increasing the height of the concrete floodwall by 18 in. The floodwall was originally constructed in 1934 and was founded on interlocking sheet piles approximately 35 ft long. The floodwall had never been overtopped, even in the great flood of record in 1937. A trench approximately 3 ft wide and 60 ft deep was to be excavated and filled with a slurry of sand and bentonite to serve as an impermeable cutoff wall that would prevent seepage under the wall from coming up on the back side. The trench was to be 1,250 ft long along the front of the floodwall.

During the last week of July 1986, the contractor began excavating the trench. The plan called for keeping the trench filled with bentonite mud at all times. It would be excavated down to a layer of relatively impermeable clay. Unfortunately, a slurry trench has no structural integrity and no lateral strength to support the hillside. It rained the previous night, and ground cracking and building damage were first noted on the morning of July 29 by one of the merchants entering his store. Sagging and subsidence of the newly extended floodwall were also noted. When alerted to the distress of the structures, the contractor immediately began backfilling the trench with the excavated materials, but the damage had already been done. The trench had been cut across the toe of a landslide. Although the rate of movement and opening of the cracks slowed markedly, new cracks continued to form. Ultimately, seven buildings in historic downtown Hickman had to be condemned and were purchased by the Corps of Engineers. The area is now a park. Other buildings suffered varying degrees of damage. The old landslide on which much of Hickman was built had moved in the past, and it was predicted that it would move again when the level of the Mississippi River rose in flood stage and backed the ground-water table up in the hillside. When the water level dropped, the high ground-water levels would create excess pore-water pressures in the unconsolidated sediments of the hillside, and the slide would move again. Although the Corps did what it could to stabilize the hillside, the predicted movement occurred and at this time many of the remaining buildings in downtown Hickman have been abandoned.

The floodwall itself settled over a foot and had to be repaired and jacked back into place through pressure-grouting on 5-ft centers. A 10-ft-wide concrete apron was also constructed in front of the floodwall and tied into the wall to prevent overturning and to stabilize the structure in the event that more movement occurred. The apron was then covered with about 3 ft of limestone riprap to aid the stability and prevent erosion.

Although the movement was not anticipated, there was ample evidence that landslides in the Hickman area were not a new occurrence. What have we learned from the occurrence? It took only a day to assemble a great deal of information on the history of landslides along the Mississippi. After gaining additional details about the problem, the Kentucky Geological Survey contacted Dr. Russell Campbell and Dr. Randall Jibson of the U.S. Geological Survey and met them in Hickman the next day. Dr. Jibson's Ph.D. dissertation, completed at Stanford University in 1985, was entitled "Landslides Caused by the 1811–1812 New Madrid Earthquakes." The old landslide at Hickman had been mapped. Dr. Jibson and Dr. David K. Keefer had a manuscript in press (USGS Professional Paper 1336-C, "Landslides Triggered by Earthquakes in the Central Mississippi Valley, Tennessee and Kentucky"). If you look at the topographic map of the Hickman 7.5-minute quadrangle, you will see that something is amiss. Closely spaced contour lines trend both to the northeast and the southwest of the town, but in the area of Hickman itself, the contours seem somewhat more widely spaced and in disarray. They appear to give a sense of movement of the hillside. Many of the streets, sidewalks, and buildings in Hickman show extensive cracking and signs of movement. A telltale sign in the window of a bait shop says "closed for the season." It was for more than the season, because the hillside had shoved through the back wall and was near the front of the building. This had occurred long before work on the floodwall began. Probably the best documented warning occurs on the 7.5-minute geologic map of the Hickman quadrangle, by Warren I. Finch, published in 1971, and readily available. It states

> Landslides have been a problem in the town of Hickman since its founding as Mills Point. A major slide occurred in the quadrangle as recently as 1962. Most of the slides occur at or near the base of loess where the hillside has become oversteepened either by natural erosion or by manmade cuts and fills. In the Hickman quadrangle, ground water seeps out of the thin continental gravel deposits, which lie between poorly permeable loess above and the impermeable silt and clay of the Jackson Formation below. This continual seepage keeps the hillside in the vicinity of the gravel constantly wet and consequently in danger of sliding. The montmorillonitic clay and silt below the gravel become slippery and weak due to the swelling clays. Under such conditions slides occur when the load exceeds the strength of the support, either by gradual decrease in strength with passage of time or after trigger events such as heavy rain or an earthquake. After movement most slides are temporarily stable, but removal of debris commonly upsets the stability and re-establishes the potential for further sliding.

This is an excellent description of the problems occurring at Hickman.

Several blocks east of the downtown area is a residential area that is actually on the loess-covered bluffs. The relief from the top of the bluff to the flood plain below is approximately 160 ft. At some point in its meandering history, the Mississippi River itself ran along the base of the bluff. The base is now part of the flood plain near the confluence of Bayou de Chien and Orion Creek. During flood stage, the entire area again becomes part of the Mississippi, and currents run along the base of the bluff and work to undercut the hillside. Historical documents indicate that as much as three blocks along the bluff have been lost to landslides and erosion since 1850. If you study the topographic map of the Hickman quadrangle, you will notice a small stream valley, an extension of "Running Slough," which heads behind the area in question. This valley probably delineates one of the original scarps of a slump block that began with the 1811–1812 earthquakes. Headward erosion has extended the valley behind the subdivision, effectively dividing that area of Hickman into two sections. There is evidence of previous sliding on both sides of the valley as well as on the bluff itself. In the mid 1980's, the Kentucky Department of Transportation studied the failing bluff and decided that any remedial action would not be cost effective. Magnolia Street, which ran along the bluff at that time, was sometimes used as an alternate route while Kentucky Highway 94 through town was being repaired. This use may also have exacerbated the situation because the heavy truck traffic along the bluff probably led to cracks that allowed surface water to seep into the loess. The city tried several methods in an attempt to retard the slumping, all of which failed. These included driving timber pilings, and when the failure surface came near the edge of the road around the edge of the bluff, they hauled numerous loads of dirt to form a berm at the edge of the road. This loaded the head of the slide, which then failed and took the edge of the road along with the fill. The next attempt at stabilization was to load the toe of the slide with debris and thousands of old and reject tires from a nearby tire plant. This accomplished nothing other than environmental degradation, and the tires remain buried at the base of the bluff.

A major failure occurred on Memorial Day in 1990, taking out all of the remaining roadway where Magnolia Street curved around the bluff. An engineering firm was hired to study and monitor the slide, and slope meters were installed. The major conclusion was that water seeping along a zone about 80 ft below the surface was responsible for the sliding. This problem had already been noted on the geologic map. It is still not known whether the source of the ground water is entirely natural or something resulting from the activities of humans. Obviously, if the source could somehow be cut off, it could help, but not entirely stop the sliding. At this point the Corps of Engineers estimated that the problem could be fixed, or at least controlled, at a cost of several million dollars.

The Corps' solution was to dredge sand in from the river and construct a huge berm of sand. This estimated 578,000 cubic yards of sand would cover a football field with sand over 300 ft high. This sand would buttress the toe of the slide and would essentially reconstruct part of the bluff. Drains were to be placed in the sand to help drain the water-bearing layer, and the sand was to be covered with large riprap to prevent river erosion. Several problems needed to be considered. When the river flooded, it would saturate the entire base of a huge pile of sand. As the river receded, it would tend to set up excess pore pressures in the sand that could lead to failure. This did not even take into consideration that an earthquake could occur while the river was in flood stage, setting the whole mass in motion. This massive pile of sand was to be placed on the thick clayey and silty flood-plain sediments, and a great deal of settling and consolidation would take place in both the sand itself and the flood-plain materials beneath. This also could lead to failure. By the time the construction began in late 1996, the cost estimate had risen to $4.3 million, and a Congressional appropriation for repair was for $4.7 million. By November 1997, articles appeared in the *Paducah Sun* and *Louisville Courier-Journal* indicating that construction had been stopped and that the contractor had been released. Observers reported that strange and unexpected things were happening to the sand pile, which had now reached a height of about 50 ft, and that sections of drain tile and culverts lay in disarray. The articles noted that the pile was unstable and had been adjusting continually almost from the day construction started. The Corps now estimates that it will cost considerably more to stabilize the bluff.

The ultimate solution is referred to as "soil nailing." Thousands of inch-thick "nails," or reinforcing rods, would be driven horizontally into the bluff on 5- to 8-ft centers and cemented in. Layers of geotextile and drainage materials would be placed and covered with a cement grout surface. Ultimately, the bluff would be reconstructed and protected with "shot-crete" to prevent erosion. The process was to be completed in 1999, and it remains to be seen if Mother Nature has been defeated or merely harassed. A panoramic view of the remediation project is shown in Figure 9.

Stop 5. Active Landslide at Columbus, Ky., *by John D. Kiefer*

The bluffs along the Mississippi River in the vicinity of Columbus-Belmont Battlefield State Park have been slumping into the river for many years, and the park continues to lose land to the river. The landslides probably began during and certainly were exacerbated by the 1811–1812 series of New Madrid earthquakes. Two other factors increase the instability. The first is the river as it undercuts the bluffs by erosion. Every time the river reaches flood stage, the ground-water table rises in the bluffs. When the river level drops again, pore pressures do not dissipate rapidly enough to prevent excess pore pressures from building up and causing failures to occur.

The second factor is earthquake effects along the edge of the bluffs. Some of our more simple models do not agree with what we observe in the field. It would appear that the bluffs cause a topographic effect of focusing the earthquake waves and amplifying the effects. If the bluff effect is modeled as an infinite wedge, a simple geometry, it indicates that the amplification will be $2\pi/\phi$, where ϕ is the inside angle of the ridge line. This, in summary, means that even relatively small earthquakes can mobilize the bluffs.

Stop 6. Seismic Hazards: Site Effects and the Kentucky Strong-Motion Stations, *by Ed Woolery*[1]

Damaging earthquakes in Kentucky are infrequent, but the largest of these can put life and infrastructure at risk. The great New Madrid earthquake sequence (~**M** 8) in the winter of 1811–1812 is evidence of this threat. The three main events caused severe to moderate damage throughout Kentucky, with effects being felt as far away as southern New England. Although the 1811–1812 sequence is the best known of the catastrophic earthquakes, other damaging events have also occurred. The October 31, 1895, **M** 6.2 earthquake in southeastern Missouri, 25 km west of Wickliffe, Ky., caused extensive damage in Paducah and Henderson, as well as much of western Kentucky. In addition to exposure to the infrequent large events, the Jackson Purchase Region is also vulnerable to seismic hazards from lesser earthquakes. This is because of the influence the thick post-Paleozoic sediment deposits of the Mississippi Embayment have on the propagation of seismic waves in the near surface. The sediments' dynamic properties and subsurface/surface configuration can often dramatically change the amplitude, frequency content, and duration of the earthquake ground motion. One of the most serious consequences of ground-motion parameter change is the phenomenon of amplification (Fig. 10). Simply stated, amplification effects result from the laws of energy conservation, and can be best demonstrated through the sediment property called impedance (the resistance to particle motion). For S-waves, often the most damaging mode in the earthquake coda, a medium's impedance is defined as the product of the density (ρ), the shear-wave velocity (β), and the cosine of the angle of incidence (ϕ). We assume, however, that the angle, ϕ, between the vertical and the direction of wave propagation is very small in the near surface; therefore $\cos\phi \approx 1$. In addition, we know that the particle velocity is inversely proportional to the

[1]Kentucky Geological Survey

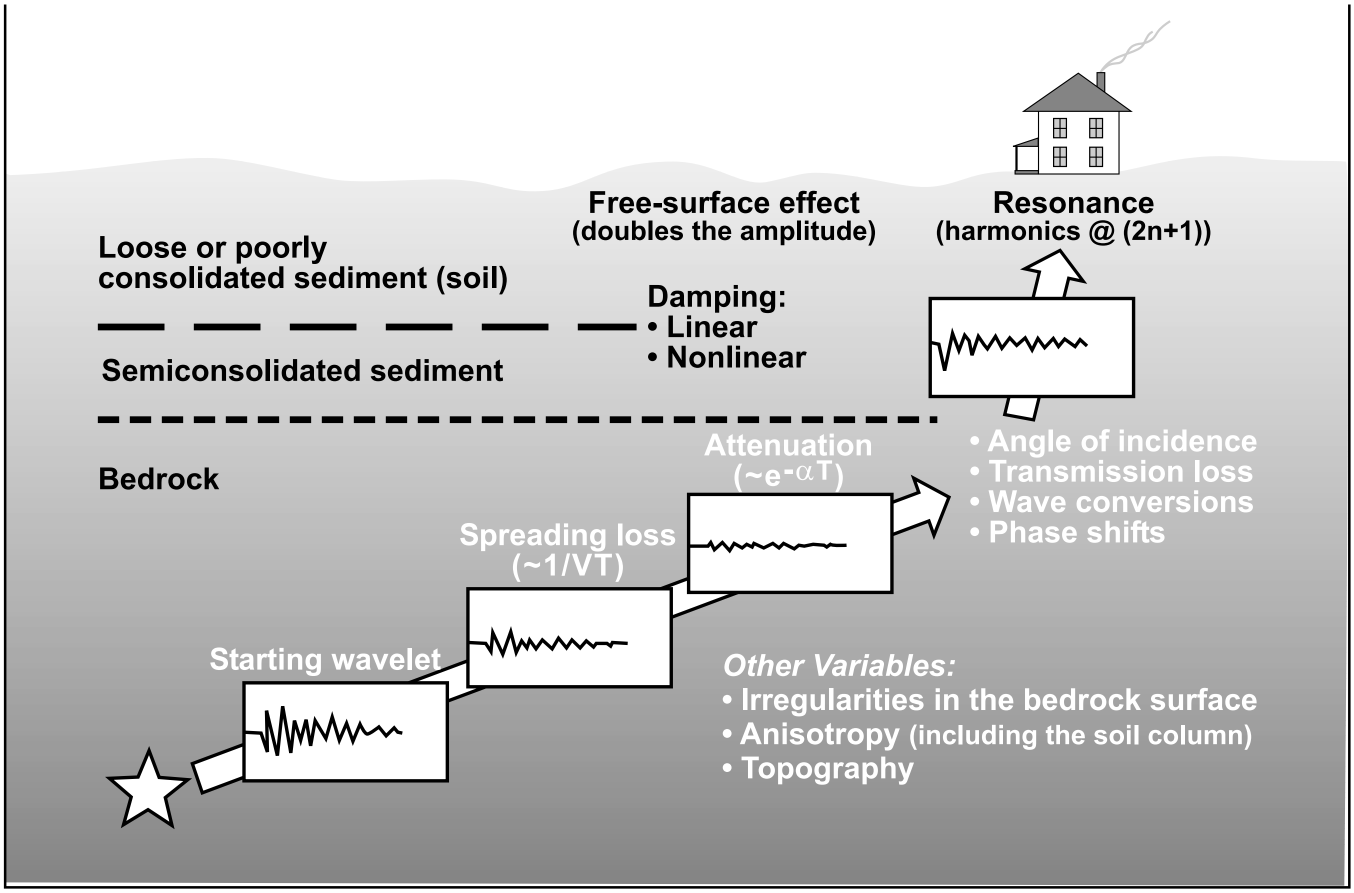

Figure 10. Seismic hazards are a function of earthquake source, path, and site effects.

material impedance. In most instances the density and shear-wave velocity of the sediment is much less than the bedrock. Therefore, if you neglect the effects of scattering and material damping, a seismic wave that passes across the high impedance contrast must proportionally increase the particle velocity (i.e., wave amplitude) in order to satisfy the requirements of energy conservation.

The University of Kentucky's seismic network (Fig. 11) has seven strong-motion stations that are used to collect the data required to understand these local site effects. The strong-motion station at Columbus-Belmont Battlefield State Park (COKY) is an example of a state-of-the-art, three-component, force-balance, Kinemetrics K-2 accelerometer that we have deployed in the region (Fig. 12). The system has a superior dynamic range relative to the last-generation accelerographs (i.e., greater than 114 dB). This provides significantly improved data resolution for earthquake engineering problems where signal fidelity and data integrity are vital.

The ultimate goal of our research is to enhance the economic development potential for several western Kentucky counties by providing engineers with credible seismic design criteria.

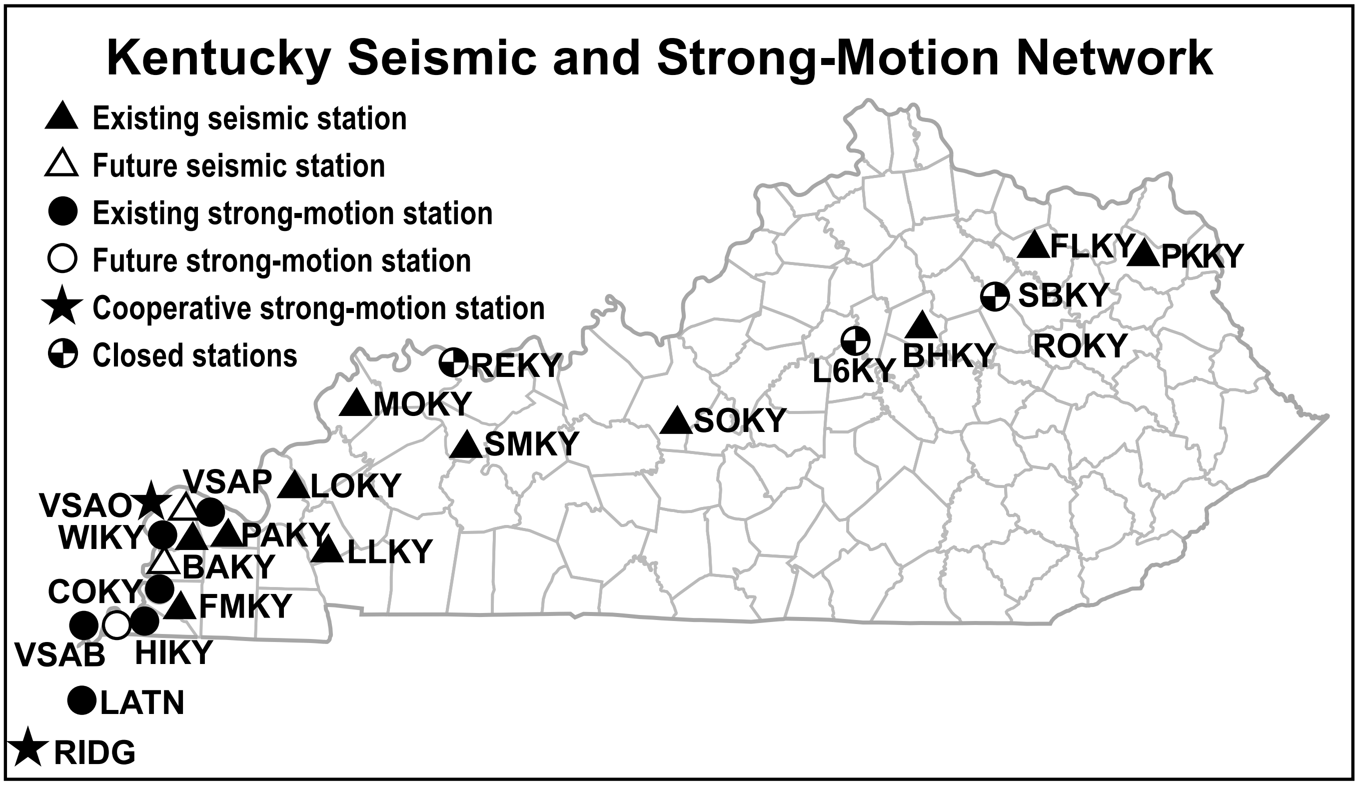

Figure 11. Map showing locations of seismic stations in the Kentucky Seismic and Strong-Motion Network.

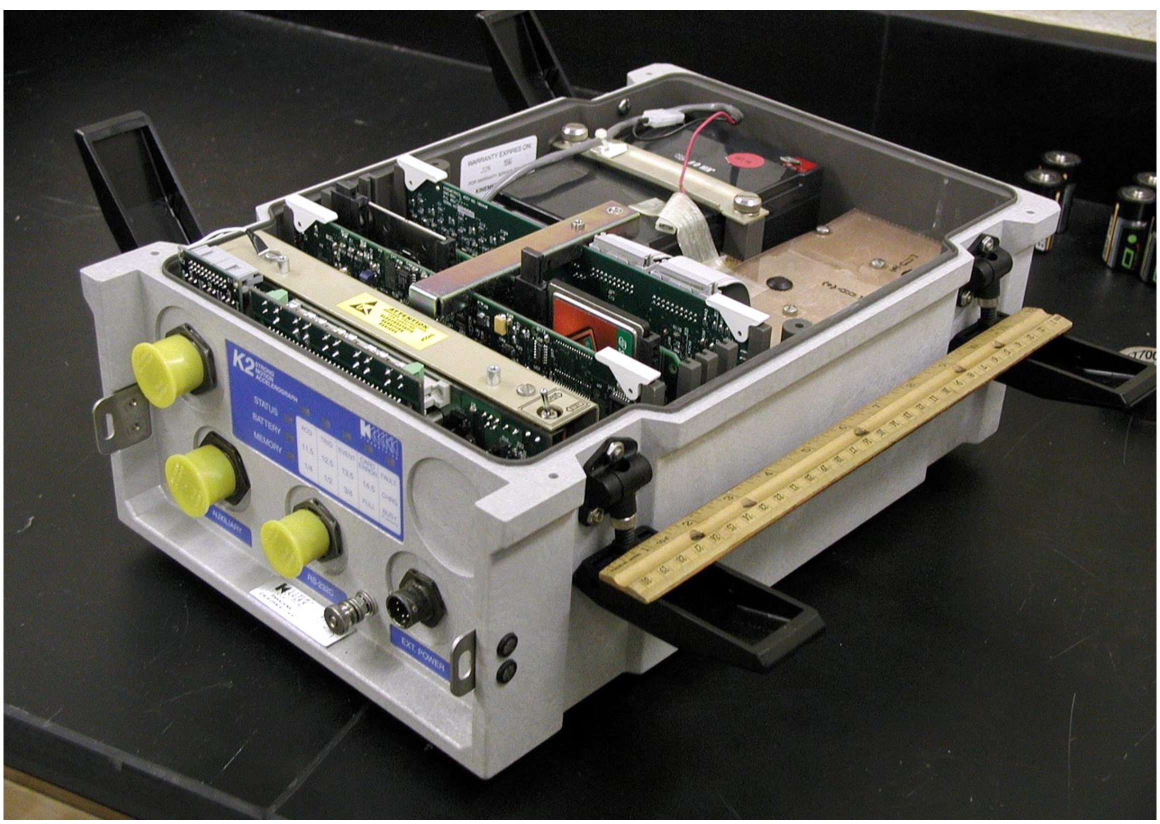

Figure 12. View of state-of-the-art Kinematics K-2 accelerometer.

Day 2

Stop 7. Vulcan Materials Reed Quarry at Grand Rivers, Ky., *by Garland R. Dever Jr.*[1]

The Reed Quarry, shown in Figure 13, is one of the largest producers of crushed stone in the United States. Annual production currently runs about 8 to 10 million tons a year. About 75 percent of the stone is shipped by barge, 15 percent by truck, and 10 percent by rail. A large part of the quarry's production currently is sent to markets in the lower Mississippi Valley, mainly in the states of Louisiana and Mississippi.

Opened in 1950 by the Clyde Reed Trucking Company, the quarry was operated for many years by the Reed Crushed Stone Company. Vulcan Materials purchased the operation in 1990.

Fifty years of quarrying has deepened and enlarged the pit, which is now more than 500 ft deep (Fig. 14). The present floor, 100 ft below sea level, is the lowest point on the surface in Kentucky. Three limestone units of Mississippian age are now visible in the quarry: in ascending order from the bottom of the quarry, the Fort Payne Formation, Warsaw Limestone, and Salem Limestone. The upper 350 ft of the Fort Payne Formation, which is about 600 ft thick, is exposed in the lower part of the quarry. The upper Fort Payne is a medium-dark-gray to dark-gray, very fine- to fine-grained, siliceous and cherty limestone, with varied amounts of fossils.

Fort Payne sediments accumulated in relatively deep water, partly in large mounds such as the one exposed in the west face of the quarry (Lineback, 1969; Lasemi and others, 1994, 1998). The mound core contains fenestrate bryozoan fronds and crinoid fragments, and scattered sponge spicules. Fine-grained carbonate sediments in the core apparently were baffled and trapped by bryozoans, crinoids, and sponges.

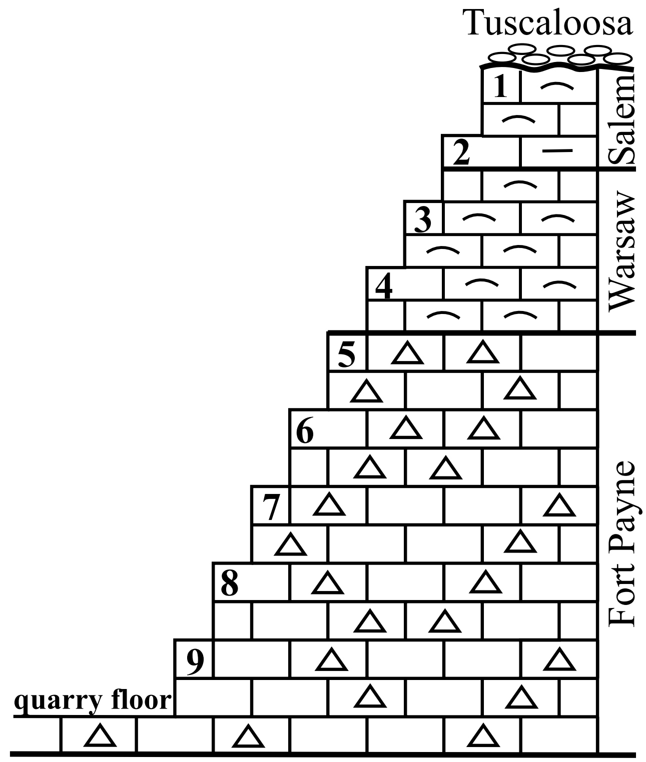

Figure 14. Generalized geologic section of the units at Reed Quarry.


Figure 13. Panoramic view of Reed Quarry in Grand Rivers, Ky.

Light-colored Warsaw Limestone overlies the dark Fort Payne Formation. The Warsaw, about 165 ft thick, mainly consists of light-gray to medium-gray, fine- to very coarse-grained, bryozoan and crinoidal limestone. The Warsaw Limestone of western Kentucky is correlative with the Ullin Limestone and lower Salem Limestone of southern Illinois (Lasemi and others, 1998). Facies in the Warsaw and Ullin include bryozoan-crinoidal bafflestone buildups and storm-generated sand waves (Lasemi and others, 1994, 1998).

Salem Limestone overlies the Warsaw in the uppermost part of the quarry. The Salem is composed of (1) olive-gray to medium-gray, fine- to very coarse-grained, bioclastic limestone and (2) olive-gray to olive-black, very finely crystalline limestone, which is partly argillaceous to shaly. Both lithologies are locally cherty.

The upper part of the Salem has been removed by erosion. At the top of the east face in the quarry, light-gray gravel of the Tuscaloosa Formation of Cretaceous age unconformably overlies the Salem.

Crushed stone currently is produced from both the Warsaw and Fort Payne. Because of its argillaceous and shaly characteristics, only small quantities of stone have been taken from the Salem in recent years.

Physical and chemical qualities of the Warsaw make the stone suitable for construction, agricultural, and industrial markets (Dever and McGrain, 1969). Construction aggregate has been the main product. Warsaw aggregate was used for construction of the Barkley Lock and Dam. The formation has furnished riprap and boulders for erosion control along waterways, filter stone for sewage-treatment plants, scrubber stone for a flue-gas desulfurization system, and it is the quarry's source of agricultural limestone.

The Fort Payne has a relatively high silica (SiO_2) content, averaging about 20 percent, but as much as 60 percent, based on company testing. The siliceous limestone is being quarried for construction aggregate, skid-resistant aggregate, railroad ballast, riprap, and filter stone (both for sewage treatment and scrubber-sludge dewatering). Most Kentucky limestones are not suitable for railroad ballast or skid-resistant aggregate because of their calcium carbonate content, but the Fort Payne, with its higher silica content, can meet specifications for these uses.

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Web Sites for Further Information

Kentucky Society of Professional Geologists: *www.kspg.org/*

USGS minerals Web site:
minerals.usgs.gov/minerals/pubs/commodity/clays/

Old Hickory Clay Company: *www.oldhickoryclay.com/*

Columbus-Belmont Battlefield State Park:
www.state.ky.us/agencies/parks/columbus.htm