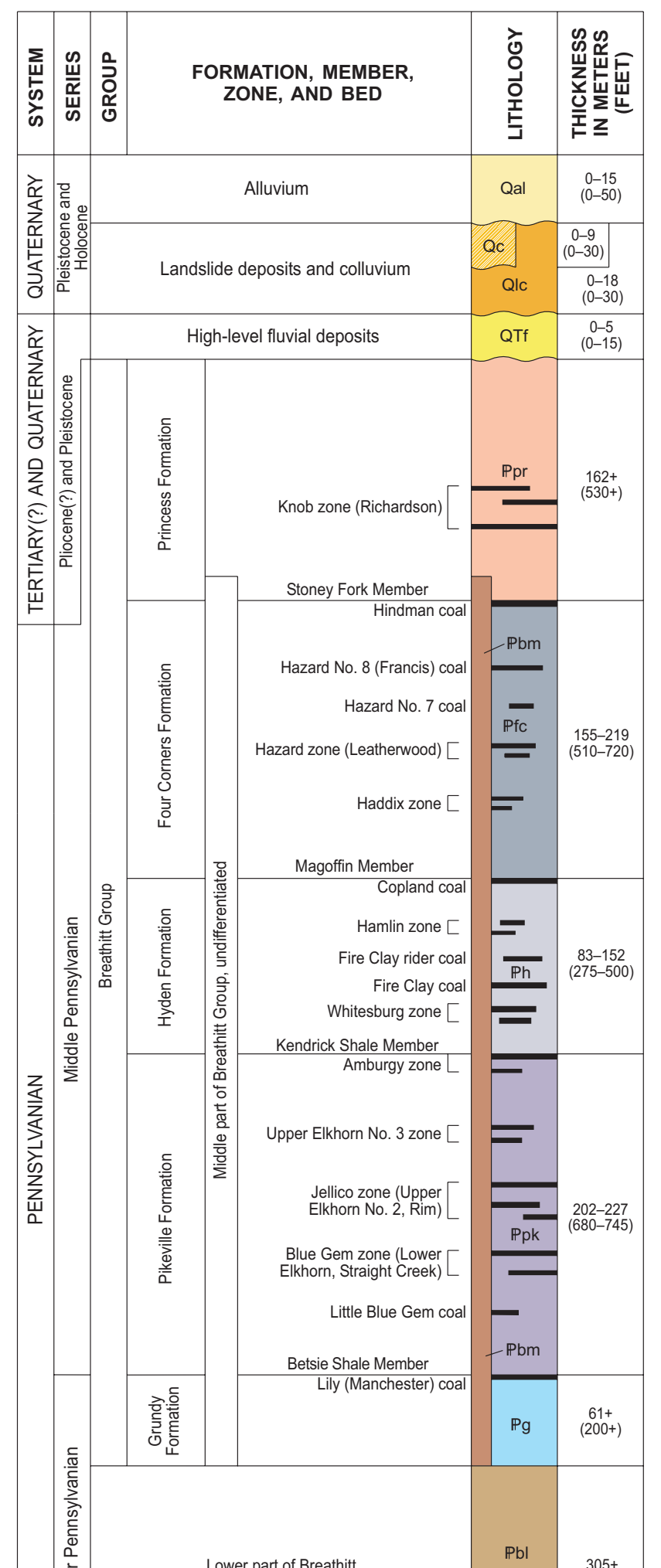
KENTUCKY GEOLOGICAL SURVEY
James C. Cobb, State Geologist and Director
UNIVERSITY OF KENTUCKY, LEXINGTON

GEOLOGIC MAP 7
Series XII, 2004



NORTH AND WEST OF PINE MOUNTAIN

Qal ALLUVIUM—Sand, silt, clay, and gravel. Sand, fine to medium, quartzose, well sorted. Silt and clay, laminated to thin-bedded, rich in organic matter. Gravel, well-rounded pebbles, cobbles, and boulders of quartz, chert, sandstone, siltstone, limestone, and coal from rocks of Mississippian and Pennsylvanian age. Occurs in unconsolidated deposits in narrow valley bottoms, in floodplain and terrace deposits of Cumberland River, and grades into colluvium along valley sides.

Qlc
Qc LANDSLIDE DEPOSITS AND COLLUVIUM—Landslide deposits commonly contain large slumped sandstone blocks and are often flanked by scarps. Colluvium is poorly sorted to unsorted, angular to rounded pebbles, cobbles, and boulders in a clay, silt, and sand matrix. Present on most slopes, mapped only where thicker than 1.5 m (5 ft); mapped by interpretation of hummocky topography and fan-shaped lobes. Colluvium also mapped with debris fans and landslides at mouths of hollows and on concave slopes, and as talus below escarpments at meanders of Cumberland River; forms veneer along north slope of White Mountain and along north slope and foot of Pine Mountain. Landslide deposits combined with colluvium in the eastern part of quadrangle in steep, narrow gullies, on north slope of Pine Mountain, and along Straight Creek, where deposits are as much as 9 m (30 ft) thick. Colluvium mapped separately in the western half of the quadrangle area.

QTf HIGH-LEVEL FLUVIAL DEPOSITS—Sand, silt, clay, and gravel. Sand, silt, and clay, yellowish- to reddish-brown; sand is fine to medium, quartzose, with scattered gravel lenses. Gravel consists of limonite-coated quartz pebbles; cobbles and boulders of sandstone; and conglomerate, quartzose sandstone. Some gravel lenses are cemented by limonite, forming conglomerate. Occurs as erosional remnants along old high-level channels of Cumberland River in Artemus and Barbourville quadrangles.

BREATHITT GROUP—The Breathitt was mapped as a formation on the 7.5-minute geologic quadrangle maps, but Chesnut (1992) elevated the Breathitt to group status and divided the group into formations based on regionally widespread shale members with marine fauna. The Breathitt Group contains sandstones, siltstones, shales, coals, and limestones. All formations in the Breathitt Group are lithologically similar and are described below.

Sandstone, fine- to coarse-grained, poorly sorted, quartzose, micaceous, with feldspar and rock fragments; occasionally contains sparse well-rounded quartz pebbles; thin-bedded to massive, crossbedded, and cliff forming. Two types of sandstones occur: quartzarenites (more than 90 percent quartz), which occur in the lower Breathitt beneath the Betsie Shale; and more common, arkosic and sublitharenitic sandstones (60 to 80 percent quartz, 2 to 15 percent feldspar, and lesser amounts of mica, opaque minerals, and rock fragments). Some sandstones are locally extensive and useful as stratigraphic markers. Siltstone and shale, micaceous, locally carbonaceous and calcareous, thin-bedded, coaly partings on some bedding planes. The marine shale members (Betsie, Kendrick, Magoffin, Stoney Fork) at the base of each formation generally contain a thin, black to dark-gray clay shale and discontinuous, dark-gray to black limestone or sideritic sandstone with common marine fossils at their base. Basal shales grade upward into laminated, dark-gray, silty shale with abundant siderite laminae and nodules, elliptical saucer-shaped carbonate concretions, and scarce fossils. Silty shales coarsen upward into thin-bedded, often bioturbated siltstone interbedded with fine-grained, ripple-bedded sandstone and shale; the siltstone-sandstone-shale unit in turn coarsens upward into massive to crossbedded sandstone, which may truncate the coarsening-upward profile. Coarsening-upward shale members are overlain by several coal zones. Each zone consists of multiple coals that may split laterally or grade into carbonaceous shales and rooted seat rocks. Coal zones are separated by shales, siltstones, and sandstones, and generally exhibit considerable lateral variability.

₽pr PRINCESS FORMATION—Previously mapped as upper part of the Breathitt Formation on 7.5-minute quadrangle maps. Renamed by Chesnut (1992) for strata above the base of the Stoney Fork Member and below the Conemaugh Formation (not present in this quadrangle). The base of the Stoney Fork Member is a thin marine carbonate, locally mapped as the Lost Creek Limestone, a dark-gray, argillaceous limestone and calcareous shale with abundant fossil fragments. Because the Stoney Fork Member was not mapped on many of the 7.5-minute quadrangle maps, the base of the Princess Formation is placed at the top of the Hindman coal bed or its inferred position. Coals include the Knob (Richardson) zone. Chert fragments found in the vicinity of the Helton quadrangle were tentatively identified as the Flint Ridge Flint. Unit occurs on hilltops in the northeastern area of the quadrangle at elevations above 600 m (2,000 ft).

₽fc FOUR CORNERS FORMATION— Mapped as part of the Breathitt Formation on earlier maps. Named by Chesnut (1992) for strata between the base of the Magoffin Member and the top of the Hindman coal bed. Basal portion is the Magoffin Member, a 1.5–24 m (5–80 ft) dark-gray, silty, calcareous, fossiliferous shale and dark-gray to black, micaceous, silty, nodular limestone with abundant marine fossils; grades upward into interbedded siltstone and shale; base of Magoffin forms distinct topographic bench. Coals include, in descending order, the Hindman (Hazard No. 9), Hazard No. 8 (Francis), Hazard No. 7, Hazard zone (Leatherwood), and Haddix zone.

₽h HYDEN FORMATION—Mapped as middle part of the Breathitt Formation on earlier maps. Named by Chesnut (1992) for strata between the base of the Kendrick Shale Member and the base of the Magoffin Member. The Kendrick is an olive-gray to dark-gray shale, slightly calcareous, with sparse to moderately abundant marine fossils (small brachiopods, pelecypods, and shell fragments); contains silty lenses, grades into siltstone, and ranges 0 to 18 m (0 to 60 ft). The Kendrick is mapped locally and where the shale is absent the base of the Hyden Formation is approximately located from the top of the Amburgy coal zone or its stratigraphic equivalent. Coals include, in descending order, the Copland, Hamlin zone, Fire Clay rider, Fire Clay, and Whitesburg zone. The Fire Clay coal contains, near its base, a distinctive 1- to 4-cm (2- to 10-in) thick, light to dark brownish-gray flint-clay parting with conchoidal fracture that was deposited as a volcanic ash. The flint clay has been radiometrically dated at 312 ±1 Ma by Lyons and others (1992) and 311 ±1 Ma by Rice and others (1994).

₽pk PIKEVILLE FORMATION—Mapped as middle part of the Breathitt Formation on earlier maps. Named by Chesnut (1992) for strata between the base of the Betsie Shale Member and the base of the Kendrick Shale Member. The Betsie Shale was defined by Rice and others in 1987 and was not mapped on the earlier 7.5-minute quadrangle maps, although it occurs just above the Lily (Manchester) coal. For this quadrangle, the Pikeville Formation was approximated between the top of the Lily coal and the top of the Amburgy coal zone or its equivalent. Coals include, in descending order, the Amburgy zone, Upper Elkhorn No. 3 zone, Jellico zone (Upper Elkhorn No. 2, Rim), Blue Gem zone (Lower Elkhorn, Straight Creek), and Little Blue Gem. The unit predominantly occurs in the northwestern corner of the quadrangle.

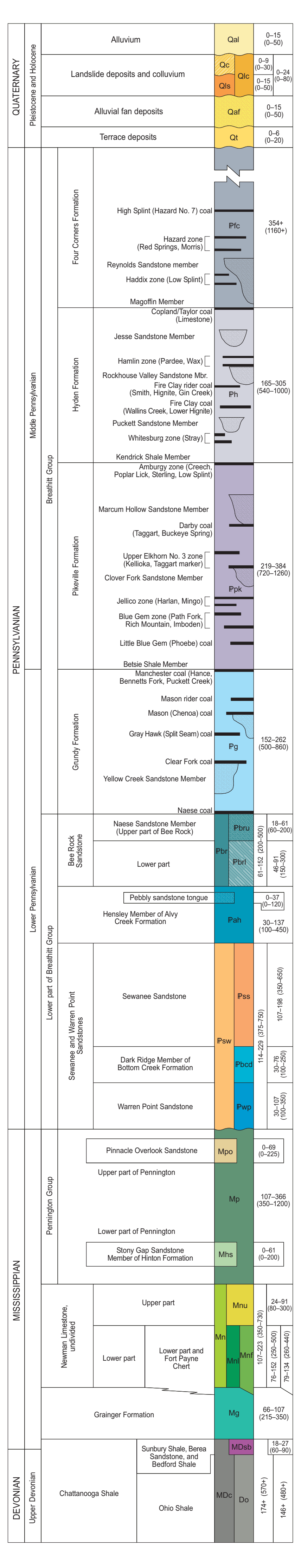
₽g GRUNDY FORMATION—Mapped as lower part of the Breathitt Formation on earlier maps. Named by Chesnut (1992) for strata from the top of the Bee Rock Sandstone to the base of the Betsie Shale. Approximately 61 m (200 ft) of the upper Grundy Formation is exposed along the crest of the Flat Lick Anticline in the Artemus 7.5-minute quadrangle. Coals include the Lily (Manchester).

₽bm MIDDLE PART OF BREATHITT GROUP, UNDIFFERENTIATED—Mapped as Breathitt Formation, undifferentiated; or Breathitt Formation, intensely deformed and undifferentiated. Occurs in two locations: a narrow belt of undifferentiated, deformed rocks adjacent to the north side of the Pine Mountain Overthrust Fault; and a north-south trending, narrow, fault-bounded belt of undifferentiated rocks along the White Mountain Fault Zone. Shale, siltstone, sandstone, and coal. Shale and siltstone, light- to dark-gray, interbedded with thin-bedded sandstone, micaceous, locally carbonaceous, in part calcareous with sparse marine fossils, locally intensely sheared. Sandstone, fine- to medium-grained, poorly to well sorted, thin- to thick-bedded, micaceous, in part quartzose and carbonaceous, crossbedded; some vertically dipping beds as much as 15 m (50 ft) thick. Coal, sheared and slickensided; several unnamed beds 0.5 m (1.5 ft) thick occur near top; a vertically dipping coal bed reported to be as much as 0.8 m (2.5 ft) thick was mined for local use along south bank of Straight Creek. Unit poorly exposed, generally covered by alluvium and colluvium.

₽bl LOWER PART OF BREATHITT GROUP—Mapped as Lee Formation, undivided, on earlier maps. Since the Lee sandstone members were elevated to formations by Chesnut (1992), the name "Lee Formation" was formally dropped in Kentucky. Sandstone, siltstone, and shale. Sandstone, white to dark-gray, fine- to coarse-grained, poorly to moderately well sorted, thin- to thick-bedded, locally friable and quartzose, in part quartzitic, micaceous, crossbedded, and conglomeratic; sheared, fractured and slickensided; vertically dipping beds form prominent ridges and cliffs. Siltstone and shale, interbedded with fine-grained sandstone, micaceous, in part carbonaceous, slickensided and fractured; dark-gray shale contains ironstone concretions. Lower part of unit is conglomeratic, with sheared, well-rounded quartz pebbles up to 2.5 cm (1 in.) in diameter. Unit exposed along northern foothills of Pine Mountain, and on north face of White Mountain. Base of unit, forming sole of Pine Mountain Overthrust Fault, is 6-m (20 ft)-thick, sheared, quartzitic, bleached and altered fine-grained sandstone; possibly includes sandstone from the Pennington Formation.

af ARTIFICIAL FILL—Compacted rock debris from highway, railroad, and earthen dam construction.

▨ MINE DUMP or MINE SPOIL—Tailings and mine waste from coal mining operations.



ALONG AND SOUTH OF PINE MOUNTAIN

Qal ALLUVIUM—Sand, silt, clay, and gravel. Similar to that previously described from north and west of Pine Mountain. Poorly stratified, unconsolidated deposits in valley bottoms; locally includes beds of silt and clay deposited when streams were ponded by landslides; unit merges with colluvium along valley sides. Mapped only in larger stream valleys and in tributaries of the Cumberland River or in the central basin of the Middlesboro impact structure. Trellis pattern noted on front and back edges of the Pine Mountain Thrust Sheet where dipping bedrock is present.

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Qc
Qls LANDSLIDE DEPOSITS AND COLLUVIUM—Similar to that previously described from north and west of Pine Mountain. Landslide deposits include large slumped blocks of bedrock and colluvial debris; in deposits as much as 24 m (80 ft) thick, often flanked by scarps; mapped separately on Kayjay 7.5-minute quadrangle map along Clear Creek. Colluvium consists of sandstone and siltstone blocks and boulders in unsorted, unbedded matrix of sand, silt, and clay; forms continuous veneer of unconsolidated slope deposits on northern foothills of Brush Mountain in the Varilla 7.5-minute quadrangle. Colluvium mapped, in part, with talus, fan, or landslide deposits as combined unit.

Qaf ALLUVIAL FAN DEPOSITS—Boulders, gravel, sand, and silt. Poorly sorted deposits spilling out from the mouths of one or more ravines along Clover Fork of the Cumberland River, and at the foot of Cumberland Mountain along Martins Fork; may include some colluvial material.

Qt TERRACE DEPOSITS—Boulders, gravel, sand, silt, and clay. In stream deposits above normal flood level, range 1.5–6 m (5–20 ft) above river level.

MIDDLE PART OF BREATHITT GROUP

₽fc BREATHITT GROUP
FOUR CORNERS FORMATION—Sandstone, siltstone, shale, coal, and limestone. Similar to that previously described from north and west of Pine Mountain. Sandstones mapped as Bryson and Hignite Formations, or Harlan Formation on earlier quadrangle maps. Top of section not present. Base of section as defined by Chesnut (1992) is base of Magoffin Member; when absent, then base of unit is mapped at top of Limestone(?) coal (Copland/Taylor equivalent). Reynolds Sandstone Member, mapped locally, fine- to coarse-grained, medium- to thick-bedded, usually crossbedded; forms prominent cliffs on highest ridges in map area; occurs near base of the unit. Coals include, in descending order, Hazard No. 7 (High Splint), Hazard zone (Red Springs and Morris), and Haddix zone (Low Splint of Hignite Formation). Unit crops out on highest mountains of Harlan County (Black Mountain and Little Black Mountain) and along elongate ridges of Log Mountain of southwestern Bell County.

₽h HYDEN FORMATION—Sandstone, siltstone, shale, coal, and minor limestone. As previously described from north and west of Pine Mountain. Mapped as Catron and upper part of the Mingo Formations, upper part of the Wise Formation, or Breathitt Formation on earlier quadrangle maps. Base of section is the base of the Kendrick Shale Member, which is locally mapped on the Pennington Gap 7.5-minute quadrangle map. Elsewhere, the base of the unit is mapped from the top of the Poplar Lick (Amburgy) coal zone or its stratigraphic equivalent. Three named sandstones are locally mapped in the unit. The Jesse, Rockhouse Valley, and Puckett Sandstone Members are fine- to coarse-grained sandstones, commonly massive, crossbedded, and cliff-forming. The Jesse is also conglomeratic at base, with white quartz pebbles, clay pellets, and rock fragments. Coals include, in descending order, Copland/Taylor (Limestone), Hamlin zone (Pardee, Wax), Fire Clay rider (Smith, Hignite, Gin Creek), Fire Clay (Wallins Creek, Lower Hignite), and Whitesburg zone (Stray).

₽pk PIKEVILLE FORMATION—Siltstone, shale, sandstone, and coal. As previously described from north and west of Pine Mountain. Mapped as lower part of the Mingo and upper part of the Hance Formations, lower part of the Wise Formation, or Breathitt Formation on earlier quadrangle maps. Base of section, base of the Betsie Shale Member, was not mapped; therefore the top of the Manchester coal equivalent (Hance, Bennetts Fork, or Puckett Creek coal) was used to map the base of the section. Two named sandstones are mapped locally in the unit. The Marcum Hollow and Clover Fork Sandstone Members are fine- to medium-grained, massive, usually crossbedded, and cliff-forming. In addition, the Clover Fork commonly contains ironstone pebbles. Coals include, in descending order, Amburgy zone (Creech, Poplar Lick, Sterling, Low Splint of Wise Formation), Darby (Taggart, Buckeye Spring), Upper Elkhorn No. 3 zone (Kellioka, Taggart Marker), Jellico zone (Harlan, Mingo), Blue Gem zone (Path Fork, Rich Mountain, Imboden), and Little Blue Gem (Phoebe).

₽g GRUNDY FORMATION—Siltstone, shale, sandstone, and coal. As previously described from north and west of Pine Mountain. Mapped as lower part of Hance Formation, or lower part of Breathitt Formation on earlier quadrangle maps. The base of the section is the top of the underlying Bee Rock Formation (Chesnut, 1992). Upper boundary is at the base of the Betsie Shale Member; where not mapped, the top of the Manchester coal (or its equivalent). Two sandstones were mapped locally in the unit, particularly on Varilla and the east side of Middlesboro North 7.5-minute quadrangle maps: an upper unnamed sandstone and the Yellow Creek Sandstone Member. Sandstones are very fine- to medium-grained, micaceous, cliff-forming; upper sandstone commonly contains argillaceous laminae; Yellow Creek Sandstone is moderately well sorted and quartzose. Mapped unit is exposed in uplifted, flat-lying strata in eastern Bell County, and in dipping beds along two narrow belts (southern foothills of Pine Mountain and northern side of Cumberland Mountain). Coals include, in descending order, Manchester (Hance, Bennetts Fork, Puckett Creek), Mason rider, Mason (Chenoa), Gray Hawk (Split Seam), Clear Fork, and Naese.

₽bd BREATHITT GROUP, INTENSELY DEFORMED—Shale, siltstone, sandstone, and coal. Mapped as Mingo and Hance Formations, undivided, or Breathitt Formation, intensely deformed. As previously described from north and west of Pine Mountain, except rock has been macrobrecciated and shattered; generally not resistant; in fault blocks in Middlesboro Basin, which is described by Englund and Roen (1963) as a meteorite impact scar.

LOWER PART OF BREATHITT GROUP

₽bl LOWER PART OF BREATHITT GROUP—Sandstone, siltstone, and shale. As previously described from north and west of Pine Mountain. Mapped as Lee Formation, undivided, on earlier maps; later redefined as lower part of the Breathitt Group (Chesnut, 1992) when "Lee Formation" was formally dropped from Kentucky nomenclature. Unit exposed in fault slices adjacent to Pine Mountain, and in the central uplift core of the Middlesboro Basin (Englund and Roen, 1963; Milam and Kuehn, 2002b).

₽br BEE ROCK SANDSTONE—Sandstone, conglomeratic sandstone, siltstone, shale, and minor coal. Mapped as member of Lee Formation on earlier quadrangle maps. Chesnut (1992) elevated Bee Rock Sandstone to formation status and included the immediately overlying Naese Sandstone Member of the Hance Formation, where mapped. Sandstone, white to light-gray, fine- to coarse-grained, well-sorted, quartzose, locally micaceous and silty in upper part, thin-bedded to massive, conspicuously crossbedded, conglomeratic at base with well-rounded white quartz pebbles 0.6 to 5 cm (1/4 to 2 in.) in diameter; forms prominent cliffs and hogbacks along south slope of Pine Mountain. Siltstone and shale, medium- to dark-gray, micaceous, carbonaceous, silty and sandy, with occasional thin unmapped coal bed. Thin shale occurs near middle of unit and forms persistent slope break, or swales, between cliff-forming sandstones.

₽bru NAESE SANDSTONE MEMBER (UPPER PART OF BEE ROCK SANDSTONE)
Upper part of unit, where previously mapped as Naese Sandstone Member, now mapped as upper part of Bee Rock Sandstone.

₽brl LOWER PART OF BEE ROCK SANDSTONE
Lower part of unit, where mapped separately, now mapped as lower part of Bee Rock Sandstone.

₽ah HENSLEY MEMBER, ALVY CREEK FORMATION—Shale, siltstone, sandstone, and minor coal. Shale and siltstone, medium- to dark-gray, sandy, micaceous, carbonaceous, thin-bedded; form swales at top and base of unit. Sandstone, very fine- to medium-grained, well to poorly sorted, thin- to thick-bedded micaceous and carbonaceous; locally forms cliffs. Pebbly sandstone, mapped locally in upper part of unit, white to medium-gray, fine-grained, well-sorted, quartzose, with well-rounded quartz pebbles, massive and crossbedded, cliff-forming. Tunnel coal bed occurs in upper shaly zone of unit, locally exposed.

₽sw SEWANEE AND WARREN POINT SANDSTONES—Conglomerate, sandstone, siltstone, and shale. Sandstone, white to light-gray, fine- to coarse-grained, quartzose, massive, strikingly crossbedded, in part conglomeratic with well-rounded quartz pebbles up to 7.6 cm (3 in.) in diameter; forms several resistant ledges. Siltstone and shale, olive- to dark-gray, micaceous, partly carbonaceous, interbedded with and grades into very fine-grained sandstone; forms narrow valleys separating sandstone ridges. Previously mapped as Middlesboro Member of the Lee Formation, but later divided into Sewanee and Warren Point Sandstones by Chesnut (1992). On this map, combined unit, Sewanee and Warren Point Sandstones, is well exposed in an elongate belt of three or four prominent hogback ridges on the south flank of Pine Mountain. Base sharp and undulating; probably unconformable with underlying units.

₽ss SEWANEE SANDSTONE—Conglomerate, sandstone, siltstone, and shale. Unit identified only where intervening Dark Ridge Member is mapped between the Sewanee and Warren Point Sandstones. Locally divided into four conglomeratic sandstone ledges; forms prominent cliffs and hogbacks on top of Rocky Face and on northwest slope of Cumberland Mountain.

₽bcd DARK RIDGE MEMBER, BOTTOM CREEK FORMATION—Shale, siltstone, sandstone, and coal. Shale and siltstone, medium- to dark-gray, slightly calcareous, locally grayish-green clay shale; interbedded with ripple-laminated siltstone and fine-grained sandstone. Sandstone, light-gray, fine- to medium-grained, lithic fragments common. Cumberland Gap coal bed locally exposed near top of unit. Previously mapped as a member of the Lee Formation, now formally a member of the Bottom Creek Formation (Chesnut, 1992).

₽wp WARREN POINT SANDSTONE—Conglomerate, sandstone, and siltstone. Originally mapped as White Rocks Sandstone Member or Chadwell Member of the Lee Formation; renamed Warren Point Sandstone by Chesnut (1992). Mapped on west side of Rocky Face Fault and forms two or more sandstone ledges near the top of Cumberland Mountain.

Mp PENNINGTON GROUP—Siltstone, shale, sandstone, and minor limestone. Mapped as two units on earlier quadrangle maps, combined as one unit for this map. Siltstone and shale, interbedded, green, gray, reddish-brown, thin-bedded to laminated, in part carbonaceous, locally calcareous with marine fossil fragments, poorly exposed; forms swales between ridges. Sandstone composed of two types: (1) light- to medium-gray, fine- to medium-grained, quartzose, well-sorted, with occasional scattered quartz pebbles with coal and rock fragments, medium- to thick-bedded, crossbedded; and (2) greenish-gray, fine-grained, thin-bedded; grades laterally into silty, ripple-bedded sandstone; forms subdued linear ridges between shale valleys. Limestone, olive-gray, argillaceous, very fossiliferous; forms discontinuous bed or found as float near base of unit. Unit forms prominent cliffs along crest and north side of Pine Mountain and near crest of Cumberland Mountain; also poorly exposed in fault slices along main thrust plane of Pine Mountain Overthrust Fault Zone. May contain parts of Stony Gap Sandstone Member or Pinnacle Overlook Sandstone.

Mpo PINNACLE OVERLOOK SANDSTONE—Sandstone, white to light-gray, fine- to coarse-grained, quartzose, in part conglomeratic with well-rounded quartz pebbles, and small cobbles up to 10 cm (4 in.), crossbedded, massive, cliff-forming; grades laterally into calcareous siltstone and shale. Mapped as lower tongue or sandstone tongue of Lee Formation, believed to be equivalent to the Princeton Sandstone; currently recognized as a sandstone formation of the upper part of the Pennington Group (Chesnut, 1992).

Mhs STONY GAP SANDSTONE MEMBER, HINTON FORMATION—Sandstone, white to light-gray, fine- to coarse-grained, well-sorted, quartzose; lower part is thick-bedded to massive, crossbedded, conglomeratic with well-rounded quartz pebbles; forms prominent cliffs along north-facing crest of Pine Mountain. Unit grades into sandstone, light- to medium-gray, fine- to medium-grained, quartzose, ripple-bedded, thin- to medium-bedded. Member locally mapped in lower part of the Pennington Group.

Mn NEWMAN LIMESTONE, UNDIVIDED—Limestone and shale. Limestone, upper part, seen only in fault slice in Balkan 7.5-minute quadrangle, is medium- to dark-gray, lustrous, partly calcareous shale with thin greenish-gray shale or siltstone interbeds. Elsewhere, identified and mapped separately as upper part of Newman Limestone and lower part of Newman Limestone or lower part of Newman Limestone and Fort Payne Chert. Detailed descriptions below.

Mnu UPPER PART OF NEWMAN LIMESTONE—Shale and limestone. Shale, light- to dark-gray, calcareous, partly laminated to thin-bedded, fossiliferous, grading to blocky claystone; interbedded with limestone. Limestone, medium- to dark-gray, thin- to medium-bedded, fossiliferous; in part argillaceous, oolitic, and bioclastic. Poorly exposed, often covered by colluvium along north slope of Pine Mountain.

Mnl LOWER PART OF NEWMAN LIMESTONE—Limestone, light- to dark-gray, cryptocrystalline to moderately crystalline, generally dense; in part granular, oolitic, and with sparry calcite cement. Upper part, dark-gray, argillaceous, fossiliferous, interbedded with thin gray and green shale, contains some oolitic beds and granular limestone. Middle portion, light-gray to buff, granular, oolitic, sparsely to abundantly fossiliferous. Lower part, usually cryptocrystalline, very dense, with abundant chert nodules or thin irregular chert layers; basal beds tan, rubbly, dolomitic limestone. Unit forms prominent cliff along north slope of Pine Mountain.

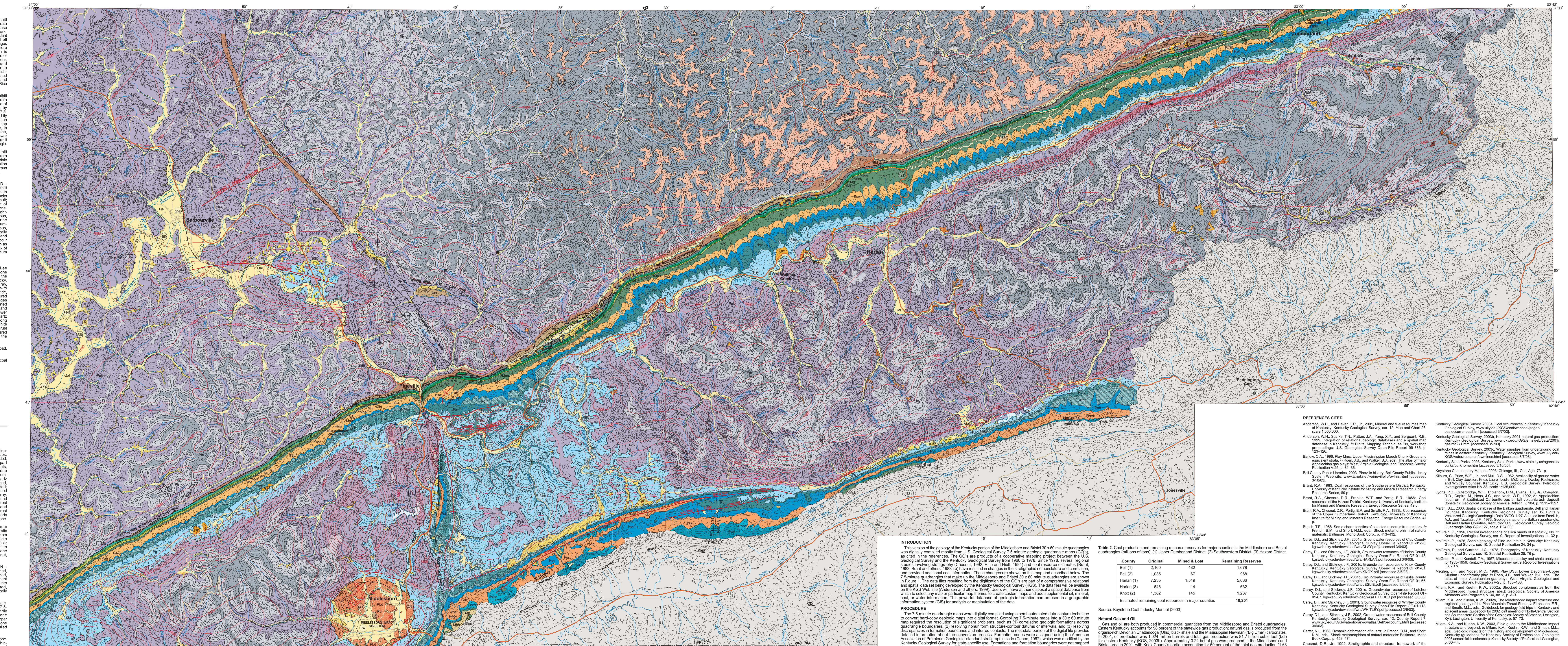
Mnf LOWER PART OF NEWMAN LIMESTONE AND FORT PAYNE CHERT—Limestone, chert, and dolomite. Mapped as a combined unit. Lower part of Newman Limestone as described in preceding paragraph. Fort Payne chert and dolomite. Chert, light-gray, pink, or white, thin-bedded to nodular, interbedded with silty shale of underlying unit. Dolomite, silty, in thin beds, interbedded with shale. Fort Payne thins eastward, only present on west side of quadrangle; intertongues with underlying Grainger Formation.

Mg GRAINGER FORMATION—Siltstone and shale, interbedded, red, green, and gray, laminated to medium-bedded; upper part more thick-bedded siltstone, lower part dominantly shale. Occurs on north face of Pine Mountain; forms steep, rubble-covered slopes, covered by colluvium and reddish-green soil. Basal contact concealed.

MDc CHATTANOOGA SHALE—Shale, dark-gray to black, weathers rust red to greenish-yellow, fissile to platy, brittle, carbonaceous, locally pyritic and silty, rare conodonts and linguloid brachiopods present, reddish-brown plant spores locally abundant. Poorly exposed, forms gentle colluvium-covered slopes along sole of Pine Mountain Overthrust Fault, locally thickened and deformed by drag folding; base not found.

MDsb SUNBURY SHALE, BEREA SANDSTONE, AND BEDFORD SHALE, UNDIVIDED—Shale and sandstone, 15 m (50 ft) thick interbedded sequence of very fine-grained, light-gray, quartzose sandstone, siltstone, and shale overlain by 3 m (10 ft) of black shale. Presence inferred by drillhole occurrence in quadrangle to northeast and by outcrop exposure in Louellen 7.5-minute quadrangle. Mapped in northeast corner of quadrangle; correlates to upper part of Chattanooga Shale immediately to the southwest.

Do OHIO SHALE—Shale, black shale as described above for Chattanooga Shale. Correlates to middle and lower exposed outcrops of Chattanooga Shale to the southwest. Poorly exposed, unit thickened by imbricate faults and drag folds above Pine Mountain Overthrust Fault; base not found.



GEOLOGIC MAP OF THE MIDDLESBORO AND PART OF THE BRISTOL 30 x 60 MINUTE QUADRANGLES, SOUTHEASTERN KENTUCKY

Thomas N. Sparks

Cartography by Terry D. Hounshell

1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 KILOMETERS
1 0 1 2 3 4 5 6 7 8 9 10 MILES
1000 0 5000 10 000 15 000 METERS
5000 0 10 000 20 000 30 000 40 000 50 000 FEET

SCALE 1:100 000

universal transverse Mercator projection, zone 17: 1927 North American datum

TOPOGRAPHIC CONTOUR INTERVAL 50 METERS

ACKNOWLEDGMENTS: This map was digitally generated from 1:24,000-scale geologic maps under the STATEMAP Program authorized by the National Geologic Mapping Act of 1992, Grant No. 02HQPA0003, and was funded in part by the U.S. Geological Survey National Cooperative Geologic Mapping Program.

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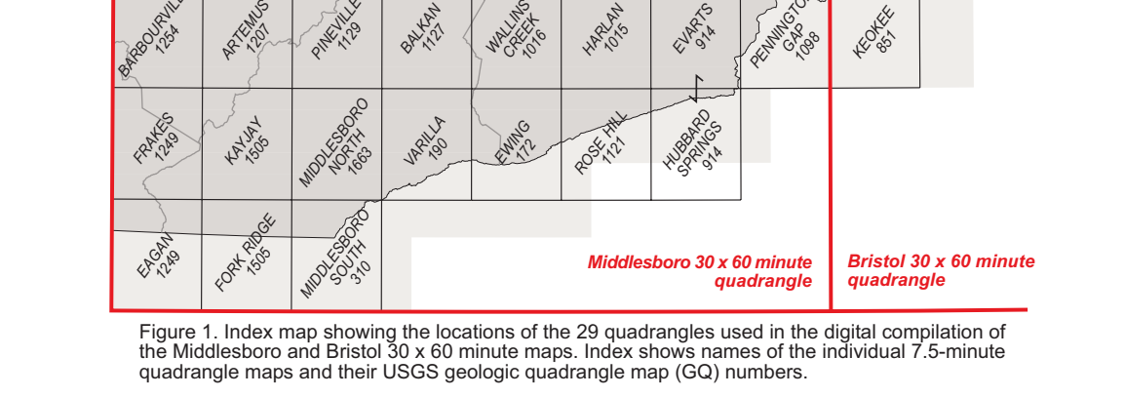


Figure 1. Index map showing the locations of the 29 quadrangles used in the digital compilation of the Middlesboro and Bristol 30 x 60 minute maps. Index shows names of the individual 7.5-minute quadrangle maps and their USGS geologic quadrangle map (GQ) numbers.

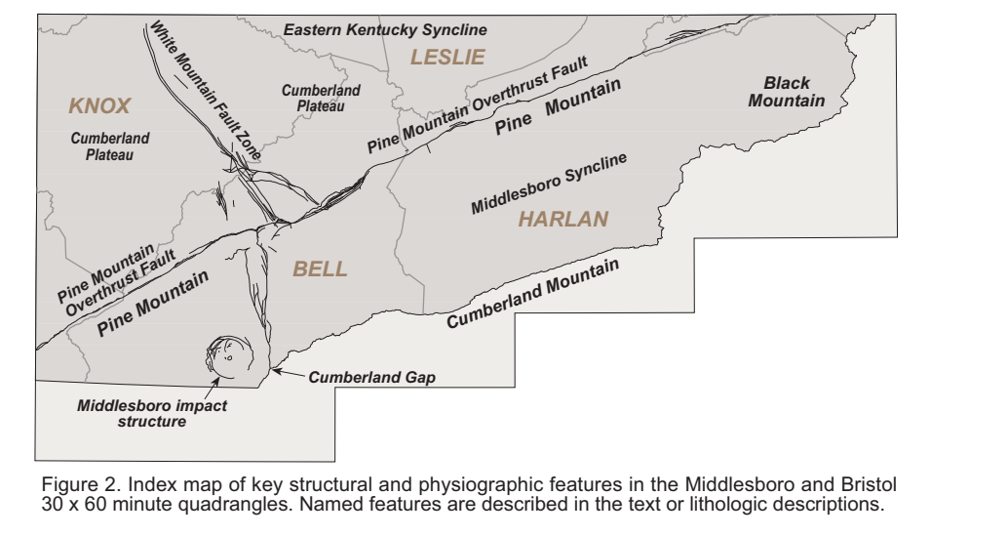

Eastern Kentucky Syncline
LESLIE
KNOX
Cumberland Plateau
White Mountain Fault Zone
Pine Mountain Overthrust Fault
Pine Mountain
Black Mountain
Middlesboro Syncline
HARLAN
BELL
Pine Mountain Overthrust Fault
Pine Mountain
Cumberland Mountain
Cumberland Gap
Middlesboro impact structure

Figure 2. Index map of key structural and physiographic features in the Middlesboro and Bristol 30 x 60 minute quadrangles. Named features are described in the text or lithologic descriptions.

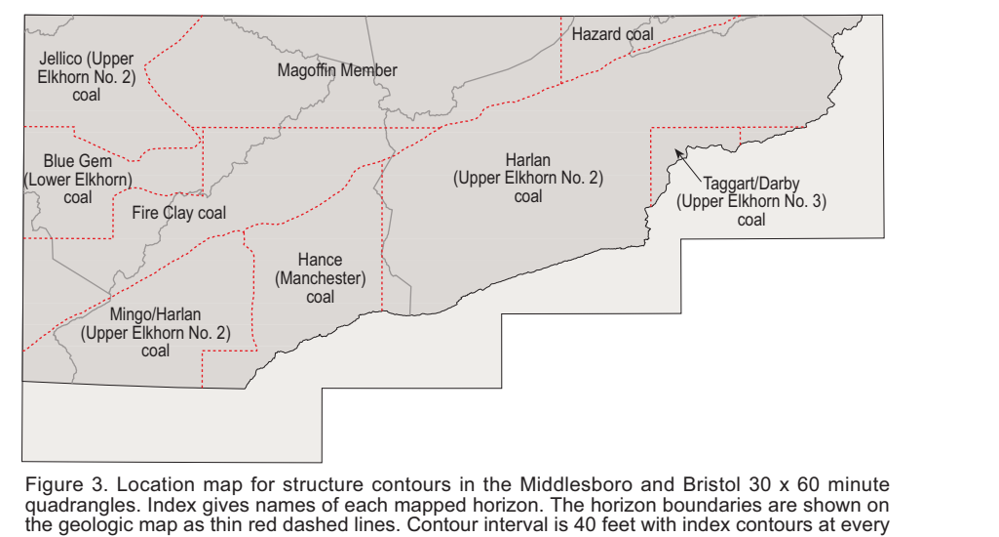
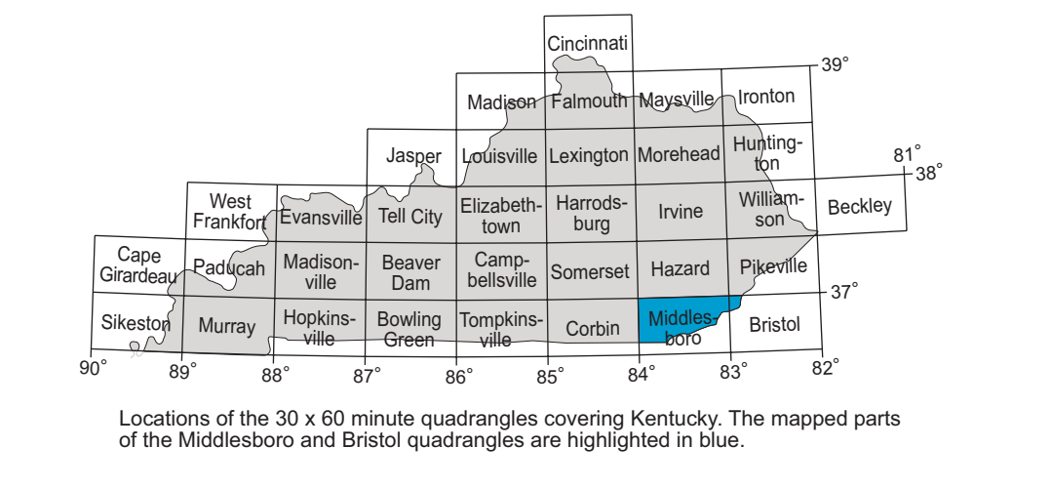
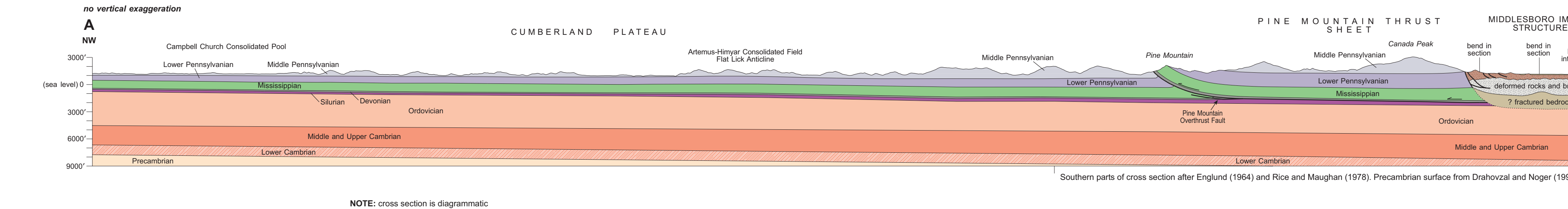

Jellico (Upper Elkhorn No. 2) coal
Magoffin Member
Hazard coal
Blue Gem (Lower Elkhorn) coal
Fire Clay coal
Harlan (Upper Elkhorn No. 2) coal
Taggart/Darby (Upper Elkhorn No. 3) coal
Hance (Manchester) coal
Mingo/Harlan (Upper Elkhorn No. 2) coal

Figure 3. Location map for structure contours in the Middlesboro and Bristol 30 x 60 minute quadrangles. Index gives names of each mapped horizon. The horizon boundaries are shown on the geologic map as thin red dashed lines. Contour interval is 40 feet with index contours at every 200 feet.



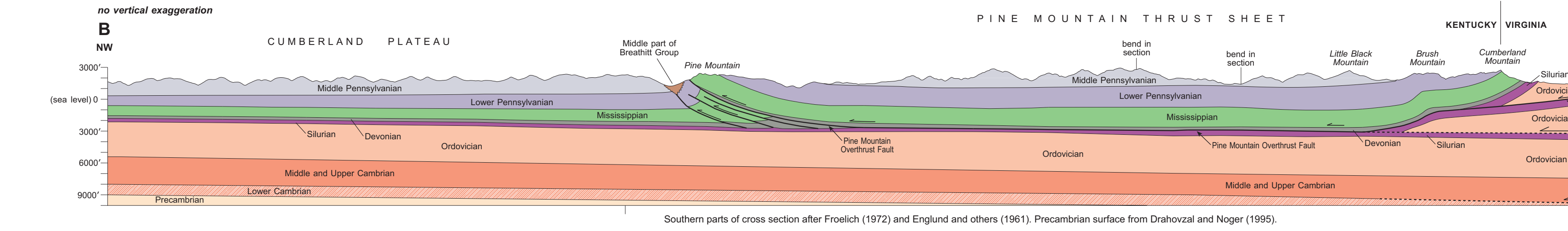
Locations of the 30 x 60 minute quadrangles covering Kentucky. The mapped parts of the Middlesboro and Bristol quadrangles are highlighted in blue.

NOTE: cross section is diagrammatic
no vertical exaggeration



Southern parts of cross section after Englund (1964) and Rice and Maughan (1978). Precambrian surface from Drahovzal and Noger (1995).

NOTE: cross section is diagrammatic
no vertical exaggeration



Southern parts of cross section after Froelich (1972) and Englund and others (1961). Precambrian surface from Drahovzal and Noger (1995).

EXPLANATION

- U.S. highway
- State highway
- State boundary
- County boundary
- City boundary
- Railroad
- Normal fault (U, upthrown side; D, downthrown side)
- Thrust fault (sawteeth on upper plate)
- Concealed thrust fault (sawteeth on upper plate)
- Small thrust fault (T, upper plate)
- Reverse fault (R, upthrown side)
- Left-lateral strike slip fault
- Right-lateral strike slip fault
- Concealed fault
- Concealed contact
- Inferred or stratigraphic contact
- 1600 Structure contour, feet
- Anticlinal axis
- Synclinal axis
- Monoclinal axis
- Structure datum boundary
- Coal bed (see note)
- Concealed coal bed
- Inferred coal bed
- ⚒ Active limestone quarry or mine
- ⚒ Abandoned limestone quarry or mine
- ⚒s Abandoned sandstone quarry
- ◪ Active mine shaft
- ◪ab Abandoned mine shaft

NOTE: Not all coals digitized under the STATEMAP Program are included on this map. Coals included on map are Clear Fork, Gray Hawk, Manchester (Hance), Blue Gem (Path Fork), Jellico (Harlan), Upper Elkhorn No. 3 (Darby), Amburgy (Creech), Fire Clay, Fire Clay rider, Taylor (Limestone), Hazard, Hazard No. 7, Hazard No. 8 (Francis), and Hindman coals.

INTRODUCTION

This version of the geology of the Kentucky portion of the Middlesboro and Bristol 30 x 60 minute quadrangles was digitally compiled mostly from U.S. Geological Survey 7.5-minute geologic quadrangle maps (GQ's), as cited in the references. The GQ's are products of a cooperative mapping project between the U.S. Geological Survey and the Kentucky Geological Survey from 1960 to 1978. Since 1978, several regional studies involving stratigraphy (Chesnut, 1992; Rice and Hiett, 1994) and coal-resource estimates (Brant, 1983; Brant and others, 1983a,b) have resulted in changes in the stratigraphic nomenclature and correlation, and provided additional coal information. These changes are shown on this map and described below. The 7.5-minute quadrangles that make up the Middlesboro and Bristol 30 x 60 minute quadrangles are shown in Figure 1. The data files resulting from the digitization of the GQ's are part of a comprehensive relational and spatial data set being developed by the Kentucky Geological Survey (KGS). The data files will be available on the KGS Web site (Anderson and others, 1999). Users will have at their disposal a spatial database from which to select any map or particular map themes to create custom maps and add supplemental oil, mineral, coal, or water information. This powerful database of geologic information can be used in a geographic information system (GIS) for analysis or manipulation of the data.

PROCEDURE

The 7.5-minute quadrangle maps were digitally compiled using a semi-automated data-capture technique to convert hard-copy geologic maps into digital format. Compiling 7.5-minute maps into a 30 x 60 minute map required the resolution of significant problems, such as (1) correlating geologic formations across quadrangle boundaries, (2) resolving nonuniform structure-contour datums or intervals, and (3) resolving discrepancies in formation boundaries and inferred contacts. The metadata portion of the digital file provides detailed information about the conversion process. Formation codes were assigned using the American Association of Petroleum Geologists' standard stratigraphic code (Cohee, 1967), which was modified by the Kentucky Geological Survey for state-specific use. Formations and formation boundaries were not mapped the same way on each of the 7.5-minute quadrangle maps, since they were compiled by various authors between 1960 and 1978. Resolution of the differences between quadrangles was necessary for efficient topological analysis in a GIS environment. In addition, numerous small members mapped on individual 7.5-minute quadrangle maps are too small to be mapped at a scale of 1:100,000 on a 30 x 60 minute quadrangle map. These problems were resolved by adhering to geologic, cartographic, and GIS standards appropriate for the scale of the map.

This map is a compilation of existing maps, and no additional geologic field work took place. When there were problems in stratigraphic correlation between quadrangles, the best current data available were used to resolve these differences.

GEOLOGIC SETTING AND STRUCTURAL GEOLOGY

The geology of the Middlesboro and Bristol 30 x 60 minute quadrangles consists of gently to steeply dipping sedimentary rocks of Late Devonian through Middle Pennsylvanian age and unconsolidated sediments of Tertiary(?) and Quaternary age. These rocks and sediments occur in the southern part of the Eastern Kentucky Coal Field along the western limb of the central Appalachian Basin. The dominant rock types for the mapped area are sandstone, siltstone, shale, coal, and limestone for the Mississippian and Pennsylvanian strata, and black, organic-rich shale, with minor gray shale and sandstone for the Devonian strata. Tertiary(?) and Quaternary strata are mostly sediments, mainly unconsolidated or semiconsolidated, and contain clay, silt, sand, and gravel deposits, some of which may be locally cemented.

Four major structural features have been identified and mapped in the Middlesboro area of Kentucky:

- Pine Mountain Thrust Sheet (with associated Pine Mountain Overthrust Fault)
- Middlesboro Syncline (south of the fault on the Pine Mountain Thrust Sheet)
- Eastern Kentucky Syncline (north of the thrust on the Cumberland Plateau)
- Middlesboro structure, a meteorite impact feature.

Pine Mountain Overthrust

The Pine Mountain Overthrust was formed during the Alleghenian Orogeny, between ~330 and 265 Ma (Late Pennsylvanian to Middle Permian) (Hatcher and others, 1989, p. 236). The Pine Mountain Thrust Sheet is the westernmost propagation and leading edge of a foreland belt of folds and thrust faults, formed by lateral compressive forces in the sedimentary rocks of the North American craton. It formed at the boundary between two structural provinces, the southern Appalachian Plateau (or Cumberland Plateau of Kentucky) to the northwest and Valley and Ridge Province to the southeast.

The thrust fault comes to the surface in Kentucky along the north flank of Pine Mountain, although it is generally concealed by alluvium and colluvium. Beds above the fault are moderately dipping, whereas undisturbed beds in front of the fault are flat-lying. Two décollement detachment surfaces are associated with this thrust; the upper is at the base of the Devonian Chattanooga Shale and crops out on the surface, and the basal horizon is along the Cambrian Rome Formation (or slightly younger Conasauga Group), which is not exposed (Hatcher and others, 1989). These low-angle fault surfaces ramp upward toward the northwest through a series of imbricate thrust blocks.

In addition to the Middlesboro Syncline, which is discussed below, other recognized structural features on the Pine Mountain Thrust Sheet are the Powell Valley Anticline and the Rocky Face Fault. Though not mapped in Kentucky, the Powell Valley Anticline is a classic ramp anticline parallel to the thrust sheet and is shown on the southern ends of the two regional cross sections. The Rocky Face Fault is a high-angle tear fault that connects the Pine Mountain Overthrust Fault with the Powell Valley Anticline in Tennessee through the Cumberland Gap (Hatcher and others, 1989). Rice and Ping (1989) stated that the Rocky Face Fault, a left-lateral strike-slip fault, is an upper splay of the Pine Mountain Thrust Fault. This thrusting resulted in local tectonic thickening of the Chattanooga Shale in a domal structure due west of the Rocky Face Fault.

Middlesboro Syncline

The Middlesboro Syncline is a large, longitudinal basin, 219 km (136 mi) long, 5,178 km² (2,000 mi²) in area, whose axis is parallel to the Pine Mountain Thrust Sheet (Potter and others, 1984). The syncline is located on the leading edge of the thrust sheet, and was formed along with the Powell Valley Anticline during movement of the detached rock layers up tectonic ramps from deeper to higher décollement surfaces (Harris and Milici, 1977). The Middlesboro Syncline has a broad, flat synclinal axis that is characteristic of central Appalachian folding (Hatcher and others, 1989). Beds that crop out on the northwest limb of the syncline along Pine Mountain have an average dip of 30° to the southeast. On the southeast side of the syncline along Cumberland Mountain, the beds generally dip 40° to the northwest (Dean and Moshier, 1989). The regional dip along the axis in the subsurface is relatively flat (1 to 2°), where the Chattanooga Shale reaches a depth of –914 m (–3,000 ft) (Potter and others, 1984).

Eastern Kentucky Syncline

The Eastern Kentucky Syncline is equivalent to the Coalburg Syncline of West Virginia, and extends across the Eastern Kentucky Coal Field in a northeast–southwest trend (Huddle and others, 1963; Chesnut, 1992). On the Middlesboro quadrangle, only the southernmost edge of the Eastern Kentucky Syncline is observed north of Pine Mountain, where over 152 m (500 ft) of structural relief is mapped on the Cumberland Plateau (see structure contours). Pennsylvanian beds gently dip northwest into the syncline, as shown on cross section B-B′, whereas the Mississippian and deeper strata dip to the southeast away from the Cincinnati Arch. Chesnut (1992) attributed part of this dip reversal to a shift of the depositional basin prior to and following Early Pennsylvanian erosion, which was followed by uplift of the basin.

Middlesboro Impact Structure

The Middlesboro impact structure, also known as the Middlesboro Basin by some geologists, is a circular topographic depression about 5.3 km (3.3 mi) in diameter, in which the entire city of Middlesboro is located. The structure is superimposed on the Pine Mountain Thrust Sheet near the junction of Kentucky, Tennessee, and Virginia. Rice and Ping (1989) concluded that the Middlesboro Basin postdates the Alleghenian Orogeny (Late Pennsylvanian to Middle Permian) because the structure's overall morphology was not deformed by movement of the thrust sheet.

Englund and Roen (1963) were the first to propose a meteorite impact origin, based on the presence of a circular basin, deformed rock, an arcuate trend of normal faults, overturned beds, shattered quartz grains, and a central core of uplifted material. The basin is not a crater, but rather the fractured and faulted material beneath the old crater; the crater itself has long since eroded away. Dietz (1966) discovered shatter cones in the central uplift area, and Bunch (1968) and Carter (1968) identified shocked quartz, further confirming an impact origin. Ehmann (2000, p. 30) determined that based on the presence of shatter cones, intense brecciation, and shocked quartz grains, a meteorite-impact origin for the Middlesboro structure was "probable." Greb and Chesnut (1998) documented the presence of brecciated, deformed gray shales, tilted coal beds, and normal faulting in coal mines in the Middlesboro structure. They concluded these features were consistent with a history of compression followed by relaxation, as would happen during an impact.

Milam and Kuehn (2002a) presented petrographic microanalyses of shocked conglomerates from the Middlesboro impact structure to describe their deformation fabrics. These included planar fractures, planar deformation features, shattering and fracturing of the conglomeratic sandstones, possible melt textures of the matrix, and sheared (microfaulted) quartzite pebbles. Milam and Kuehn (2002b, 2003) also presented an updated guide to the Middlesboro impact structure describing its central uplift, transient crater rim, modification stage, and modified crater rim.

ECONOMIC GEOLOGY

Coal, natural gas, and oil are the principal economic mineral resources in the Middlesboro and Bristol quadrangles. Limestone, sand, gravel, and shale are also available as mineral resources for general construction purposes and for use in the coal industry. The locations of industrial mineral resources, including limestone and sand operations in Bell, Harlan, and Letcher Counties, were mapped and described by Anderson and Dever (2001) and Glass and Malone (2002).

Coal production and reserves

The Middlesboro and Bristol quadrangles comprise a major part (more than 90 percent) of the Upper Cumberland Coal Reserve District, significant parts of the Hazard District, and parts of the Southwestern District, as described by Brant (1983) and Brant and others (1983a,b). The quadrangles encompass the majority of Bell, Harlan, and Knox Counties, with lesser parts of Clay, Laurel, Leslie, Letcher, Perry, and Whitley Counties (see Figure 2). Of the counties that make up these quadrangles, Harlan is ranked second in the state for cumulative coal production (Pike County is first). Total coal production from the three major counties is summarized in Table 1.

Table 1. Cumulative coal production (millions of tons) by county and mining method (1829–2000).

County	Undifferentiated	Underground	Surface	Total
Bell	34.055	154.845	103.900	292.800
Harlan	27.178	786.925	57.120	871.223
Knox	15.410	33.265	24.510	73.185
Total	76.643	975.035	185.530	1,237.208

Source: Kentucky Geological Survey coal production database, kgsweb.uky.edu/DataSearching/Coal/Production [accessed 3/7/03].

The Middlesboro and Bristol quadrangles are bisected by the Pine Mountain Thrust Fault. On the part of the quadrangle north of Pine Mountain (the Cumberland Plateau) at least 17 coal beds have been mined or prospected. The 10 most important beds in the Hazard and Southwestern Districts are, in ascending stratigraphic order: Lily, Blue Gem, Jellico, Upper Elkhorn No. 3, Amburgy, Fire Clay (Hazard No. 4), Fire Clay rider, Hazard No. 7, and Francis (Hazard No. 8). Twenty-one coals are mapped in the Middlesboro Syncline south of the Pine Mountain Thrust Fault. The principal coal beds in the Upper Cumberland District (located on the Pine Mountain Thrust Sheet) are, in ascending stratigraphic order: Hance (Manchester), Path Fork (Lower Elkhorn), Harlan (Upper Elkhorn No. 1 and No. 2), Darby (Upper Elkhorn No. 3), and Creech (Amburgy). The quality of most coals from this area is generally good to high. The Upper Cumberland District coals are of high volatile A or B bituminous rank, with a range of mean heating values of 13,100 to 13,789 Btu/lb; north of Pine Mountain, the coals range from 12,537 to 13,837 Btu/lb (Keystone Coal Industry Manual, 2003).

Coal-availability studies for selected 7.5-minute quadrangles in or adjacent to the mapped area have been completed (Sergeant and others, 1989; Davidson and others, 1990; Greb and others, 1999a,b). Coal-resource and -thickness maps from the availability studies have been published for the Lower Elkhorn coal (Thacker and others, 1998, 2000a), the Fire Clay coal (Thacker and others, 2000b,c), the Upper Elkhorn No. 3 coal (Esterle and others, 2000a–c), and the Amburgy coal (Shultz and others, 2003). Remaining coal reserves for the three largest counties in the Middlesboro and Bristol quadrangles have been tabulated (see Table 2). Coal-availability studies from selected quadrangles in eastern Kentucky indicate that approximately 50 percent of the remaining coal resources are available for mining by current methods, so the actual recoverable reserves may be less (KGS, 2003a).

Table 2. Coal production and remaining resource reserves for major counties in the Middlesboro and Bristol quadrangles (millions of tons). (1) Upper Cumberland District, (2) Southwestern District, (3) Hazard District.

County	Original	Mined & Lost	Remaining Reserves
Bell (1)	2,160	482	1,678
Bell (2)	1,035	67	968
Harlan (1)	7,235	1,549	5,686
Harlan (3)	646	14	632
Knox (2)	1,382	145	1,237
Estimated remaining coal resources in major counties			**10,201**

Source: Keystone Coal Industry Manual (2003)

Natural Gas and Oil

Gas and oil are both produced in commercial quantities from the Middlesboro and Bristol quadrangles. Eastern Kentucky accounts for 98 percent of the statewide gas production; natural gas is produced from the organic-rich Devonian Chattanooga (Ohio) black shale and the Mississippian Newman ("Big Lime") carbonates. In 2001, oil production was 1.024 million barrels and total gas production was 81.7 billion cubic feet (bcf) for eastern Kentucky (KGS, 2003b). Approximately 3.24 bcf of gas was produced in the Middlesboro and Bristol area in 2001, with Knox County's portion accounting for 50 percent of the total gas production (1.63 bcf). The Middlesboro and Bristol quadrangles had a minor component of the overall oil production, amounting to 28,000 barrels (or 1 percent of the state total).

As of February 2003, 1,262 wells had been drilled in the mapped area to an average depth of 2,842 ft. Of these wells, 907 were classified as gas, 54 as oil and gas, 46 as oil, and 248 as dry and abandoned. More than 55 named pools and fields have been identified in the Middlesboro quadrangle (Watson and others, 1997). An additional five pools and fields are in the Bristol area. Between 1997 and 2002, increased drilling activity has resulted in the discovery of at least 10 new fields or pools and in the expansion of several others in southern Knox, eastern Whitley, and western Harlan Counties (Anna Watson, Kentucky Geological Survey, personal communication, 3/7/03).

The greatest concentration of gas wells is in south-central Knox County, centered on the Artemus and Barbourville 7.5-minute quadrangles, on the flanks of the Flat Lick Anticline. This complex includes the Artemus-Himyar Consolidated, Barbourville Southwest Consolidated, Meadow Creek Consolidated, and Indian Creek Fields, along with the Campbell Church Consolidated Pool. Significant gas zones and their approximate range of depths throughout the quadrangle area as identified by Wilson and Sutton (1976) are:

- Pennsylvanian "Salt" sands (600–1,970 ft)
- Mississippian "Maxon sands" of Pennington Group (1,085–1,140 ft)
- Mississippian Newman "Big Lime" Limestone (1,174–3,940 ft)
- Mississippian "Waverly sands" or Borden Formation (1,335–1,616 ft)
- Devonian Ohio or Chattanooga black shale (3,200–6,000 ft)
- Silurian "Corniferous" Lockport Dolomite and Big Six sand (1,979–3,855 ft)
- Silurian "Clinton shale" or Rose Hill Formation (2,000+ ft)

Many of the oil wells drilled in these quadrangles are producing from the Newman Limestone or Big Lime. Reservoir rocks include fractured limestone, porous dolostone, and porous oolitic limestone. Hydrocarbon traps in the Big Lime are predominantly stratigraphic, with the thicker limestone section being deposited in erosional channels of the underlying Borden Formation (Harris and Sparks, in preparation).

Detailed reservoir studies are available for selected fields: KayJay Consolidated Pool, Mississippian "Maxon" Pennington Group (Barlow, 1996); Stoney Fork Field, Mississippian Newman Big Lime Limestone (Smosna, 1996); Artemus-Himyar Consolidated Field; Silurian Lockport; and Big Six (Meglen and Noger, 1996).

Limestone, Sand, Gravel, and Shale

Three active limestone quarries are present in the area: one each in Bell, Harlan, and Letcher Counties (Glass and Malone, 2002). Large reserves suitable for construction purposes are present from the lower member of the Newman Limestone along the north face of Pine Mountain. The limestone is quarried and crushed for use as road metal, blacktop mix, agricultural lime, and concrete aggregate.

Limestone suitable for coal-mining operations (with low-silica and high-calcium properties) is also available in the Newman Limestone along the top of Pine Mountain. Low-silica limestone is carbonate rock with 95 percent or more calcium carbonate (CaCO$_3$), and is used as a neutralizing agent in surface-mine reclamation and acid-drainage control. Dever and others (1991, 1992) measured several zones of low-silica stone, 3 to 20 m (10 to 64 ft) thick, that had corresponding intervals of high-calcium limestone present in the lower member of the Newman Limestone in selected quarries and outcrop exposures in Harlan and Letcher Counties.

Smaller quarries, now abandoned, were in operation to quarry silica sand and gravel from well-sorted, friable quartzose sandstone beds of the lower Breathitt Group, and from the pebbly quartzarenites of the Sewanee–Warren Point Sandstones and the Bee Rock Sandstone of the Breathitt Group ("Lee" sandstones of McGrain, 1956). Sand and gravel are also available from alluvial deposits. Clay shale below the Blue Gem coal zone of the Breathitt Group has been found to be satisfactory for use in lightweight aggregate and in the manufacture of common brick and structural tile (McGrain and Kendall, 1957).

ENGINEERING GEOLOGY

The highly dissected topography in the Middlesboro and Bristol area, in conjunction with the steeply dipping bedrock exposed along Pine Mountain, has contributed to a history of landslides and also present a future potential for engineering and maintenance problems. The interbedded sequence of sandstone, shale, and coal in the Grundy Formation, on the south-dipping flank of Pine Mountain, is prone to failure by landslide and creep. Numerous slumps and landslides also surround the central uplift in the Middlesboro impact structure. The presence of prominent landslide scars and slumped bedrock indicate that future landslides may occur where these relatively unstable beds are undercut by rivers and their tributaries or by construction work for roads and mines. Because the geologic factors apparently contributing to instability are known, potentially slide-prone areas can be outlined and construction can be planned to avoid disturbing natural conditions of equilibrium (Froelich, 1970). Logging, clearcutting, and removal of vegetation for construction can destabilize slopes. Coal-mining activities can also precipitate landslides, removing vegetation, steepening slopes, and cutting the toes of old slides. Landslides of colluvium from hillsides pose engineering hazards and have damaged roads and railroads.

The escarpment of Pine Mountain (the north-facing flank) has created several naturally occurring, precipitous overhangs of large sandstone boulders, which are an imminent hazard to the communities below. One prominent example is the hanging or Chained Rock at Pineville. This boulder is a thrust sheet remnant, which has minimal basal support and is "held in place" by a thick chain 100 ft long and weighing 1.5 tons. This chain obviously would not prevent a rock fall if the basal support of this boulder were removed. The chain was placed there by local citizens in 1933 more for a publicity stunt than as a safety precaution (Bell County Public Libraries, 2003). The threat is real, however; and caution must be exercised wherever construction may remove material from along the north slope of Pine Mountain.

HYDROGEOLOGY

The Middlesboro and Bristol quadrangles cover parts of the Cumberland River and Kentucky River Basin watersheds. The availability and quality of groundwater in this area are discussed in Price and others (1962) and Kilburn and others (1962). Carey and Stickney (2001a–f, 2002) have written a series of Web-based groundwater resource reports for Bell, Clay, Harlan, Knox, Leslie, Letcher, and Whitley Counties.

Water Quality and Production

Soft to moderately hard water at rates adequate for domestic supply is available from most sandstone beds of the Breathitt Group at shallow to moderate depth across much of the quadrangle area. Groundwater comes from joints and bedding planes in sandstone, shale, and coal. Naturally occurring contaminants that may be present in objectionable amounts in the groundwater are sulfate, salt (sodium chloride), iron, and manganese. In some locations, abandoned oil and gas wells have contaminated shallow, freshwater aquifers with salt water brought up from deeper formations. High iron and manganese levels, found in many wells, can produce objectionable taste and stain laundry and porcelain fixtures. Coal mining increases the amount of fresh surface area of the rocks exposed to oxidation, which can increase the sulfate and metals concentrations (Carey and Stickney, 2001a–f, 2002).

Some wells drilled into permeable units of the lower Breathitt and Pennington Groups, and the Newman Formation south of Pine Mountain, may produce artesian flow. Wells from the lower member of the Newman Limestone on Pine Mountain yield as much as 400 gallons per minute (gpm) near Pineville (Froelich and Tazelaar, 1974). The most prolific wells and springs produce water from solution cavities in the limestone. Most springs throughout the area, however, generally produce at 5 to 10 gal/min (Carey and Stickney, 2001b,c, 2002).

Most of the wells drilled in valley bottoms are adequate for a modern domestic supply; however, fewer wells drilled on hillsides and ridgetops supply adequate yields. Wells drilled into bedrock deeper than 61 m (200 ft) below the valley bottoms may produce enough water for small municipal or industrial supplies. Municipal water-supply resources have also been developed from abandoned underground coal mines. Detailed analyses at sites in Letcher, Perry, Clay, and Harlan Counties (KGS, 2003c) indicate recharge rates ranging from 120,000 to 700,000 gallons per day, and storage volumes ranging from 260 to 480 million gallons. Even though water from abandoned underground mines tends to have higher concentrations of sulfate and dissolved metals (iron, manganese, and magnesium), municipal water systems successfully use this source of water after conventional treatment methods.

Karst

Pine Mountain is one of the four major karst regions in Kentucky (Currens, 2001). Caves and other karst features (sinkholes, vertical shafts, and springs) develop in and along a long, narrow strip of exposed, tilted Newman Limestone. The exposure of the Newman Limestone is the result of the faulting and folding of the Mississippian carbonates during movement of the Pine Mountain Thrust, and the subsequent erosion of overlying strata. The limestone is bounded by sandstones and shales, and karst development is further limited by the area of limestone exposed and by structure restricting groundwater circulation. Many springs are located at major gaps or in small hollows on the northern slope of the mountain. Sinkholes are small and scattered because of rapid infill by downslope movement of debris and by widely distributed joints and bedding planes.

TOURISM AND SITES OF SPECIAL INTEREST

Pine Mountain and Cumberland Mountain, with their many spectacular sandstone cliffs and hogbacks, are among the most scenic places in southeastern Kentucky. This rugged beauty has been deemed worthy of preservation and development for outdoor recreational purposes.

Two areas of special scenic interest in Bell County are Pine Mountain State Park, on Pine Mountain overlooking Pineville (McGrain, 1975), and Cumberland Gap National Historic Park, south of Middlesboro, which covers part of Cumberland Mountain (Dean and Moshier, 1989; Englund and Harris, 1961). Cumberland Gap, a remnant of an ancient stream channel, is at an elevation of 502 m (1,648 ft). The gap was the gateway through the Cumberland Mountain barrier for early settlers more than 200 years ago, and today is an important route for north–south motor vehicle traffic (McGrain and Currens, 1978; Dean and Moshier, 1989).

The Dr. Thomas Walker State Historic Site at Barbourville, located in adjacent Knox County, commemorates the site where the surveyor and physician led the first expedition through Cumberland Gap in 1750, preceding the pioneer Daniel Boone by 17 years. Kingdom Come State Park, in Cumberland, Ky. (Harlan County), named after the popular Civil War novel *The Little Shepherd of Kingdom Come* by Kentucky author John Fox Jr., preserves 1,283 acres of rugged wilderness and some of the most extraordinary rock formations in the state. The park offers a spectacular view of Black Mountain to the south, which at an elevation of 1,263 m (4,145 ft) is the highest point in Kentucky (McGrain and Currens, 1978; Kentucky State Parks, 2003).

In March 2002, the Kentucky legislature passed a bill calling for the creation of the Pine Mountain Trail State Linear Park. The proposed trail will be more than 193 km (120 mi) long and extend from the Breaks Interstate Park on the Kentucky-Virginia border near Elkhorn City, Ky. (Pike County), to the Cumberland Gap National Park at Middlesboro, eventually connecting to the Cumberland Trail into Tennessee. As of spring 2003, 45 km (28 mi) of the trail has been completed (Pine Mountain Trail Conference, 2003). When completed, the Pine Mountain Trail will traverse terrain replete with pioneer homesteads, waterfalls, cliffs, rock shelters, caves, upland bogs, and many other scenic features.

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