KENTUCKY GEOLOGICAL SURVEY
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SYSTEM	SERIES	GROUP	FORMATION, MEMBER, ZONE, AND BED		LITHOLOGY	THICKNESS IN METERS (FEET)
QUATERNARY	Holocene			Alluvium	Qal	0–18 (0–60)
	Pleistocene or Holocene			Terrace deposits	Qt	0–15 (0–50)
TERTIARY OR QUATERNARY	Pliocene or Pleistocene			High-level fluvial deposits	QTf	0–24 (0–80)
PENNSYLVANIAN	Middle Pennsylvanian	Breathitt Group*	Princess Formation	Laurel coal Flint Ridge Flint of Morse (1931) Skyline/Richardson coal zone Tiptop coal Broas coal zone	Ppr	30–91 (100–300)
				Stoney Fork Member Hindman coal		0–3 (0–10)
			Four Corners Formation	Peach Orchard coal zone: Sebastian/Fugate (Hazard No. 8) coal Mudseam/Nickell/Oakley (Hazard No. 7) coal Prater coal zone: Prater/Adele/Index/Hazard coal Colvin/Haddix coal	Pfc	58–73 (190–240)
				Magoffin Member		0–20 (0–65)
			Hyden Formation	Copland/Taylor coal Hamlin coal zone Fire Clay rider coal Fire Clay (Hazard No. 4) coal Whitesburg coal zone	Ph	37–64 (120–210)
				Kendrick Shale Member		9–27 (30–90)
			Pikeville Formation	Cannel City/Amburgy coal zone Van Lear/Little Caney/Upper Elkhorn No. 3 coal Grassy/Jellico coal zone Blue Gem/Vires coal	Ppk	30–101 (100–330)
				Betsie Shale Member		6–12 (20–40)
	Lower Pennsylvanian		Grundy Formation	Manchester/Zachariah coal Corbin Sandstone Member	Plc	9–91 (5–300)
				Gray Hawk coal Beattyville coal Olive Hill clay bed Contrary coal	Pg	34–76 (110–250)
			Alvy Creek Formation		Pac	0–15 (0–50)
MISSISSIPPIAN			Paragon Formation		Mp	0–32 (0–105)
			Slade Formation	Poppin Rock Member Maddox Branch Member Ramey Creek Member Tygarts Creek Member Rosslyn Member Mill Knob Member Warix Run Member Ste. Genevieve Member St. Louis Member Renfro Member	Msla	0–73 (0–240)
			Borden Formation	Nada Member Cowbell Member Nancy Member Farmers Member	Mb	115–166 (380–545)
DEVONIAN	Middle and Upper Devonian		New Albany Shale		MDna	18–61 (60–200)
			Boyle Dolomite		Db	0–7 (0–22)
SILURIAN	Lower and Middle Silurian		Bisher Dolomite		Sbi	0–18 (0–60)
			Crab Orchard Formation and Brassfield Dolomite	Crab Orchard Formation Brassfield Dolomite	Scb	6–38 (20–125)
ORDOVICIAN	Upper Ordovician		Drakes Formation	Preachersville Member Rowland Member	Od	33–43 (110–140)
			Ashlock Formation	Reba Member Sunset Member Terrill Member Grant Lake Member Tate Member	Oa	40–43 (130–140)
			Calloway Creek Limestone		Occ	24–30 (80–100)
	Middle and Upper Ordovician		Garrard Siltstone		Og	10–20 (35–65)
			Clays Ferry Formation		Ocf	15+ (50+)

*Breathitt Group replaces Breathitt Formation (Chesnut, 1992). Group is divided into formations based upon widespread shales with marine fossils (all previously recognized as members). Formations occurring in this quadrangle are the Grundy, Pikeville, Hyden, Four Corners, and Princess (Chesnut, 1992).

ACKNOWLEDGEMENTS: 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. 1434HQ97PA00027, and was funded in part by the U.S. Geological Survey National Cooperative Geologic Mapping Program.

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DESCRIPTIONS OF MAPPED UNITS

Qal	ALLUVIUM—Silt, clay, sand, and gravel. Silt, clayey; clay, mostly silty and sandy; sand, very fine- to coarse-grained. Gravel includes sandstone, siltstone, chert, quartz, limestone, dolomite, shale, ironstone, and coal. Unit commonly grades into unmapped colluvium along valley sides. Contacts approximately located.
Qt	TERRACE DEPOSITS—Sand, silt, clay, and gravel; occurs above valley alluvium. Sand, very fine- to coarse-grained. Unit contains higher percentage of gravel than younger alluvium. Gravel includes chert, quartz, silicified fossils, geodes, sandstone, siltstone, and shale. Contacts approximately located.
QTf	HIGH-LEVEL FLUVIAL DEPOSITS—Sand, clay, silt, and gravel. Gravel at and near base of unit includes chert, sandstone, conglomeratic sandstone, quartz, and ironstone. Deposits occur between about 240 to 295 m (780 to 960 ft) elevation along North and Middle Forks of Kentucky River. Mapped on three 7.5-minute quadrangle maps. Contacts approximately located.

BREATHITT GROUP—The Breathitt was mapped as a formation on the 7.5-minute geologic quadrangle maps that were used to construct the Irvine 30 x 60 minute quadrangle map, but Chesnut (1992) elevated the Breathitt to group status and divided the group into formations based on regionally widespread shale members with marine fauna. Two of these shale members were mapped on the 7.5-minute maps and are described below. Two others were described on lithologic columns of many of the 7.5-minute maps but were not mapped. The Breathitt Group contains conglomerates, sandstones, siltstones, shales, coals, claystones, and limestones. Two types of sandstones occur: quartzarenites (more than 90 percent quartz), in the Corbin Sandstone Member, which was previously assigned to the Lee Formation, but was reassigned to the Grundy Formation by Chesnut (1992); and more common in the rest of the Breathitt Group, arkosic and sublitharenitic sandstones, which consist of 60 to 80 percent quartz, 2 to 15 percent feldspar, and lesser amounts of mica, opaque minerals, and rock fragments. Conglomerates in the Corbin are composed of quartz pebbles; in other Breathitt sandstones they consist of shale, siderite, and coal clasts.

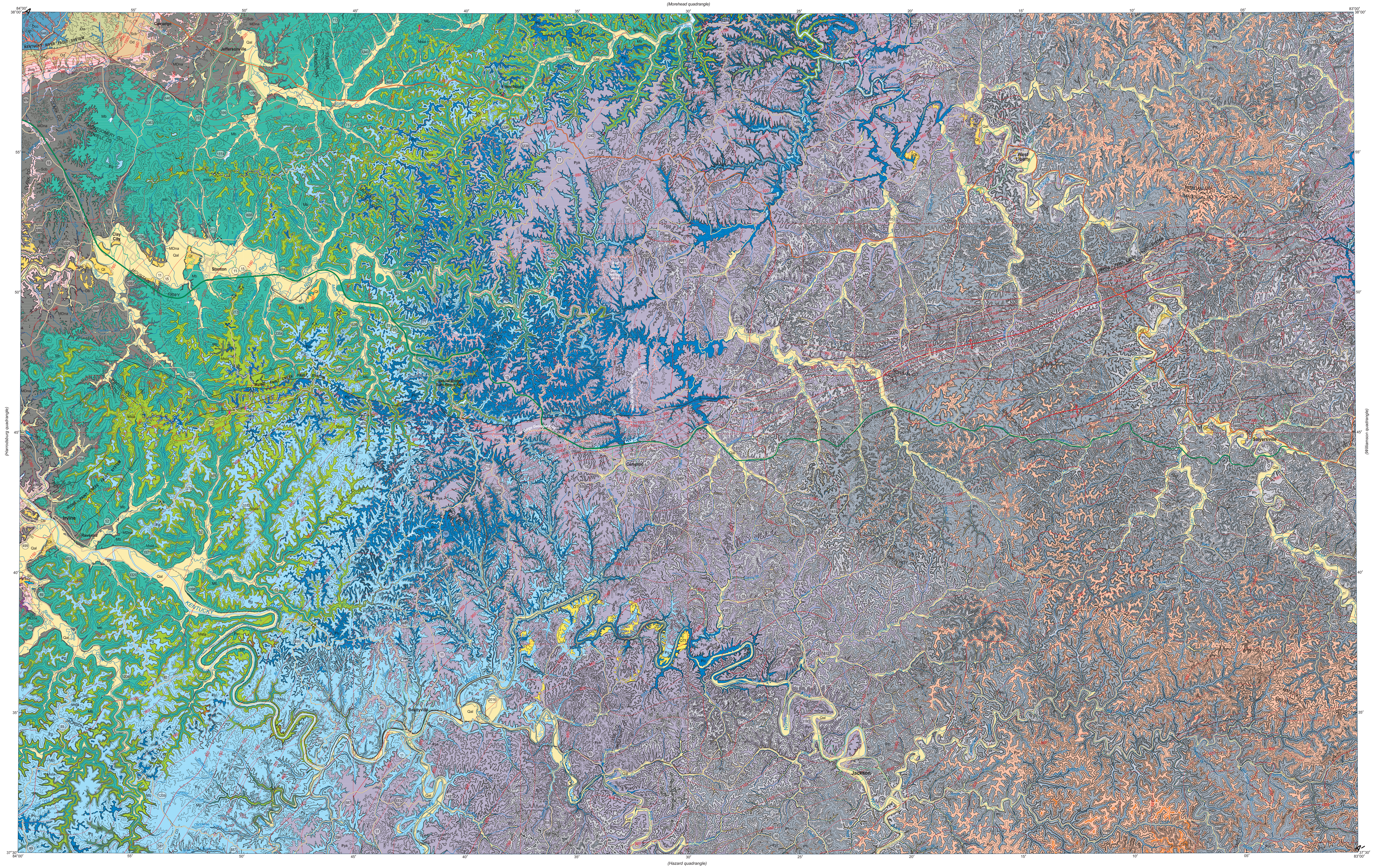
All the formations in the Breathitt Group are lithologically similar. The shale members (Betsie, Kendrick, Magoffin, Stoney Fork) at the base of each formation generally contain a thin, black to dark-gray clay shale and discontinuous, dark-gray to black limestone or sideritic sandstone with common marine fossils (summarized in Chesnut, 1991). 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 four to five coal zones. Each zone consists of multiple coals that may split laterally or grade into carbonaceous shales and rooted seat rocks, although at least one of the coals is usually extensive and mapped on the 7.5-minute quadrangle maps. Coal zones are separated by shales, siltstones, and sandstones, and generally exhibit considerable lateral variability. Some sandstones are locally extensive and useful as stratigraphic markers.

Ppr	PRINCESS FORMATION—Named by Chesnut (1992) for strata between the base of the Stoney Fork Member and the base of the Conemaugh Formation, which is not preserved in this quadrangle. The formation is equivalent to a unit mapped as the upper Breathitt Formation by Rice (1985). The base of the Stoney Fork Member (Ping and Rice, 1979) is locally a thin 1.2 m (4 ft) thick carbonate, which was mapped on some 7.5-minute quadrangle maps as the Lost Creek Limestone of Morse (1931); the Lost Creek Limestone is not currently recognized as a formal bed. In the northeastern part of the Hazard quadrangle, a second carbonate, the Flint Ridge Flint (Morse, 1931), occurs above the Skyline coal zone and is mapped on some 7.5-minute quadrangle maps. The Flint Ridge Flint consists of tan chert and yellowish-gray to dark-gray, sparsely fossiliferous, thin-bedded limestone and sandstone; it is generally less than 1 m (3 ft) thick, although it may be as much as 7 m (23 ft) thick in some areas (Donnell and Johnston, 1963). Coals in the Princess Formation, in descending order, are the Laurel, Skyline/Richardson zone, the Tiptop coal or coal zone, and the upper part of the Broas zone. In some parts of the quadrangle the Stoney Fork Member is thin or replaced by sandstone, and the base of the Princess Formation is mapped as the top of the Hindman coal (Lower Broas zone). Where the Stoney Fork Member is exposed, the Hindman coal occurs just beneath it.
Pfc	FOUR CORNERS FORMATION—Named by Chesnut (1992) for strata between the base of the Magoffin Member and the base of the Stoney Fork Member. The Magoffin Member (Outerbridge, 1976), which is equivalent to the Magoffin Beds of Morse (1931) and earlier usage, is the most widely recognized of the marine zones in the Breathitt Group, although it thins or is replaced by sandstone northward in the quadrangle. The base of the unit was used as a color break on many of the 7.5-minute quadrangle maps that comprise the Irvine quadrangle. Coals in the Four Corners Formation, in descending order, are the Hindman (Lower Broas); the Peach Orchard zone, including the Sebastian/Fugate (equivalent to the Hazard No. 8) and Nickell/Mudseam/Oakley (equivalent to the Hazard No. 7); the Prater coal or coal zone, including the Prater/Hazard/Index/Adele coals; and the Haddix/Colvin coal.
Ph	HYDEN FORMATION—Named by Chesnut (1992) for strata between the base of the Kendrick Shale Member and the base of the Magoffin Member. The Kendrick (Jillson, 1919) varies from 9 to 27 m (30 to 90 ft) in thickness in the Irvine quadrangle. Where the Kendrick Member is missing, the top of the Amburgy coal is considered the base of the Hyden Formation. Coals in the formation, in descending order, are the Copland/Taylor, Hamlin zone, Fire Clay rider, Fire Clay (Hazard No. 4), and Whitesburg zone. The Fire Clay coal contains a distinctive 5- to 23-cm-thick (2- to 9-in.), black to brown flint clay with conchoidal fracture that was deposited as a volcanic ash deposit. Sanidines in the flint clay have been radiometrically dated at 312 ±1 Ma by Lyons and others (1992) and 311 ±1 Ma by Rice and others (1994).
Ppk	PIKEVILLE FORMATION—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 (1987) and was not shown on 7.5-minute quadrangle maps, although it normally occurs just above the Manchester/Zachariah/Van Cleve coal, which was extensively mapped in 7.5-minute quadrangles in the western part of the Irvine quadrangle. Coals in the Pikeville Formation that were mapped on 7.5-minute quadrangle maps are, in descending order, the Cannel City/Amburgy, Van Lear/Little Caney/Upper Elkhorn No. 3, Grassy/Jellico zone, and the Vires/Bruin/Blue Gem zone. The Upper Elkhorn No. 3 coal is overlain by a carbonaceous shale containing marine fossils, called the Elkins Fork Shale, which was described on several 7.5-minute quadrangle maps but not mapped. A sandstone beneath the Vires coal is locally extensive and was mapped on several 7.5-minute quadrangle maps as the Frozen Sandstone Member.
Pg	GRUNDY FORMATION—Named by Chesnut (1992) for strata from the top of the Bee Rock Sandstone to the base of the Betsie Shale. The upper part of the formation is locally dominated by thick, crossbedded sandstones and quartz-pebble conglomerates. The top of the Grundy Formation is mapped at the top of the Manchester/Zachariah/Van Cleve coal, which is 1.5 to 18 m (5 to 60 ft) above the Corbin Sandstone Member (described below). Coals beneath the Zachariah, in descending order, are the Grayhawk and Beattyville coals, although numerous unnamed and unmapped thin coals occur locally. The Corbin occurs as a lateral sandstone facies at the top of the Grundy. Thinner orthoquartzites locally occur at the base of the formation where they are incised into underlying Mississippian strata (Black, 1977). The base of the formation locally truncates Upper Mississippian strata to the Cowbell Member of the Borden Formation (Weir and Richards, 1974), and may be marked by paleokarst and subaerial crusts (Anderson and Hester, 1977). In the northwestern part of the quadrangle, the Olive Hill clay bed of Crider (1913), a refractory-grade clay, occurs just above the base of the formation, and is as much as 4 m (13 ft) thick (Pipiringos and others, 1968).
Plc	CORBIN SANDSTONE MEMBER OF THE GRUNDY FORMATION—Sandstone and conglomeratic sandstone. Sandstone, generally medium-grained to very coarse-grained, quartzose, crossbedded; white quartz and gray chert pebbles as conglomeratic layers are common near base. Fairly resistant, forms steep cliffs and ledges. The Corbin is more than 91 m (300 ft) thick in the eastern part of the quadrangle and is well exposed in the Red River Gorge and Natural Bridge State Park (McFarlan, 1954; Hester and Taylor, 1977; McGrain, 1983; Rice, 1984; Barnhill, 1994). Previously mapped as a member of the Lee Formation, reassigned to the Grundy Formation (Chesnut, 1992).
Pac	ALVY CREEK FORMATION—Shale, siltstone, sandstone, and coal. Shale, locally carbonaceous and silty; at places contains widely spaced layers of flat, discoidal concretions of ironstone; locally contains films of plant remains; in part fissile. Siltstone, commonly limonite-stained; abundant fine grains of quartz, micaceous; outcrops yield chips and flakes; grades laterally and vertically into fine-grained sandstone. Sandstone, commonly iron-stained; fine-grained, in part medium-grained, composed of subangular to subrounded quartz grains and trace to minor amounts of muscovite and dark-gray mineral grains; weakly cemented by silica or iron minerals, friable where weathered; locally, where sandstone overlies Mississippian carbonate rocks, contains pods cemented by calcite; commonly contains casts and impressions of plant material; weathered iron-impregnated beds have honeycombed surfaces locally. Coal beds as much as 2 ft thick, discontinuous, occur only locally, generally poorly exposed. Base unconformable, with channels cut into underlying Paragon (Pennington) and Slade (Newman Limestone) Formations as much as 18 m (60 ft) deep. Unit mapped locally on three adjoining 7.5-minute quadrangles (Beattyville, Cobhill, and Heidelberg) from mapped presence of Contrary coal bed. Previously mapped as lower part of the Lee Formation, reassigned to the Alvy Creek Formation (Chesnut, 1992).
Mp	PARAGON FORMATION—Unit consists of rocks assigned to Pennington Formation during U.S. Geological Survey–Kentucky Geological Survey cooperative mapping project, 1960–78 (Ettensohn and others, 1984). Common erosional removal below pre-Breathitt unconformity. Shale, siltstone, sandstone, dolomite, and limestone. Shale, sparsely fossiliferous, partly silty, grading into siltstone. Siltstone, clayey to sandy, locally grading into sandstone. Sandstone, very fine- to fine-grained, locally up to 9 m (30 ft) thick. Dolomite, silty. Limestone, micrograined to coarse-grained, fossiliferous. Basal contact sharp.
Msla	SLADE FORMATION—Unit consists of 10 members, in ascending order, the Renfro, St. Louis, Ste. Genevieve, Warix Run, Mill Knob, Rosslyn, Tygarts Creek, Ramey Creek, Maddox Branch, and Poppin Rock Members (Ettensohn and others, 1984). Slade includes rocks assigned to Newman Limestone and Renfro Member of Borden Formation during U.S. Geological Survey–Kentucky Geological Survey cooperative mapping project. Common erosional thinning and local removal below pre-Breathitt unconformity. Limestone, dolomite, and shale. Limestone, micrograined to coarse-grained, bioclastic, oolitic, peloidal, partly cherty, fossiliferous, brecciated, clayey, sandy. Dolomite, microcrystalline to very finely crystalline, clayey, silty; dominant lithology in basal 3 to 21 m (10 to 70 ft). Minor amounts of shale as partings and interbeds; percentage generally increases upward. Basal contact gradational to sharp.
Mb	BORDEN FORMATION—Unit consists of four members, in ascending order, the Farmers, Nancy, Cowbell, and Nada Members. Former uppermost carbonate-rich Renfro Member of the siliciclastic-dominated Borden was reassigned to the overlying Slade Formation by Ettensohn and others (1984). Local erosional thinning below pre-Breathitt unconformity. Shale, siltstone, limestone, and dolomite. Shale, clayey in basal part, grades upward into very silty shale and siltstone in middle and upper part; ironstone and siliceous concretions; sparsely fossiliferous. Bed of sandstone to sandy siltstone, up to 1 m (3 ft) thick, near base; pinches out laterally. In uppermost part, 3 to 23 m (10 to 75 ft) thick, shale, clayey to silty, siltstone, and minor amounts of limestone and dolomite; fossiliferous. Basal contact sharp.
MDna	NEW ALBANY SHALE—Shale and dolomite. Shale, carbon-rich, fissile, pyritic; sparse interbeds of silty, clayey shale in upper part. Dolomite, very finely to finely crystalline, carbonaceous, clayey, silty, partly intraclastic; local contorted bedding; interbedded with black shale in lower part. Basal contact sharp, conformable where unit overlies Boyle Dolomite; elsewhere base unconformable.
Db	BOYLE DOLOMITE—Unit pinches out locally. Dolomite and limestone. Dolomite, very finely to coarsely crystalline, cherty, partly vuggy petroliferous, partly fossiliferous. Limestone, very fine- to medium-grained, partly fossiliferous. Base sharp, unconformable.
Sbi	BISHER DOLOMITE—Erosional remnants below pre-Boyle unconformity. Limestone and dolomite. Limestone, dolomitic, finely to very coarsely crystalline, porous, fossiliferous. Dolomite, finely crystalline.
Scb	CRAB ORCHARD FORMATION AND BRASSFIELD DOLOMITE—Unit is composed of two formations, in ascending order, Brassfield Dolomite, 2 to 8 m (7 to 26 ft) thick, and Crab Orchard Formation, 1 to 30 m (3 to 100 ft) thick. Crab Orchard, in turn, consists of five members, in ascending order, the Plum Creek, Oldham, Lulbegrud Shale, Waco, and Estill Shale Members; formation thinned by erosion below pre-Boyle unconformity. Shale and dolomite. Shale, clayey, plastic. Dolomite, micrograined to coarse-grained, partly fossiliferous, partly vuggy petroliferous; sparsely cherty in northernmost outcrops. Dolomite is dominant lithology in lower part of unit and interbedded with shale in middle and upper parts. Basal contact sharp. Units later revised by McDowell (1983) as Crab Orchard Group to include all Silurian rocks below Bisher Dolomite in Kentucky east of Cincinnati Arch (see adjacent Morehead 30 x 60 minute geologic quadrangle to the north [Petersen and others, 2006]).
Od	DRAKES FORMATION—Unit consists of two members, in ascending order, the Rowland and Preachersville Members. Mudstone and dolomite. Mudstone, clayey, dolomitic. Dolomite, medium- to coarse-grained, vuggy petroliferous, partly fossiliferous, interbedded with mudstone in upper part. Basal contact sharp.
Oa	ASHLOCK FORMATION—Unit consists of five members, in ascending order, the Tate, Grant Lake, Terrill, Sunset, and Reba Members. Limestone, mudstone, and shale. Limestone, fossiliferous, mainly nodular-bedded and rubbly weathering. Mudstone, clayey, mostly dolomitic, partly calcareous. Minor amount of shale interbedded with limestone. Base gradational.
Occ	CALLOWAY CREEK LIMESTONE—Limestone, shale, and siltstone. Limestone, fossiliferous, in irregular beds in lower part, and nodular-bedded and rubbly weathering in upper part. Shale, calcareous, interbedded with limestone. Minor amount of interbedded siltstone near base. Base gradational.
Og	GARRARD SILTSTONE—Siltstone, shale, and limestone. Siltstone, calcareous, in planar to contorted beds. Shale, clayey, interbedded with siltstone. Minor amount of interbedded limestone. Base gradational.
Ocf	CLAYS FERRY FORMATION—Limestone, shale, and siltstone. Limestone, micrograined to coarse-grained, locally fossiliferous; in planar beds, interbedded in about equal proportions with calcareous shale. Minor amount of interbedded siltstone. Unit contains tongue of Kope Formation, about 6 m (20 ft) thick, composed of same lithologies, but consisting of as much as 70 percent shale. Base of formation not exposed.
af	ARTIFICIAL FILL—Compacted rock debris from highway or railroad construction.
dump	DUMP—Mine dump, mine tailings, and displaced overburden.

Not all coals digitized under the STATEMAP Program are included on this map. Coals on map, in ascending order, are Contrary, Beattyville/Warm Fork, Gray Hawk, Vancleve, Manchester/Zachariah, Blue Gem/Vires, Jellico zone (including Grassy), Upper Elkhorn No. 3 (including Little Caney/Van Lear/Tom Cooper), Amburgy zone (Cannel City/Gun Creek), Whitesburg, Fire Clay, Copland, Haddix/Colvin, Prater zone (Hazard/Adele/Index), Lower Peach Orchard zone (Hazard No. 7/Lenox/ Oakley/Nickell/Mudseam), Upper Peach Orchard zone (Sebastian/Fugate), Broas zone (including Hindman), Tiptop, Skyline zone, and Laurel.

Note: Significant parts of the above listed coals may not be shown because the coals are too close together in some places to display at this scale.



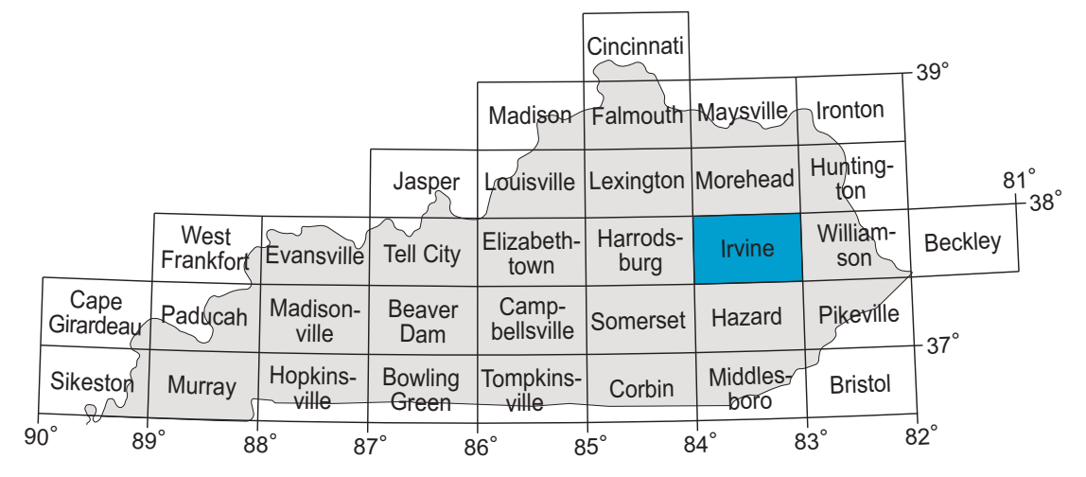
GEOLOGIC MAP OF THE IRVINE 30 x 60 MINUTE QUADRANGLE, EASTERN KENTUCKY

Thomas N. Sparks, Warren H. Anderson, and Lance G. Morris

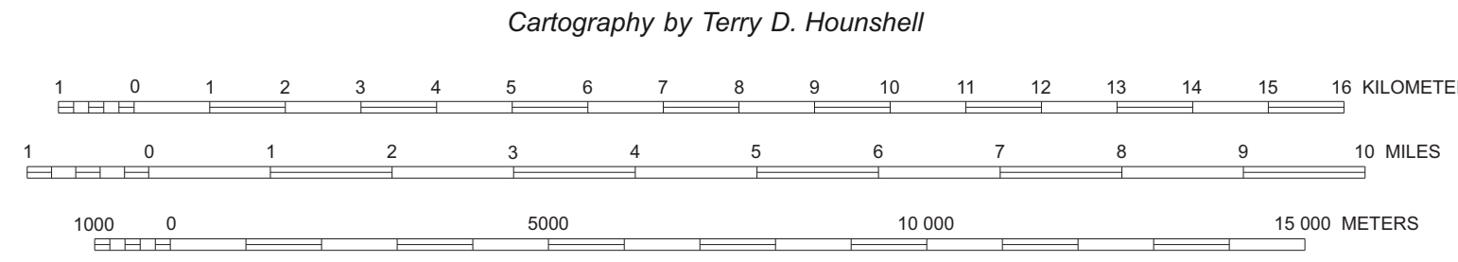
Cartography by Terry D. Hounshell

EXPLANATION

- Interstate highway or parkway
- U.S. highway
- State highway
- County boundary
- City boundary
- Railroad
- Normal fault (U, upthrown side; D, downthrown side)
- Concealed fault
- Contact
- Concealed contact
- Inferred contact
- Structure contour, feet
- Datum horizon boundary
- Coal bed
- Concealed coal bed
- Inferred coal bed
- Olive Hill clay bed; dashed where concealed
- Flint Ridge Flint
- Active stone quarry or mine
- Abandoned stone quarry or mine
- Active pit; clay
- Abandoned pit; clay or iron ore
- Prospect; iron ore
- Strip mine



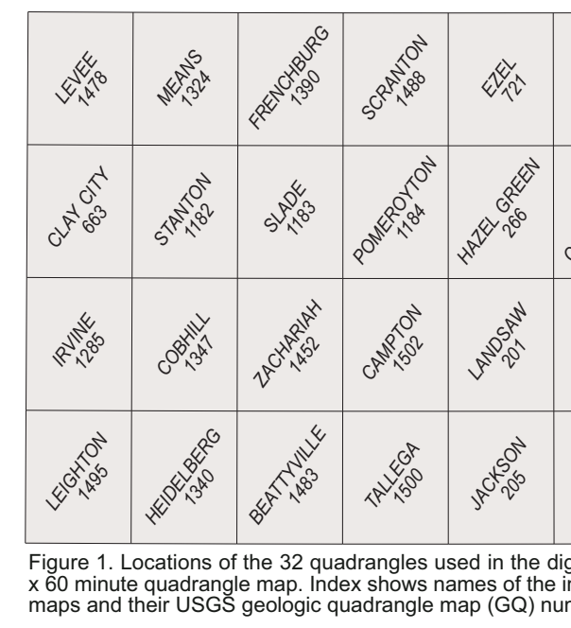
Locations of the 30 x 60 minute quadrangles covering Kentucky. The location of the Irvine quadrangle is highlighted in blue.



SCALE 1:100 000

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

TOPOGRAPHIC CONTOUR INTERVAL 50 METERS



LEVEE 1478	MEANS 1324	FRENCHBURG 1390	SCRANTON 1488	EZEL 721	WEST LIBERTY 589	LENOX 181	DINGUS 1463
CLAY CITY 663	STANTON 1182	SLADE 1183	POMEROYTON 1184	HAZEL GREEN 266	CANNEL CITY 1498	WHITE OAK 1480	SALYERSVILLE NORTH 276
IRVINE 1285	COBHILL 1347	ZACHARIAH 1452	CAMPTON 1502	LANDSAW 201	LEE CITY 198	SEITZ 1435	SALYERSVILLE SOUTH 1373
LEIGHTON 1495	HEIDELBERG 1340	BEATTYVILLE 1483	TALLEGA 1500	JACKSON 205	QUICKSAND 240	GUAGE 1416	TIPTOP 1410

Figure 1. Locations of the 32 quadrangles used in the digital compilation of the Irvine 30 x 60 minute quadrangle map. Index shows names of the individual 7.5-minute quadrangle maps and their USGS geologic quadrangle map (GQ) numbers.

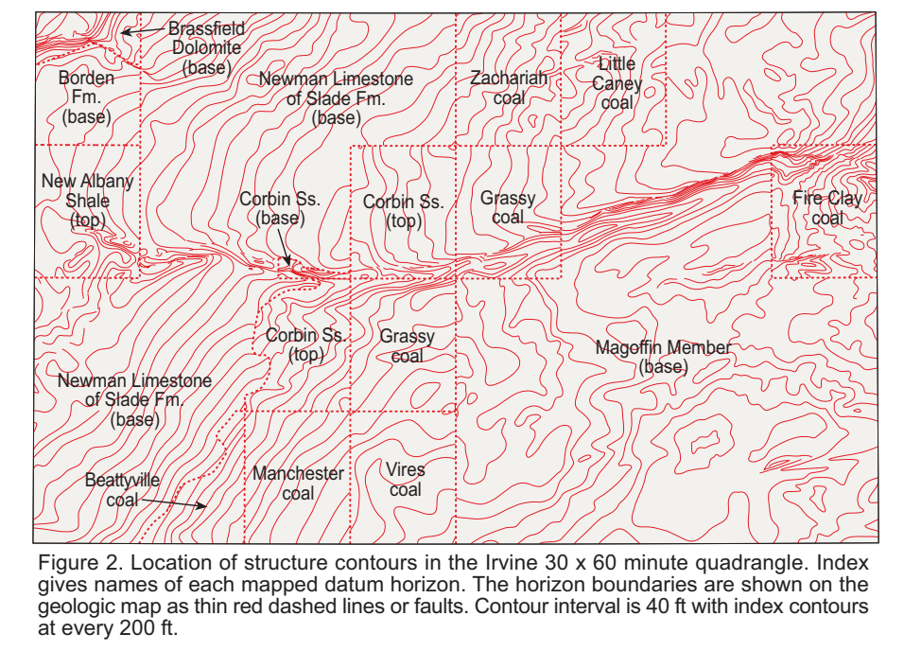
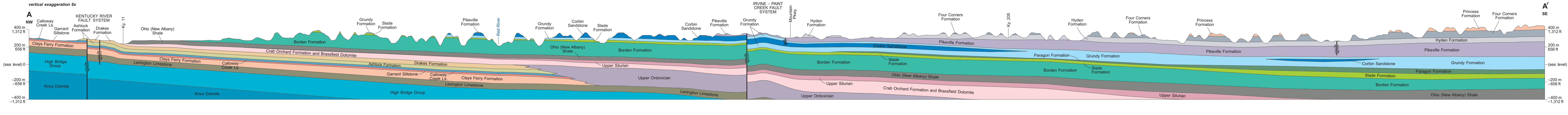


Figure 2. Location of structure contours in the Irvine 30 x 60 minute quadrangle. Index gives names of each mapped datum horizon. The horizon boundaries are shown on the geologic map as thin red dashed lines or faults. Contour interval is 40 ft with index contours at every 200 ft.

NOTE: cross section is diagrammatic
vertical exaggeration 6x



INTRODUCTION

The geology of the Irvine 30 x 60 minute quadrangle was digitally compiled mostly from U.S. Geological Survey 7.5-minute geologic quadrangle maps (GQ's), as cited in the references. The original GQ's were products of a cooperative mapping project between the U.S. Geological Survey and the Kentucky Geological Survey from 1960 to 1978. The conversion into digital format has been another USGS-KGS cooperative program funded through the National Cooperative Geologic Mapping Program (STATEMAP). Since 1978, several regional studies involving map compilations (Rice, 1985), stratigraphy (Chesnut, 1992), 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. The 7.5-minute quadrangles that make up the Irvine 30 x 60 minute quadrangle are shown in the index map (Fig. 1).

The data files resulting from the digitization of the GQ's are part of a comprehensive relational and spatial data set, being released as Digitally Vectorized Geologic Quadrangles (DVGQ's) by the Kentucky Geological Survey (Anderson and others, 1999). These DVGQ's are available on CD-ROM, and will be released via the Internet in the near future. Users of the DVGQ data can prepare custom geologic maps by overlaying data using their own GIS or CAD software. KGS has also developed an Internet map server where users can prepare similar maps without purchasing DVGQ's via an interactive Geologic Map Information Service (kgsmap.uky.edu/website/ KGSGeology) (Weisenfluh and others, 2005).

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 and members across quadrangle boundaries, (2) determining the boundary of problematic member level Borden Formation units, and (3) resolving discrepancies in other Quaternary alluvium boundaries and inferred contacts. The metadata portion of the digital file provides detailed sources of data and 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 KGS for state-specific use. Formations and formation boundaries were not mapped consistently on each of the 7.5-minute quadrangle maps, as they were compiled between 1960 and 1978. Resolution of the differences between quadrangles was necessary for 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 field work was attempted. 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 Irvine 30 x 60 minute quadrangle consists of gently to moderately dipping sedimentary rocks of Ordovician through Pennsylvanian age and unconsolidated sediments of Tertiary and Quaternary age. These rocks occur along the eastern flank of the north-trending Cincinnati Arch, a structural feature that extends from Ohio through central Kentucky to Tennessee, and into the Eastern Kentucky Coal Field along the western limb of the central Appalachian Basin. The dominant rock types for the mapped area, from west to east, are limestone, shale, siltstone, and dolomite for the Ordovician and Silurian strata; black, organic-rich shale and dolomite for the Devonian section; interbedded sandstone, siltstone, shale, coal, and limestone for the Mississippian and Pennsylvanian units; and terrace and alluvial deposits for the Tertiary and Quaternary strata. The Tertiary and Quaternary sediments are mainly unconsolidated or semiconsolidated, and contain clay, silt, sand, and gravel deposits, some of which may be locally cemented.

Two major fault systems lie within the mapped quadrangle, the Kentucky River and Irvine–Paint Creek Fault Systems (see structure contour map, Fig. 2) and their associated anticlines and synclines along the fault axes. The Kentucky River Fault System on the northwestern boundary and the Irvine–Paint Creek Fault System trending east-west across the central part of the quadrangle together represent the northern boundary of the Rome Trough (Drahovzal and Noger, 1995). The Rome Trough is characterized as an asymmetrical half graben with more growth faulting along the northern border of the faults. Detailed investigations of the Rome Trough and the Irvine–Paint Creek Fault System may be found in Harris and Drahovzal (1996) and Drahovzal and Noger (1995). Several oil fields have been discovered along these fault systems, and other anticlinal structures may play an important role in the accumulation of petroleum resources, particularly the Cambrian gas potential in the quadrangle.

Another major structural feature identified on the Irvine map is the Eastern Kentucky Syncline. The Eastern Kentucky Syncline comprises the eastern half of the map and is evident by the widely spaced synclinal contours in Breathitt, Magoffin, and Morgan Counties. The synclinal axis is generally oriented northeast-southwest and is bordered on the west with regional southeast dip in Estill, Lee, Menifee, and Powell Counties (see also cross section).

ECONOMIC GEOLOGY

Coal, oil, and natural gas are the principal mineral resources for the Irvine 30 x 60 minute quadrangle. 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, were mapped and described by Anderson and Dever (2001) and Glass and Malone (2008).

Coal Production and Reserves

The Irvine quadrangle extends almost completely across the middle of the Eastern Kentucky Coal Field. Coal has been mined here for more than 100 years by a variety of surface and underground mining techniques (Cecil and others, 1992). All of the mined coals are Pennsylvanian in age. Mined coals are bituminous and have mean ash yields of 4.9 to 12.3 percent, mean sulfur contents of 1.0 to 2.5 percent, and Btu values of 12,268 to 13,121 (Cobb and others, 1985; Kentucky Geological Survey, 1986, 2008).

Production statistics for beds in this quadrangle are difficult to compile because of the variety of names applied to the same coal beds, and the tendency for coals to occur in zones. With that in mind, the top five producing coals in the Irvine quadrangle between 1982 and 1992 were the Hindman/Lower Broas coal horizon, with 13.6 million short tons (MT) mined; the Skyline/Richardson coal zone (including the 5 Block coal), with 12.5 MT mined; the Lower Peach Orchard/Mudseam/Nickell/Hazard No. 7 coal, with 6.7 MT mined; undifferentiated Peach Orchard zone, with 6.0 MT mined; and the Tiptop coal, with 4.5 MT mined. These coals occur in the Princess and Four Corners Formations. The leading producer of the Hyden Formation for the same period was the Fire Clay coal, with 2.4 MT mined, and the leading producer of the Grundy Formation was the Zachariah/Manchester coal, with 1.9 MT mined.

Analyses of these coals can be searched on the KGS Web site and are also provided by the Kentucky Geological Survey (1986). Most of the coal mined in the Irvine quadrangle is produced to meet compliance coal needs of Ohio Valley utilities and other electric-utility markets.

The Irvine 30 x 60 minute quadrangle covers most of the Licking River and the northern parts of the Southwestern and Hazard coal reserve districts. The quadrangle produces coal from six counties: Breathitt, Lee, Magoffin, Menifee, Morgan, and Wolfe Counties. Total coal production from the five leading counties is summarized in Table 1.

Table 1. Cumulative coal production (million tons) by county and mining method (1800–2004).

County	Undifferentiated	Underground	Surface	Total
Breathitt	1.398	14.969	192.050	208.417
Lee	1.862	2.905	3.724	8.491
Magoffin	0.007	9.437	46.942	56.386
Morgan	1.486	2.221	11.517	15.224
Wolfe	0.030	0.896	6.239	7.165
Total	**4.783**	**30.428**	**260.472**	**295.683**

Source: Kentucky Geological Survey coal production database, ksgweb.uky.edu/DataSearching/Coal/Production/prodsearch.asp [accessed 03/03/08].

Resource studies by Brant (1983) and Brant and others (1983a, b) calculated total remaining resources of more than 3.5 billion short tons for the quadrangle, although 75 percent of that resource was less than 28 in. thick. Coal availability studies, which take into account technological and land-use limitations to mining, for the Salyersville South quadrangle indicate that less than 50 percent of the quadrangle's original resource may be available for mining with present technology (Andrews and others, 1994). Coal-resource and -thickness maps from the availability studies for the Lower Elkhorn coal by Thacker and others (1998, 2000a), for the Fire Clay coal by Thacker and others (2000b, c), and for the Upper Elkhorn No. 3 coal by Esterle and others (2000a–c) have been published. Because mining has historically targeted the thickest and most easily accessible coal resources, future mining will increasingly have to target thinner and less accessible resources, including below-drainage coals (Greb and others, 1999). Remaining coal reserves for the five largest coal-producing counties in the Irvine quadrangle have been tabulated (see Table 2).

Table 2. Coal production and remaining resource reserves for major counties in the Irvine quadrangle (million tons). (1) Hazard District, (2) Southwestern District, (3) Licking River District.

County	Original	Mined & Lost	Remaining Reserves
Breathitt (1)	4,122	397	3,715
Lee (2)	364	17	347
Magoffin (3)	1,969	109	1,860
Morgan (3)	849	30	819
Wolfe (3)	444	14	430
Estimated remaining coal resources in major counties: 7,171			

Source: Keystone Coal Industry Manual (2003)

Petroleum and Natural Gas

Several major oil and gas fields occur along the southern border of the Irvine–Paint Creek Fault System (Wilson and Sutton, 1976). Cumulative production, where available, is reported in millions of barrels of oil (MMbbl) or billions of cubic feet of natural gas (Bcf). The Irvine-Furnace (23 MMbbl), Big Sinking (85 MMbbl), Campton, Cannel City, and Oil Springs (32 MMbbl) oil fields and Holly Creek (7 Bcf), Taulbee (4 Bcf), and Royalton gas fields occur on the south side of the Irvine–Paint Creek Fault System. Additional gas fields such as the Janet (1 Bcf), Grassy Creek (4.4 Bcf), and Rothwell storage (11Bcf) occur on the north side of the fault. The Irvine-Furnace, Big Sinking, and Oil Springs fields are currently undergoing secondary recovery operations.

Many of these fields are productive from the Lower Devonian–Upper Silurian unconformity ("Corniferous") or the Upper Silurian Lockport–Big Six plays (Meglen and Noger, 1996; Noger and others, 1996). Additional productive zones include the Mississippian Maxon sandstone and Borden (Weir) sands. Potential zones include the "Big Lime" carbonates (Newman Limestone/Slade Formation), Ordovician St. Peter Sandstone and Knox Dolomite, and Cambrian Rome Formation. For more information on the geology and production in these fields, see additional articles in *The Atlas of Major Appalachian Gas Plays* (Roen and Walker, 1996).

Limestone, Sand, Gravel, and Shale

Limestone suitable for construction aggregate and agricultural products is being mined from the Slade Formation (Anderson and Dever, 2001). Sandstone, sand, and gravel have also been mined in the quadrangle, but most operations are inactive. Active limestone quarry operations are ongoing near Stanton, south of Frenchburg, south of Jeffersonville (Montgomery-Powell County line), while a quarry with underground mining activities occurs near Ravenna. Permitted limestone operations west of Beattyville and sand-and-gravel operations at Stanton are currently inactive (Glass and Malone, 2008). Clay from the Borden Formation is being used for the manufacture of brick at a plant in Stanton. Selected clays and shales from the Breathitt Group may have potential for industrial clay uses. Analysis of samples from above and below the Manchester coal and other underclays indicates potential for industrial uses in the brick and tile industry and for use as lightweight aggregate (McGrain and others, 1960). Siltstone and sandstone may also have use as flagstone and aggregate.

ENGINEERING GEOLOGY

The highly dissected topography in the eastern part of the Irvine quadrangle has a potential for engineering and maintenance problems. The interbedded sequence of sandstone, shale, siltstones, and coal in the Breathitt Group is prone to failure by landslide and creep. Slope instability in these thick sequences of the Breathitt can affect construction and engineering projects. Landslides or slumps could occur when slopes are saturated with water. Slumping may also occur where these relatively unstable beds are undercut by rivers and their tributaries or by construction work for roads and mines. Logging, clear-cutting, 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 can damage roads and railroads.

Significant foundation and structural problems have developed in several large buildings constructed in an area of North Irvine, Estill County. These buildings are sited in the Devonian Chattanooga (New Albany) Shale, which caused the structural failures (Anderson, 2008). The Estill County Middle School, Carhartt factory, and Marcum and Wallace Memorial Hospital auxiliary buildings all have foundation problems such as cracked and heaving floors and cracked walls, ceilings, and sidewalks. The Irvine Bypass (Ky. 499) has also had pavement and heaving problems in segments of the roadway near the schools, but the pavement is sited in the Crab Orchard Formation (Beckham and Hopkins, 2005).

The Chattanooga Shale contains various clay and iron sulfide minerals (pyrite) that react with water to form sulfates and a mild sulfuric acid. This formation of sulfates and creation of sulfuric acid causes the shale to weather very rapidly and degrade into unstable clay and sulfate minerals; the process is commonly called pyrite oxidation or pyrite swelling. These mineralogic changes in the shale make unstable foundation material, and adequate geologic and engineering investigations should be conducted prior to construction in this area.

HYDROGEOLOGY

The availability of groundwater in the quadrangle is discussed in Price and others (1962), Minns (1993), and Wunsch (1993). Carey and Stickney (2004a,b; 2005a–g) have written a series of groundwater resource reports for Breathitt, Estill, Lee, Magoffin, Menifee, Montgomery, Morgan, Powell, and Wolfe Counties. Most fresh groundwater is obtained from shallow bedrock wells that are generally less than 100 ft deep and from shallow, dug wells in alluvium and regolith. Water in bedrock aquifers of the Breathitt Group is derived from sandstone, siltstone, and coal seams (which have enhanced permeability because of fractures). Vertical permeability is restricted by underclays and shales that act as aquitards. Salty water is typically encountered in wells deeper than 100 ft below the valley bottoms of third-order or higher streams (Wunsch, 1993). Wells in alluvium near major streams may provide adequate water for farms or commercial operations. The water resource in large, reclaimed surface mines is discussed in Wunsch and others (1996).

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