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Coal Availability in Western Kentucky

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Report of Investigations 8 Series XII, 2001

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ISSN 0075-5591

Technical Level

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Coal Availability in Western Kentucky

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Abstract

Fourteen quadrangles in five separate areas of the Western Kentucky Coal Field were studied to determine what factors affect the availability of coal for mining. Each study area consisted of at least two adjacent 7.5-minute quadrangles in order to account for the geologic variability across broad distances in western Kentucky, and determine how this variability affects availability. Areas both north and south of the Rough Creek Fault System were selected to measure the effect of different geologic, structural, and overburden settings on coal availability. The study emphasized the coals occurring stratigraphically between the Springfield and the Baker.

About 90 percent of western Kentucky coal resources is associated with only six beds, and one bed, the Springfield (W. Ky. No. 9), constitutes 25 percent of the entire estimate. Seventy percent of the resource is greater than 56 in. thick. Most mining in the Western Kentucky Coal Field is currently by underground methods; only 25 percent is by surface mining.

A geographic information system (GIS) was used to estimate tonnages. Point data were obtained from over 5,000 drill-hole and geophysical-log descriptions, and included coal thickness, parting thickness, elevation, and stratigraphic position. Outcrops were digitized from U.S. Geological Survey (USGS) 7.5-minute geologic quadrangle maps, and land-use restrictions from USGS 7.5-minute topographic quadrangle maps. Mined-out areas were obtained from the Kentucky Department of Mines and Minerals, and locations of oil and gas wells from the Kentucky Geological Survey. A digital elevation model was obtained from the U.S. Geological Survey.

Land-use restrictions can apply to both surface and deep mining. Technological restrictions in this study generally apply only to deep mining, and include barriers around existing mines, mining within 40 vertical feet of a seam, active oil and gas wells, coal too thin for current underground mining methods (less than 28 in.), and small mine blocks. Many technological restrictions in western Kentucky could be overcome if the relatively low profit margins in the region increased.

Tonnage estimates for each bed are reported by categories of coal thickness, overburden thickness, and reliability of the estimate. Thickness categories used in this study are 14 to 28 in., 28 to 42 in., and greater than 42. in. Overburden categories are surface-mineable, deep-mineable, and too deep to mine with current technology. Reliability categories, based on distance from coal-thickness measurements, are measured (within ¼ mi of a data point), indicated (between ¼ and ¾ mi), inferred (between ¾ and 3 mi), and hypothetical (beyond 3 mi).

Total original resources for the assessed coals in the 14 studied quadrangles are estimated at 5.55 billion tons (BT). Almost half this total is accounted for by the Springfield coal, and nearly a quarter by the Baker. About 77 percent of the coal is considered deep-mineable.

A total of 1.084 BT, or 20 percent of the original resource, has been mined out or lost to mining. Thus, 4 BT, or 80 percent of original resources, remain.

The average amount of restricted coal is 26 percent of original resources, and 88 percent of this restricted amount is by technological factors. The most important technological restriction was coal too thin to mine. Small interburden thickness between two mineable seams is a key factor in some areas; other locally important factors are mine barriers and small mine blocks.

The average availability of coal in the 14 studied quadrangles is 54 percent. The results by quadrangle range from 9 to 91 percent, which confirms the necessity of studying larger areas.

Deep-mineable coal between 28 and 42 in. thick and surface-mineable coal between 14 and 28 in. thick is considered available, but uneconomic. The uneconomic resources account for 14 percent of the original resource, leaving 40 percent of the coal that is both available and economic.

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Introduction

Coal mining and its support industries constitute one of the most important parts of the Kentucky economy. The coal industry is crucial to the Commonwealth in terms of tax receipts, but particularly so for the livelihoods of the people who occupy the two regions of the state that produce the coal—the Eastern and Western Kentucky Coal Fields. About 8 billion tons (BT) of bituminous coal have been mined in Kentucky since the beginning of the 19th century; recent production levels average 165 million tons (MT) per year. About three-fourths of this production now comes from the eastern field. Though the total historical extraction of coal is a small portion of the estimates of in-place resource (Smith and Brant, 1978), there is increasing concern that current production levels may be difficult to sustain in the near future. Recent and expected reductions in Kentucky's production are partly related to market competition from low-sulfur coal from Montana and Wyoming. Equally important is the fact that some of Kentucky's coal resources may not be economically mineable with current technology, while other resources may be unavailable for mining because of competing land uses. These latter issues were the impetus for a nationally coordinated program to estimate the amounts of coal that are available for development in different regions of the country.

The Availability of Coal Resources for the Development of Coal is a U.S. Geological Survey (USGS) program that is conducted cooperatively with state geological surveys. Its objectives are to characterize and quantify the kinds of factors that impede the development of coal in different regions of the country. These factors are broadly categorized as competing land uses that arise from regulatory law and technological constraints (engineering and geological) related to the mineability of the coal. The program was initially conducted within the Appalachian region, and has since expanded to the Eastern Interior and Western coal fields. Each study is conducted at a scale of 1:24,000 to include one or more 7.5-minute quadrangles. A companion program, Coal Recoverability, was implemented by the U.S. Bureau of Mines (later moved under the auspices of the USGS) and evaluates additional engineering and economic factors to estimate the degree to which available coal could be mined, given a range of market conditions.

Nine studies of individual quadrangles in the Eastern Kentucky Coal Field have been completed, and the results of these are summarized in Andrews and others (1994). This report gives an overview of the characteristics of the Western Kentucky Coal Field and the results of studies of 14 quadrangles located in five separate areas within this region.

General Setting of the Western Kentucky Coal Field

Geology

The Western Kentucky Coal Field (Fig. 1) comprises the southern tip of the Carboniferous Eastern Interior (Illinois) Basin of Illinois, Indiana, and Kentucky. Detailed information about the geology and stratigraphy of the Western Kentucky Coal Field can be found in Greb and others (1992). The coal-bearing strata are underlain by the Caseyville Formation, which is typically a quartzose sandstone or pebbly sandstone. Although coal beds occur throughout the Pennsylvanian strata (Fig. 2), most commercially important beds are confined to the Carbondale and lower Shelburn Formations—an interval 90 to 125 m thick. These beds include the Davis (W. Ky. No. 6), Springfield (W. Ky. No. 9), Herrin (W. Ky. No. 11), Paradise (W. Ky. No. 12), Baker (W. Ky. No. 13), and Coiltown (W. Ky. No. 14). These coal beds (except for the Coiltown) are of mineable thickness over relatively large areas and have significant historical production, yet typically yield medium-sulfur products. Coal beds below the Davis, within the Tradewater Formation, are discontinuous in thickness and highly variable in quality (Baynard and Hower, 1984; Graese and others, 1984), but can be very low in sulfur content (Hower and others, 1982; Williams and others, 1990). Coal beds above the Coiltown are typically thin and only mineable in limited areas by surface methods.

The structure of the Western Kentucky Coal Field is distinctly different on either side of the east–west-trending Rough Creek Fault System (Fig. 1). This fault zone is about 5 km wide and is characterized by a complex association of horsts and grabens. North of the Rough Creek Fault System, the rocks dip gently to the west at a rate of about 15 to 20 ft/mi. This area is part of the eastern limb of a broad north–south, asymmetrical syncline that forms much of the basin to the north in Illinois and Indiana. In addition to having gentle dip, the principal coal beds of the area north of the Rough Creek Fault System are generally within 500 ft of the surface. Surface access to these coal beds is limited to small areas on the east side of the basin between the Rough Creek Fault System and the Indiana state line, however. South of the Rough Creek Fault System, the structure is characterized by east–west-oriented synclines with much steeper dips. Dips within the Moorman Syncline east of the Central Fault System

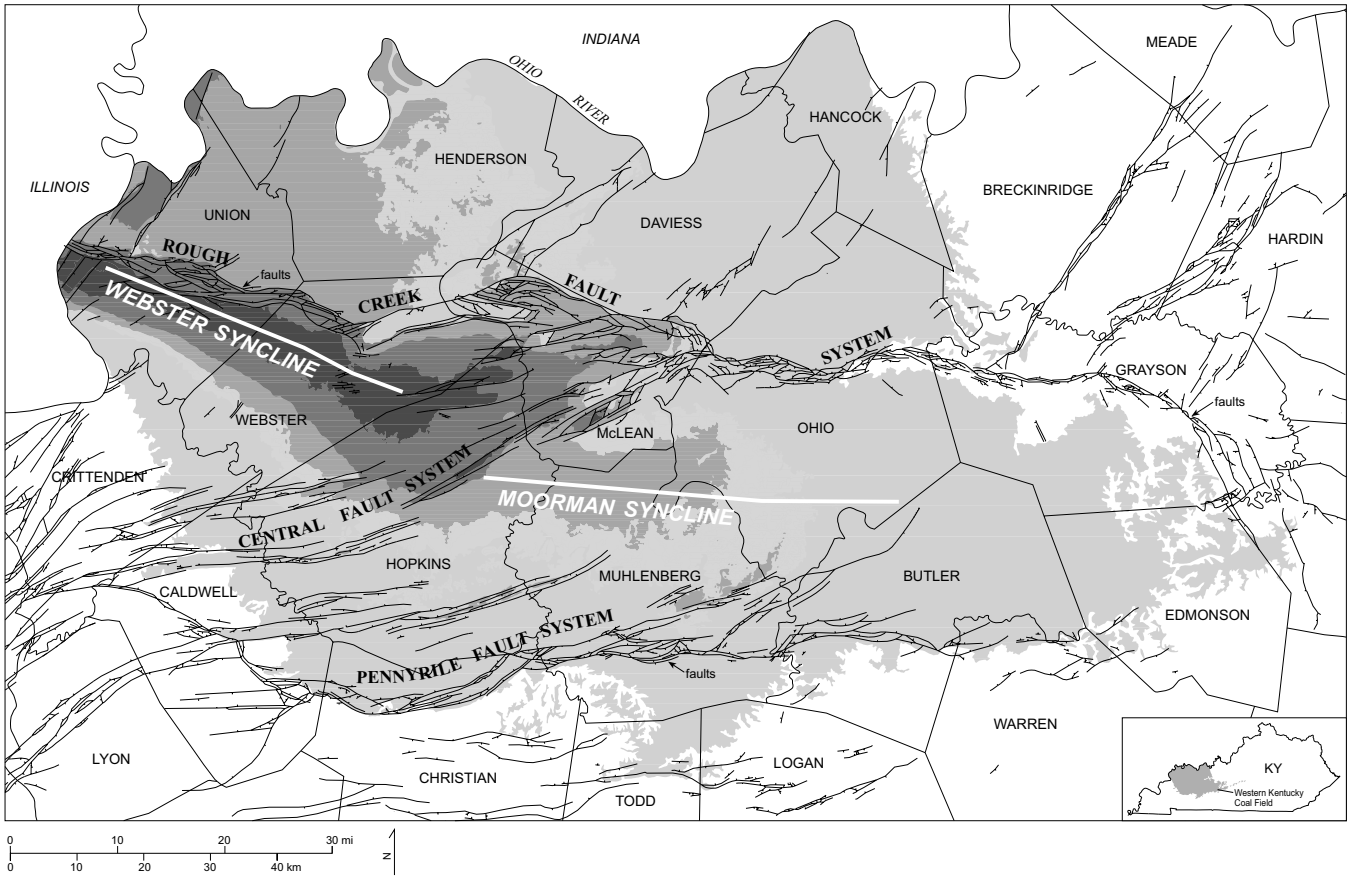

Figure 1. Structure of the Western Kentucky Coal Field. Darker shading represents deeper areas of the basin.

range between 50 and 65 ft/mi. Dips in the Webster Syncline west of the Central Fault System are as great as 250 ft/mi. Along the axis of these southern synclines and within some grabens, maximum depths to the lower Carbondale coal beds can exceed 1,500 ft. The area north of the Rough Creek Fault System has limited outcrop access to mineable coal beds, whereas the southern area has a broad outcrop belt, which has led to extensive surface mining of the principal coal beds. Both the northern and southern structural areas are modified by a number of northeast-trending grabens, many with considerable displacement.

Physiography and Land Use

The topography of the Western Kentucky Coal Field is characterized by low relief, with average local differences in elevation of 300 ft. This terrain is dissected by broad Quaternary alluvial valleys in which streams flow north toward the Ohio River. As a result of the subdued topography and synclinal basin structure, potential surface outcrops of individual coal beds are confined to belts around the margin of the basin, and exposures are typically limited to surface mines and small roadcuts. Therefore, most data pertaining to the thickness and quality of coal beds comes from subsurface drilling records. The physiography of western Kentucky has also affected the style of surface mining in that region. The eastern part of the Western Kentucky Coal Field is deeply dissected and has high relief, which favors contour methods of surface mining, whereas the western part of the coal field has low relief, which permits large-area mines (draglines) within the near-surface outcrop belts.

Land use in western Kentucky is predominantly cropland and pasture (57 percent) and forest (40 percent). These categories include wetland areas associated with low-lying alluvial valleys. Urban or other residential uses are very limited in the region.

Previous Resource Estimates

The most recent comprehensive coal-resource estimates for western Kentucky defined an original resource of 41 BT for 33 coal beds (Smith and Brant, 1978). These estimates were prepared at a scale of 1:24,000.

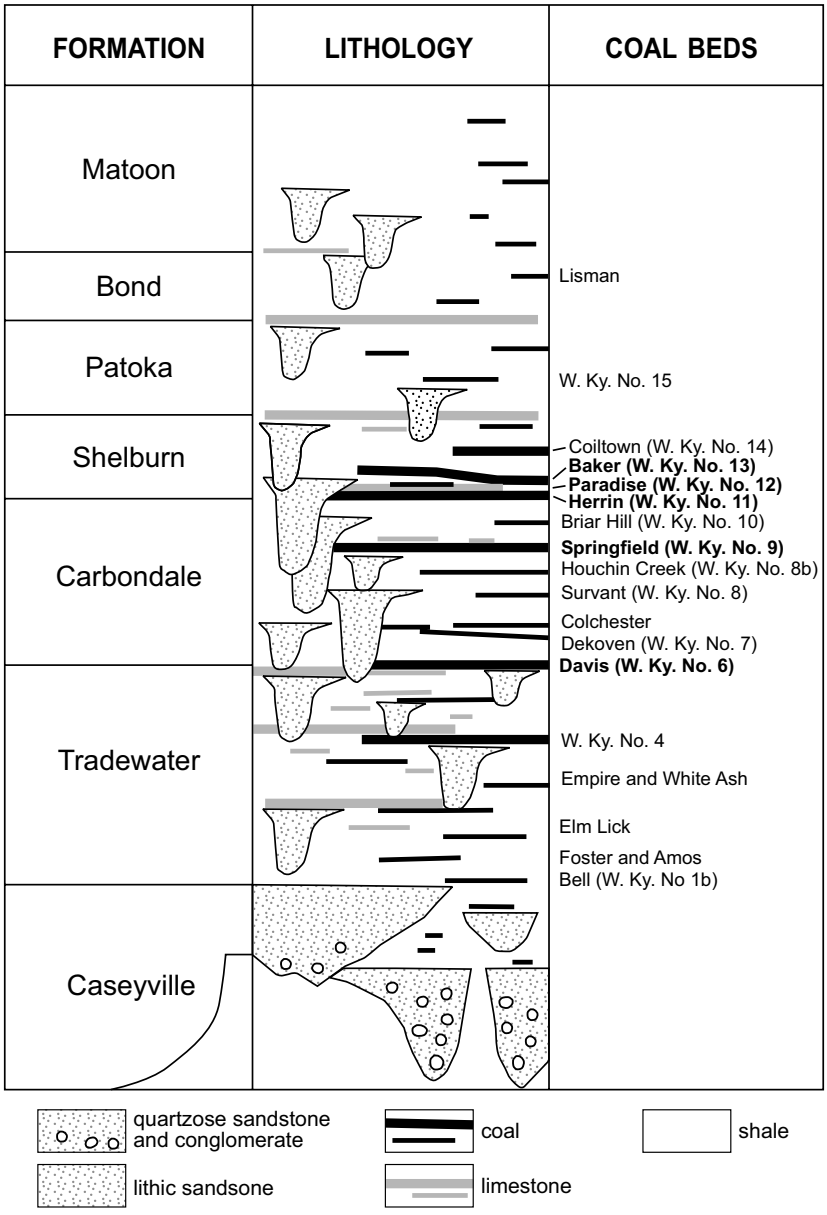

Figure 2. Stratigraphy of the Western Kentucky Coal Field.

About 90 percent of the 41 BT is associated with only six of these beds (Fig. 3), and one bed, the Springfield (W. Ky. No. 9), constitutes 25 percent of the entire estimate. Unlike in eastern Kentucky, where much of the resource is in thin beds, 70 percent of western Kentucky's coal resource is greater than 56 in. thick.

Historical Mining

The first recorded coal production in western Kentucky was in 1820. The initial 100 years of mining was by underground methods and amounted to 182 MT. By 1922, surface-mining methods were in use, but did not exceed underground production until 1957. From that time until 1985, production from surface mining was greater than from underground mining; maximum annual surface-mining production was 33 MT. Since 1985, surface mining has consistently diminished and currently accounts for only 25 percent of western Kentucky production. According to annual records of the Kentucky Department of Mines and Minerals, a total of 2.5 BT of coal has been mined in western Kentucky, about one-third of the state's total production. Until the last 10 years, conventional mining (undercutting and blasting) was prevalent in the Western Kentucky Coal Field, but now both continuous and longwall mining systems are used. This change in mining methods has resulted in higher productivity of mines at the expense of reduced labor needs and increased out-of-seam impurities that require costly preparation.

Regional Bed Studies

In order to place the coal-availability studies in a regional context, new coal-resource maps were prepared for the three coal beds in the Carbondale Formation that have the greatest production. Part of the reason for repeating the assessment for these beds was that abundant new data were available that were not used for the previous studies. Compilation of these new data resulted in a better definition of the limits of mineability of the coal beds and in revised resource estimates. The earlier estimates were prepared at a scale of 1:24,000, but time constraints required the current work to be compiled at a scale of 1:125,000. Total-coal thickness maps were prepared by interpolating point data using an inverse-distance weighted algorithm with a 100-m cell resolution. Generalized outlines of surface and underground mines from 1:24,000-scale compilations available at the Kentucky Department of Mines and Minerals, as well as mine maps on file at KGS, were plotted on 1:125,000-scale base maps. Resource calculations were performed with ArcView Spatial Analyst software using the above-mentioned maps. The smaller scale of this analysis resulted in somewhat re-

duced accuracy, but it is adequate for characterizing regional trends and patterns. Comparison of the current estimate totals to those of previous workers (Table 1) shows significant differences between the two studies for some coal beds.

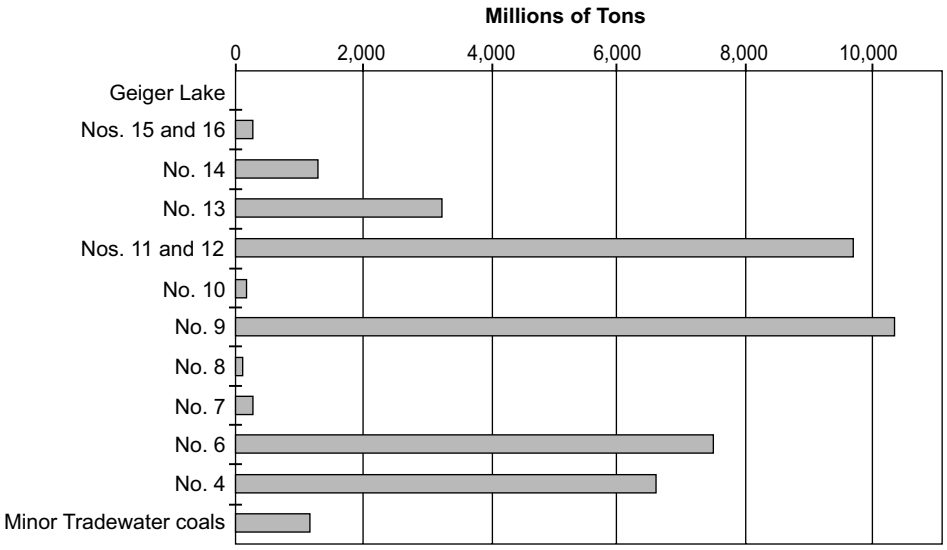

Figure 3. Original resources of the Western Kentucky Coal Field according to coal bed, in billion tons (Smith and Brant, 1978).

Springfield Coal (W. Ky. No. 9)

This coal bed has the greatest lateral continuity of any in Kentucky. Ninety-three percent of the outcrop area is estimated to be greater than 42 in. thick (Fig. 4). Coal in the southwestern half of the area is generally greater than 56 in. thick. There are few documented discontinuities in the Springfield coal bed (aside from faulting) in Kentucky. The best known discontinuity is the Henderson Channel, a south–southwest-oriented area of no coal less than 2 km wide (Beard and Williamson, 1979). This channel appears to be a result of contemporaneous sedimentation, but evidence of post-depositional erosion has also been found. Many Springfield coal mines in Illinois and Indiana are next to similar contemporaneous channels because sulfur contents are lower in these areas. The Henderson Channel does not appear to be an important consideration for mine locations. The Springfield coal bed typically occurs without rock partings except near contemporaneous channels, although it does contain layers of fusain and mineralized organic matter.

The revised estimate of total original resources is 9.92 BT, and 97 percent of this amount is for coal greater than 42 in. thick. This compares closely to the estimates of 10.27 BT and 96 percent for the previous estimate (Fig. 3, Table 1).

Mining of the Springfield coal has been primarily by underground methods (Fig. 5, Table 2). South of the Rough Creek Fault System, mining has been mostly limited to a belt about 8 km from the edge of the outcrop. Beyond this distance, overburden thickness typically exceeds 1,000 ft. North of the Rough Creek Fault System, some mining has occurred near the eastern outcrop limit, but the largest mines are located in the west, where the coal lies at greater depths. Near-surface access and greater coal thickness are responsible for the concentration of mining in the southern and western parts of the coal field. An estimated 2.40 BT, or 24 percent of the original resource, has been mined out or lost in mining, based on the mapped extent of documented mined areas. Underground methods account for 81 percent of this amount, and 99 percent of the mined coal is from areas with coal thicker than 42 in. Remaining resources are estimated at 7.51 BT.

Table 1. Comparison of previous original coal resource estimates to the current study for three coals, categorized by thickness (million tons).[1]

	Smith and Brant (1978)				Current Study				
Coal Bed	14–28	28–42	> 42	Total	14–28	28–42	> 42	Total	Difference
Baker	350	907	1,949	3,206	1,037	1,021	1,763	3,820	+19%
Herrin*	139	606	8,875	9,620	207	570	3,162	3,939	NA
Springfield	0	386	9,879	10,265	11	218	9,689	9,917	–3%

[1]Totals may not equal sum of components because of independent rounding.
*Herrin bed was combined with the Paradise bed in Smith and Brant (1978).

Herrin Coal (W. Ky. No. 11)

The Herrin coal is the second most important bed in western Kentucky in terms of historical production. In contrast to the Springfield, the Herrin exhibits much greater variability in thickness and is less widespread (Fig. 6). Mineable coal occurs in two distinct coal bodies. The thickest of these lies in a narrow, east-trending belt along the southern outcrop margin. A substantial area of this coal body is greater than 70 in. thick. The second coal body lies north of the Rough Creek Fault System in Union County. Each coal body is thinner at its margin over a short horizontal distance, usually 100 to 200 m; the missing coal has been replaced by a limestone facies (Hower and others, 1987). The mineable coal typically contains a thin rock parting near the base of the seam (informally called the "blue band") and is generally overlain by fossiliferous shale and limestone. The two thick coal bodies occupy only about 50 percent of the total Herrin coal bed extent.

The revised estimate of total original coal resources is 3.94 BT, and for coal greater than 42 in. thick is 3.16 BT (Table 3). These estimates cannot be directly compared with earlier estimates, since Smith and Brant (1978) combined the tonnages of the Herrin and Paradise coals because of the historical practice of simultaneously surface mining both beds in many areas. Because the Paradise coal is thinner and less extensive, it is believed to have fewer original tons than the Herrin. Moreover, the combined estimate for the two beds in Smith and Brant (1978) was 9.62 BT; therefore, the current estimate for the Herrin coal (3.94 BT) is likely significantly less than Smith and Brant's estimate.

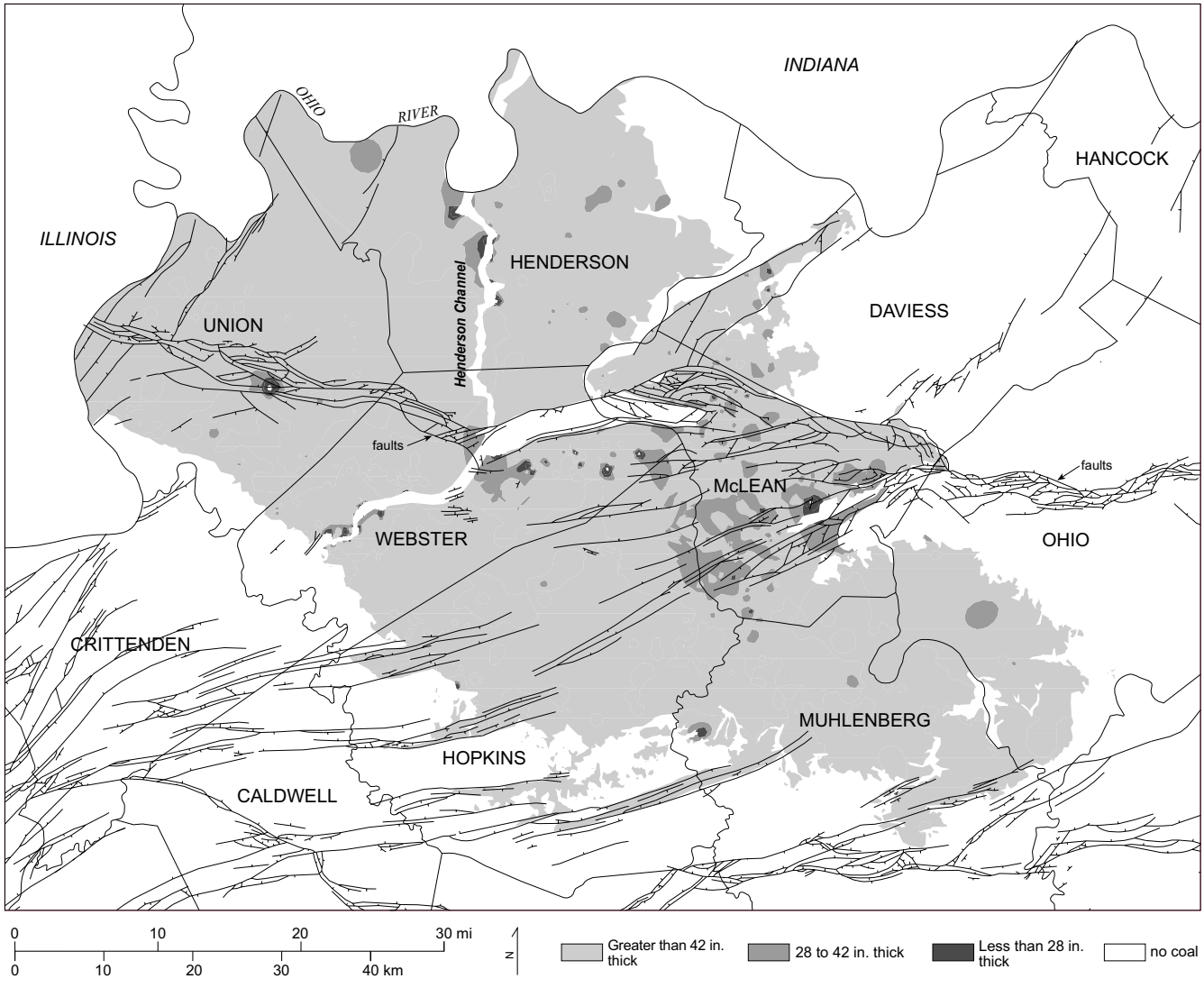

Figure 4. Total thickness of the Springfield coal in western Kentucky.

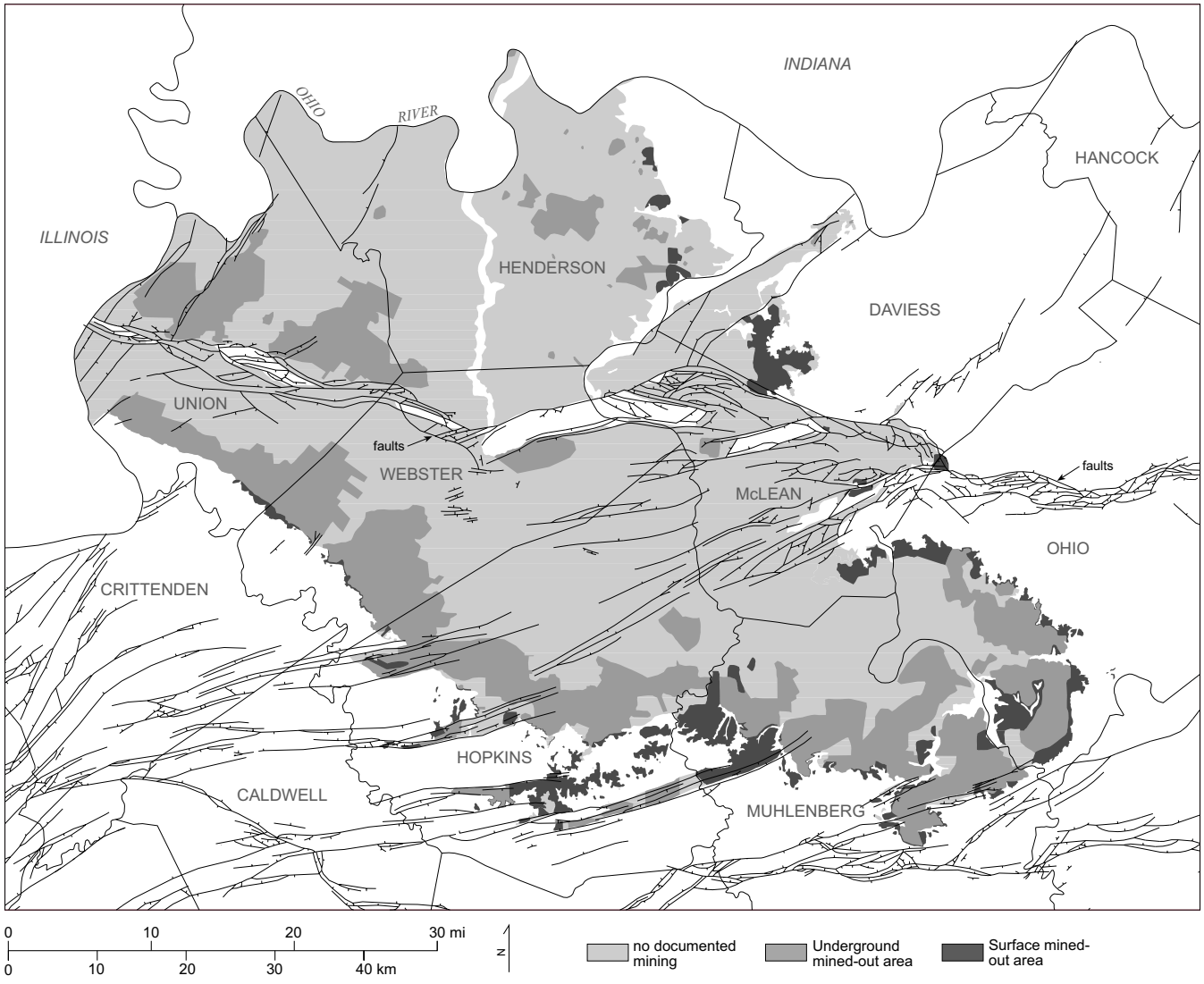

Figure 5. Areas of the Springfield coal mined by surface and underground methods.

Table 2. Summary of resource estimates for the Springfield coal bed (million tons).[1]

Thickness Categories	Original	Mined-Out Surface	Mined-Out Deep	Mined-Out Total	Remaining	Percent Mined Out
14–28	10.992	0.833	0.378	1.211	9.781	11
28–42	217.502	9.445	3.275	12.721	204.781	6
> 42	9,688.779	452.645	1,936.438	2,389.083	7,299.696	25
Total	9,917.273	462.923	1,940.092	2,403.014	7,514.259	24

[1]Totals may not equal sum of components because of independent rounding.

Most of the historical mining of the Herrin coal has been in the southern coal body in Hopkins and Muhlenberg Counties (Fig. 7). The coal was developed in large-area surface mines in areas with little overburden along with the Paradise coal and, in some cases, the Baker coal. Large underground mines have also been developed down-dip from the surface mines. More recent and smaller underground mines have been developed in the northwestern part of the coal field. An estimated 1.03 BT, or 26 percent of the original resource, has been mined out or lost in mining (Table 3), based on the areal extent of documented mined areas. Underground mining accounts for 58 percent of the mined-out total, and 98 percent of the mined-out coal was greater than 42 in. thick. Remaining resources are estimated at 2.91 BT.

Baker Coal (W. Ky. No. 13)

The Baker coal zone lies 40 to 60 ft above the Herrin. Unlike the Springfield and Herrin coal beds, the Baker is a complex zone of coals with mineable beds consisting of multiple benches separated by rock partings. Thick coal bodies are typically found where the Herrin and Paradise coal beds are thin or absent. Two distinct bodies are well documented: one south of the Rough Creek Fault System and one north of it (Fig. 8). Each coal body is either bisected or bounded by contemporaneous or post-depositional sandstone paleochannels that split or entirely replace the coal. Isolated pods of thicker coal also occur along the eastern margin of the outcrop area.

The revised estimate of total original Baker resources is 3.82 BT, and for coal greater than 42 in. is

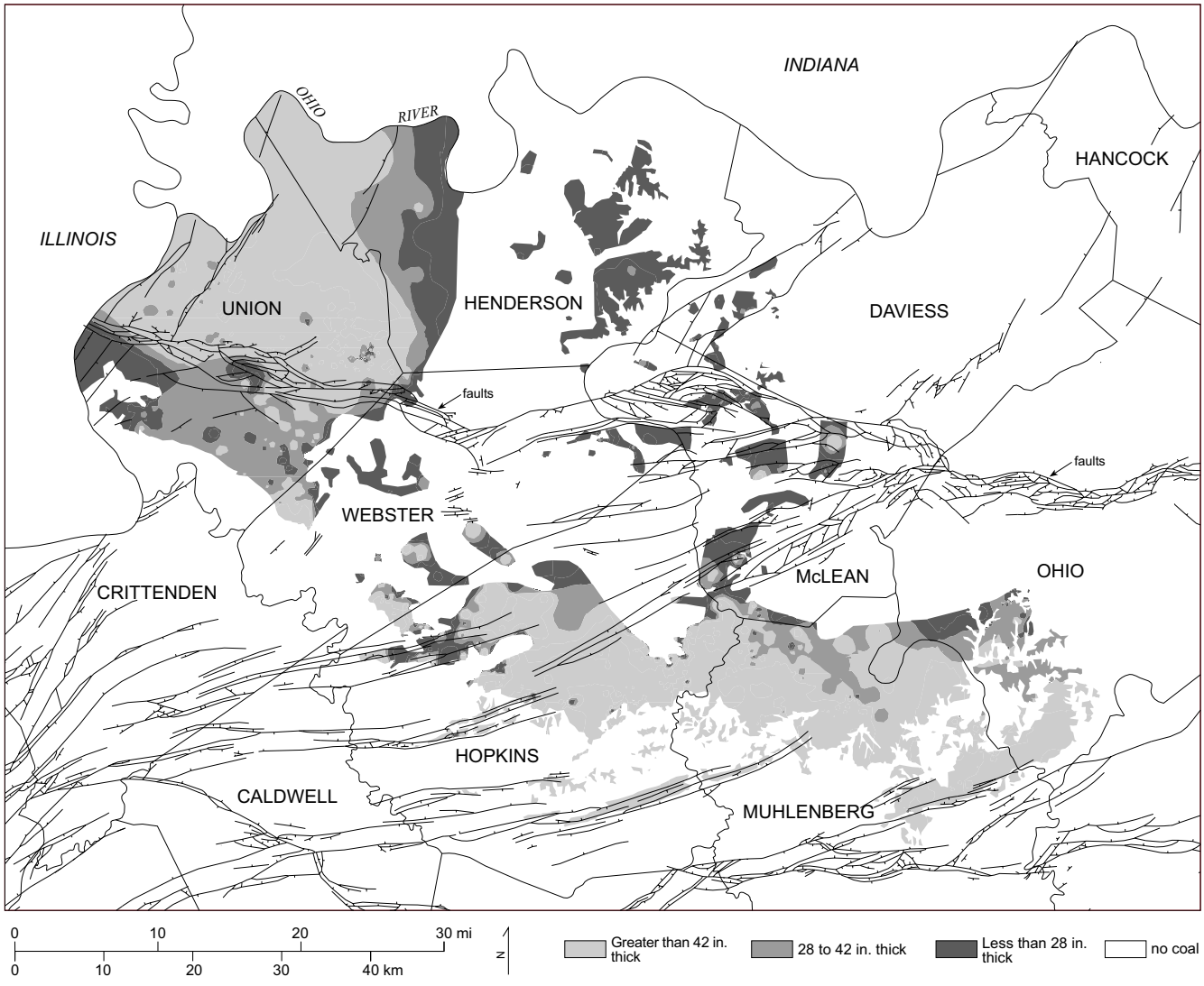

Figure 6. Total thickness of the Herrin coal in western Kentucky.

Table 3. Summary of resource estimates for the Herrin coal bed (million tons).[1]

Thickness Categories	Original	Mined-Out Surface	Mined-Out Deep	Mined-Out Total	Remaining	Percent Mined Out
14–28	207.152	1.526	1.389	2.915	204.237	1
28–42	569.669	8.638	8.282	16.920	552.750	3
> 42	3,162.026	423.858	588.092	1,011.950	2,150.077	32
Total	3,938.847	434.022	597.762	1,031.784	2,907.063	26

[1]Totals may not equal sum of components because of independent rounding.

1.76 BT (Table 4). The new estimate is 19 percent higher than that of Smith and Brant (1978); however, a smaller proportion of the resource in the current estimate is greater than 42 in. thick (Table 1).

Most of the historical mining of the Baker coal zone has been by surface methods along the southern and eastern margin of the coal field (Fig. 9). In most areas, this mining was done in multiseam mines that included the Herrin and Paradise coals where the Baker

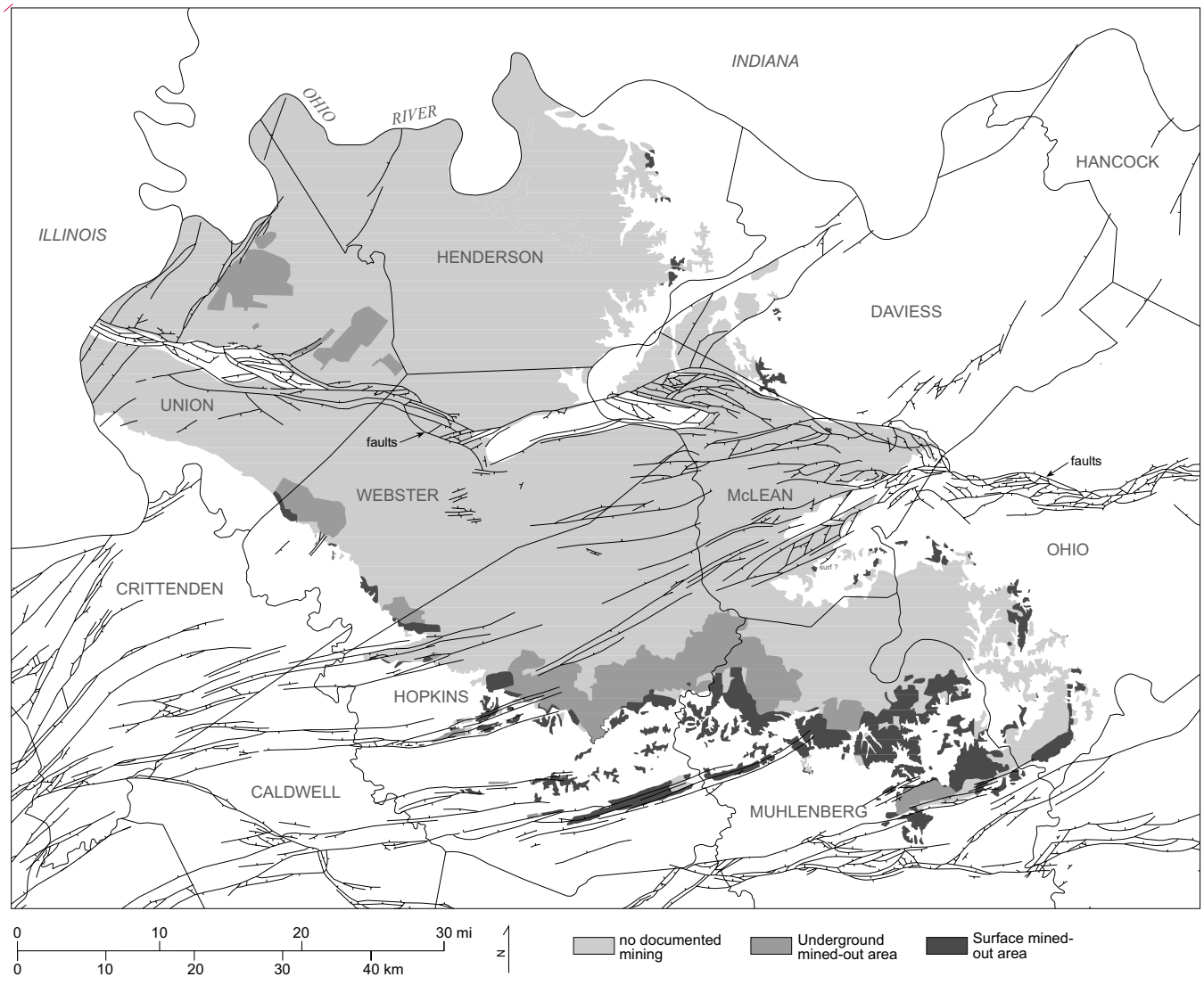

Figure 7. Areas of the Herrin coal mined by surface and underground methods.

Table 4. Summary of resource estimates for the Baker coal bed (million tons).[1]

Thickness Categories	Original	Mined-Out Surface	Mined-Out Deep	Mined-Out Total	Remaining	Percent Mined Out
14–28	1,036.631	33.095	0.065	33.161	1,003.470	3
28–42	1,021.078	27.738	0.879	28.617	992.461	3
> 42	1,762.612	61.039	61.949	122.988	1,639.624	7
Total	3,820.322	121.872	62.893	184.765	3,635.556	5

[1]Totals may not equal sum of components because of independent rounding.

may not have been of sufficient thickness to mine alone. There is one large underground mine in the vicinity of Providence, within the thickest body of the Baker coal. Total resources mined and lost in mining (Table 4) are estimated at 185 MT, or 5 percent of the original resource. Surface mining accounts for 66 percent of the mined-out total, and only 67 percent of the mined-out coal was greater than 42 in. thick. Remaining resources for the Baker coal are estimated at 3.64 BT.

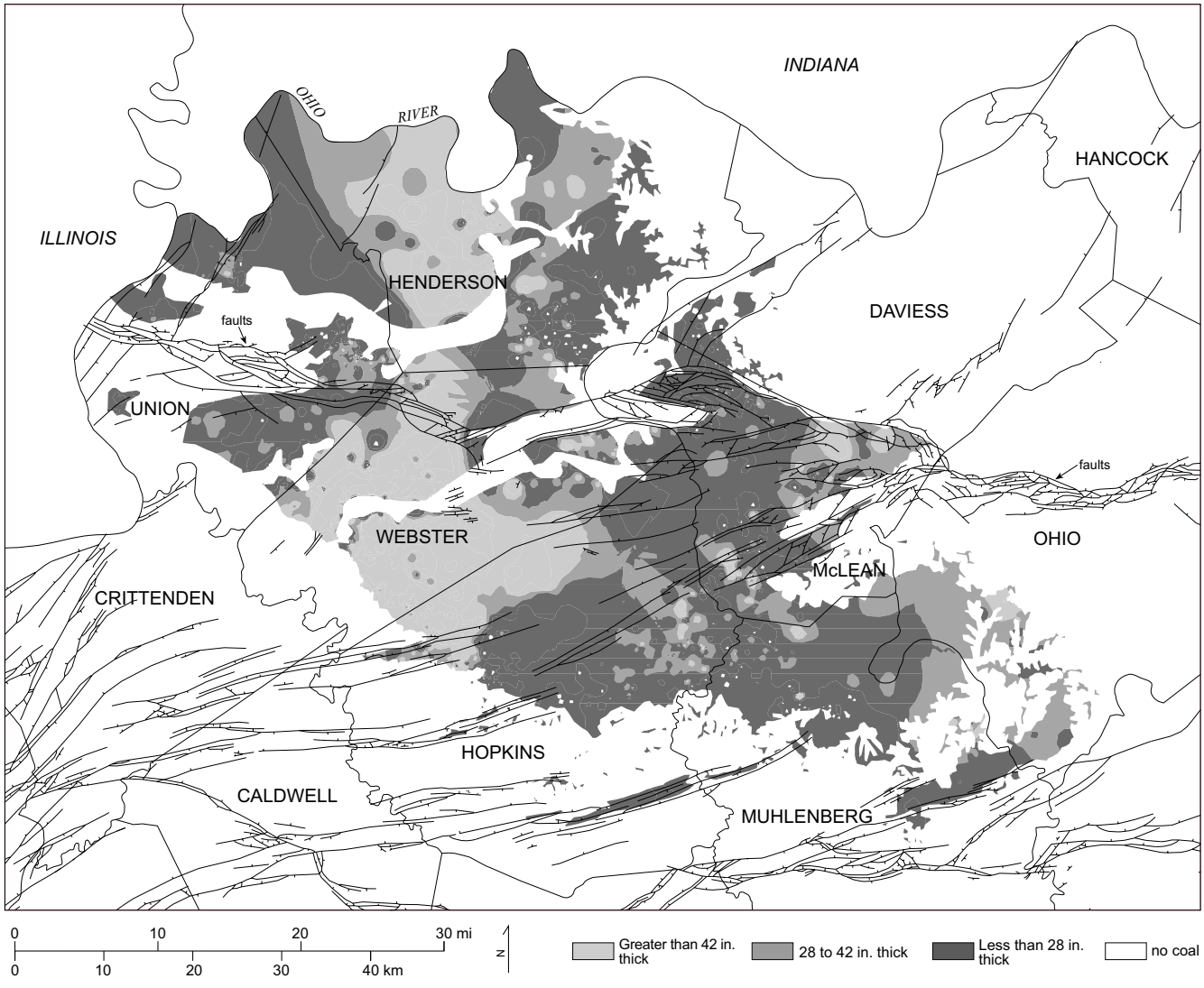

Figure 8. Total thickness of the Baker coal in western Kentucky.

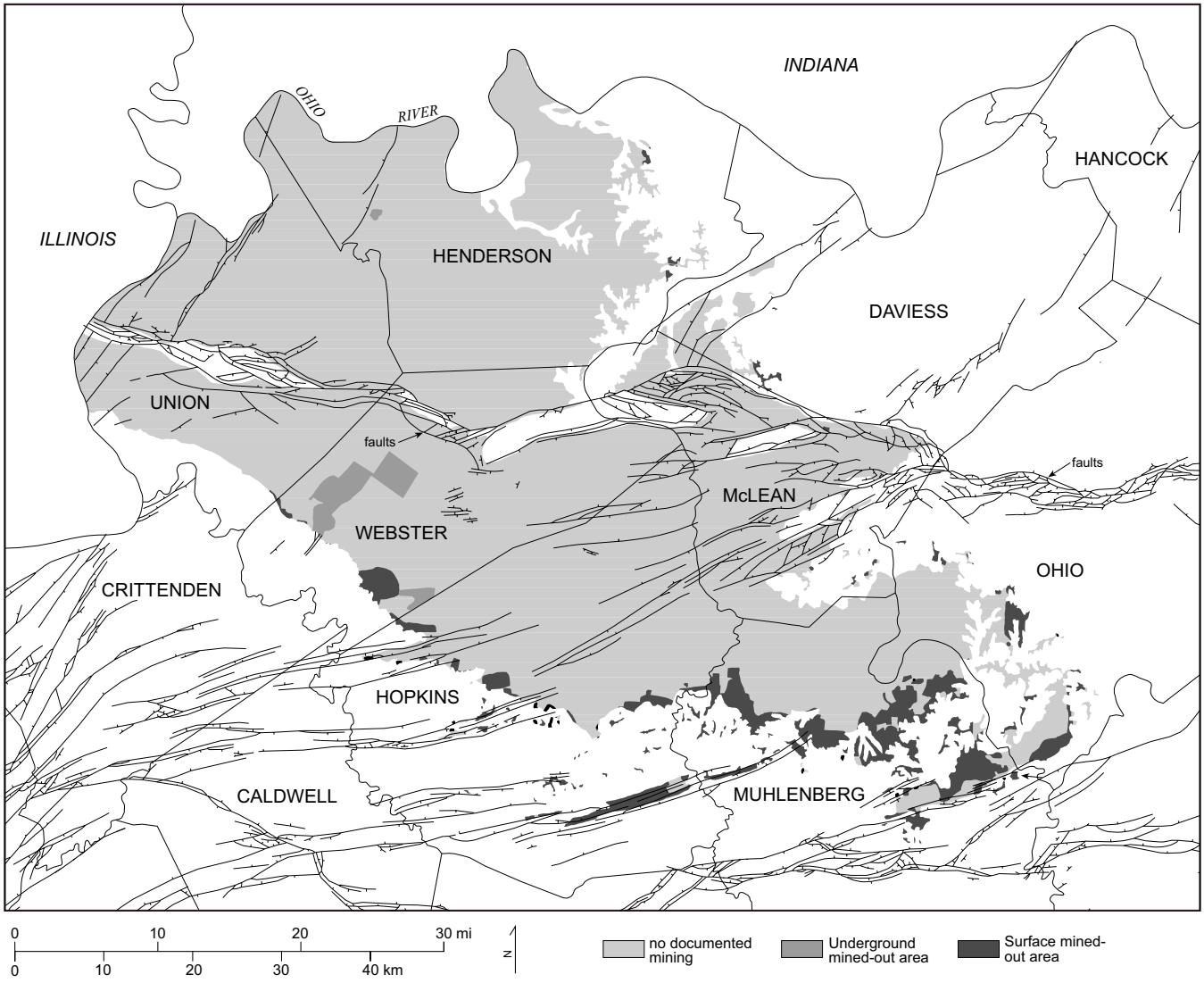

Figure 9. Areas of the Baker coal mined by surface and underground methods.

Coal-Availability Summary

Rationale for Selecting Study Areas

Experience has shown that geologic variability occurs across broader distances in western Kentucky than in eastern Kentucky. In order to adequately measure geologic factors that affect availability, areas larger than a single 7.5-minute quadrangle were necessary for study. Therefore, at least two adjacent quadrangles were used for each coal-availability study in western Kentucky. The 1:24,000-scale accuracy for data collection and analysis was still used for these multiquadrangle areas.

Because the beds between the Springfield and the Baker coals (W. Ky. No. 9 through No. 13) comprise 56 percent of western Kentucky's estimated original resource of 41 BT (Smith and Brant, 1978), have greater lateral continuity than other western Kentucky beds, have adequate amounts of subsurface data, and are limited in area to the central half of the Pennsylvanian outcrop, the first phase of studies was designed to emphasize these historically important coal beds.

The final consideration was to select areas north and south of the Rough Creek Fault System to measure the effect of different geologic, structural, and overburden settings on coal availability.

The beds below the Springfield coal present a much different coal-availability problem than for the beds above it. Most of the information suitable for accurate thickness characterization of these beds is limited to the area outside the Springfield outcrop, whereas few reliable data are available in the central, deep part

of the basin. Much of our knowledge about these beds is based on interpretations of oil and gas geophysical logs that lack adequate resolution to define coal thickness with acceptable precision. Stratigraphically lower Carbondale coals such as the Dekoven and Davis present correlation problems. Underlying Tradewater coals exhibit even greater lateral variability, so that the fundamental problem for these coals is geologic characterization. Coal beds below the Springfield account for 37 percent of the total resource (Smith and Brant, 1978) and have potential for low sulfur values (Williams and others, 1990), however. Methods for dealing with lack of data will be addressed in the next phase of studies.

Coal beds above the Coiltown are generally thin, and given the abundance of resources in the underlying strata, they will probably not be seriously considered as important mineable resources.

Methods

In order to estimate the amount (tons) of coal present within a given area, its volume must be known. The two factors necessary for calculating volume are area (which is defined by the outcrop of the coal bed) and thickness (which is estimated from point measurements along the outcrop and in subsurface boreholes). Resource categories, mined-out areas, and restrictions are other factors for determining the whole area of each coal bed. Because the primary task is one of determining and measuring map areas, a computerized geographic information system (GIS) was selected to perform the analysis. This type of system allows digital map information to be stored and automated comparisons and calculations to be made for one or more maps. The primary effort of this type of study is preparing analog point-source and map information and rendering them in digital form.

Point Data. The point data for the Western Kentucky Coal Field were obtained from descriptions made by geologists and engineers from over 5,000 exploration drill holes and geophysical logs. These data include measurements of a coal bed's thickness, thickness of rock partings (if present), elevation (calculated from surveyed collar elevations or estimated by altimeter or from topographic maps), and the stratigraphic position of the coal bed. The data were processed and extracted using a borehole database program. Additional information about the thickness and elevation of coal beds was obtained from surface-mine permits from the Kentucky Natural Resources and Environmental Protection Cabinet. After all data were examined to verify correlations and accuracy in measurement, the locations and measurements were then prepared as digital data files, with location coordinates in zone 16 of the universal transverse Mercator (UTM) system, thickness measurements in decimal inches, and elevations in feet above sea level.

Map Data. Outcrop data were compiled from 7.5-minute, 1:24,000-scale geologic quadrangle maps. These and other kinds of map information were digitized from stable map media (Mylar tracings or photo reproductions) using the program ARC/INFO 7.1.1. Land-use restrictions were digitized from U.S. Geological Survey (USGS) 7.5-minute topographic base maps. Mined-out areas were obtained from the Kentucky Department of Mines and Minerals. The locations of oil and gas wells were obtained from the Kentucky Geological Survey. Digital elevation models (DEM's), which are digital representations of topographic maps, were obtained from the USGS for each 7.5-minute quadrangle in the study area. Restrictions and mined-out areas were, in some cases, field checked for accuracy.

Restrictions to Mining. The two restriction categories used for this study are land-use and technological. Most land-use restrictions are outlined under the Kentucky Natural Resources and Environmental Protection Cabinet document 405 KAR (Kentucky Administrative Register), 24:040, "Areas Unsuitable for Mining." This document relates to KRS (Kentucky Revised Statutes) 350.465 and 350.610, which define the regulatory program for surface mining in Kentucky. Land-use restrictions can apply to both surface- and deep-mineable coals, as shown in Table 5. For western Kentucky studies, the only land-use issues that affect deep-mineable coal are towns and dense fields of active oil and gas wells. Although these areas are not legally restricted from mining, most companies do not mine in these areas as a practical measure. Similarly, most companies do not mine under major streams for safety reasons. Each area was evaluated for these situations on an individual basis. With the exception of federally funded highways, nationally protected lands, and cemeteries, variances are often granted for many of the listed restrictions.

Technological restrictions for these studies generally apply to potentially deep-mineable coals. These factors include barriers around existing underground mines, potential for mining or previous mining within 40 vertical feet of a seam, active oil and gas wells, and coal too thin (less than 28 in.) for current underground mining methods (Table 5). An additional category that was not identified in the eastern Kentucky studies but is important for western Kentucky is small mine blocks. These areas occur adjacent to older mines or as small isolated pods of mineable coal surrounded by thinner

coal. They are considered unavailable because it is unlikely that the coal in them will be recovered under any foreseeable market conditions.

Western Kentucky contains much coal that would be considered available, both in a technological and regulatory sense, if it were economical to mine it. The relatively low profit margins to mine the coals in the region render this coal uneconomical. For this report, these categories were subtracted from the availability totals. They include deep-mineable coal less than 42 in. thick, surface-mineable coal less than 28 in. thick, and coal immediately underlying (within 100 ft) valleys of Quaternary alluvium. The latter case is an economic concern because of the added costs of pre-mine planning necessary to identify coal discontinuities, inadequate bedrock thickness, and potential water problems. No mines have opened under these conditions in recent times, and are unlikely under foreseeable market conditions. Coal restricted by these factors is tabulated under the category "Economic" in subsequent tables and appendices of this report.

Data Analysis. The GIS software used for this project was GRASS (Geographical Resources Analysis Support System), a U.S. government package developed primarily by the U.S. Army Corps of Engineers, the Soil Conservation Service, and the USGS. GRASS is a raster-based GIS, which means that map data are rendered as matrices of equal-sized grid cells. Maps stored in a GRASS database must be oriented to a particular coordinate system. The UTM system, based on the Clark 1866 spheroid, was chosen for these studies. In order to use map information for calculations, the original vector data (points, lines, or areas) must be converted to raster (gridded) data files. The size of grid cells (resolution) for each map must be specified, but can vary between maps. Table 6 lists the method of preparation and resolution for the maps prepared for this report.

In the case of thickness and elevation point data, a gridding algorithm was used to interpolate cell nodes between data points. Two algorithms were used. The first, "s.surf.pln," accepts unequally spaced data and applies a first-order trend-surface fit to the nearest neighbors found by the specified search. This program works best on structural data, which have a large first-order component. It also works adequately on thickness data that are relatively closely spaced. Interpolation problems occur in areas of sparse data and in the vicinity of closely spaced points that differ substantially in thickness. The second algorithm, "s.surf.idw," uses a simple inverse-distance weighting function. This program is efficient at honoring data points, but is inaccurate farther away from the points. In most cases it was used for modeling the thickness of coal beds.

Once all maps were prepared, the USGS program RESOURCES used GRASS commands to calculate areas (in square meters) for all resource categories (original, mined-out, remaining, restricted, available, and economic). Using the following definitions, these data were then converted to acres, and tons were calculated:

$$1 \text{ acre} = 4{,}047 \text{ m}^2$$

1 acre-ft of bituminous coal=1,800 short tons

Resource Categories. Tonnage estimates for each bed are reported by categories of coal thickness, overburden thickness, and reliability of the estimate. Standard USGS procedures (Wood and others, 1983) stipulate thickness categories in multiples of 14 in. up to 42 in., and multiples of 42 in. up to 168 in. Categories above 168 in. are aggregated. For the coal-availability studies in western Kentucky, only three categories are used: 14 to 28 in., 28 to 42 in., and greater than 42 in. This is because coal less than 28 in. thick is generally not technologically mineable by underground

Table 5. Potential restrictions with buffer zones and the mining categories to which they apply.

Restrictions	Buffer Size	Surface	Underground
Land-Use			
Airports	area + 100	X	X
Bridges	area + 100	X	
Cemeteries	area + 100	X	
Faults	area + 100	X	X
Oil & gas wells	200 ft	X	
Public lands	area	X	X
Pipelines	area + 100	X	
Power lines	area + 100	X	
Railroads	area + 100	X	
Roads	area + 100	X	
Streams	area + 100	X	
Parks, National	area	X	X
Parks, State	area	X	
Municipalities	area + 300	X	X
Technological			
Coal too thin	area		X
Coal too deep	area		X
Faulting	area		X
Interburden < 40 ft	area		X
Mine barriers	250 ft		X
Mining within 40 ft	area		X
Oil & gas wells	200 ft		X
Oil & gas fields	area		X
Small mine blocks	area		X

methods and coal less than 42 in. thick is not considered economically mineable by underground methods.

Overburden categories are also based on the potential effect on mining method. Three categories are defined: surface-mineable, deep-mineable, and too deep to mine with current technology. The footages for these categories can vary depending on topographic relief and seam and interburden thickness, as well as potential for multiseam mining. Mining practice in western Kentucky dictates that 0 to 150 ft of overburden is generally surface-mineable and 150 to 1,500 ft is deep-mineable. In actuality, maximum overburden height for surface mining is generally determined by a ratio of overburden to coal thickness. The fixed footage used in these studies only provides an estimate of surface-mineable and deep-mineable areas.

Reliability categories are determined by distance from coal-thickness measurements. "Measured" resources lie within ¼ mi of a data point, "indicated" resources between ¼ and ¾ mi, "inferred" resources between ¾ and 3 mi, and "hypothetical" resources beyond 3 mi. It is generally accepted that the rate of thickness variation differs for most coal beds; hence, reliability can only be interpreted in this context. The reliability categories do provide an indication of data spacing, however.

Results of Quadrangle Studies

Fourteen 7.5-minute quadrangles in the Western Kentucky Coal Field were studied (Fig. 10). These studies were conducted in five separate areas in order to determine the main factors affecting mineability of the coal beds in the Carbondale and lower Shelburn Formations. The emphasis was on the coals between the Springfield and Baker coals; however, preliminary results for some underlying and overlying beds are included for some quadrangles because they were locally important. Results are given as percentages in Table 7 and as tonnages in Appendix A. Certain coal beds were excluded from specific quadrangles for several reasons—the coal bed was absent, insufficient thickness for mining, or insufficient data to characterize the bed.

Original Resources. Total original resources for the assessed coal beds in the studied quadrangles are estimated at 5.55 BT (Appendix A). This represents 14 percent of the total resources for the entire coal field. Almost half of the current estimate is accounted for by the Springfield coal, and nearly a quarter of the estimate by the Baker coal. About 77 percent of the resources in the 14-quadrangle area occurs at depths between 150 and 1,500 ft and is considered primarily deep-mineable (Appendix B). Seventy-one percent of the coal is greater than 42 in. thick. This result is heavily influenced by the large amount of the Springfield coal

Table 6. Map types and data sources for GRASS data analysis.

Map Type	Data Source	Method	Cell Resolution	Comments
Map border	Corner points		5 m	Used as data mask
Outcrops	1:24,000 USGS GQ	Digitized	5 m	Used for original resource maps
Mines	Ky. Dept. of Mines & Minerals	Digitized	5 m	Used for mined-out and remaining-resource calculations
Land-use restrictions	1:24,000 topographic maps	Digitized	5 m	Used for available-resource calculations
Oil & gas wells	KGS Geologic Data Center	s.poly output	5 m	Restriction
Reliability arcs	Derived from thickness locations	s.poly output	5 m	Reliability categories
Digital elevation model	1:24,000 USGS digital files		30 m	Used for creating overburden maps
Structure contour	Borehole elevations	s.surf.pln	30 m	Used for creating overburden maps
Thickness isopach	Point-source thickness data	s.surf.idw	30 m	Used for volume calculations

present in the area. Likewise, the magnitude of original estimates for specific quadrangles is mainly a function of the extent of the Springfield coal in each area.

Mined-Out and Remaining Resources. Measurements of mined-out resources are based on the digitized outlines of mine maps on file at the Kentucky Department of Mines and Minerals. Consequently, the estimates include pillars and barriers of coal that are lost in the course of mining. Though some older mines may have been unrecorded, every effort was made to identify the locations of large mined-out areas. Twenty percent of the original resource (1.084 BT) for the lower Carbondale coal beds has been mined or lost in mining (Appendix A). This amount compares well with the regional assessments of historical mining. Coal mined by underground methods comprises 70 percent of the total production. Historical mining generally reflects the magnitude of the original resource and has been influenced by coal quality. The Springfield coal comprises 53 percent of the mined-out total, whereas the Herrin and Baker coals amount to 14 and 9 percent, respectively.

Remaining resources for the 14 quadrangles are 4 BT, or 80 percent of original resources (Table 7, Appendix A). Of this amount, 81 percent is in the deep-mineable overburden category and 65 percent is greater than 42 in. thick (Appendix B). Local variability of mined-out and remaining resources is high (Table 7), and this relates to the specific history of mining in local areas as well as the geologic characteristics of the beds.

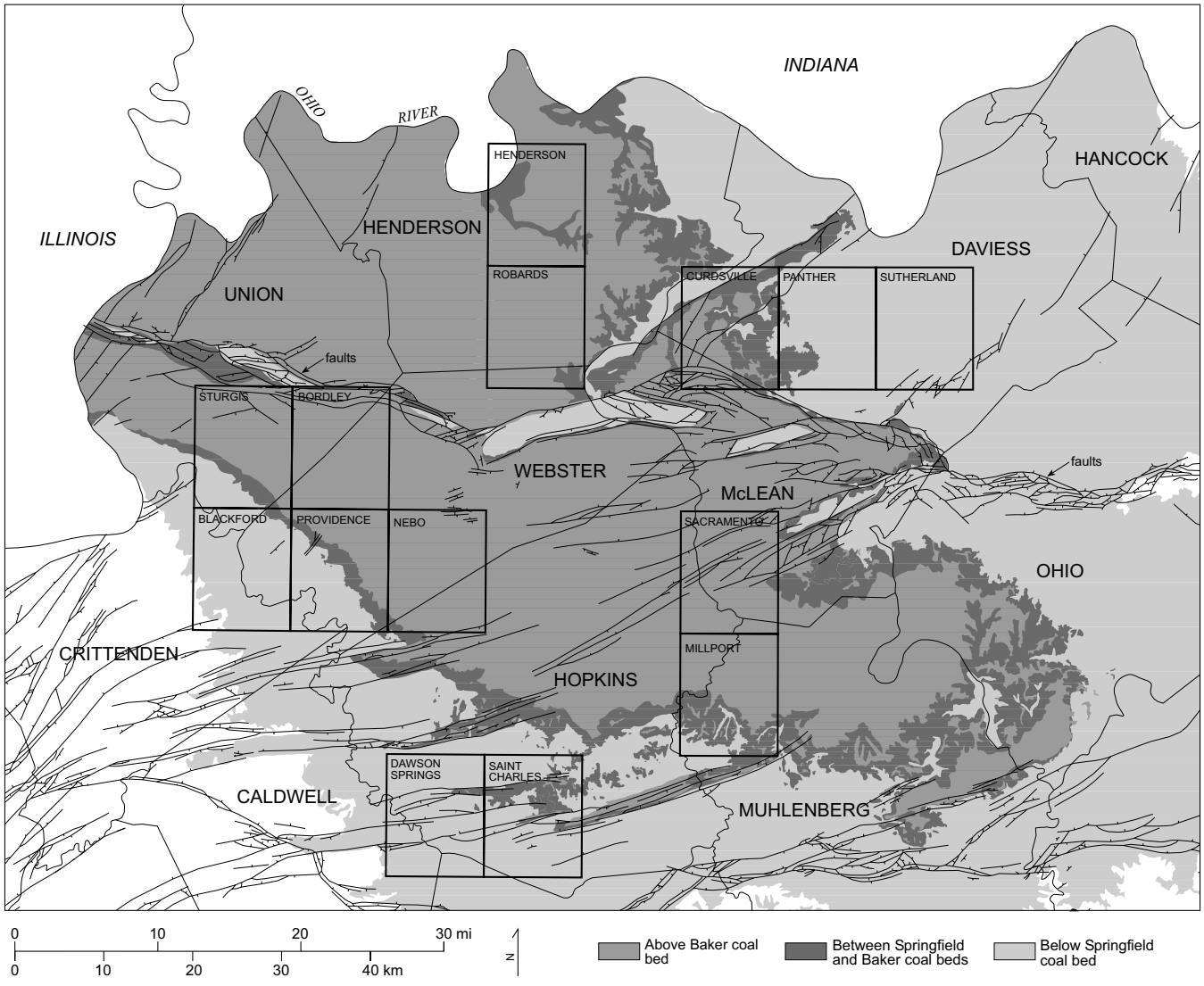

Figure 10. Locations of the 14 quadrangles studied.

Table 7. Available resources for all coal beds in 14 studied quadrangles (percent of original resources).

Quadrangle	Original Resources (million tons)	Mined Out	Remaining	Land-Use Restrictions	Technological Restrictions	Available	Economic
Blackford	13	81	19	7	3	9	9
Bordley	735	13	87	0	39	47	40
Curdsville	372	10	90	3	39	49	33
Dawson Springs	117	31	69	5	5	59	45
Henderson	376	11	89	10	18	61	30
Millport	758	47	53	6	16	30	29
Nebo	784	17	83	1	13	69	68
Panther	127	10	90	2	38	49	9
Providence	311	51	49	11	12	27	25
Robards	407	0	100	2	6	91	48
Sacramento	622	4	96	0	38	58	38
Saint Charles	325	27	73	2	2	69	57
Sturgis	580	14	86	3	34	49	26
Sutherland	22	1	99	20	0	79	7
Average*	396	20	80	3	23	54	40

*Average weighted by original resources

Restricted and Available Resources. The average amount of coal restricted from mining is 26 percent of original resources (Table 7). As in most previous coal-availability studies, the largest portion of restrictions (88 percent) is technological in nature. Land-use restrictions that were identified in this study are primarily associated with municipal areas and major waterways. Most other regulatory factors either affect too small an area to have a significant impact on resources or are routinely mitigated through variances or negotiations with landholders.

Several technological issues were found to be important in the Western Kentucky Coal Field. The largest factor is coal too thin to be mined by underground methods. This factor is less significant here than in eastern Kentucky, however, because there is still abundant thick coal remaining. Moreover, some beds, like the Herrin, are either of mineable thickness or are entirely absent; there is very little resource of intermediate thickness. Coal thickness will be a problem for development of the Davis coal (W. Ky. No. 6) because of its large below-drainage extent and generally thin character.

Small interburden thickness between two mineable seams is also a key factor in some areas. The Herrin and Paradise coal beds both exceed 5 ft in thickness in areas where they are less than 15 ft apart (Hopkins and Muhlenberg Counties). This is advantageous where overburden thickness permits surface mining, but a significant amount of deep-mineable coal has been or will be "sterilized" by mining of one of the beds. In all cases, the Herrin coal is favored for mining over the Paradise coal, because of its greater thickness and better quality characteristics.

In areas that have been heavily mined, mine barriers and small isolated blocks constitute an important impediment to mining. Because many of the older mines were not accurately surveyed, larger mine buffers are often required for safe development of adjacent mines. Moreover, the economics of coal development in this region preclude the mining of smaller tracts between existing mines or otherwise geologically isolated areas that would be mineable in eastern Kentucky where there is greater surface access to coal.

Faulted strata are much more prevalent in western Kentucky than in the east. They are not necessarily a restriction to mining, because many faulted areas have been successfully mined where overburden thickness is small. Some of the structures associated with the major fault zones are so complexly faulted, however, that they result in many small and isolated mine blocks, and so the resources were restricted. Because much of the remaining resource is only deep-mineable, it is likely that many undetected fault structures will be encountered. The impact of these faults on coal availability is difficult to quantify.

In some areas overburden will be too thick to make deep mining practical. These areas are associated with deep grabens and the deepest parts of the Webster and Moorman Synclines (Fig. 1). The impact of this restriction will not be immediate, because ample coal remains at shallower depths.

Buffers around oil and gas wells can be a technological restriction for both surface and underground mining. The spacing of wells in some western Kentucky oil and gas fields could be a significant deterrent to mining. Interviews with mining company personnel suggest that in most cases, the locations of these wells can be incorporated into mine plans with minimal loss of reserves. This technique has been used in gas fields with regular well spacings of 660 ft. Therefore, in western Kentucky the only fields that have been entirely restricted from mining are those with close and irregular well spacing.

After mining and restricted coal are taken into account, the average availability of coal in the 14 quadrangles is 54 percent (Table 7). The results by quadrangle range from 9 to 91 percent, which confirms the necessity of studying larger areas.

Economic Coal Resources. The assessment of available coal resources assumes the technological limit of 28 in. for deep-mineable coal. From an engineering standpoint this is correct, but in practice little coal less than 42 in. thick has been mined by underground methods. Because this is an economic constraint more than a technological limit, these thinner resources were considered available, but uneconomic. This categorization was applied to deep-mineable coal between 28 and 42 in. thick and to surface-mineable coal between 14 and 28 in. thick. As such, it is a simple estimate and not intended to evaluate the many other factors that influence the economics of coal mining. These thin resources account for another 14 percent of the original estimate, leaving 40 percent of the coal that is both available and economic (Table 7).

Results for Individual Coal Beds

Davis Coal. Results for quadrangles in which the Davis coal was assessed are given in Table 8 and Appendix B. The Davis is present in all quadrangles, but was not studied in all of them because of a lack of information. These conclusions should be considered preliminary. The Davis coal has not been mined extensively, so most of the resource is still remaining. Two key availability issues relate to this coal bed. First, the bed is too thin in large areas for economic mining, particularly in the eastern part of the coal field. This is compounded by the problem that much of the data used to characterize its thickness is of poor quality. Second, the Davis and Dekoven (W. Ky. No. 7) coals are within 20 vertical feet of each other in significant areas in the western part of the coal field, and both are of mineable thickness and at depths requiring underground mining. Large amounts of one of these beds will thus be unavailable if adjacent beds are mined.

Springfield Coal. Results for quadrangles in which the Springfield coal was assessed are given in Table 9 and Appendix B. One of the most important factors relating to its availability is the large amount of mined-out coal. Much of this historical mining has been from the thickest parts of the seam—greater than 56 in. thick. Other factors are less important, primarily because most of the remaining resource is deep-mineable and has adequate thickness for economic recovery. Several issues will affect the future development of the Springfield coal. Some coal in areas north of the Rough Creek Fault System is too deep for surface mining but lies under relatively thin bedrock cover or Quaternary alluvial valleys. This has resulted in the low economic resource estimates for the Henderson quadrangle, for example. These resources should be considered technologically available for mining, but the added costs of pre-mine exploration and development may be prohibitive. South of the Rough Creek faults the coal is thicker, but at greater depths. These resources will be more challenging to develop because of potential undocumented faulting and roof-control problems arising from the greater depths of mining and associated in situ stresses.

Herrin Coal. Results for quadrangles in which the Herrin coal was assessed are given in Table 10 and Appendix B. Although the average percentage of mined-out Herrin coal is less than for the Springfield

Table 8. Summary of available Davis coal by quadrangle (percent of original resources).

Quadrangle	Original Resources (million tons)	Mined Out	Land-Use Restrictions	Technological Restrictions	Available	Economic
Curdsville	137	0	0	83	17	0
Panther	96	0	2	51	47	0
Sutherland	22	1	20	0	79	7
Average*	85	11	4	28	48	2

*Average weighted by original resources

Table 9. Summary of available Springfield coal by quadrangle (percent of original resources).

Quadrangle	Original Resources (million tons)	Mined Out	Land-Use Restrictions	Technological Restrictions	Available	Economic
Blackford	8	89	6	5	0	0
Bordley	310	19	0	16	65	65
Curdsville	235	15	5	13	67	52
Dawson Springs	6	59	1	0	40	40
Henderson	251	17	1	26	55	28
Millport	294	38	10	5	47	46
Nebo	341	31	1	9	59	59
Panther	31	42	1	0	56	38
Providence	152	65	11	19	5	5
Robards	284	0	1	5	94	56
Sacramento	254	2	0	11	86	66
Saint Charles	70	20	4	0	76	76
Sturgis	250	27	4	10	59	52
Average*	191	23	3	12	62	51

*Average weighted by original resources

coal, this factor is probably of greater importance for the Herrin coal. This is because of the smaller extent of mineable resources for the Herrin coal. Moreover, surface resources of the Herrin coal are significantly depleted. The other factor that affects this coal is resources that are too thin to mine. Some of this estimated thin coal may result from digital methods for interpolation of thickness data. Improved characterization of the limit of thick coal bodies will reduce this tendency and the associated restricted tonnages. Future mining of the Herrin coal will likely be adjacent to existing reserves and will be largely by underground methods.

Paradise Coal. Results for quadrangles in which the Paradise coal was assessed are given in Table 11 and Appendix B. As for the Herrin coal, the surface-mineable resources of the Paradise have been significantly reduced. There have been no documented underground mines in this coal bed. This is because areas that contain Paradise coal of mineable thickness coincide with those of the underlying Herrin coal, and the Herrin is generally preferable for mining because of its greater thickness and better quality characteristics. The two beds are separated by very small rock intervals (less than 3 m), and this has led to frequent sterilization of the Paradise coal bed. In view of the

Table 10. Summary of available Herrin coal by quadrangle (percent of original resources).

Quadrangle	Original Resources (million tons)	Mined Out	Land-Use Restrictions	Technological Restrictions	Available	Economic
Blackford	4	87	11	0	2	2
Bordley	95	8	0	55	37	12
Dawson Springs	3	65	1	0	33	33
Henderson	0	0	0	0	0	0
Millport	244	28	4	4	64	13
Nebo	76	17	2	77	4	4
Providence	22	36	25	9	29	25
Robards	0	0	0	0	0	0
Sacramento	90	21	0	39	40	19
Saint Charles	27	77	3	0	20	20
Sturgis	157	8	2	13	78	8
Average*	51	21	3	25	51	12

*Average weighted by original resources

Table 11. Summary of available Paradise coal by quadrangle (percent of original resources).

Quadrangle	Original Resources (million tons)	Mined Out	Land-Use Restrictions	Technological Restrictions	Available	Economic
Dawson Springs	1	64	1	0	35	35
Millport	150	35	5	37	23	23
Sacramento	15	0	0	96	4	3
Saint Charles	19	63	5	0	33	33
Average*	61	35	4	38	22	22

*Average weighted by original resources

diminished surface reserves of this bed, the future availability of the Paradise coal will be small.

Baker Coal. Results for quadrangles in which the Baker coal was assessed are given in Table 12 and Appendix B. Substantial resources are associated with this bed, yet mining has been limited to a small number of areas where the coal is thickest. This pattern is reflected in the large range of mined-out tonnages in the different quadrangles. Availability of the Baker coal is mainly a function of coal thickness and quality, and this varies significantly among the quadrangles. Another factor in its underground mining is the occurrence of rider beds in the roof of mineable seams, which results in poor roof conditions and higher development costs.

Mannington Coal. A preliminary analysis of the Mannington (W. Ky. No. 4) coal was conducted in the Dawson Springs and Saint Charles quadrangles. Results for these quadrangles are given in Table 13 and Appendix B. The Mannington has been extensively mined by surface and underground methods near the area of outcrop under relatively shallow cover. Much of the data for this study area is near the existing coal mining operations along the margin of the basin, and as a result, confidence in the interpolated thicknesses at greater depths within the basin is low. Therefore, estimates of available coal and economically available coal should be considered preliminary. Additional studies are needed to address the regional problem of insufficient data for this coal bed.

Summary

About 90 percent of western Kentucky coal resources is associated with only six beds, and one bed, the Springfield (W. Ky. No. 9), constitutes 25 percent of the entire estimate. Seventy percent of the resource is greater than 56 in. thick.

Total original resources for the assessed coals in the 14 studied quadrangles are estimated at 5.55 billion tons (BT). Almost half this total is accounted for by the Springfield coal, and nearly a quarter by the Baker. About 77 percent of the coal is considered deep-mineable.

A total of 1.084 BT, or 20 percent of the original resource, has been mined out or lost to mining. Thus, 4 BT, or 80 percent of original resources, remain.

Table 12. Summary of available Baker coal by quadrangle (percent of original resources).

Quadrangle	Original Resources (million tons)	Mined Out	Land-Use Restrictions	Technological Restrictions	Available	Economic
Blackford	2	32	1	0	67	67
Bordley	211	15	0	32	53	40
Henderson	125	0	27	1	72	33
Millport	50	1	2	77	21	9
Nebo	368	4	1	4	91	90
Providence	136	37	7	6	50	48
Robards	122	0	6	9	86	28
Sacramento	138	0	1	61	38	14
Sturgis	59	1	4	88	8	5
Average*	134	8	5	23	64	48

*Average weighted by original resources

Table 13. Summary of available Mannington coal by quadrangle (percent of original resources).

Quadrangle	Original Resources (million tons)	Mined Out	Land-Use Restrictions	Technological Restrictions	Available	Economic
Dawson Springs	107	29	5	6	61	46
Saint Charles	209	20	0	4	76	58
Average*	158	23	2	4	71	54

*Average weighted by original resources

The average amount of restricted coal is 26 percent of original resources, and 88 percent of this restricted amount is by technological factors. The most important technological restriction was coal too thin to mine. Small interburden thickness between two mineable seams is a key factor in some areas; other locally important factors are mine barriers and small mine blocks.

The average availability of coal in the 14 studied quadrangles is 54 percent. The results by quadrangle range from 9 to 91 percent, which confirms the necessity of studying larger areas.

Deep-mineable coal between 28 and 42 in. thick and surface-mineable coal between 14 and 28 in. thick is considered available, but uneconomic. The uneconomic resources account for 14 percent of the original resource, leaving 40 percent of the coal that is both available and economic.

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Appendix A. Coal-availability summaries for all coal beds in 14 quadrangles in western Kentucky (million tons)[1].

Quadrangle	Original Resources	Mined Out	Remaining	Land-Use Restrictions	Technological Restrictions	Available	Economic
Blackford	13	10	2	1	0	1	1
Bordley	735	99	637	0	288	349	296
Curdsville	372	35	336	11	144	182	123
Dawson Springs	117	37	80	5	6	69	53
Henderson	376	43	333	37	68	228	112
Millport	758	359	399	48	123	228	217
Nebo	784	133	651	8	105	538	534
Panther	127	13	114	3	49	63	12
Providence	311	157	153	33	38	82	78
Robards	407	1	406	10	24	371	194
Sacramento	622	25	597	2	235	359	235
Saint Charles	325	89	236	5	8	224	187
Sturgis	580	81	498	17	196	286	150
Sutherland	22	0	22	4	0	17	2
Total	5,550	1,084	4,466	184	1,284	2,997	2,193
Average*	396	77	319	13	92	214	157

[1]Totals may not equal sum of components because of independent rounding
*Average weighted by original resources

Appendix B. Coal-availability results for 14 quadrangles in western Kentucky (thousand tons). Totals may not equal sum of components because of independent rounding.

Blackford Quadrangle

Resource Category	0–150'				150–1,500'				Thickness Totals			Totals
	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	
Original	0	340	10,799	11,138	0	0	1,766	1,766	0	340	12,565	12,904
Mined out, surface	0	66	4,840	4,905	0	0	0	0	0	66	4,840	4,905
Mined out, deep	0	65	4,180	4,245	0	0	1,349	1,349	0	65	5,529	5,594
Mined out, total	0	131	9,020	9,150	0	0	1,349	1,349	0	131	10,369	10,500
Remaining	0	209	1,779	1,988	0	0	417	417	0	209	2,196	2,405
Land-use restrictions	0	19	858	877	0	0	0	0	0	19	858	877
Technological restrictions	0	0	0	0	0	0	404	404	0	0	404	404
Total restrictions	0	19	858	877	0	0	404	404	0	19	1,262	1,281
Available	0	189	921	1,111	0	0	13	13	0	189	935	1,124
Economic	0	189	921		0	0	13	13	0	189	935	1,124

Bordley Quadrangle

Resource Category	0–150'				150–1,500'				Thickness Totals			Totals
	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	
Original	0	156	382	538	144,610	97,912	491,800	734,322	144,610	98,068	492,183	734,861
Mined out, surface	0	0	0	0	0	0	0	0	0	0	0	0
Mined out, deep	0	0	25	25	64	1,322	97,466	98,852	64	1,322	97,491	98,876
Mined out, total	0	0	25	25	64	1,322	97,466	98,852	64	1,322	97,491	98,876
Remaining	0	156	358	514	144,546	96,590	394,334	635,470	144,546	96,746	394,692	635,984
Land-use restrictions	0	0	1	1	0	0	0	0	0	0	1	1
Technological restrictions	0	0	0	0	144,546	44,302	98,438	287,287	144,546	44,302	98,438	287,287
Total restrictions	0	0	1	1	144,546	44,302	98,438	287,287	144,546	44,302	98,440	287,288
Available	0	156	357	513	0	52,288	295,895	348,183	0	52,444	296,252	348,696
Economic	0	156	357	513	0	0	295,895	295,895	0	156	296,252	296,408

Curdsville Quadrangle

Resource Category	0–150'				150–1,500'				Thickness Totals			Totals
	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	
Original	133	4,859	124,429	129,421	103,443	34,651	104,328	242,422	103,576	39,510	228,757	371,843
Mined out, surface	0	1,574	30,310	31,883	0	58	790	847	0	1,631	31,099	32,731
Mined out, deep	0	0	2,663	2,663	0	0	0	0	0	0	2,663	2,663
Mined out, total	0	1,574	32,973	34,547	0	58	790	847	0	1,631	33,763	35,394
Remaining	133	3,285	91,456	94,874	103,443	34,594	103,539	241,575	103,576	37,879	194,995	336,449
Land-use restrictions	19	309	10,808	11,136	0	0	0	0	19	309	10,808	11,136
Technological restrictions	0	0	0	0	103,443	9,735	30,431	143,609	103,443	9,735	30,431	143,609
Total restrictions	19	309	10,808	11,136	103,443	9,735	30,431	143,609	103,462	10,044	41,239	154,745
Available	114	2,976	80,648	83,739	0	24,859	73,107	97,966	114	27,835	153,755	181,705
Economic	0	1,151	65,837	66,988	0	0	56,000	56,000	0	1,151	121,837	122,988

Dawson Springs Quadrangle

Resource Category	0–150'				150–1,500'				Thickness Totals			Totals
	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	
Original	1,276	9,133	55,345	65,754	1,074	16,851	32,996	50,921	2,350	25,984	88,341	116,675
Mined out, surface	494	1,213	7,470	9,177	0	5	1	6	494	1,218	7,471	9,183
Mined out, deep	10	1,556	10,158	11,724	7	1,143	14,531	15,680	17	2,698	24,689	27,404
Mined out, total	504	2,769	17,627	20,899	7	1,147	14,532	15,686	511	3,916	32,159	36,586
Remaining	772	6,364	37,718	44,855	1,067	15,704	18,464	35,235	1,839	22,068	56,182	80,090
Land-use restrictions	6	68	5,361	5,435	0	0	0	0	6	68	5,361	5,435
Technological restrictions	0	0	0	0	1,063	614	4,237	5,914	1,063	614	4,237	5,914
Total restrictions	6	68	5,361	5,435	1,063	614	4,237	5,914	1,069	682	9,598	11,349
Available	766	6,296	32,357	39,419	4	15,090	14,227	29,321	770	21,386	46,584	68,740
Economic	152	6,240	32,357	38,749	1	34	14,227	14,263	154	6,274	46,584	53,012

Henderson Quadrangle

Resource Category	0–150'				150–1,500'				Thickness Totals			Totals
	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	
Original	27,182	73,791	56,379	157,353	1,707	3,583	213,653	218,943	28,889	77,374	270,033	376,296
Mined out, surface	0	0	0	0	0	0	0	0	0	0	0	0
Mined out, deep	0	0	11,635	11,635	0	0	31,245	31,245	0	0	42,880	42,880
Mined out, total	0	0	11,635	11,635	0	0	31,245	31,245	0	0	42,880	42,880
Remaining	27,182	73,791	44,745	145,718	1,707	3,583	182,408	187,698	28,889	77,374	227,153	333,415
Land-use restrictions	7,737	19,980	9,354	37,070	0	0	0	0	7,737	19,980	9,354	37,070
Technological restrictions	0	0	0	0	1,707	600	65,827	68,134	1,707	600	65,827	68,134
Total restrictions	7,737	19,980	9,354	37,070	1,707	600	65,827	68,134	9,443	20,580	75,181	105,205
Available	19,445	53,811	35,391	108,648	0	2,983	116,580	119,563	19,445	56,794	151,971	228,211
Economic	0	33,921	17,602	51,523	0	0	60,448	60,448	0	33,921	78,050	111,972

Millport Quadrangle

Resource Category	0–150'				150–1,500'				Thickness Totals			Totals
	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	
Original	10,479	7,695	220,153	238,327	41,136	33,616	444,722	519,474	51,615	41,310	664,875	757,800
Mined out, surface	832	6,295	126,773	133,901	15	0	10,197	10,212	847	6,295	136,970	144,113
Mined out, deep	8	223	28,506	28,738	162	3,276	182,383	185,822	170	3,499	210,890	214,559
Mined out, total	840	6,519	155,279	162,638	177	3,276	192,580	196,033	1,018	9,795	347,860	358,672
Remaining	9,639	1,176	64,874	75,688	40,959	30,340	252,142	323,440	50,597	31,516	317,016	399,129
Land-use restrictions	358	165	34,435	34,958	537	81	12,500	13,118	895	246	46,935	48,077
Technological restrictions	0	0	0	0	34,974	22,521	65,957	123,452	34,974	22,521	65,957	123,452
Total restrictions	358	165	34,435	34,958	35,511	22,602	78,457	136,570	35,869	22,767	112,892	171,529
Available	9,281	1,011	30,439	40,730	5,447	7,738	173,685	186,870	14,728	8,748	204,124	227,600
Economic	9,281	1,011	30,439	40,730	0	2,369	173,685	176,054	9,281	3,380	204,124	216,784

Nebo Quadrangle

Resource Category	0–150'				150–1,500'				Thickness Totals			Totals
	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	
Original	1,663	2,559	44,427	48,649	17,809	19,944	698,090	735,844	19,472	22,504	742,517	784,492
Mined out, surface	718	1,546	10,269	12,533	0	0	5,870	5,870	718	1,546	16,139	18,403
Mined out, deep	0	0	13,352	13,352	0	14	101,333	101,347	0	14	114,685	114,699
Mined out, total	718	1,546	23,621	25,885	0	14	107,203	107,217	718	1,561	130,824	133,102
Remaining	945	1,013	20,805	22,763	17,809	19,930	590,887	628,627	18,754	20,943	611,693	651,390
Land-use restrictions	124	67	7,705	7,896	0	0	0	0	124	67	7,705	7,896
Technological restrictions	0	0	0	0	17,809	16,424	71,007	105,240	17,809	16,424	71,007	105,240
Total restrictions	124	67	7,705	7,896	17,809	16,424	71,007	105,240	17,933	16,491	78,713	113,137
Available	822	946	13,100	14,867	0	3,506	519,880	523,386	822	4,452	532,980	538,254
Economic	0	946	13,100	14,046	0	0	519,880	519,880	0	946	532,980	533,926

Panther Quadrangle

Resource Category	0–150'				150–1,500'				Thickness Totals			Totals
	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	
Original	22,701	3,713	26,545	52,959	47,115	26,192	1,171	74,478	69,817	29,905	27,716	127,437
Mined out, surface	1	2,129	10,641	12,771	0	0	0	0	1	2,129	10,641	12,771
Mined out, deep	0	0	365	365	0	0	0	0	0	0	365	365
Mined out, total	1	2,129	11,006	13,136	0	0	0	0	1	2,129	11,006	13,136
Remaining	22,701	1,583	15,539	39,823	47,115	26,192	1,171	74,478	69,816	27,775	16,710	114,301
Land-use restrictions	2,136	184	272	2,592	0	0	0	0	2,136	184	272	2,592
Technological restrictions	0	0	0	0	47,115	1,722	0	48,837	47,115	1,722	0	48,837
Total restrictions	2,136	184	272	2,592	47,115	1,722	0	48,837	49,251	1,906	272	51,429
Available	20,564	1,399	15,267	37,231	0	24,470	1,171	25,641	20,564	25,870	16,438	62,872
Economic	0	986	10,934	11,920	0	0	0	0	0	986	10,934	11,920

Providence Quadrangle

Resource Category	0–150'				150–1,500'				Thickness Totals			Totals
	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	
Original	2,786	7,269	131,883	141,937	1,929	10,959	156,065	168,954	4,716	18,228	287,948	310,891
Mined out, surface	478	752	37,612	38,842	0	0	1,882	1,882	478	752	39,494	40,725
Mined out, deep	0	93	40,002	40,094	219	2,646	73,802	76,666	219	2,738	113,803	116,760
Mined out, total	478	845	77,613	78,937	219	2,646	75,684	78,548	697	3,491	153,297	157,485
Remaining	2,308	6,423	54,269	63,001	1,711	8,313	80,382	90,406	4,019	14,737	134,651	153,407
Land-use restrictions	554	977	31,165	32,695	0	0	0	0	554	977	31,165	32,695
Technological restrictions	0	0	0	0	1,711	5,651	30,864	38,225	1,711	5,651	30,864	38,225
Total restrictions	554	977	31,165	32,695	1,711	5,651	30,864	38,225	2,264	6,627	62,028	70,920
Available	1,754	5,447	23,105	30,306	0	2,663	49,518	52,181	1,754	8,110	72,623	82,486
Economic	0	5,447	23,105	28,552	0	0	49,518	49,518	0	5,447	72,623	78,069

Robards Quadrangle

Resource Category	0–150'				150–1,500'				Thickness Totals			Totals
	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	
Original	42,106	46,479	49,588	138,173	9,989	4,148	254,629	268,767	52,095	50,628	304,217	406,940
Mined out, surface	0	0	0	0	0	0	0	0	0	0	0	0
Mined out, deep	0	0	296	296	0	0	892	892	0	0	1,188	1,188
Mined out, total	0	0	296	296	0	0	892	892	0	0	1,188	1,188
Remaining	42,106	46,479	49,292	137,877	9,989	4,148	253,738	267,875	52,095	50,628	303,029	405,752
Land-use restrictions	3,535	2,518	4,102	10,155	0	0	0	0	3,535	2,518	4,102	10,155
Technological restrictions	0	0	0	0	9,989	213	14,228	24,430	9,989	213	14,228	24,430
Total restrictions	3,535	2,518	4,102	10,155	9,989	213	14,228	24,430	13,524	2,731	18,330	34,585
Available	38,571	43,961	45,189	127,722	0	3,935	239,510	243,445	38,571	47,897	284,699	371,168
Economic	0	22,553	16,556	39,109	0	0	154,491	154,491	0	22,553	171,047	193,600

Sacramento Quadrangle

Resource Category	0–150'				150–1,500'				Thickness Totals			Totals
	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	
Original	30,727	1,554	792	33,072	181,716	158,368	249,158	589,242	212,443	159,922	249,949	622,314
Mined out, surface	0	49	0	49	0	0	0	0	0	49	0	49
Mined out, deep	0	0	0	0	123	685	24,608	25,416	123	685	24,608	25,416
Mined out, total	0	49	0	49	123	685	24,608	25,416	123	734	24,608	25,465
Remaining	30,727	1,505	792	33,023	181,593	157,683	224,550	563,826	212,320	159,188	225,341	596,849
Land-use restrictions	921	84	141	1,146	933	171	89	1,193	1,854	255	230	2,339
Technological restrictions	0	0	0	0	172,080	38,062	24,974	235,115	172,080	38,062	24,974	235,115
Total restrictions	921	84	141	1,146	173,012	38,233	25,063	236,308	173,934	38,316	25,204	237,454
Available	29,806	1,421	650	31,878	8,581	119,450	199,487	327,518	38,386	120,872	200,137	359,395
Economic	29,804	1,421	650	31,876	0	3,713	1,240	203,200	29,804	5,135	1,891	235,076

Saint Charles Quadrangle

Resource Category	0–150'				150–1,500'				Thickness Totals			Totals
	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	
Original	65	8,832	152,361	161,258	204	38,773	124,897	163,874	269	47,606	277,258	325,132
Mined out, surface	0	492	51,165	51,657	0	0	0	0	0	492	51,165	51,657
Mined out, deep	0	113	19,723	19,835	86	1,169	16,098	17,352	86	1,282	35,821	37,188
Mined out, total	0	605	70,821	71,426	86	1,169	16,098	17,352	86	1,774	86,919	88,779
Remaining	65	8,228	81,539	89,832	119	37,604	108,799	146,522	184	45,832	190,338	263,354
Land-use restrictions	0	279	4,769	5,048	0	0	0	0	0	279	4,769	5,048
Technological restrictions	0	0	0	0	118	490	6,898	7,506	118	490	6,898	7,506
Total restrictions	0	279	4,769	5,048	118	490	6,898	7,506	118	770	11,666	12,554
Available	65	7,948	76,771	84,784	1	37,114	101,901	139,016	66	45,062	178,672	223,800
Economic	1	7,824	76,771	84,596	1	281	101,901	102,183	1	8,105	178,672	186,778

Sturgis Quadrangle

Resource Category	0–150'				150–1,500'				Thickness Totals			Totals
	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	
Original	4,633	16,953	34,832	56,418	96,924	160,679	212,888	470,491	101,557	177,632	247,720	526,909
Mined out, surface	294	576	7,630	8,502	0	0	0	0	294	578	7,630	8,502
Mined out, deep	0	599	12,831	13,430	135	2,547	56,789	59,470	135	3,146	69,619	72,900
Mined out, total	294	1,177	20,461	21,932	135	2,547	56,789	59,470	428	3,724	77,250	81,402
Remaining	4,339	15,776	14,371	34,486	96,789	158,132	156,100	411,021	101,129	173,908	170,470	445,507
Land-use restrictions	1,766	4,770	10,073	16,608	0	0	0	0	1,766	4,770	10,073	16,608
Technological restrictions	0	0	0	0	96,789	53,063	21,603	171,456	96,789	53,063	21,603	171,456
Total restrictions	1,766	4,770	10,073	16,608	96,789	53,063	21,603	171,456	98,555	57,833	31,676	188,064
Available	2,574	11,006	4,298	17,878	0	105,069	134,497	239,566	2,574	116,075	138,794	257,443
Economic	0	11,006	4,298	15,304	0	0	134,497	134,497	0	11,006	138,794	149,801

Sutherland Quadrangle

Resource Category	0–150'				150–1,500'				Thickness Totals			Totals
	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	Total	14–28"	28–42"	> 42"	
Original	18,575	1,954	1,227	21,756	74	0	0	74	18,649	1,954	1,227	21,830
Mined out, surface	223	0	0	223	0	0	0	0	223	0	0	223
Mined out, deep	0	0	0	0	0	0	0	0	0	0	0	0
Mined out, total	223	0	0	223	0	0	0	0	223	0	0	223
Remaining	18,352	1,954	1,227	21,533	74	0	0	74	18,426	1,954	1,227	21,608
Land-use restrictions	3,304	780	254	4,337	0	0	0	0	3,304	780	254	4,337
Technological restrictions	0	0	0	0	74	0	0	74	74	0	0	74
Total restrictions	3,304	780	254	4,337	74	0	0	74	3,378	780	254	4,412
Available	15,048	1,175	973	17,196	0	0	0	0	15,048	1,175	973	17,196
Economic	0	820	689	1,508	0	0	0	0	0	820	689	1,508