Kentucky Geological Survey
Donald C. Haney, State Geologist and Director
University of Kentucky, Lexington

Tar-Sand Resources of Western Kentucky

Martin C. Noger

Reprinted from the 1984 Eastern Oil Shale Symposium, November 26–28, 1984, sponsored by the University of Kentucky Institute for Mining and Minerals Research and the Kentucky Energy Cabinet.

Reprint 45

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Mission Statement

The Kentucky Geological Survey at the University of Kentucky is a State-mandated organization whose mission is the collection, preservation, and dissemination of information about mineral and water resources and the geology of the Commonwealth. KGS has conducted research on the geology and mineral resources of Kentucky for more than 150 years, and has developed extensive public databases for oil and natural gas, coal, water, and industrial minerals that are used by thousands of citizens each year. The Survey's efforts have resulted in topographic and geologic map coverage for Kentucky that has not been matched by any other state in the Nation.

One of the major goals of the Kentucky Geological Survey is to make the results of basic and applied research easily accessible to the public. This is accomplished through the publication of both technical and nontechnical reports and maps, as well as providing information through open-file reports and public databases.

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TAR-SAND RESOURCES OF WESTERN KENTUCKY

Martin C. Noger

Abstract

Tar-sand deposits in western Kentucky have been recognized as a potentially significant mineral resource since the middle of the 19th century. Deposits of bitumen-bearing Late Mississippian and Early Pennsylvanian sandstones have been reported both at the surface and in the subsurface for a distance of approximately 100 miles along the southeastern rim of the Eastern Interior Basin.

Prior to 1981, published studies of western Kentucky tar-sand deposits had concentrated on the outcrop areas where bitumen-bearing sandstones were present at or near the surface. In-place oil resources were estimated at less than 50 million barrels (MMbbl). Reports that delineated subsurface occurrences of asphaltic sandstones in western Kentucky were not available.

In 1981 the Kentucky Geological Survey initiated a project to inventory and evaluate the oil-resource potential of the asphaltic sandstones in the subsurface of western Kentucky. A preliminary report on the Big Clifty (Late Mississippian) was published in 1982.

In 1982 this project was combined with the Interstate Oil Compact Commission's (IOCC) project to catalog and evaluate the tar-sand-resource potential of the United States. Results of investigations by the Kentucky Geological Survey, in conjunction with Lewin and Associates, who were selected to compile the IOCC report, have confirmed that major tar-sand resources are present in western Kentucky. In-place resources are calculated to be in excess of 3 billion barrels (Bbbl).

Geologic Setting of Tar-Sand Occurrences

Tar-sand deposits in western Kentucky occur along the southeastern rim of the Eastern Interior Basin and dip approximately 30 to 50 feet per mile (ft/mi) to the north, northwest, and west into the basin. Regional structure is modified by east–west-trending faults (Fig. 1).

The principal stratigraphic units that contain tar-sand deposits (also referred to as asphaltic sandstones, heavy-oil deposits, or bitumen-impregnated sandstones) are the Kyrock and Bee Spring Sandstones of Early Pennsylvanian age and the Tar Springs, Hardinsburg, and Big Clifty Sandstones of Late Mississippian age (Fig. 2).

No single geological control will adequately explain the localization of all the Kentucky deposits (McGrain, 1976; McGrain and Ponsetto, 1981). In northern Logan County, northern Warren County, northern Grayson County, and elsewhere, the proximity of deposits to known faults suggests structural control and orientation. Locations of some surface deposits in Edmonson County appear to be related to a deep sandstone-filled paleovalley. Other deposits can be explained only as stratigraphic traps or local porous zones in the enclosing rock. Much detailed subsurface information is needed to provide the answers.

There is a diversity of opinion regarding the source of hydrocarbons that formed the bitumen in the sandstones. Some writers (Russell, 1933; Sedimentation Seminar, 1978) have concluded that the marine shales of Late Mississippian age were the source of the oil from which the asphalt-like material was produced, whereas Walters (1974) suggested that the source was the deeper Devonian-age Chattanooga Shale.

Resource Evaluations and Geologic Aspects

Prior to 1981, published studies (U.S. Army Corps of Engineers, 1951; Ball Associates, Ltd., 1965) had concentrated on outcrop areas where bitumen-bearing sandstones were present at or near the surface. In-place oil resources were estimated at about 50 million barrels (MMbbl). Reports that delineated subsurface occurrences of asphaltic sandstones in western Kentucky were not available.

In 1981 the Kentucky Geological Survey initiated a project to inventory and evaluate the oil-resource potential of asphaltic sandstones in the subsurface of western Kentucky. A preliminary report (Williams and others, 1982) on the Big Clifty Sandstone (Late Mississippian) was published.

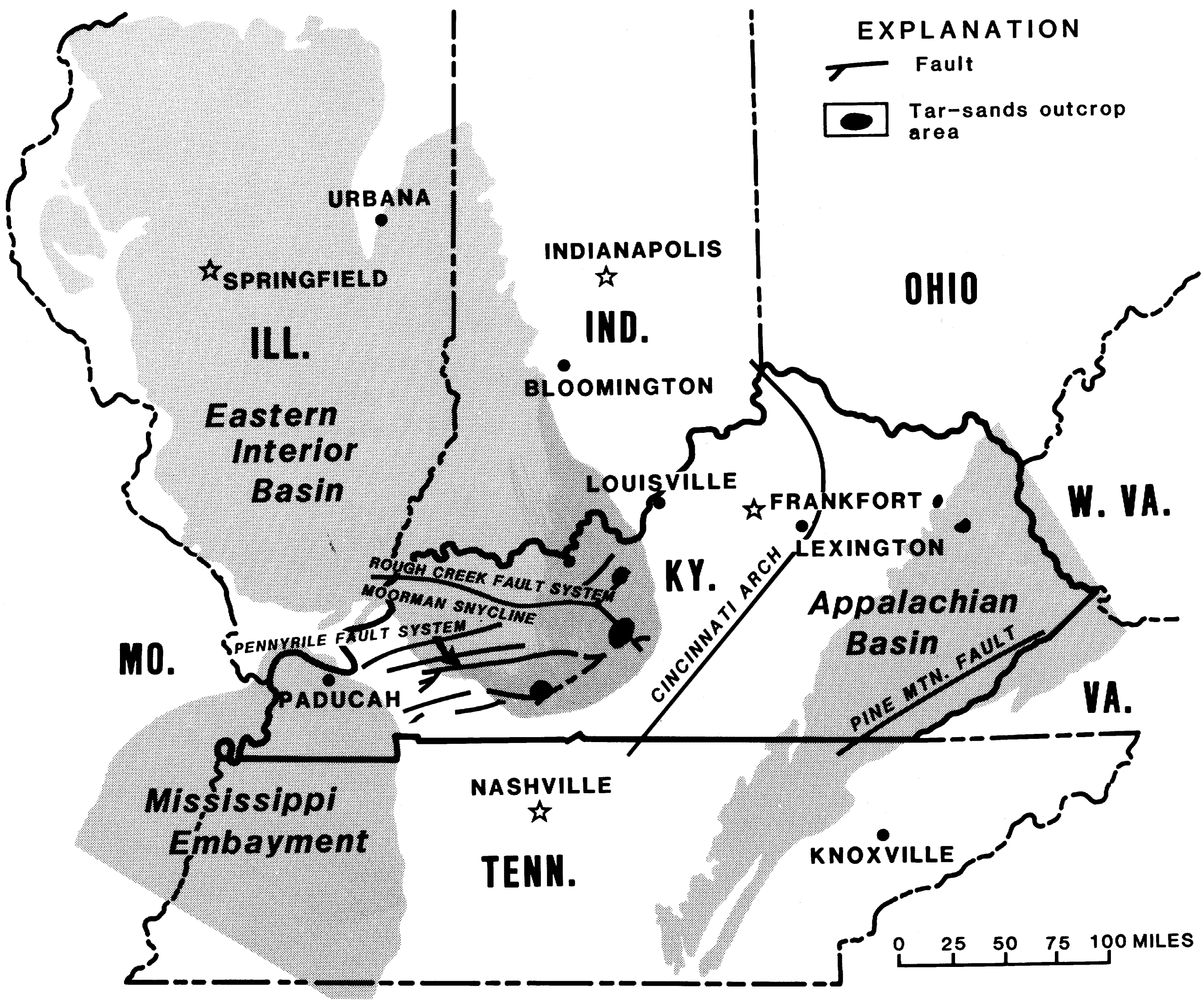


Figure 1. Regional surface tectonic features and areas of tar-sand outcrop in Kentucky.

In 1982 this project was combined with the Interstate Oil Compact Commission's (IOCC) study to catalog and evaluate the tar-sand and heavy-oil resources of the United States. Results of the investigations by the Kentucky Geological Survey, in conjunction with Lewin and Associates, who were selected to compile the IOCC report (IOCC, 1984), have confirmed that major tar-sand resources are present in western Kentucky. In-place resources for tar-bearing sandstones are calculated to be 3.4 billion barrels (Bbbl).

Resource assessment includes two categories: measured and speculative. Measured resource is defined as that part of the resource that can be deduced to exist from well control, primarily using core analyses. Speculative resource is defined as that part of the resource that is presumed to exist from reported tar shows on drillers' logs, occasional core analyses, and geological interpretations (IOCC, 1984).

Resource evaluations and geologic aspects of the individual asphaltic sandstones of western Kentucky are discussed in the following sections, starting with the oldest, the Big Clifty Sandstone of Late Mississippian age.

Big Clifty Sandstone Member of the Golconda Formation

The Big Clifty Sandstone Member of the Golconda Formation consists predominantly of sandstone with variable amounts of shale, siltstone, and minor amounts of limestone. The composite thickness of the unit may be as great as 100 feet (ft). The sandstone facies ranges from very fine to medium; fine-grained sandstone predominates. The sandstone is thin to massive bedded, with some crossbedding and thin, ripple-bedded sandstones near the top of the unit. Outcrop

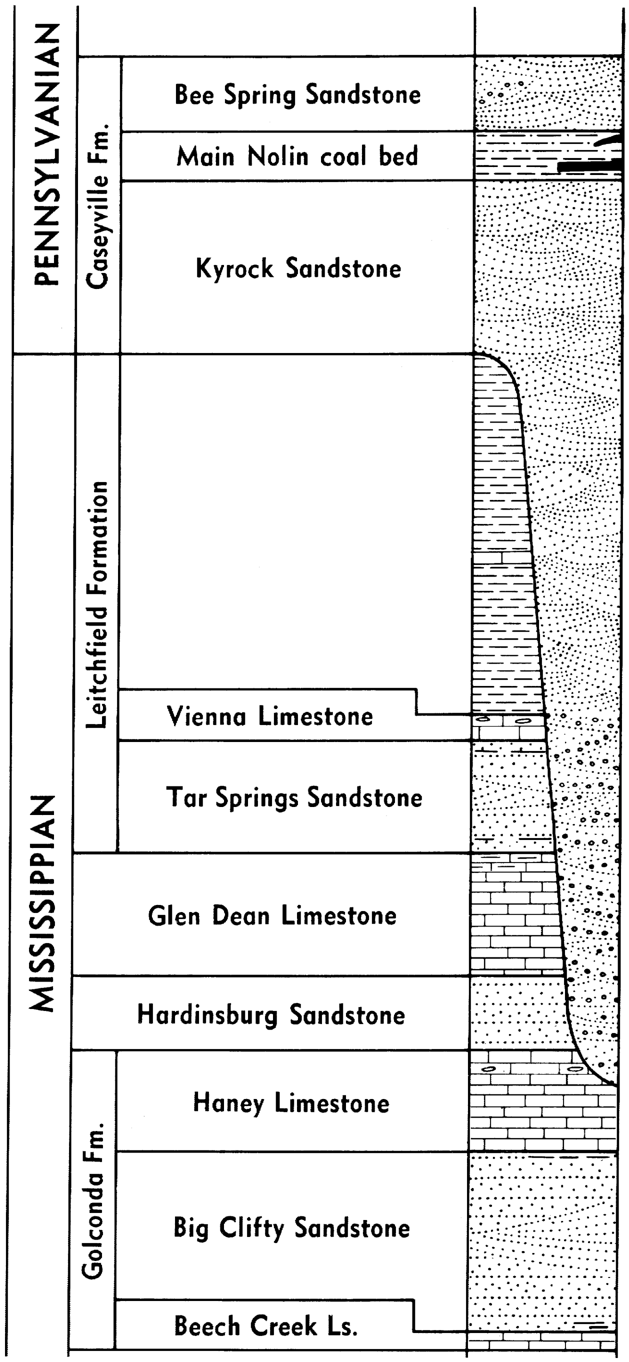


Figure 2. Generalized columnar section showing principal tar-sand units in western Kentucky. From McGrain, 1976.

area of the Big Clifty Sandstone and location of quarries and surface exposures of asphaltic sandstones in the Big Clifty shown on some of the following illustrations were compiled from 1:24,000-scale geologic quadrangle maps (Williams and others, 1982).

An isopach map of bitumen-impregnated sandstones in the Big Clifty indicates a northeast–southwest trend of thicker sand bodies (Fig. 3). The geometric configuration of one of these sand bodies is delineated on stratigraphic cross section A–A' (Fig. 4). Where the sandstone facies is thin or absent, the Big Clifty consists of shale and siltstone. A sequence of green shale and siltstone generally overlies the sandstone, but is absent in some areas, and the sandstone facies directly underlies the Haney Limestone Member of the Golconda Formation (Fig. 2). The Big Clifty Sandstone Member overlies the Beech Creek Limestone Member of the Golconda Formation. A sequence of black shale generally underlies the sandstone facies, but is absent in some areas where sandstone exceeds 60 ft in thickness. The local absence of the basal shale may be the result of scouring.

A preliminary interpretation based on stratigraphic studies of 26 cores in Edmonson County, other surface and subsurface information, and published literature (Potter, 1967) suggests a near-shore, shallow-marine depositional environment for the Big Clifty Sandstone. Geological data supporting this interpretation are the conformable contacts with the overlying and underlying limestones; the presence of marine benthonic fossils along with some terrestrial plant fossils in the shales, siltstones, and sandstones (Weller, 1927); and occurrences of limestone lenses within the Big Clifty sandstones. Near-shore deposition is also suggested by the presence in some areas of a coaly, carbonaceous shale above the Big Clifty Sandstone. A characteristic feature of the near-shore marine environment would be sandstone bars, or remnants of bars, separated by finer grained deposits. Although preliminary information indicates that such features may occur within the Big Clifty, available data are insufficient to make a definitive interpretation of the environment of deposition (Williams and others, 1982).

The major structural features of the tar-sand study area in Butler, Edmonson, Grayson, Logan, and Warren Counties are the Pennyrile Fault System and an unnamed fault system to the south. Faults that are part of the eastern end of the Rough Creek Fault System are present in the northeastern corner of the study area in Grayson and Hart Counties (Fig. 1). The Pennyrile Fault System (Schwalb, 1975) extends eastward across southern Butler County and into Warren and Edmonson Counties. The unnamed fault system south of the Pennyrile Fault System extends across northern Logan and Warren Counties. This unnamed system trends generally northeastward, and it appears to merge with the Pennyrile system in northeastern Warren County. The merged systems may intersect the Rough Creek system in southeastern Grayson and northwestern Hart Counties.

Surface geologic maps, published at a scale of 1:24,000 by the U.S. Geological Survey in cooperation with the Kentucky Geological Survey, indicate that faults in the Pennyrile Fault System and in the unnamed system to the south are en

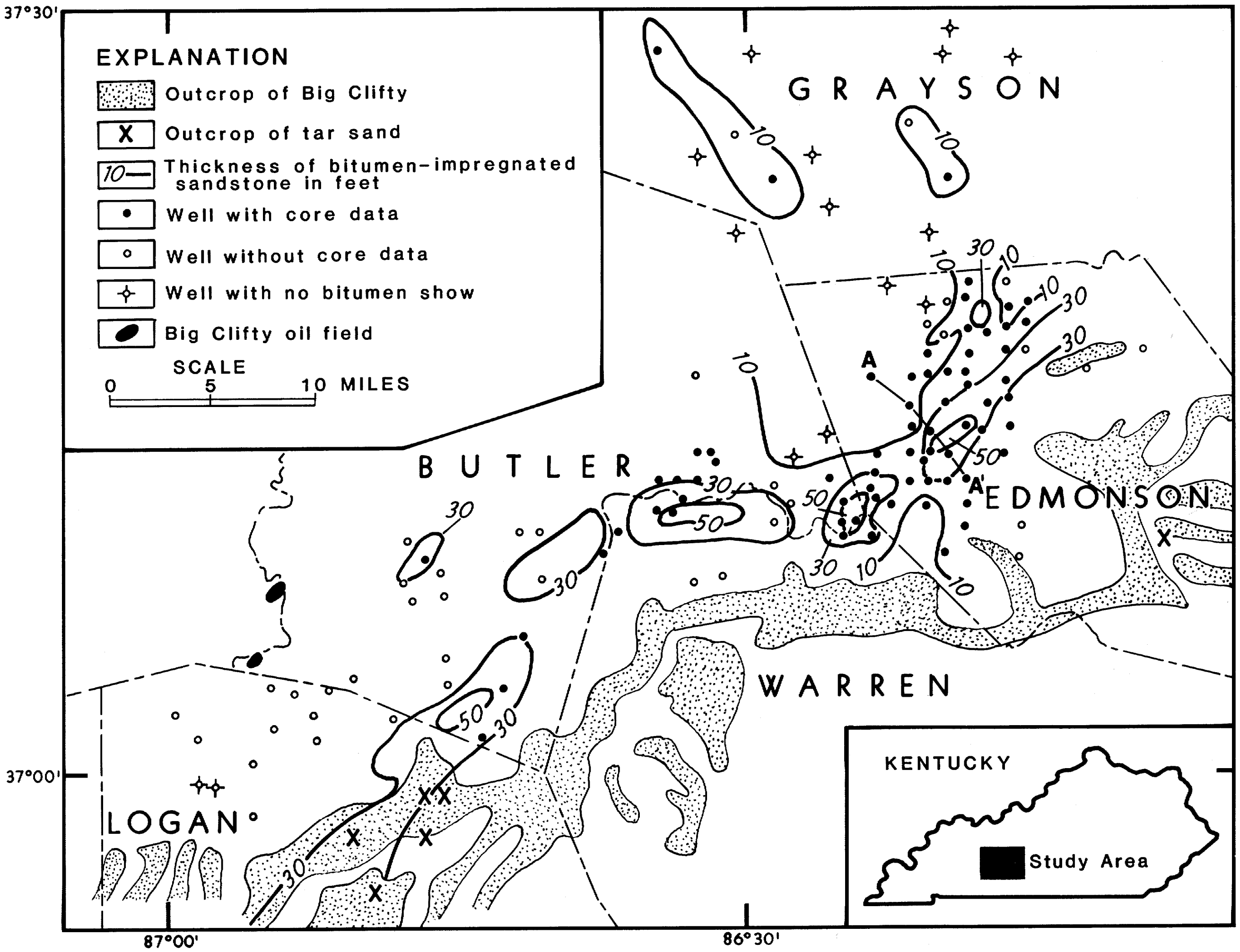


Figure 3. Isopach map of bitumen-impregnated sandstone in the Big Clifty Sandstone Member of the Golconda Formation, Butler, Edmonson, Grayson, Logan, and Warren Counties, Kentucky.

echelon in some areas and bifurcating in others. In the study area, relative fault displacement in both systems is predominantly down to the north. All faults appear to be high angle, and normal, with throws of about 100 ft or less.

Structure contours on top of the Beech Creek Limestone Member of the Golconda Formation (Fig. 2) indicate that the unit is more than 600 ft above sea level in northern Logan County and about 1,000 ft below sea level in northwestern Butler County, a difference of about 1,600 ft (Fig. 5). Surface geologic maps indicate a regional dip of 30 to 50 ft/mi, suggesting that about one-third of the structural difference in elevation is probably due to faulting.

The structural configuration of other tar-sand deposits (Fig. 2) of Late Mississippian and Early Pennsylvanian ages in Butler, Edmonson, Grayson, Logan, and Warren Counties appears to conform to the structural pattern on top of the Beech Creek Limestone.

Measured and speculative resource areas of the Big Clifty Sandstone were outlined using data from core holes, drillers' logs, outcrops of tar sand, and geological interpretations of the thickness of bitumen-impregnated sandstones (Figs. 6–7). Area outlines are generally extrapolated one section out from the nearest well.

Well data consisting of 70 core analyses, more than 50 outcrop samples from industrial sources, and 15 drillers' logs were used to determine the boundaries of areas of measured resource. In addition, three core analyses from industrial sources, more than 50 drillers' logs, outcrops of bitumen-impregnated sandstone, and outcrop areas were used to establish the boundaries of speculative areas.

Average reservoir properties for the Big Clifty are: porosity, 15 percent; permeability, 100 millidarcys; oil saturation, 45 percent; depths, 0 to 600 ft. Oil gravity is 10° API.

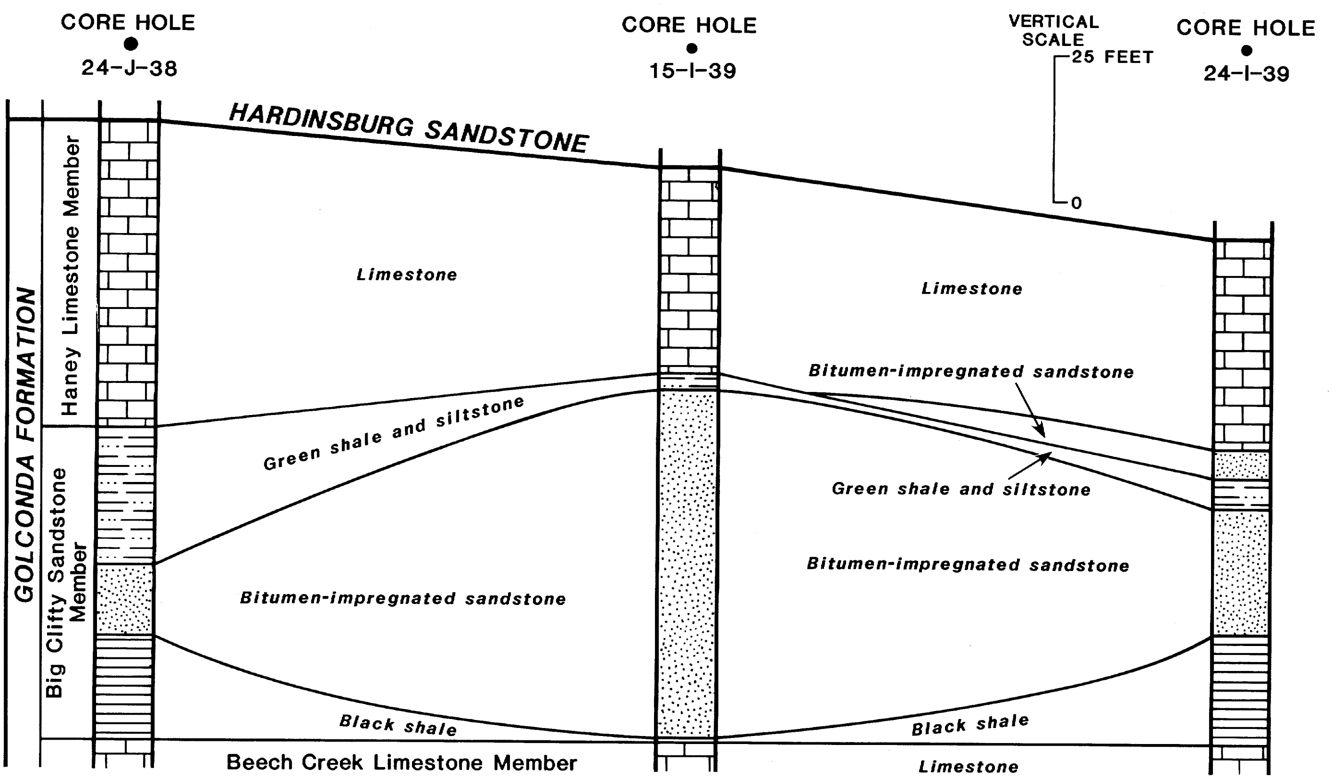


Figure 4. Stratigraphic cross section of the Big Clifty Sandstone Member of the Golconda Formation, Edmonson County, Kentucky. No horizontal scale.

Boundaries for richness categories measured in barrels per acre for in-place resources of measured and speculative areas of the Big Clifty Sandstone are delineated on Figures 8 and 9.

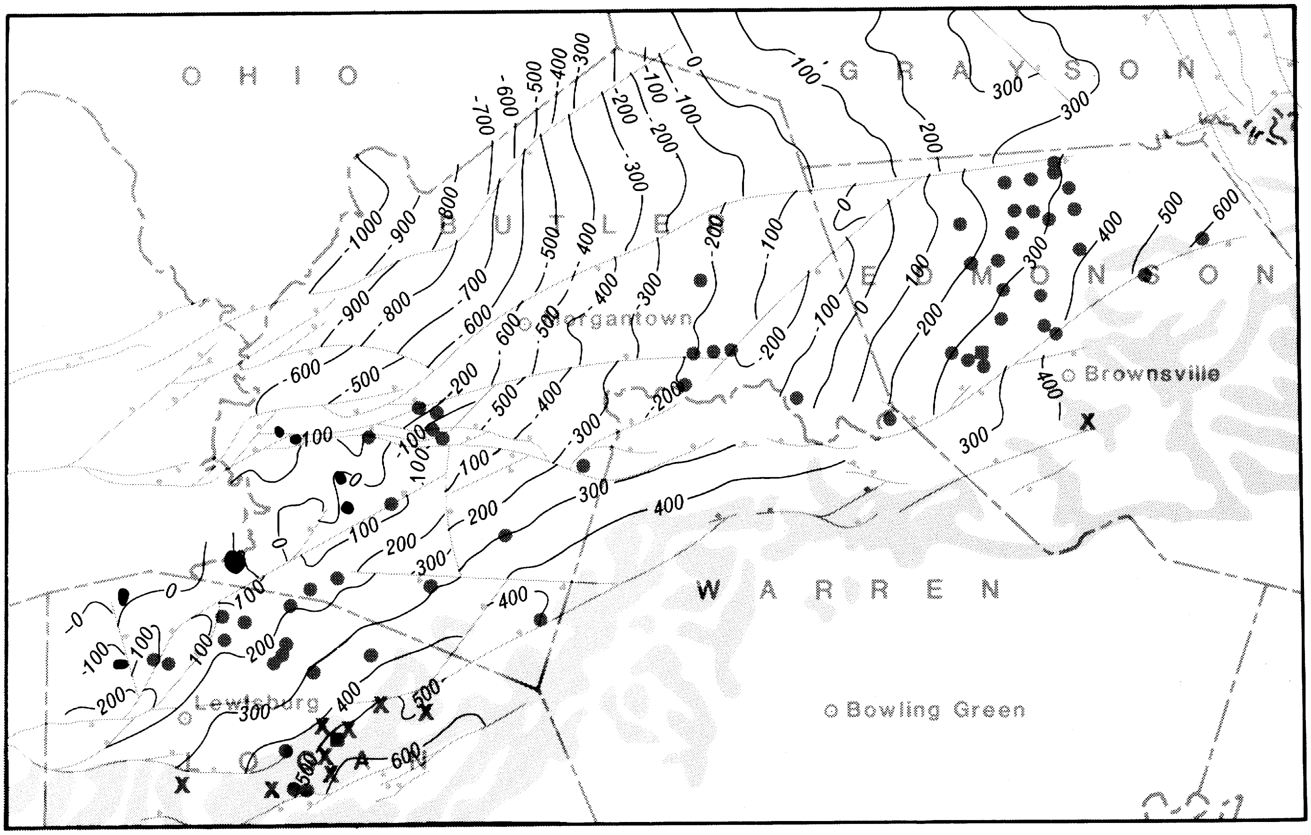
In-place resource assessments for the measured and speculative areas of the Big Clifty Sandstone and other tar-sand deposits were derived in the following manner. In general, the value of the barrels per acre (B/A) assumed for each area of richness is 40 percent of the difference between the richness categories that define an area. For example, when calculating the resource in-place for an area falling between the richness category outlines for 0 B/A and 10,000 B/A, the assumed average for the area would be 40 percent of 10,000 B/A, or 4,000 B/A. The values used for the richness areas not falling between categories are full original designations. In certain areas, a subjective evaluation, based on core, results in a higher or lower assumed B/A value. For example, core data in the Bee Spring Area (Fig. 8) show that the area within the 20,000 B/A richness category generally contains more oil than 20,000 B/A (Table 1). Thus, the B/A value used in determining the in-place resource has been increased by 4,000 B/A.

The acreage of an area was determined by the number of sections multiplied by 625 acres. Kentucky sections based on the Carter coordinate system, which is determined from longitude and latitude lines, contain about 660 acres. The acreage within a richness category multiplied by the barrels per acre equals the resource in-place.

The Bee Spring-Brownsville Area, encompassing about 67,000 acres, contains the largest measured in-place resource of 520 MMbbl (Table 1). The Cooperstown-Gasper Area, covering 43,000 acres, contains 390 MMbbl. The Riverside Area, encompassing 14,500 acres, contains 160 MMbbl. The Dimple Area, which covers 1,900 acres, contains 120 MMbbl. The total in-place measured resource has an areal extent of about 144,000 acres and contains about 1.2 Bbbl.

The Main Area, with an areal extent of 150,000 acres, has the largest speculative in-place resource of 685 MMbbl (Table 2). The Welchs Creek Area, covering 13,000 acres, contains 65 MMbbl. The Shrewsbury Area, covering 10,000 acres, contains 40 MMbbl. The Nolin Area, covering 5,500 acres, contains 20 MMbbl. The West Short Creek and McDaniels-Outcrop Areas, encompassing 6,000 and 17,000 acres, contain 30 and 70 MMbbl, respectively. The total in-place speculative resource, covering about 200,000 acres, contains about 910 MMbbl.

The total in-place resource for the Big Clifty from measured (1,190 MMbbl) and speculative (910 MMbbl) areas is calculated to be about 2.1 Bbbl.



EXPLANATION

800	Structure contour	X	Outcrop of tar sand
	Fault. Ball on downthrown side		Outcrop area of Big Clifty Sandstone
	Test hole which encountered asphaltic sandstone		Oil or gas field producing from Big Clifty

Figure 5. Preliminary structure map on top of the Beech Creek Limestone.

Hardinsburg Sandstone

The Hardinsburg Sandstone of Late Mississippian age consists of sandstone and shale. The composite thickness of the unit is about 60 ft. The sandstone facies ranges from 0 to 40 ft in thickness. Grain size of the sandstone facies is very fine. The sandstone is thin to thick bedded, with occasional crossbeds. The shales are green and red.

Sandstone bodies of the Hardinsburg appear to be the product of terrigenous detrital deposition of westward- and southward-prograding deltaic systems (IOCC, 1984).

An isopach map of bitumen-impregnated sandstone in the Hardinsburg Sandstone indicates a northeast–southwest trend of thicker sand bodies (Fig. 10). The bodies generally coincide with areas of thicker sand bodies of Big Clifty Sandstone (Fig. 3). In some of the area, the Hardinsburg consists entirely of sandstone. In areas where the sandstone facies is thin or absent, the unit consists of red and green shale. Channeling during the Early Pennsylvanian eroded the Hardinsburg in parts of Edmonson and Butler Counties (Fig. 10).

Measured and speculative resource areas of the Hardinsburg are outlined on Figures 11 and 12. Data from 30 core analyses, 20 drillers' logs, outcrops of tar sand, and geological interpretations of the thickness of asphaltic sandstone determined the boundaries of the areas of measured resource (Fig. 11).

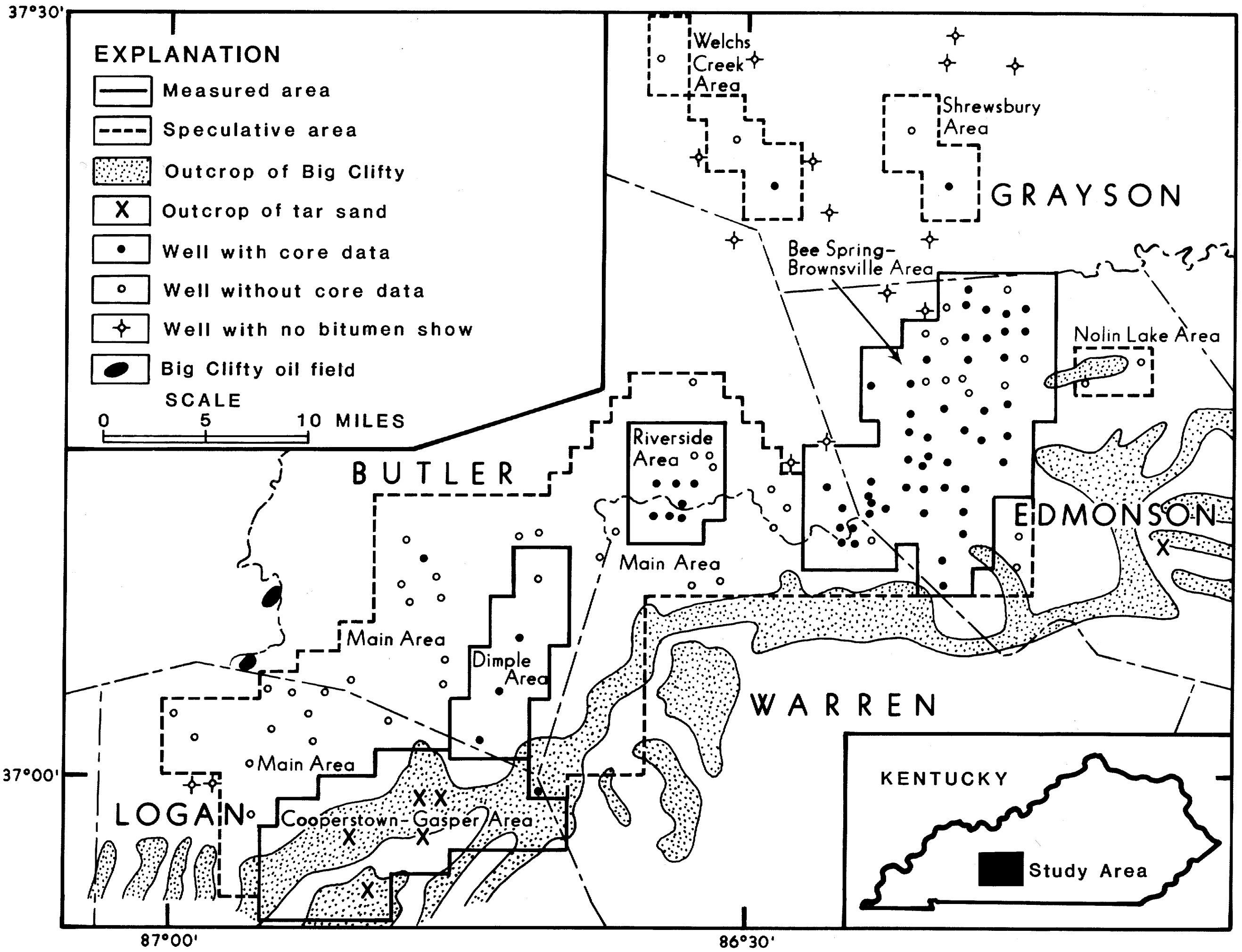


Figure 6. Outline of resource areas in the Big Clifty Sandstone Member of the Golconda Formation, Butler, Edmonson, Grayson, Logan, and Warren Counties, Kentucky. From IOCC (1984). Reprinted, by permission, from the Interstate Oil and Gas Compact Commission (IOGCC).

The boundaries of the speculative areas were established by data from one core analysis, about 15 drillers' logs, outcrops of tar sand, outcrop area, and geological interpretation of the thickness of bitumen-impregnated sandstone. The boundaries of the two speculative areas (Fig. 12) in northern Grayson and southwestern Breckinridge Counties are based on reported shows of tar sand on drillers' logs.

Key reservoir properties for the Hardinsburg are: porosity, 14 percent; permeability, 10 to 400 millidarcys; oil saturation, 40 to 70 percent; depth, 125 to 440 ft. Oil gravity is 10° API.

The boundaries for richness categories measured in barrels per acre for in-place resources for measured and speculative areas of the Hardinsburg Sandstone are delineated on Figures 13 and 14.

The Bee Spring-Brownsville Area, with an areal extent of 44,000 acres, contains the largest measured in-place resource of 180 MMbbl (Table 3). The Riverside Area, covering about 10,000 acres, contains 40 MMbbl, and the Dimple Area, encompassing about 12,000 acres, contains 30 MMbbl. The in-place measured resource has an areal extent of 66,000 acres and contains an estimated 250 MMbbl.

The Main Area, covering about 73,000 acres, has the largest speculative in-place resource of 150 MMbbl (Table 4). The Nolin Lake Area, covering 2,500 acres, contains 5 MMbbl. The West Short Creek and East Fordsville Areas, covering 8,000 and 4,500 acres, contain an estimated 15 and 10 MMbbl, respectively. The total in-place speculative resource, covering about 88,000 acres, is calculated to be 180 MMbbl.

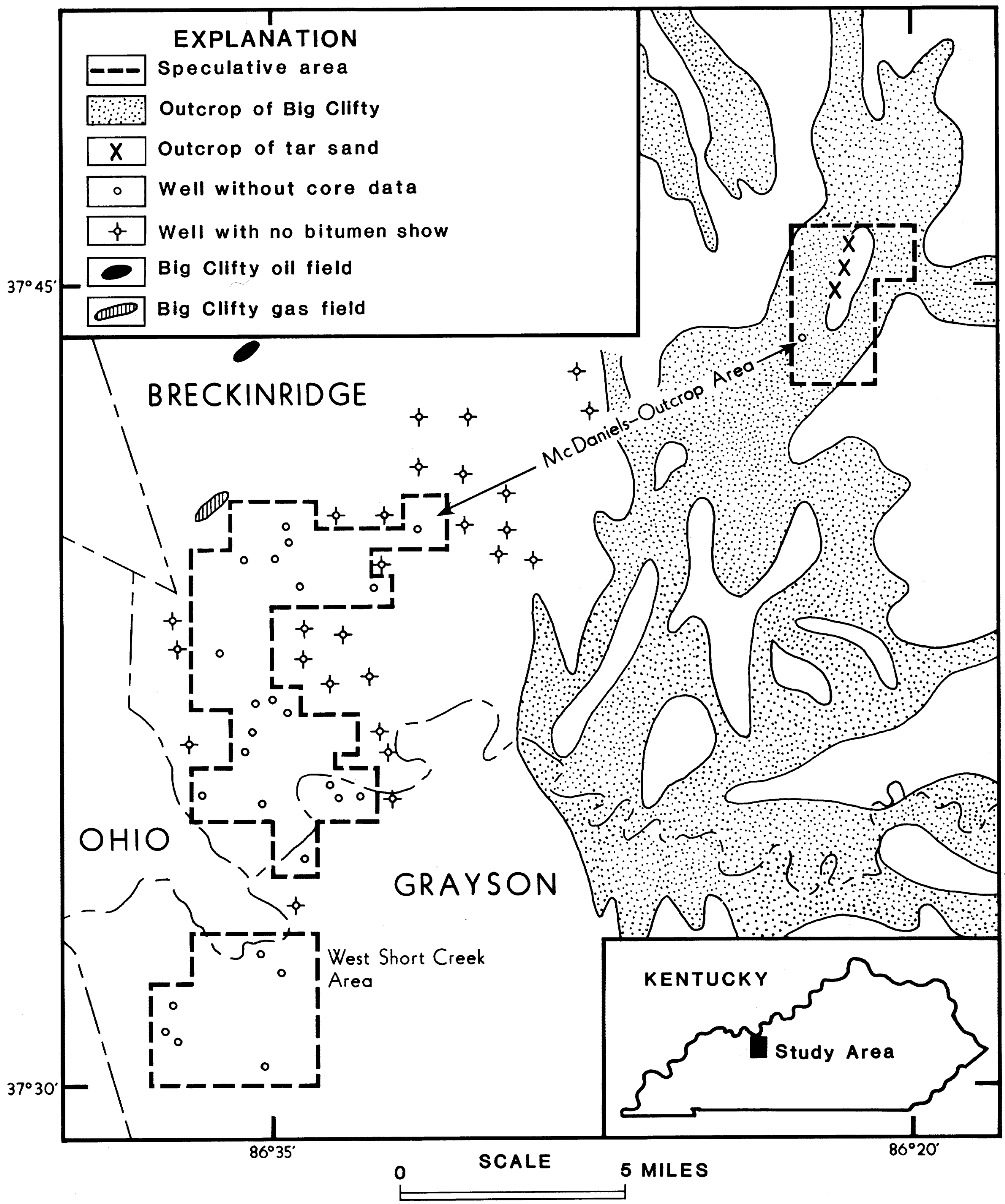


Figure 7. Outline of resource areas in the Big Clifty Sandstone Member of the Golconda Formation, Breckinridge, Grayson, and Ohio Counties, Kentucky. From IOCC (1984). Reprinted, by permission, from the IOGCC.

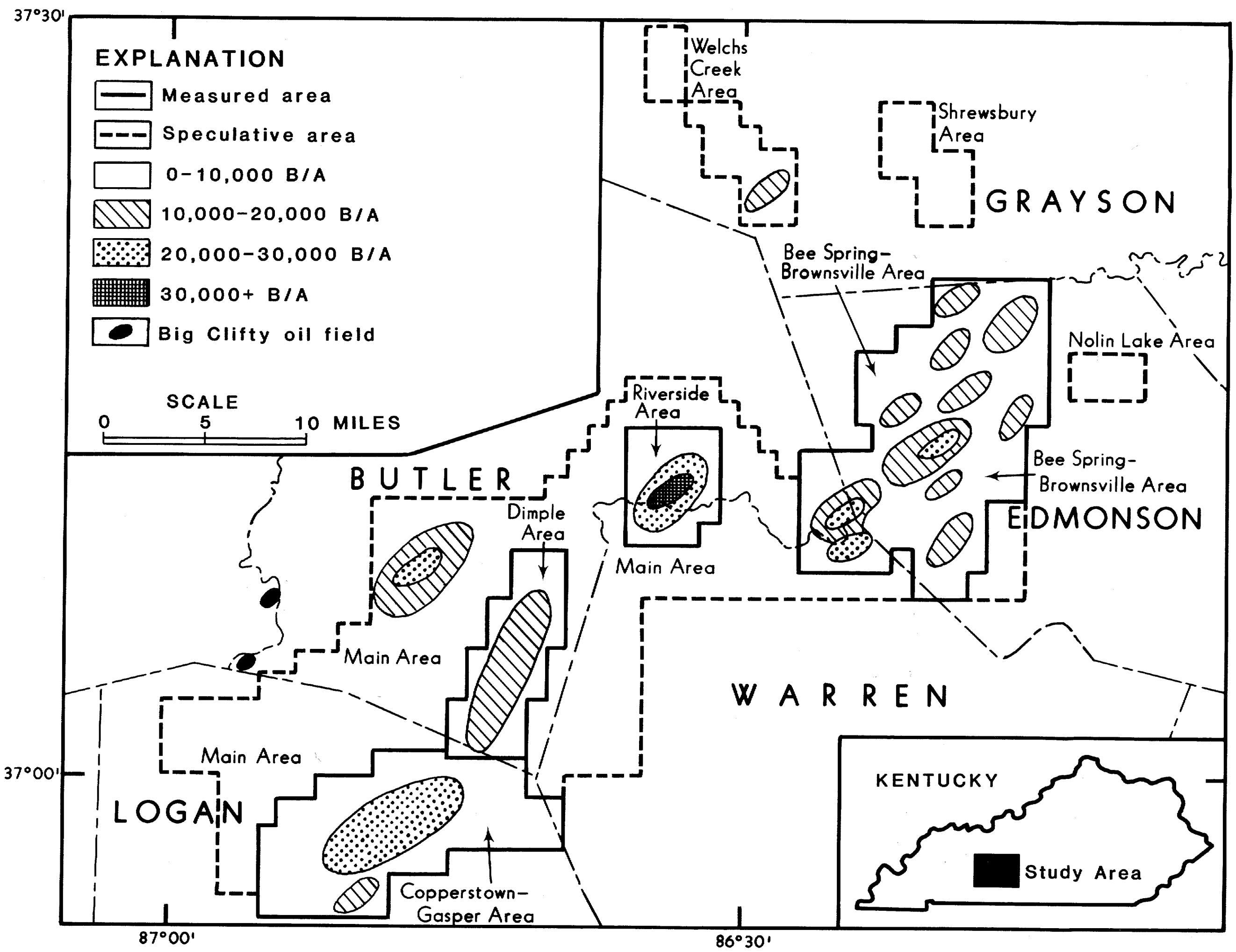


Figure 8. Resource-richness map of the Big Clifty Sandstone Member of the Golconda Formation, Butler, Edmonson, Grayson, Logan, and Warren Counties, Kentucky. From IOCC (1984). Reprinted, by permission, from the IOGCC.

Tar Springs Sandstone of the Leitchfield Formation

The Tar Springs Sandstone of the Leitchfield Formation consists predominantly of sandstone and shale. The sandstone facies is about 60 ft thick in Breckinridge County, where it crops out as cliff-forming sandstone. The Tar Springs is characterized by rapid lateral facies changes from sandstone to shale. Grain size varies from coarse to fine to medium. Shales are medium gray to black.

Tar Springs sandstones appear to have originated from terrigenous detrital deposits, which were deposited by a southward- and southwestward-prograding delta (IOCC, 1984). A near-shore barrier-island depositional environment has been suggested for the Tar Springs in Breckinridge County (Neeley, 1982).

The speculative resource area of the Tar Springs Sandstone in Breckinridge County was outlined using data from more than 30 drillers' logs (Fig. 15). The speculative area in Butler County was outlined using data from 19 drillers' logs and three cable tool cores (Fig. 16). No areas were considered to be in the measured category because of the paucity of core analyses.

The Breckinridge and Dimple Areas were considered to have similar reservoir characteristics, based on data from core analyses of the three cable tool cores from the Dimple Area. Average reservoir properties for the Tar Springs Sandstone are: porosity, 20 percent; permeability, 100 millidarcys; oil saturation, 25 percent; oil gravity, 14 to 17° API. However, the above reservoir properties may be too low for the Breckinridge Area. A recently acquired analysis of a core from the

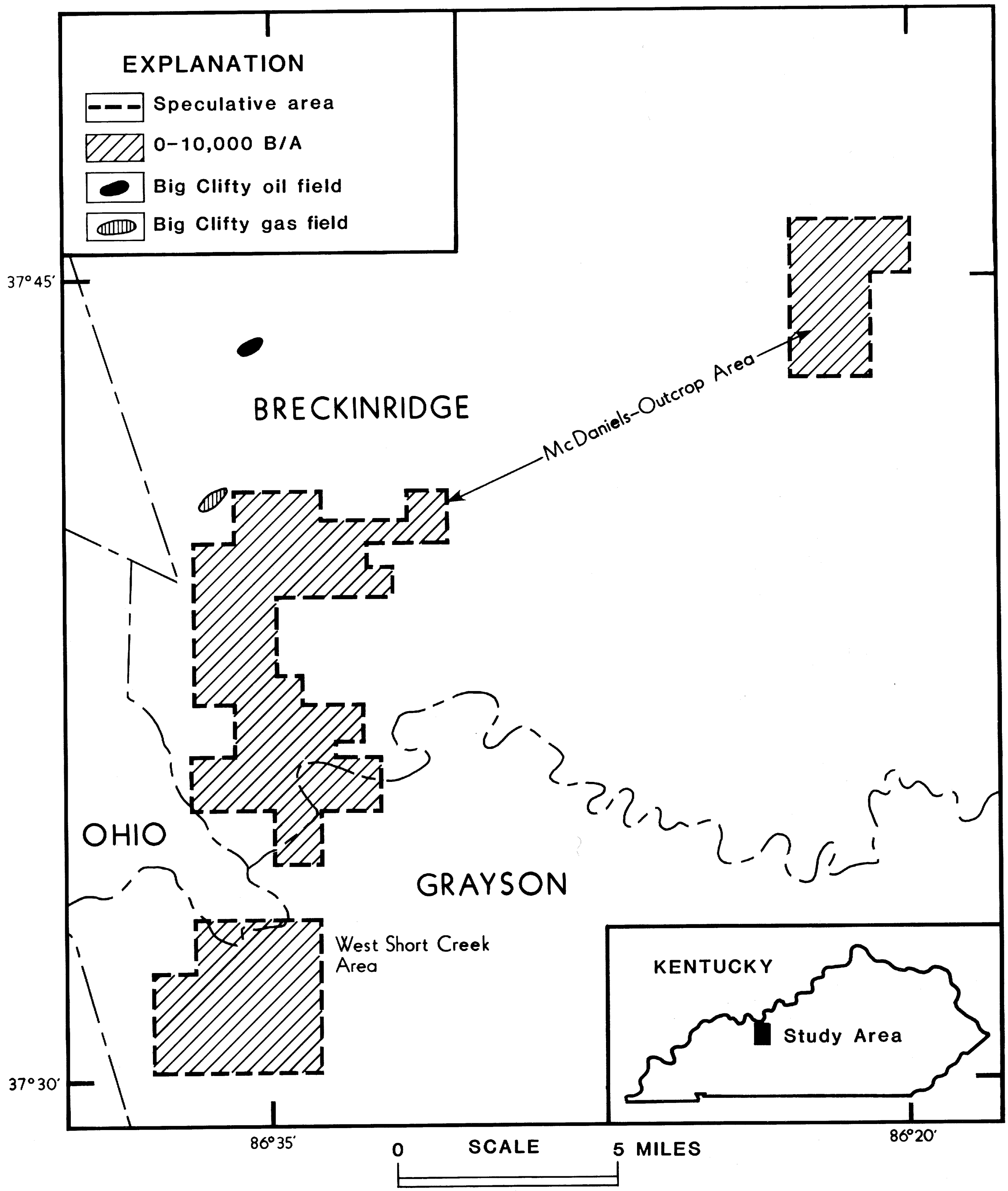


Figure 9. Resource-richness map of the Big Clifty Sandstone Member of the Golconda Formation, Breckinridge, Grayson, and Ohio Counties, Kentucky. From IOCC (1984). Reprinted, by permission, from the IOGCC.

Table 1. Measured in-place resource of the Big Clifty Sandstone. From IOCC (1984). Reprinted, by permission, from the IOGCC.

Resource-Richness Category	*Barrels per Acre-Foot (average)*	*Net Pay, Feet (average)*	*Barrels per Acre (average)*	*Areal Extent (average)*	*In-Place Resource (MMbbl)*
Cooperstown-Gasper Area					
20,000 + B/A	750	26	22,000	10,000	220
10,000–20,000 B/A	520	20	10,000	1,250	10
0–10,000 B/A	350	14	5,000	32,000	160
Bee Spring-Brownsville Area					
20,000 + B/A	600	40	24,000	3,000	70
10,000–20,000 B/A	560	25	14,000	14,000	200
0–10,000 B/A	500	10	5,000	50,000	250
Riverside Area					
30,000 B/A	700	43	30,000	2,500	75
10,000–30,000 B/A	500	35	18,000	2,500	45
0–10,000 B/A	400	10	4,000	9,500	40
Dimple Area					
10,000 B/A	400	26	10,000	8,000	80
0–10,000 B/A	100	40	4,000	11,000	40
			Total measured in-place resource	143,750	1,190

Table 2. Speculative in-place resource of the Big Clifty Sandstone. From IOCC (1984). Reprinted, by permission, from IOGCC.

Resource-Richness Category	*Barrels per Acre-Foot (average)*	*Net Pay, Feet (average)*	*Barrels per Acre (average)*	*Areal Extent (acres)*	*In-Place Resource (MMbbl)*
Main Area					
20,000 B/A	500	40	20,000	1,000	20
10,000–20,000 B/A	560	25	14,000	6,400	90
0–10,000 B/A	400	10	4,000	142,000	575
Welchs Creek Area					
10,000 + B/A	400	25	10,000	2,000	20
0–10,000 B/A	400	10	4,000	11,000	45
Shrewsbury Area					
0–10,000 B/A	400	10	4,000	10,000	40
Nolin Lake Area					
0–10,000 B/A	400*	10	4,000	5,500	20
West Short Creek Area					
0–10,000 B/A	400*	10	4,000	6,000	30
McDaniels-Outcrop Area					
0–10,000 B/A	400*	10	4,000	17,000	70
			Total Speculative In-Place Resource	200,900	910
			Total Measured In-Place Resource	143,750	1,190
			Total In-Place Resource	344,650	2,100

*Assumed same as the reservoir properties of the 0–10,000 resource contour of measured area.

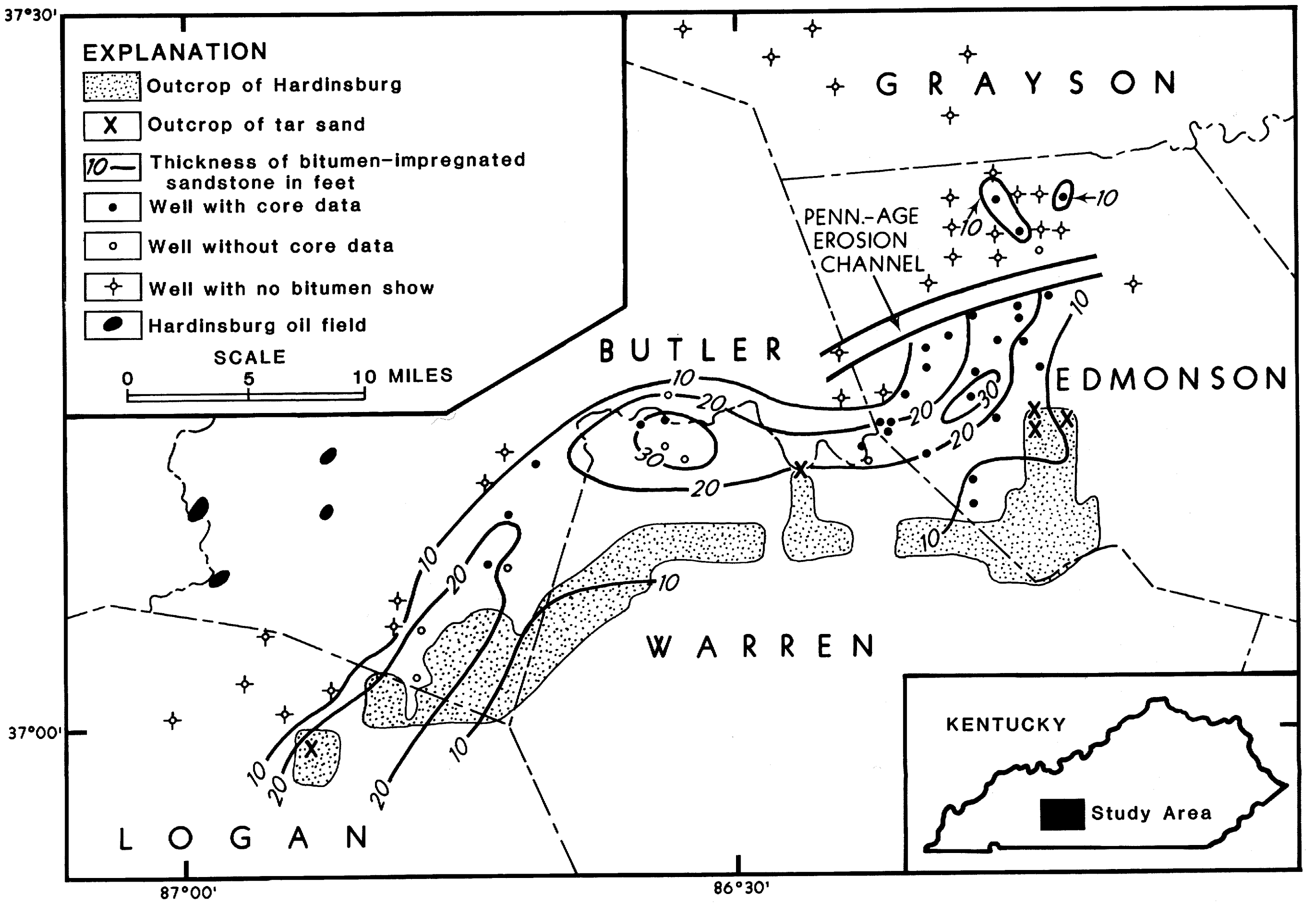


Figure 10. Isopach map of the bitumen-impregnated sandstone of the Hardinsburg Sandstone, Butler, Edmonson, Logan, and Warren Counties, Kentucky.

Tar Springs Sandstone from a depth of 125 to 139 ft lists average reservoir properties as: porosity, 24 percent; permeability, 696 millidarcys; and oil saturation, 58 percent.

The boundaries for the richness categories measured for in-place resources of the Tar Springs Sandstone for the Breckinridge and Dimple Areas are shown on Figures 17 and 18. The Dimple Area, covering 12,500 acres, is calculated to contain an in-place speculative resource of 125 MMbbl (Table 5). The Breckinridge Area, encompassing 21,500 acres, is calculated to contain 215 MMbbl.

The total in-place speculative resource for the Tar Springs Sandstone is calculated to be 340 MMbbl.

Caseyville Formation

The Caseyville Formation of Early Pennsylvanian age contains two bitumen-impregnated sandstones: the Bee Spring and Kyrock. In some areas these sandstones are separated by the Main Nolin coal bed. In other areas the Main Nolin coal bed is absent and the two sandstone bodies are indistinguishable. In this report the two sandstone bodies are referred to as the Caseyville Formation. Outcrop areas of Pennsylvanian-age formations and outcrops of bitumen-impregnated sandstone are shown on Figure 19.

In central Edmonson County the Caseyville consists of two sandstone bodies about 200 ft thick deposited in a northeast–southwest-trending paleovalley. The lower body consists of medium- to coarse-grained, crossbedded sandstone. The upper body is fine- to medium-grained, crossbedded sandstone that contains some shale. The lower sandstone may have been deposited by a low-sinuosity braided stream; the upper sandstone was deposited by a series of small, high-sinuosity meandering streams. The upper unit was deposited by more variable paleocurrents and extends beyond the limits of the erosional valley (Sedimentation Seminar, 1978).

Measured and speculative resource areas of the Caseyville Formation were outlined using data from core and drillers' logs (Fig. 20). The measured resource area boundary was es-

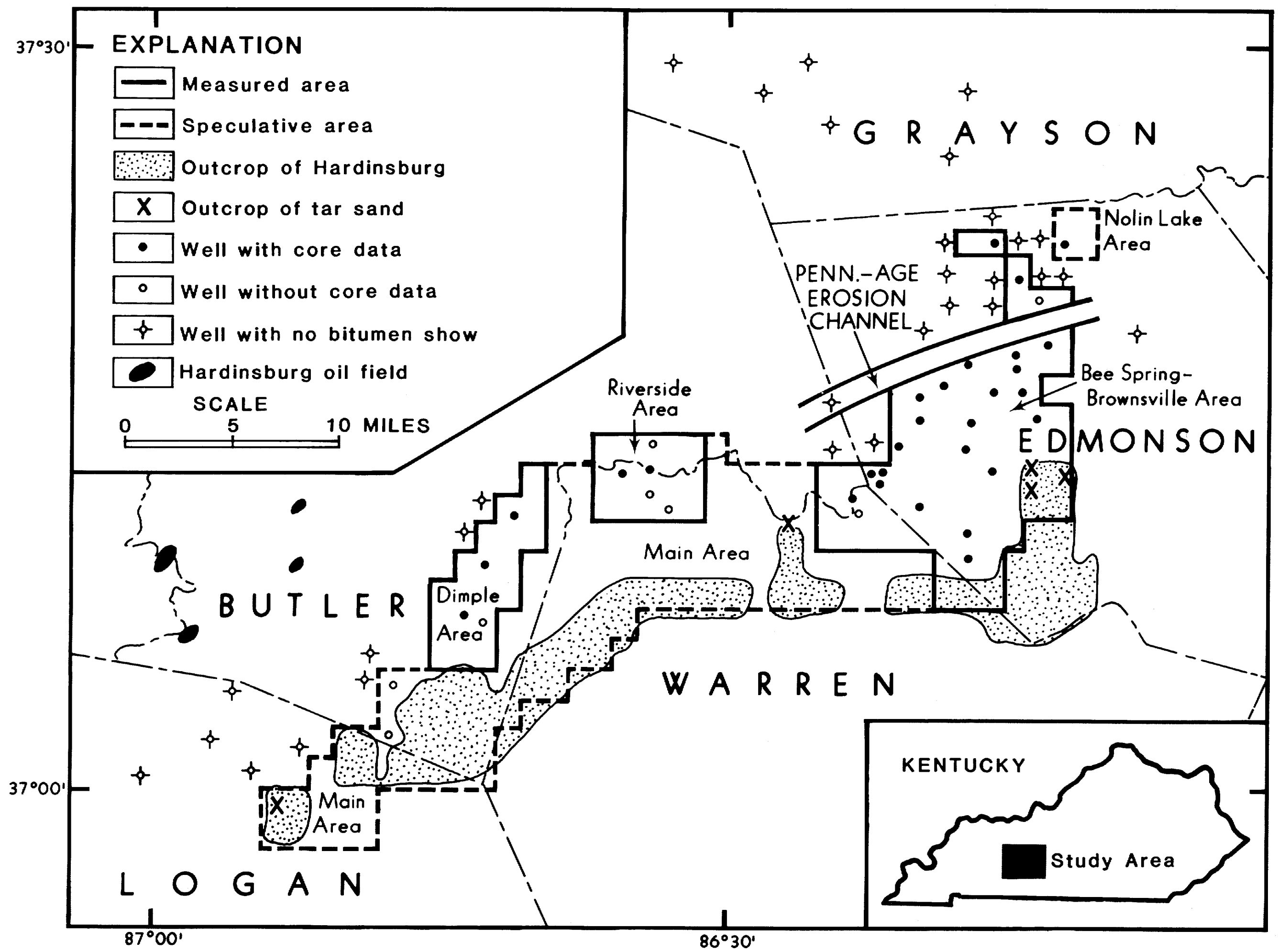


Figure 11. Outline of resource areas in the Hardinsburg Sandstone, Butler, Edmonson, Logan, and Warren Counties, Kentucky. From IOCC (1984). Reprinted, with permission, from the IOGCC.

tablished from 25 cores from industrial sources. Speculative area boundaries were determined from six cores and four drillers' logs.

Reservoir characteristics of the Caseyville Formation are highly lenticular bitumen-impregnated sandstones and highly variable oil saturations. Intervals of tar sand can change from 40 to 5 ft in short lateral distances, and oil saturations change rapidly from almost barren to over 60 percent. Permeability is moderate to high, generally over 100 millidarcys.

Boundaries for richness categories measured in barrels per acre for in-place resources of measured and speculative areas of the Caseyville are shown on Figure 21.

The Bee Spring-Brownsville Area, covering 35,000 acres, contains a measured in-place resource of 300 MMbbl and generally overlies the measured in-place resources of Hardinsburg and Big Clifty Sandstones for the same area (Table 6).

The Nash Area, covering 14,000 acres, contains an in-place speculative resource of 140 MMbbl (Table 7). The East Welchs Creek Area, encompassing 16,000 acres, contains 40 MMbbl; the Nolin Area, covering 8,000 acres, contains 40 MMbbl; and the East Shrewsbury Area, covering 6,000 acres, contains 30 MMbbl.

The total in-place resource for the Caseyville Formation for measured (300 MMbbl) and speculative (250 MMbbl) areas is calculated to be 550 MMbbl.

The total measured (1,730 MMbbl) and speculative (1,680 MMbbl) in-place resource for tar-sand deposits in western Kentucky is calculated to be 3.42 Bbbl (Table 8).

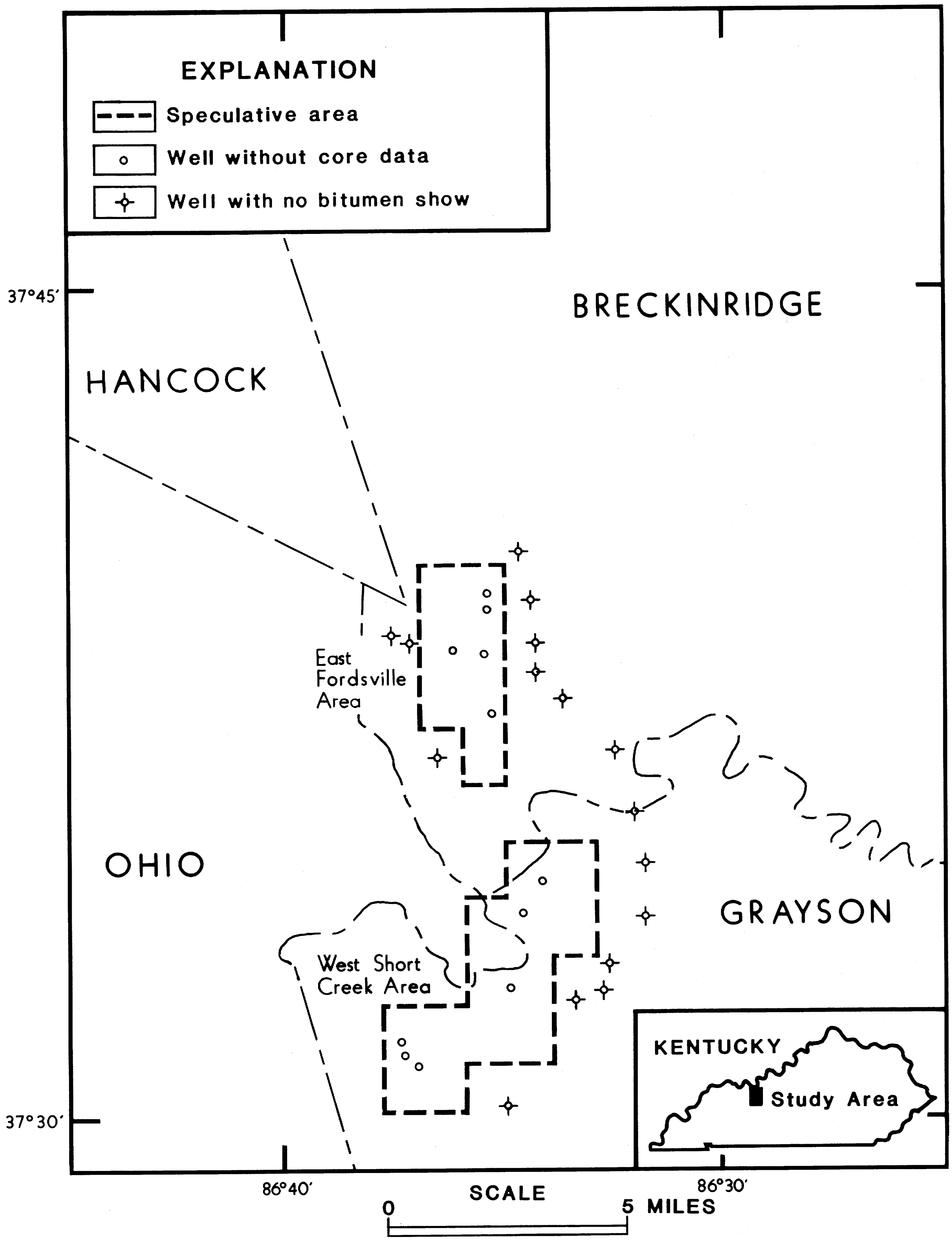


Figure 12. Outline of resource areas in the Hardinsburg Sandstone, Breckinridge, Grayson, and Ohio Counties, Kentucky. From IOCC (1984). Reprinted, by permission, from the IOGCC.

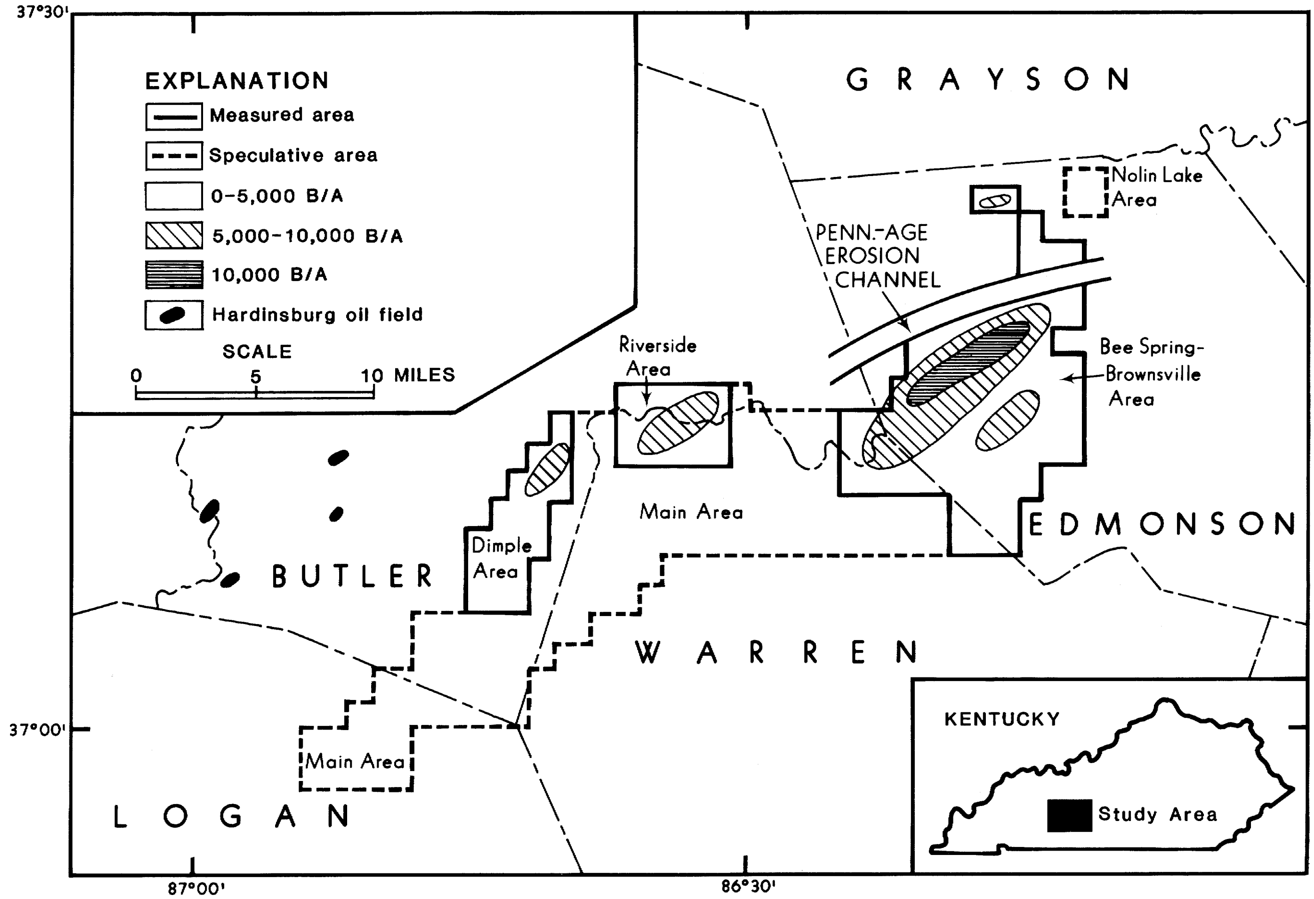


Figure 13. Resource-richness map of the Hardinsburg Sandstone, Butler, Edmonson, Logan, and Warren Counties, Kentucky. From IOCC (1984). Reprinted, by permission, from the IOGCC.

Tar-Sand Development

The first known plant designed to extract bitumen from a sandstone of Early Pennsylvanian age was constructed in Grayson County in 1891, but it was shut down after about 80 bbl of oil had been extracted (Weller, 1927).

In the early 1900's several companies opened quarries or surface mines in the Caseyville Formation or Big Clifty Sandstone for the production of paving materials. Peak production was between 1923 and 1931. The largest mines were in Edmonson County (McGrain and Ponsetto, 1981).

During 1959 and 1960, a major energy company conducted a field pilot test of forward combustion in a bitumen-impregnated sandstone of Early Pennsylvanian age near Bee Spring in Edmonson County (Fig. 22). In a recent report on the project, it was concluded that fireflooding through a system of induced horizontal fractures was a technically feasible method for producing oil from the tar-sand deposit at that locality (Terwilliger, 1976).

In northeastern Warren County, Sunset Petroleum Company drilled 10 closely spaced wells in 1969 into shallow (approximately 270 ft deep) Big Clifty Sandstone for an in situ recovery project. The test was reported to be successful in producing oil, but was discontinued before technical results could be made available.

In 1974, an independent group set up an experimental operation, also near Bee Spring, Edmonson County, to produce crude petroleum by mixing crushed asphaltic sand with a patented chemical solution. Results of the endeavor are not known (McGrain and Ponsetto, 1981).

In 1981, Tarco, Inc., constructed a pilot plant in Logan County for the extraction of oil from bitumen-impregnated sandstones of the Big Clifty Sandstone. Oil was successfully extracted from crushed and disaggregated sandstone by use of a solvent (Hastings, 1982). The pilot plant is not being operated at the present time.

In 1981, Westken Petroleum Corporation began a pilot project in Edmonson County to recover oil from bitumen-impregnated sandstones of the Big Clifty by an in situ com-

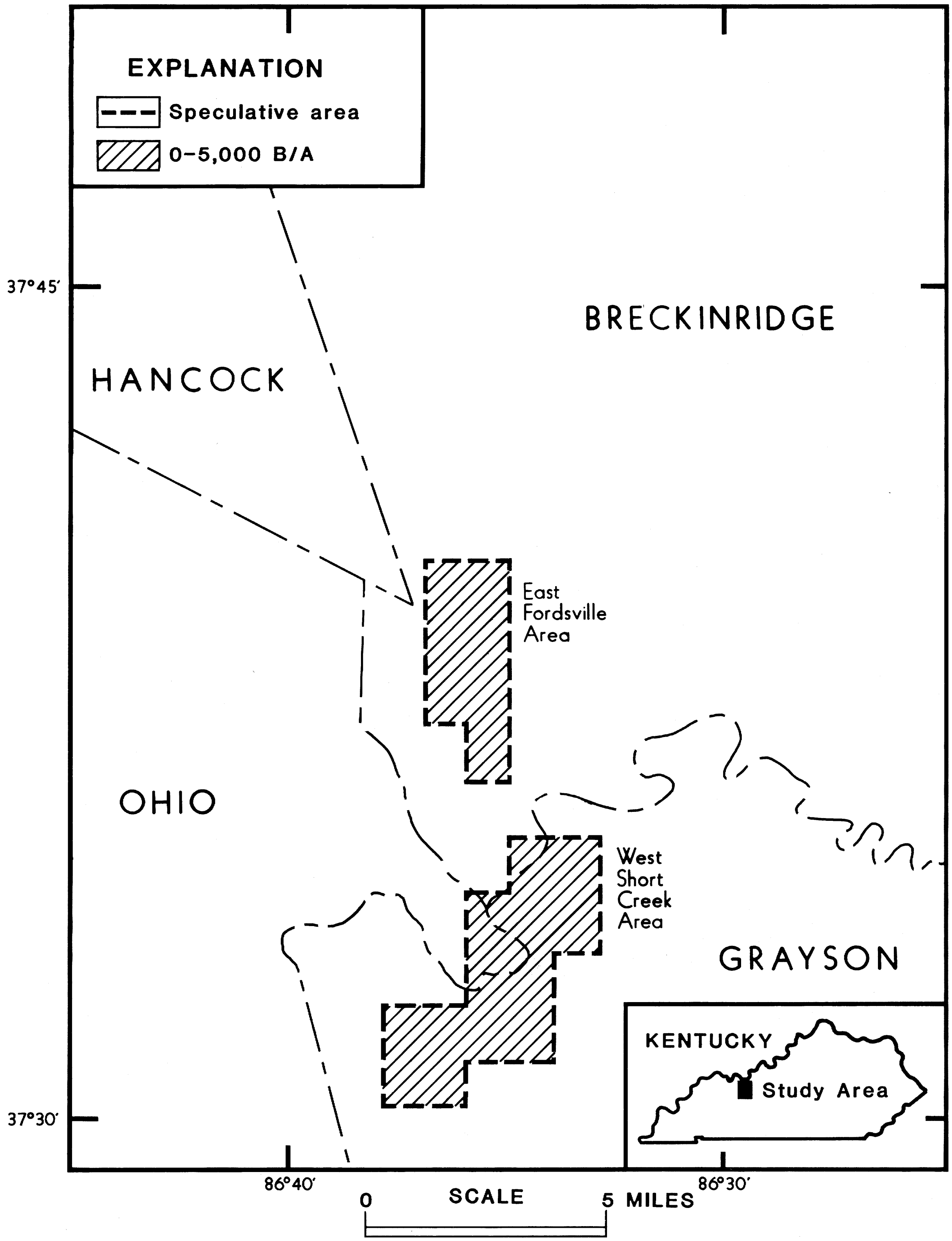


Figure 14. Resource-richness map of the Hardinsburg Sandstone, Breckinridge, Grayson, and Ohio Counties, Kentucky. From IOCC (1984). Reprinted, by permission, from the IOGCC.

Table 3. Measured in-place resource of the Hardinsburg Sandstone. From IOCC (1984). Reprinted, by permission, from the IOGCC.

Resource-Richness Category	*Barrels per Acre-Foot (average)*	*Net Pay, Feet (average)*	*Barrels per Acre (average)*	*Areal Extent (acres)*	*In-Place Resource (MMbbl)*
Bee Spring-Brownsville Area					
10,000 + B/A	550	18	10,000	4,000	40
5,000–10,000 B/A	450	13	6,000	15,000	90
0–5,000 B/A	340	6	2,000	25,000	50
Riverside Area					
5,000 + B/A	500	12	6,000	5,000	30
0–5,000 B/A	500	4	2,000	5,000	10
Dimple Area					
5,000 + B/A	310	7	6,000	2,000	10
0–5,000 B/A	275	7	2,000	10,000	20
			Total measured in-place resource	66,000	250

bustion process. A forward wet combustion process, preceded by a steam preheat to establish good communication with producing wells, was selected for a 1-acre pilot test area. Overall results of the pilot are considered very satisfactory, with high production rates per unit of displacing fluid having been achieved (Ward and Ward, 1984). Efforts are being made to raise funds to construct a 1,000-barrel-per-day commercial module.

In 1983, Cresset Corporation constructed a pilot plant in Logan County to extract oil from surface-mined asphaltic sandstones of the Big Clifty by use of a solvent. Test runs using daily mine samples of 200 tons have been successful. The plant is presently on a standby operating basis.

Boark Oil and Gas Company is currently involved in a demonstration project in Breckinridge County to heat heavy oil in the Tar Springs Sandstone by use of a microwave technique.

Conclusions

1. Exploration and development activities indicate that significant oil resources are present in subsurface tar-sand deposits in western Kentucky.
2. Pilot studies have demonstrated that technologies are available for the successful recovery of oil from both subsurface and surface deposits.

Table 4. Speculative in-place resource of the Hardinsburg Sandstone. From IOCC (1984). Reprinted, by permission, from the IOGCC.

Resource-Richness Category	*Barrels per Acre-Foot (average)*	*Net Pay, Feet (average)*	*Barrels per Acre (average)*	*Areal Extent (acres)*	*In-Place Resource (MMbbl)*
Main Area					
0–5,000 B/A	340*	6*	2,000	73,000	150
Nolin Lake Area					
0–5,000 B/A	340*	6*	2,000	2,500	5
West Short Creek Area					
0–5,000 B/A	340*	6*	2,000	8,000	15
East Fordsville Area					
0–5,000 B/A	340*	6*	2,000	4,500	10
			Total speculative in-place resource	88,000	180
			Total measured in-place resource	66,000	250
			Total resource in place	154,000	430

*Assumed similar in reservoir properties to the low resource contour of the Bee Spring-Brownsville Area measured in-place resource.

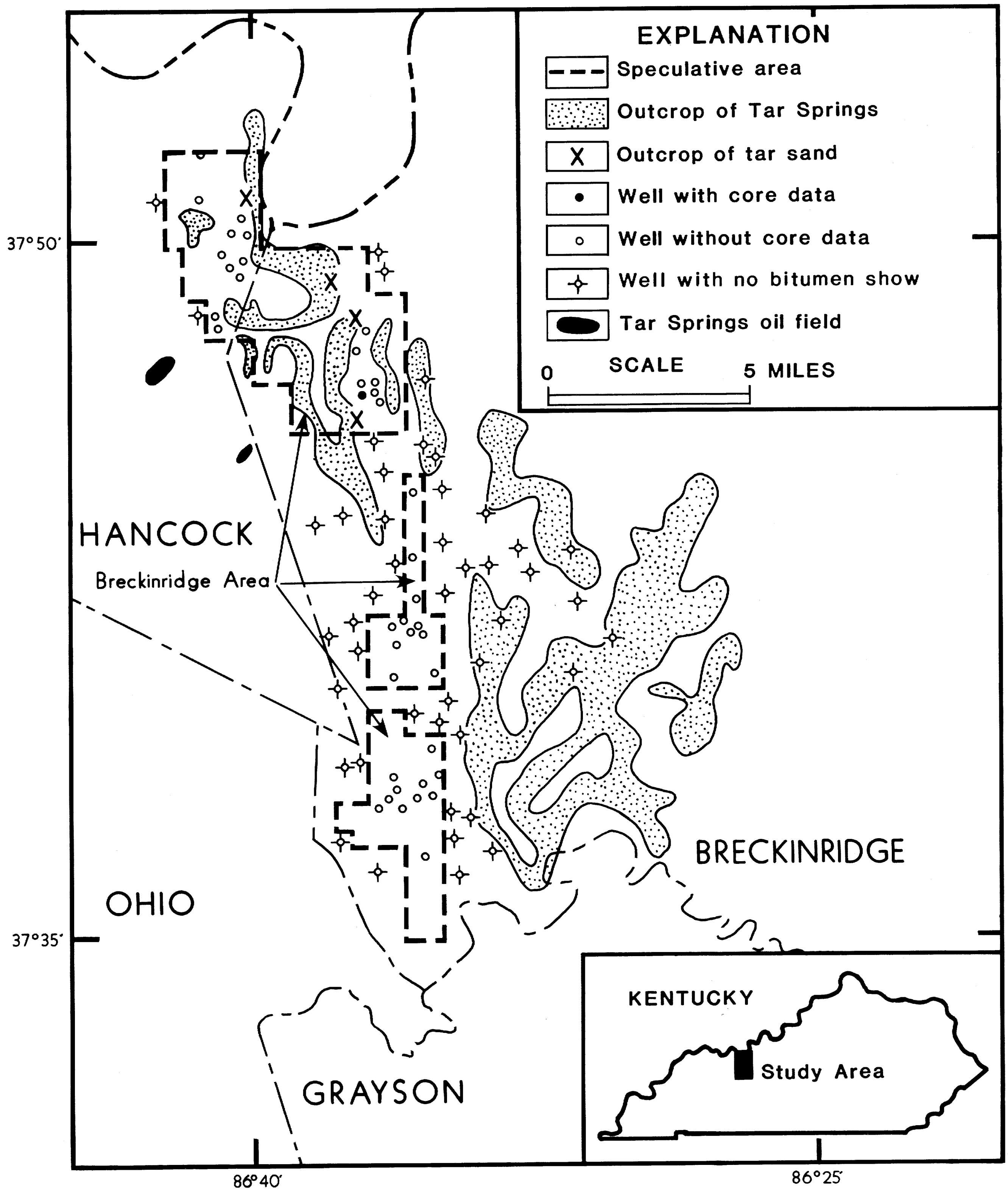


Figure 15. Outline of resource areas in the Tar Springs Sandstone, Breckinridge and Hancock Counties, Kentucky. From IOCC (1984). Reprinted, by permission, from the IOGCC.

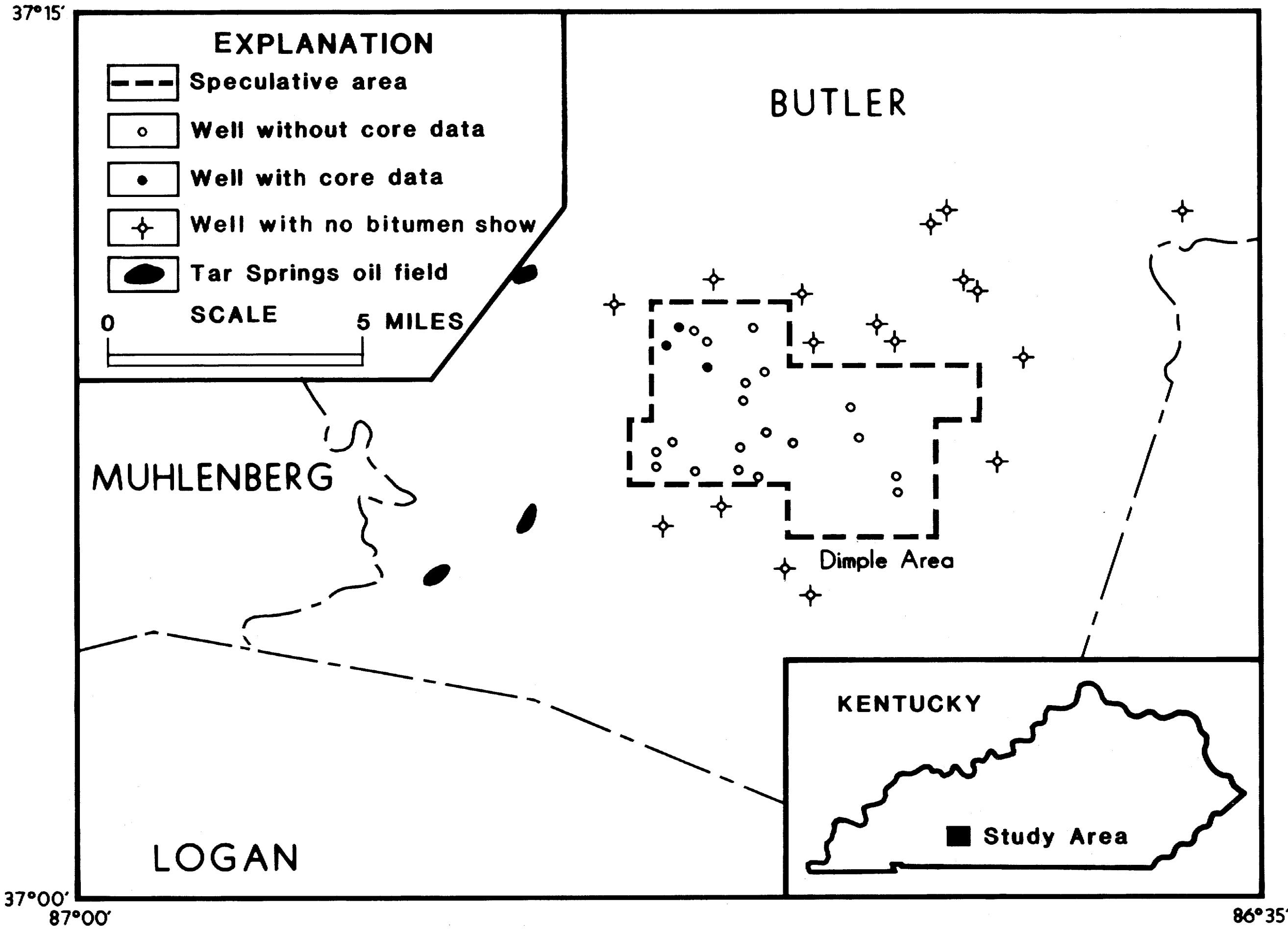


Figure 16. Outline of resource areas in the Tar Springs Sandstone, Butler County, Kentucky. From IOCC (1984). Reprinted, by permission, from the IOGCC.

3. The majority of resource areas contain two, and sometimes three, tar-sand deposits in vertical sequences, enhancing the economic attractiveness of the areas.
4. Economic factors supporting the potential development of the tar-sand deposits are accessibility to transportation, relatively shallow depths (0–600 ft), and lease availability.

Recommendations

1. Additional core drilling for analytical data on reservoir characteristics is needed, especially in resource areas listed as speculative, for a more accurate resource determination.
2. The Kentucky Geological Survey should continue to monitor drilling activities in the tar-sand area in western Kentucky and request sample cuttings from test holes to further delineate the tar-sand deposits.
3. Additional research, including studies of well samples, construction of stratigraphic and structural cross sections, and source-rock analyses, should be undertaken to further determine the geological factors responsible for localization of western Kentucky tar-sand deposits.

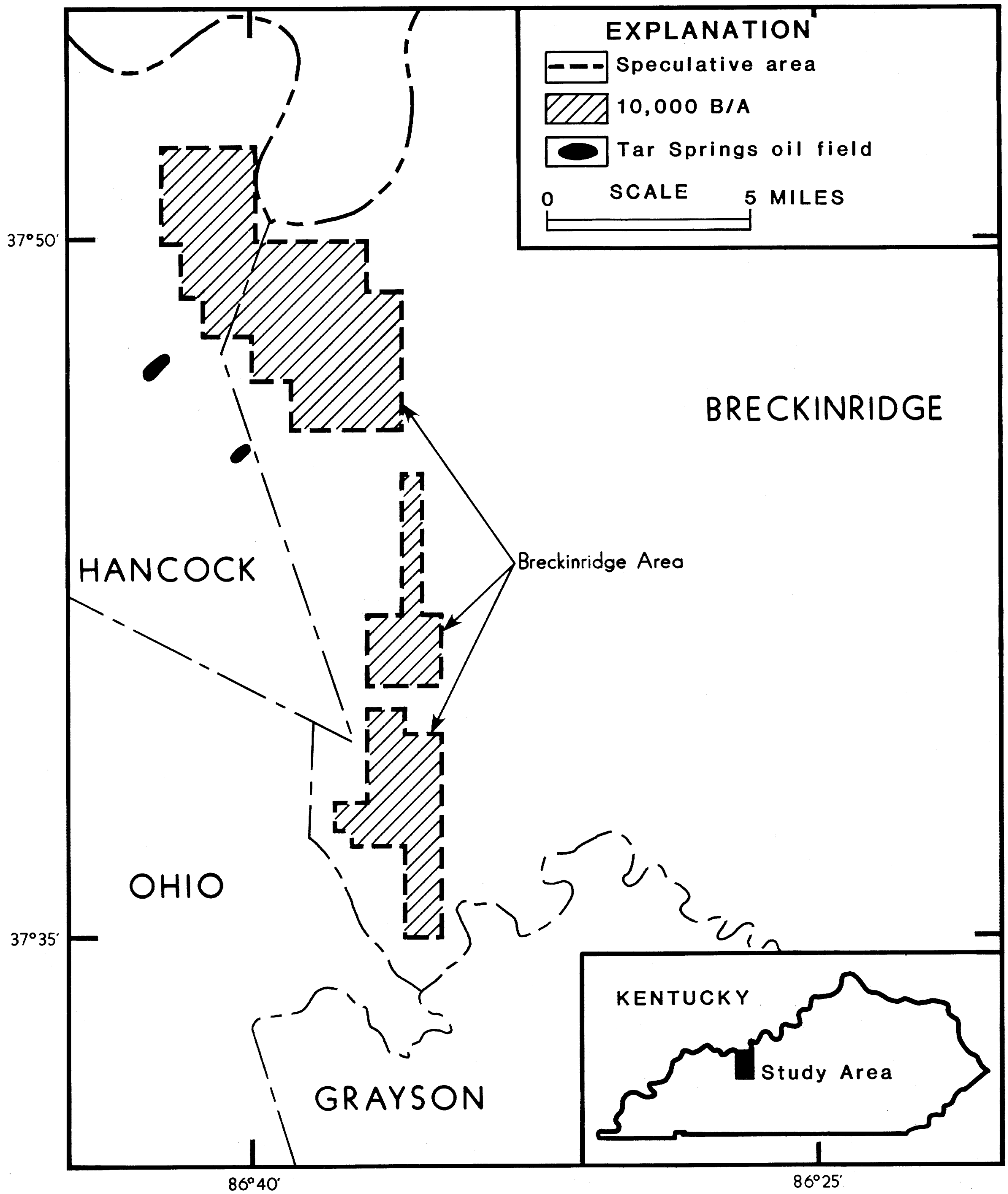


Figure 17. Resource-richness map of the Tar Springs Sandstone, Breckinridge and Hancock Counties, Kentucky. From IOCC (1984). Reprinted, by permission, from the IOGCC.

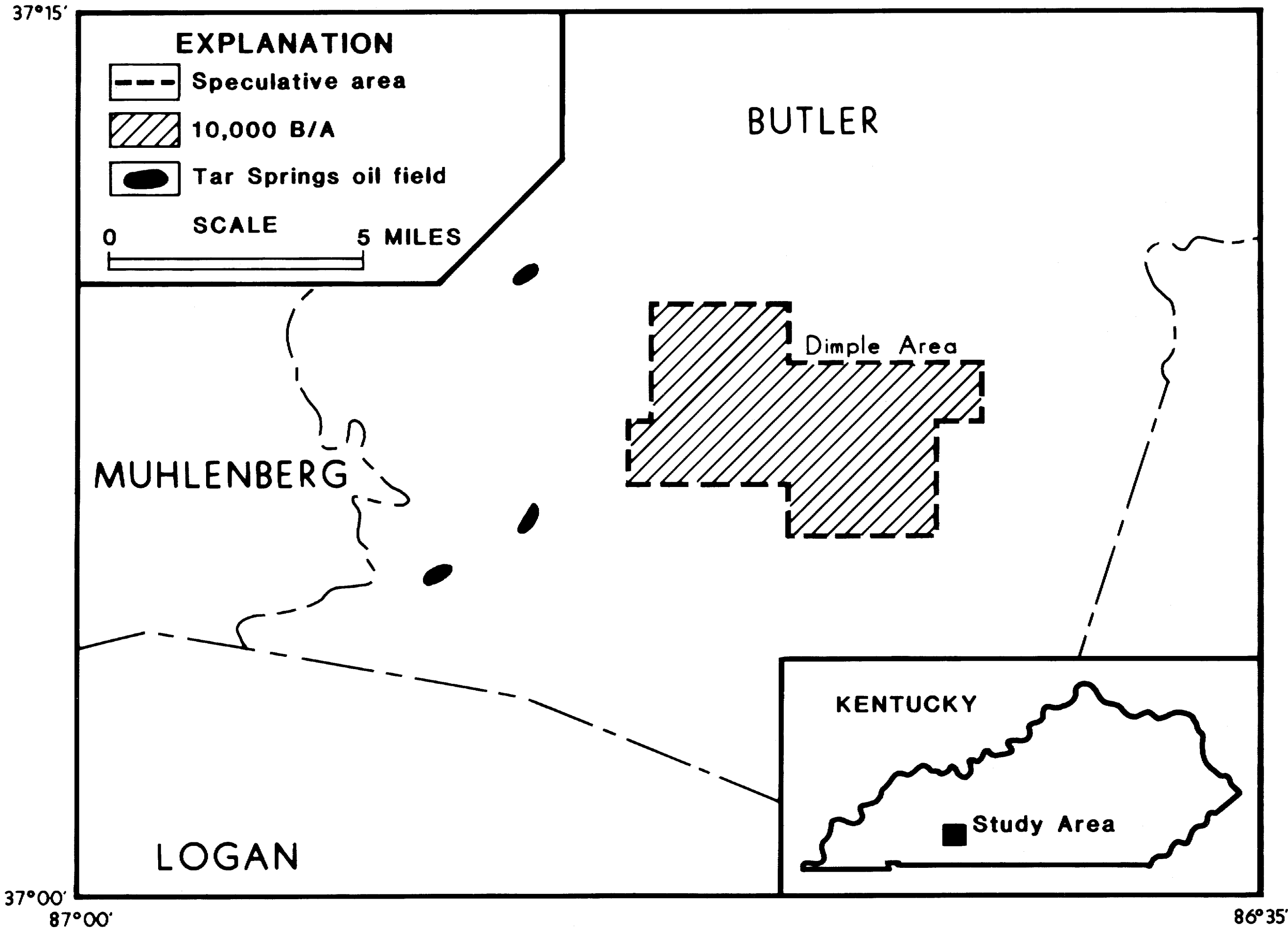


Figure 18. Resource-richness map of the Tar Springs Sandstone, Butler County, Kentucky. From IOCC (1984). Reprinted, by permission, from the IOGCC.

Table 5. Speculative in-place resource of the Tar Springs Sandstone. From IOCC (1984). Reprinted, by permission from the IOGCC.

Resource-Richness Category	*Barrels per Acre-Foot (average)*	*Net Pay, Feet (average)*	*Barrels per Acre (average)*	*Areal Extent (acres)*	*In-Place Resource (MMbbl)*
Dimple Area 10,000 B/A	430	25	10,000	12,500	125
Breckinridge Area 10,000 B/A	430*	25	10,000	21,500	215
		Total speculative in-place resource		34,000	340

*Assumed the same as the Dimple Area.

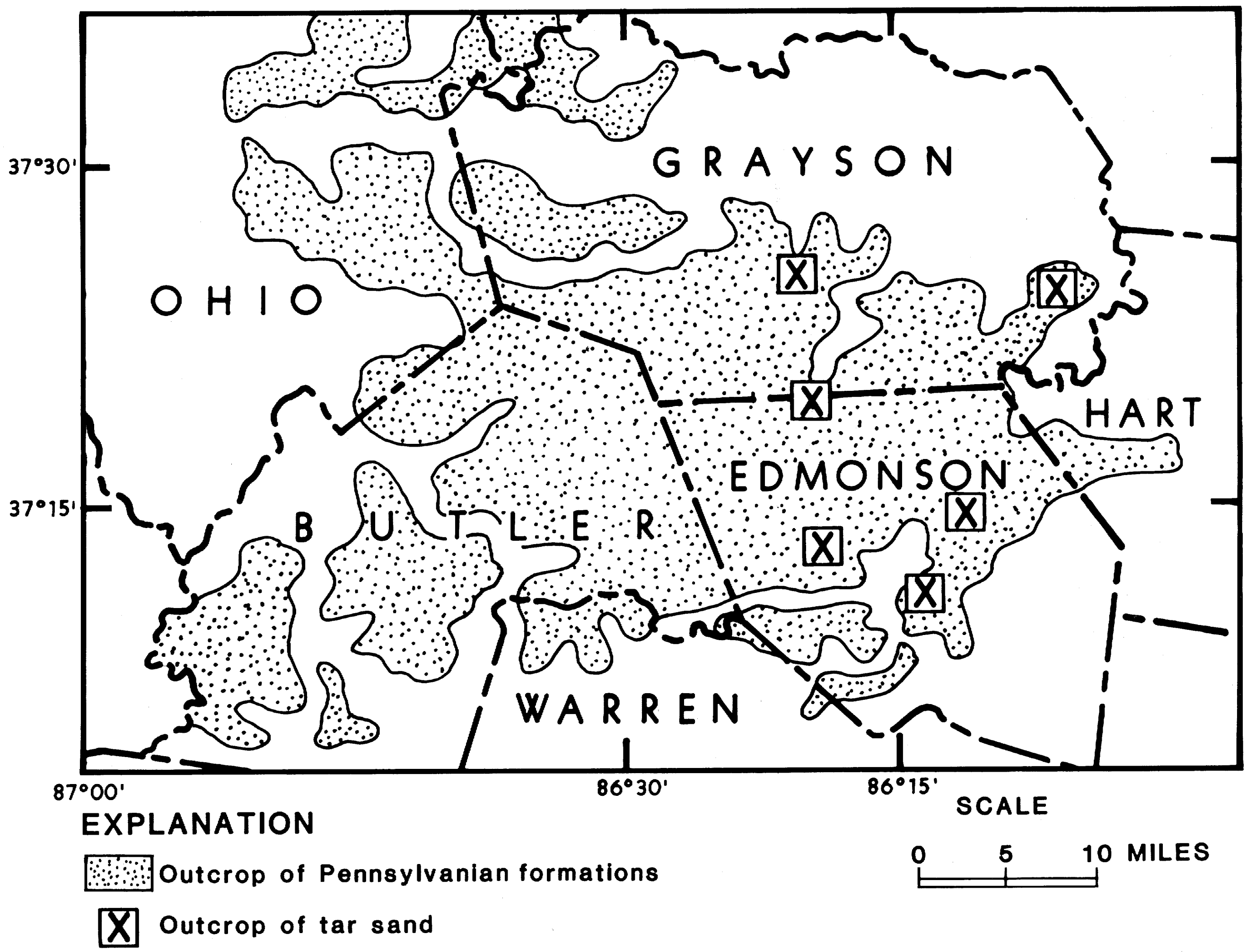


Figure 19. Generalized outcrop map of Pennsylvanian formations, Butler, Edmonson, Grayson, Hart, Ohio, and Warren Counties. From IOCC (1984). Reprinted, by permission, from the IOGCC.

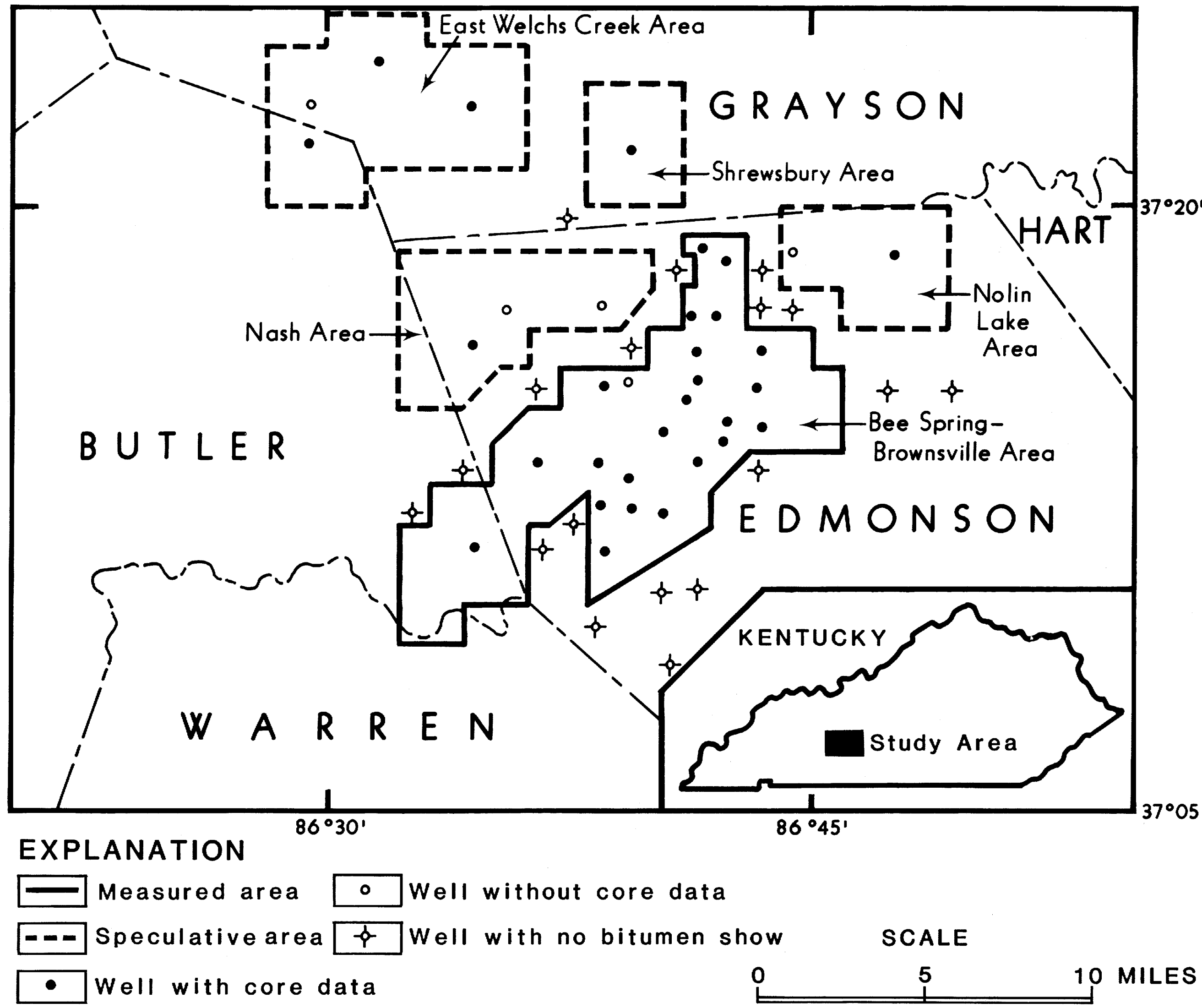


Figure 20. Outline of resource areas of the Caseyville Formation, Butler, Edmonson, Grayson, and Warren Counties, Kentucky. From IOCC (1984). Reprinted, by permission, from the IOGCC.

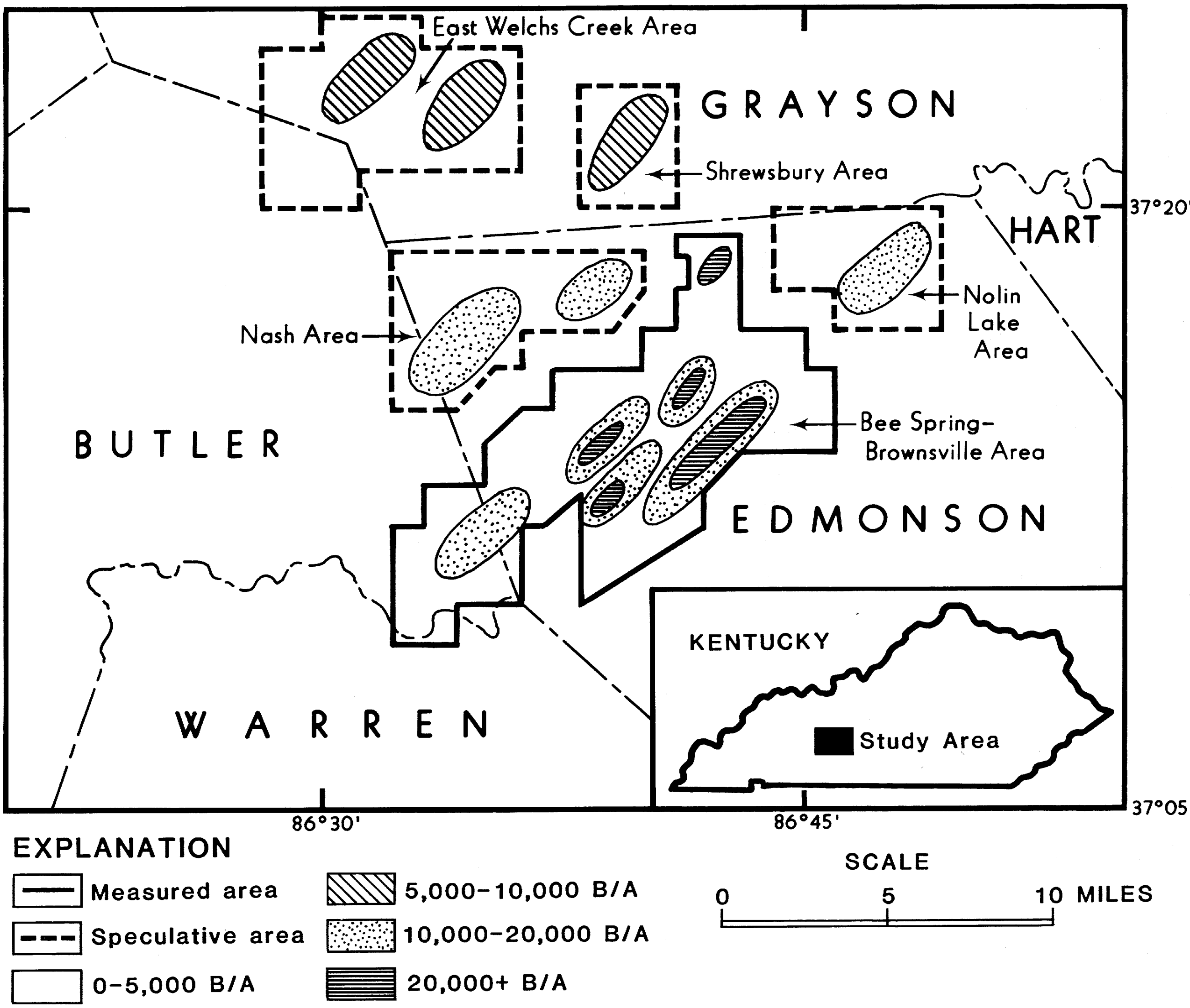


Figure 21. Resource-richness map of the Caseyville Formation, Butler, Edmonson, Grayson, and Warren Counties, Kentucky. From IOCC (1984). Reprinted, by permission, from the IOGCC.

Table 6. Measured in-place resource of the Caseyville Formation. From IOCC (1984). Reprinted, by permission, from the IOGCC.

Resource-Richness Category	*Barrels per Acre-Foot (average)*	*Net Pay, Feet (average)*	*Barrels per Acre (average)*	*Areal Extent (acres)*	*In-Place Resource (MMbbl)*
Bee Spring-Brownsville Area					
20,000 + B/A	800	30	24,000	4,000	100
10,000–20,000 B/A	700	20	14,000	8,000	110
0–10,000 B/A	600	7	4,000	23,000	90
			Total measured in-place resource	35,000	300

Table 7. Speculative in-place resource of the Caseyville Formation. From IOCC (1984). Reprinted, by permission, from the IOGCC.

Resource-Richness Category	*Barrels per Acre-Foot (average)*	*Net Pay, Feet (average)*	*Barrels per Acre (average)*	*Areal Extent (acres)*	*In-Place Resource (MMbbl)*
Nash Area					
10,000–20,000 B/A	500	30	15,000	4,000	60
0–10,000 B/A	600	13	8,000	10,000	80
Nolin Lake Area					
10,000 + B/A	500	20	10,000	2,000	20
0–10,000 B/A	500	26	4,000	6,000	20
East Shrewsbury Area					
5,000 + B/A	600	10	5,000	3,000	20
0–5,000 B/A	380	7	2,000	3,000	10
East Welchs Creek Area					
5,000 + B/A	600	10	5,000	4,000	20
0–5,000 B/A	380*	7	2,000	12,000	20
		Total speculative in-place resource		44,000	250
		Total measured in-place resource		35,000	300
		Total in-place resource		79,000	550

*Assumed the same as the 0–5,000 resource contour of the East Shrewsbury Area.

Table 8. Western Kentucky in-place tar-sand resource. From IOCC (1984). Reprinted, by permission, from the IOGCC.

Major Deposits	*Measured Resource (MMbbl)*	*Speculative Resource (MMbbl)*
Big Clifty Sandstone	1,180	910
Hardinsburg Sandstone	250	180
Tar Springs Sandstone	–	340
Caseyville Sandstone	300	250
Totals	1,730	1,680
Total in-place resource: 3,420,000,000 MMbbl		

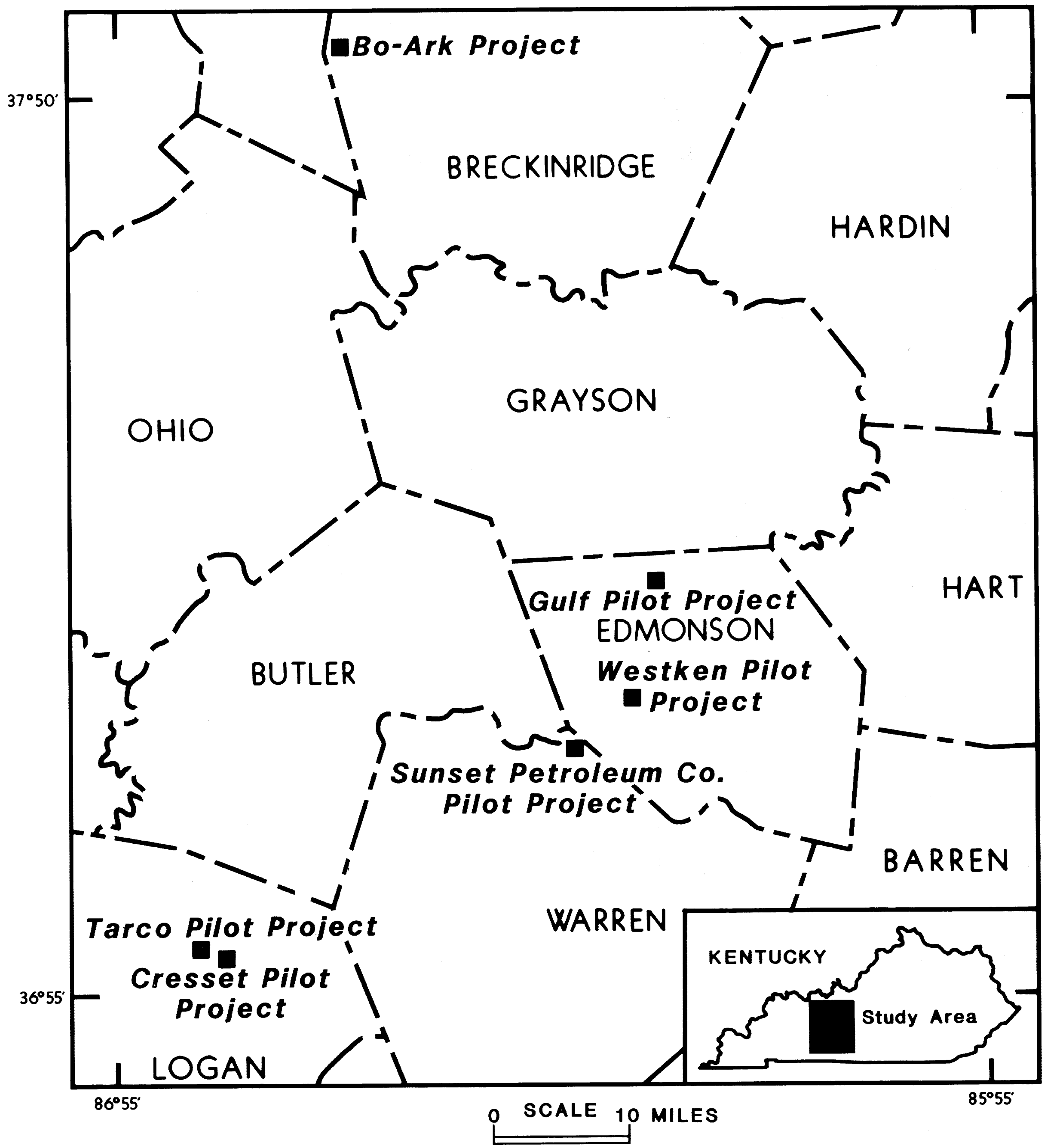


Figure 22. Tar-sand development projects in western Kentucky.

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