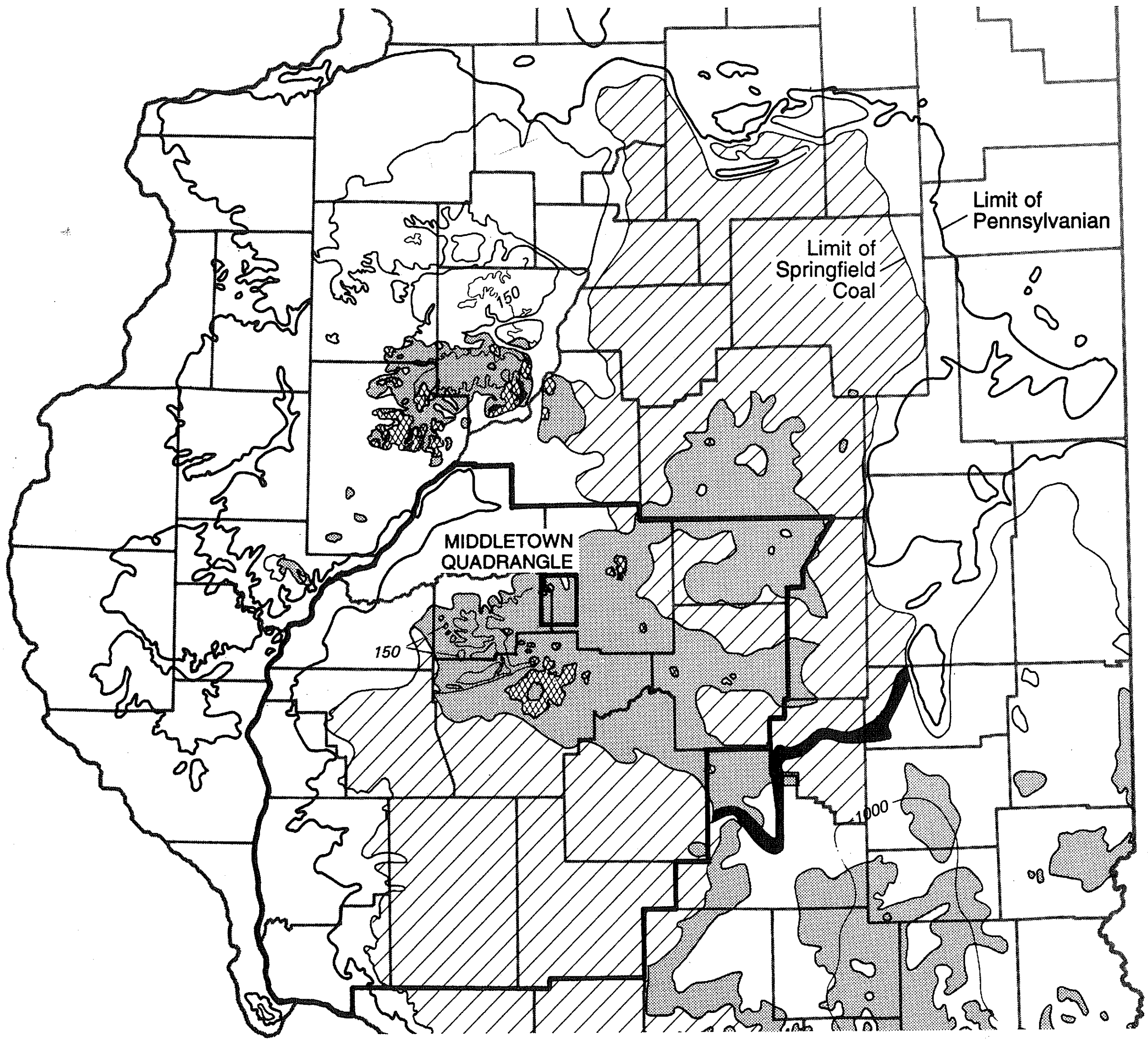
Availability of Coal Resources for Mining in Illinois
Middletown Quadrangle, Central Illinois

Colin G. Treworgy, Gayla K. Coats, and Margaret H. Bargh



Circular 554 1994

Department of Energy and Natural Resources
ILLINOIS STATE GEOLOGICAL SURVEY

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Cover photo General extent, depth, and thickness of the Springfield Coal in Illinois. Region 3 and the Middletown Quadrangle are outlined.

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ABSTRACT

Many of the geologic and physiographic conditions common to west-central Illinois are found in the Middletown Quadrangle, the focus of this report. It is the first of a series that will examine the availability of coal resources for development in Illinois.

Environmental and regulatory restrictions, sociocultural features (towns, highways), mining technology, geologic conditions, coal quality, and economic conditions all affect resource availability. Interviews with experts from coal companies and state government indicated how these various geologic and land use conditions restrict mining.

Coal resources and related geologic features were described and mapped for this report. Original resources for the six seams underlying the quadrangle total 385 million tons; 383 million tons remain in the ground, and 211 million tons are estimated to be available for mining.

No surface minable resources are available and only 58% of the original deep minable resources (55% of the original total) are available for mining. If underground mining is restricted to room and pillar techniques (thus excluding longwall mining), unfavorable roof and floor conditions reduce the amount of available resources to a low 195 million tons—51% of the total original resources.

Technological factors, including bedrock and seam thicknesses as well as roof and floor conditions, account for 98% of the unavailable tonnage. Land use restrictions due to towns, interstate highways, mines, cemeteries, and other sociocultural features account for the remaining 2% of unavailable tonnage. These factors probably also restrict the mining of significant quantities of coal resources elsewhere in central Illinois.

Consequently, the amount of coal available for development in the Middletown area may be considerably lower than has been indicated by earlier studies.

INTRODUCTION

Accurate estimates of the amount of coal resources available for mining are needed for planning by federal and state agencies, utilities, and other energy consumers and producers. Inventories of coal resources in Illinois are relatively accurate estimates of the total amount of coal in the ground. There is serious doubt, however, regarding the percentage of coal resources that can actually be mined. Environmental and regulatory restrictions, the presence of towns and other cultural resources, current mining technology, geologic conditions, coal quality, and other factors significantly reduce the amount of coal available for mining.

This Middletown Quadrangle report is the first of a series in which the Illinois State Geological Survey (ISGS) will examine the availability of coal resources for development in the state. The Middletown area was selected as representative of many of the geologic and physiographic conditions in west-central Illinois. Coal resources and related geologic features were described and mapped. Mining experts from coal companies and state government were interviewed for information about how various geologic and land-use conditions might restrict mining of these deposits.

Investigations of Available Coal Resources

The difference between estimates of Illinois' total coal resources and the portion of the resources available for development was discussed as early as 1969 by Risser and later by Attanasi and Green (1981). Zwartendyk (1981) described this difference as a major problem with all estimates of mineral resources.

Recognizing the need for estimates of available coal, Treworgy et al. (1978) used a relatively simple set of criteria to make a general, statewide assessment of surface minable resources in Illinois. Treworgy and Bargh (1982) conducted a similar examination of deep minable resources in the state. The latter study ranked coal into four categories of development potential: high, moderate, low, and restricted. Deposits with a high potential for development had characteristics similar to deposits currently being mined; whereas those with moderate or low potential had less favorable characteristics. Restricted deposits were considered unminable because of constraints due to surface land use or oil fields.

As these two studies demonstrated, a large portion of the state's coal resources have characteristics that restrict their development potential. Because of the statewide approach used in these studies, however, many factors that restrict the development of coal were not considered; for example, the geology of roof and floor strata, thickness of the interval between seams, and thickness of the bedrock overburden. The actual amount of available coal may thus be significantly lower than indicated by the initial estimates. Treworgy et al. (1978) estimated that 6 billion of the 20 billion tons of surface minable resources are suitable for mining. Industry sources have suggested that the amount of surface minable coal available is actually much lower. The steady decline since about 1970 in the number of surface mines in the state (down from 35 to 15 mines) and the annual percentage of the state's total production from surface mines (down from 51% to 26%) appears to confirm this view.

In 1987, the National Coal Council concluded that lack of information on the availability of coal resources is a nationwide problem that should be rectified. In the late 1980s, the U.S. Geological Survey (USGS) began sponsoring assessments of the availability of coal resources in eastern Kentucky (Eggleston et al. 1988,

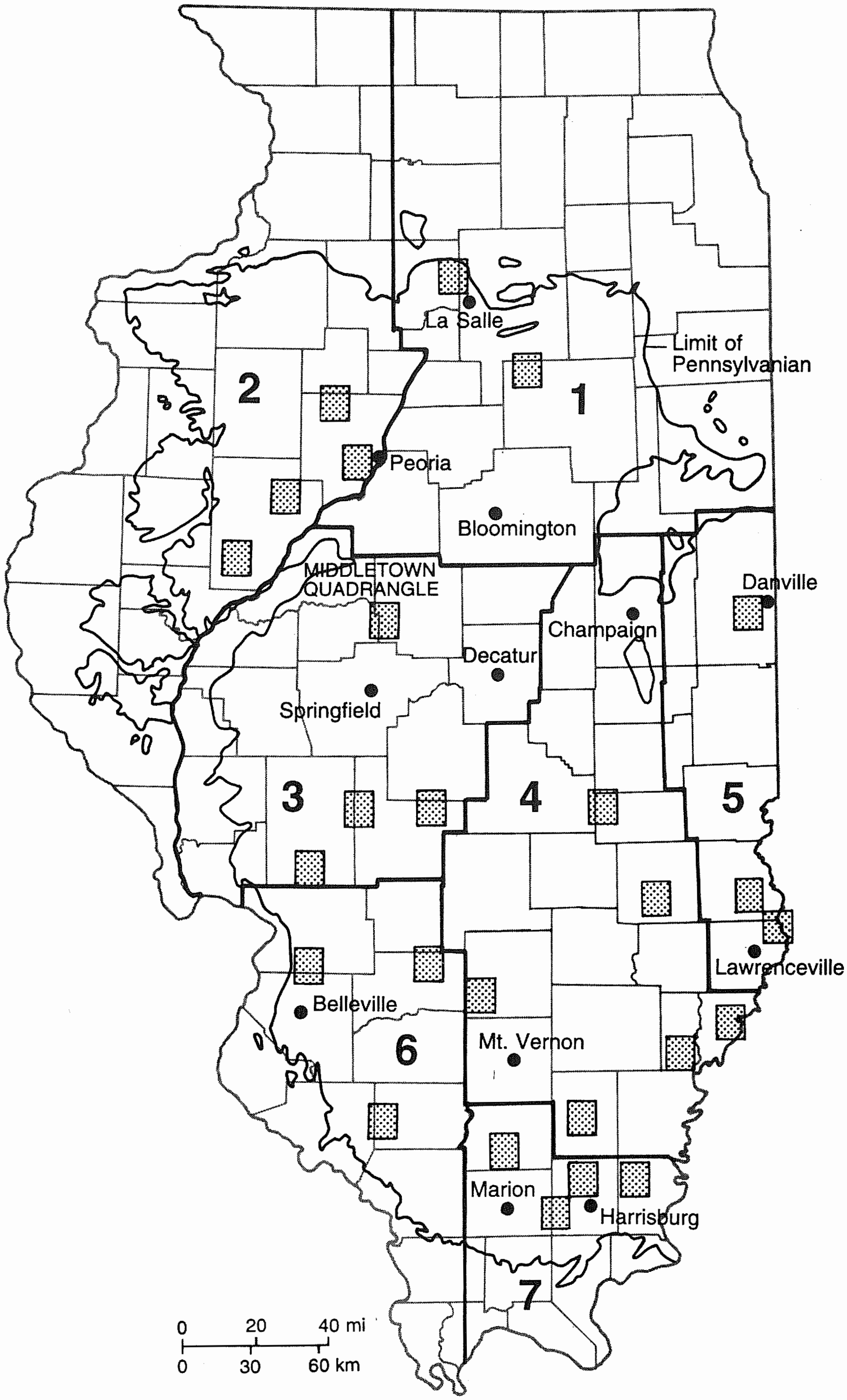


Figure 1 Coal resource regions and proposed quadrangles for coal availability assessments.

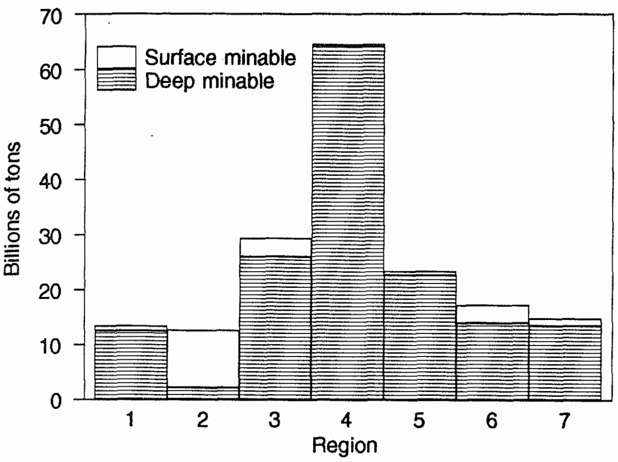


Figure 2 Remaining coal resources.

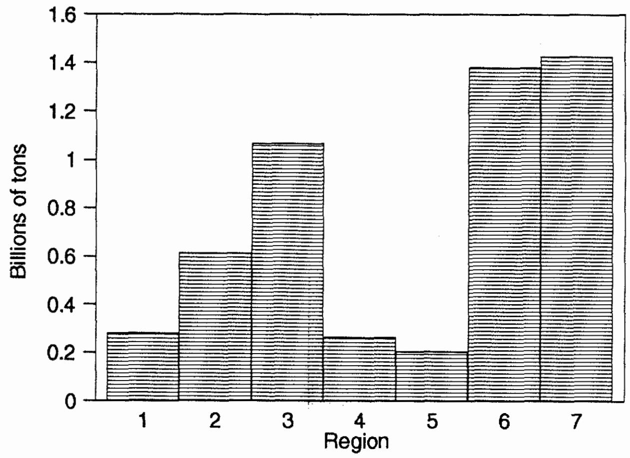


Figure 3 Historical record of coal production.

Carter and Gardner 1989). These studies have since been expanded to include West Virginia, Virginia, and Ohio (Jake 1989, Carter et al. 1990, Sites et al. 1991).

The USGS-sponsored studies examine in detail the factors affecting the availability of coal for mining within a 7.5-minute quadrangle (about 56 square miles). The relatively small study areas permit more complete and comprehensive data collection and assessment than is practical or economical to conduct for a larger area (Eggleston et al. 1990). The quadrangles selected represent the geology and mining conditions found in surrounding quadrangles, and the results of these detailed investigations can be used to estimate the availability of coal resources in these regions.

Framework for Studies of Available Coal in Illinois

The results from the study of the Middletown Quadrangle, along with the results from the assessments of available coal in other quadrangles, will be extrapolated to larger regions of Illinois. This research will provide a basis for updating, refining, and expanding earlier work by Treworgy et al. (1978) and Treworgy and Bargh (1982). These quadrangle studies will provide complete, up-to-date documentation of the criteria for determining available coal in the state. The criteria will be sufficiently detailed to account for regional variations in geology and physiography that affect mining practices.

The Illinois coal field was divided into seven regions, which serve to guide the selection of study areas (fig. 1). Although the boundaries of the regions are somewhat arbitrary, each region represents a distinct combination of geologic and physiographic characteristics. Significant quantities of coal resources remain in all regions (fig. 2). All regions have had a significant amount of production (fig. 3), and all but region 1 currently produce some coal (fig. 4). Two to four quadrangles in each region will be selected for an assessment of available coal resources. This number of quadrangles should be sufficient to evaluate the full range of mining conditions in a region.

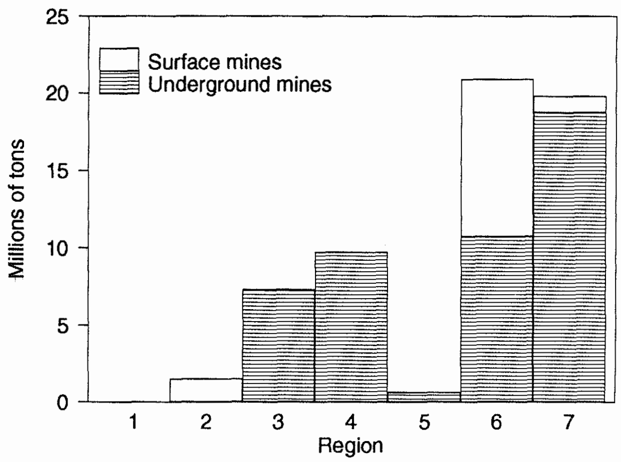


Figure 4 1991 coal production.

Geologic and Physiographic Setting of Region 3

The Middletown Quadrangle represents many of the geologic and physiographic conditions found in west-central Illinois (region 3). The quadrangle is located about 12 miles north of the city of Springfield (fig. 1). Flat, highly productive farmland covers the broad uplands, which are dissected by relatively narrow zones of gently rolling pasture and woodland along the streams and rivers.

About 3% of the land in region 3 is covered by towns or other development. The remainder is farmland, pasture, water, woods, and wetlands. Excluding Springfield and Decatur, the only extensive urban areas in this region, only about 1% of the area is occupied by towns. There are more than 100 state parks and natural areas in this region. About one-third of these lie outside of the area of coal-bearing strata. With a few minor exceptions, areas in which extensive drilling for oil and gas may impact coal mining are relatively small and confined to eastern Sangamon, southwestern Macon, and northern Christian Counties.

Throughout region 3 and central Illinois, the bedrock surface is concealed by a thick layer of glacial deposits consisting of clay, silt, sand, and gravel (fig. 5). The bedrock surface is dissected by a well developed, preglacial drainage system (fig. 6). Glacial deposits are less than 50 feet thick on the preglacial upland surfaces and more than 400 feet thick where they fill major bedrock valleys. The bedrock strata dip southeast at a low angle towards the south-central part of the state (fig. 7).

The major geologic structures found in this region are broad anticlines and domes; some of the domes are used for storage of natural gas. There are no known major fault zones in the region. A strike-slip fault, possibly traceable for several miles, has been reported in Macoupin County (Nelson and Nance 1981). Minor faults that have a few feet of displacement have been observed in mines in the region (Krausse et al. 1979, Nelson and Nance 1981, DeMaris and Nelson 1990).

Region 3 is underlain by several widespread coal seams that range from a few inches to 7 feet thick. The coals are shallow enough to be surface minable in areas where they crop out below the glacial deposits. Away from the subcrops, the major coals are generally less than 600 feet deep. The Springfield Coal (informally known as the No. 5 Coal) is the thickest seam in the area just south of the city of Springfield northward (fig. 8). This coal has been mined at several locations. The Herrin Coal (informally known as the No. 6 Coal) is the state's largest coal resource; it is best developed south of the city of Springfield (fig. 9). North of the city, the Herrin Coal is thinner and more variable in thickness; it is thick enough to mine only in small, lenticular pods. Other coal seams, including the Chapel (formerly No. 8), Danville (formerly No. 7), Houchin Creek (formerly Summum or No. 4), Survant (formerly Shawneetown or No. 2A), and Colchester (formerly No. 2), are present in this region; but they are generally too thin to be economically mined.

Previous Investigations of Coal in Region 3

Smith (1961) and Nance and Treworgy (1981) mapped coals that were surface minable (1.5 feet thick or more, and less than 150 feet deep). Because of the lack of outcrops and drilling data, these studies included no mapping of surface minable resources in the Middletown Quadrangle.

The availability of surface minable resources in region 3 was partially evaluated by Treworgy et al. (1978). Their study demonstrated how factors such as stripping ratio, size and configuration of mining block, and certain categories of surface land use limit the availability of surface minable resources. Of the more than 2 billion tons of surface minable resources in the region, less than 13% were found to be suitable for mining. Several significant factors were not evaluated in that study, including average stripping ratios of mine blocks, loss of resources in minor seams because of preferential mining of thicker, underlying seams, and proximity of mine blocks to towns and important natural areas.

Deep minable coal resources in this region were mapped by Treworgy and Bargh (1982). Their study evaluated these resources with respect to thickness, depth, proximity to areas densely drilled for oil, and selected categories of surface land use (towns, interstate highways, public lands, cemeteries). Of the more than 28 billion tons of deep minable resources in the region, almost 63% (including almost all resources in the Middletown Quadrangle) were ranked as having a high potential for development. Other factors remain to be evaluated, however, including thickness and composition of strata between seams, recovery of coal above or below previously mined areas, proximity of channels and faults, partings and clastic dikes in seams, roof and floor conditions, size and configuration of mining blocks, and thickness of bedrock overburden.

Coal Resource Classification System

The ISGS follows the terms and definitions of the USGS coal resource classification system (Wood et al. 1983). With minor modifications to suit local conditions, these definitions generally provide a standardized basis for compilations and comparisons of nationwide coal resources and reserves. Some ISGS publications written prior to the development of this classification system in 1976 use terms in a manner different from their current definitions. For example, the term "reserves," as used by Smith (1961) is comparable to the term "resources," as now defined.

Other ISGS studies have used terms that are not part of the USGS system. As previously noted, Treworgy and Bargh (1982) created a classification to rank the potential for development of coal deposits in Illinois. Their categories of high, moderate, and low development potential are roughly equivalent to the USGS categories of economic, marginally economic, and subeconomic reserve base.

The term "available coal" is also not a formal part of the USGS system, although commonly used by the USGS, the U.S. Bureau of Mines, and many State Geological Surveys. Eggleston et al. (1990) described the rationale and general methodology for estimating available coal, but did not explain the relationship of available coal to the formal categories of the USGS resource classification system. In this study, "available coal" is considered to be equivalent to the reserve base and inferred reserve base categories of the USGS system. Available coal is also roughly equivalent to the high and moderate development potential categories used by Treworgy and Bargh (1982).

Available coal, as used in this report, is not meant to imply that particular coal deposits can be mined economically at the present time. Rather, the term is used to designate deposits that have no significant characteristics likely to render them technically, legally, or economically unminable for the forseeable future. Further engineering assessments are needed to determine the actual cost and profitability of mining these deposits.

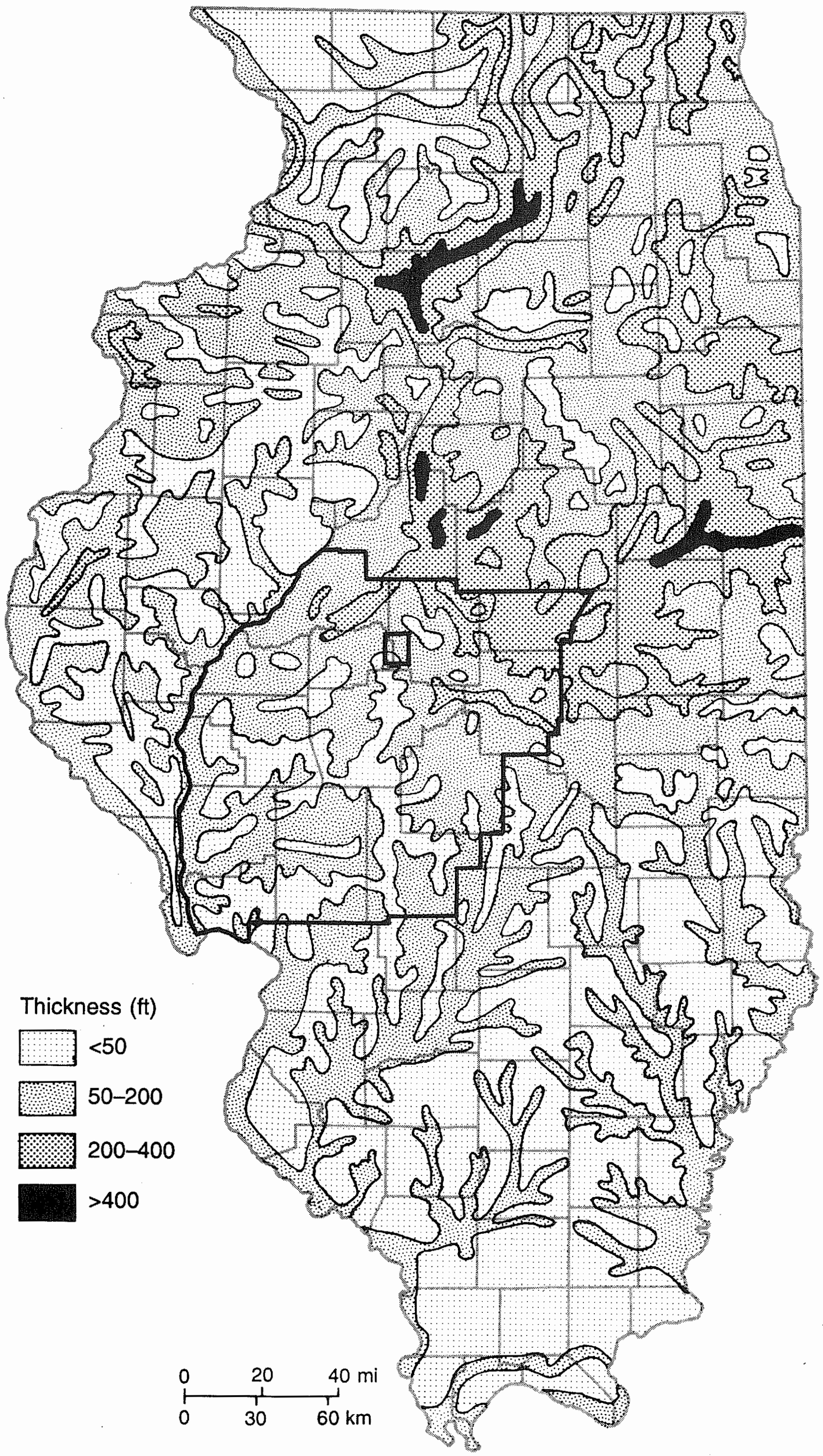


Figure 5 Thickness of Pleistocene deposits in Illinois (from Willman and Frye 1970). Region 3 and the Middletown Quadrangle are outlined.

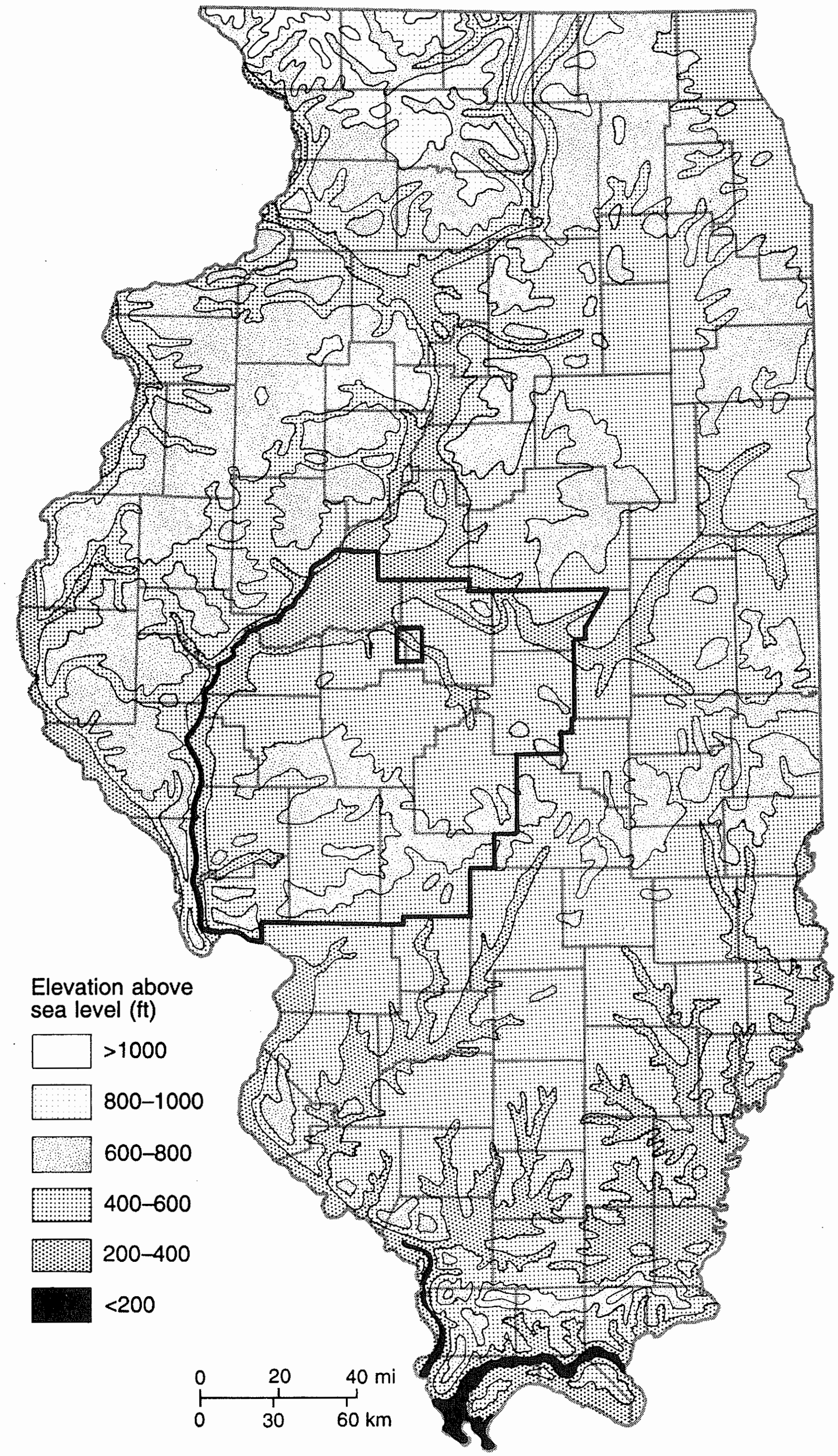


Figure 6 Topography of the bedrock surface in Illinois (from Willman and Frye 1970). Region 3 and the Middletown Quadrangle are outlined.

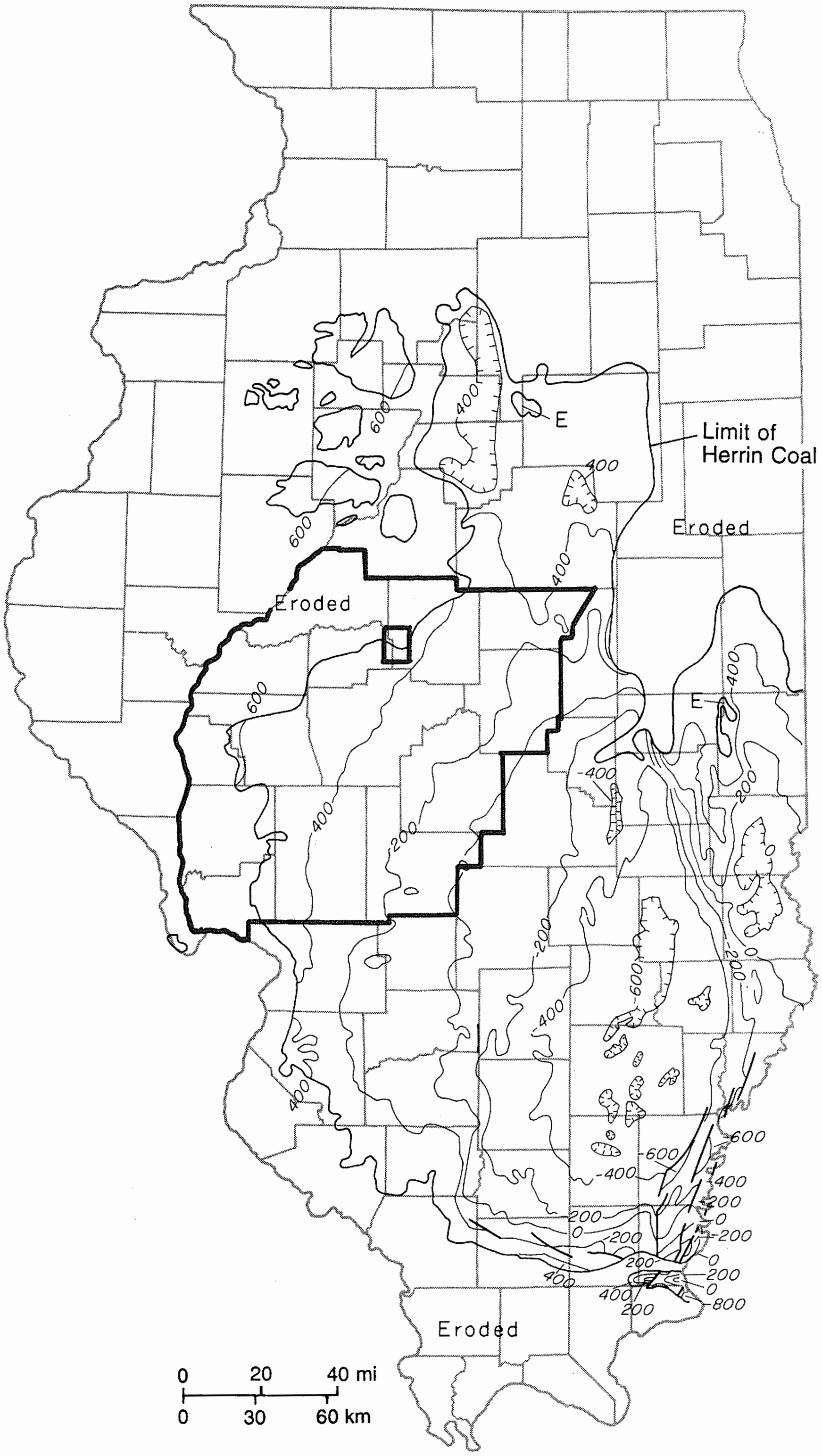


Figure 7 Elevation of the top of the Herrin Coal (from Willman et al. 1975). Contour interval is 200 feet. Region 3 and the Middletown Quadrangle are outlined.

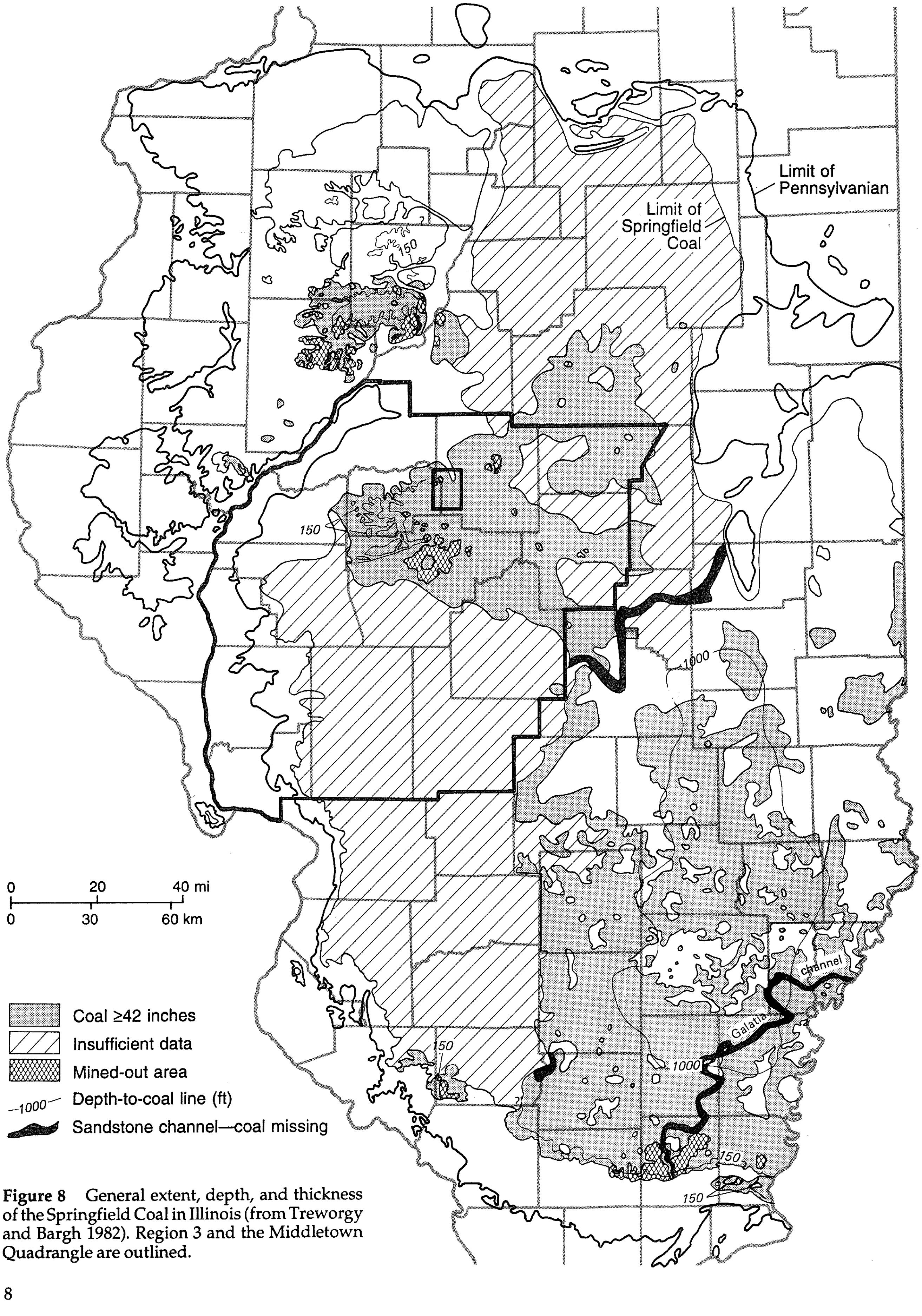


Figure 8 General extent, depth, and thickness of the Springfield Coal in Illinois (from Treworgy and Bargh 1982). Region 3 and the Middletown Quadrangle are outlined.

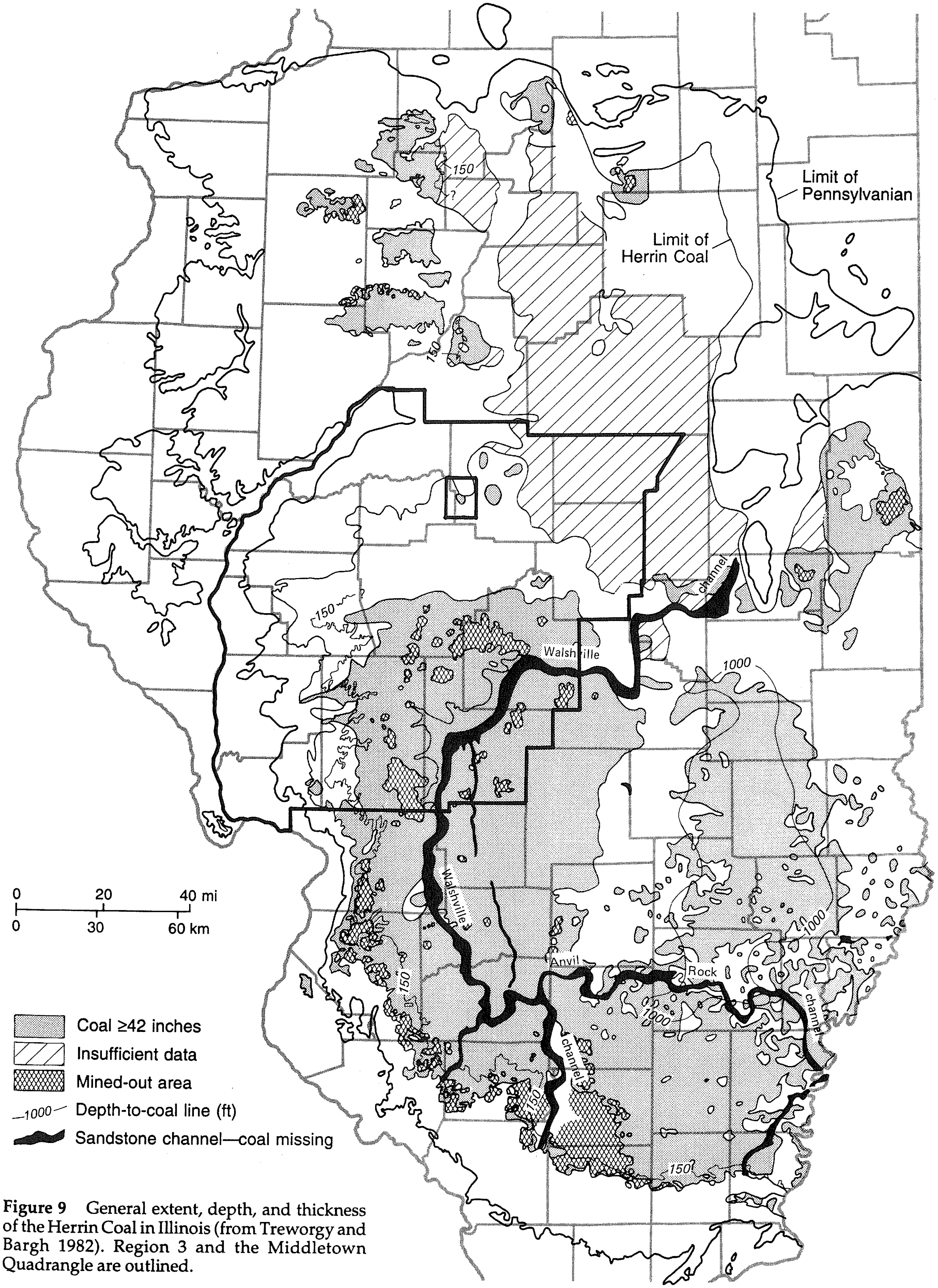


Figure 9 General extent, depth, and thickness of the Herrin Coal in Illinois (from Treworgy and Bargh 1982). Region 3 and the Middletown Quadrangle are outlined.

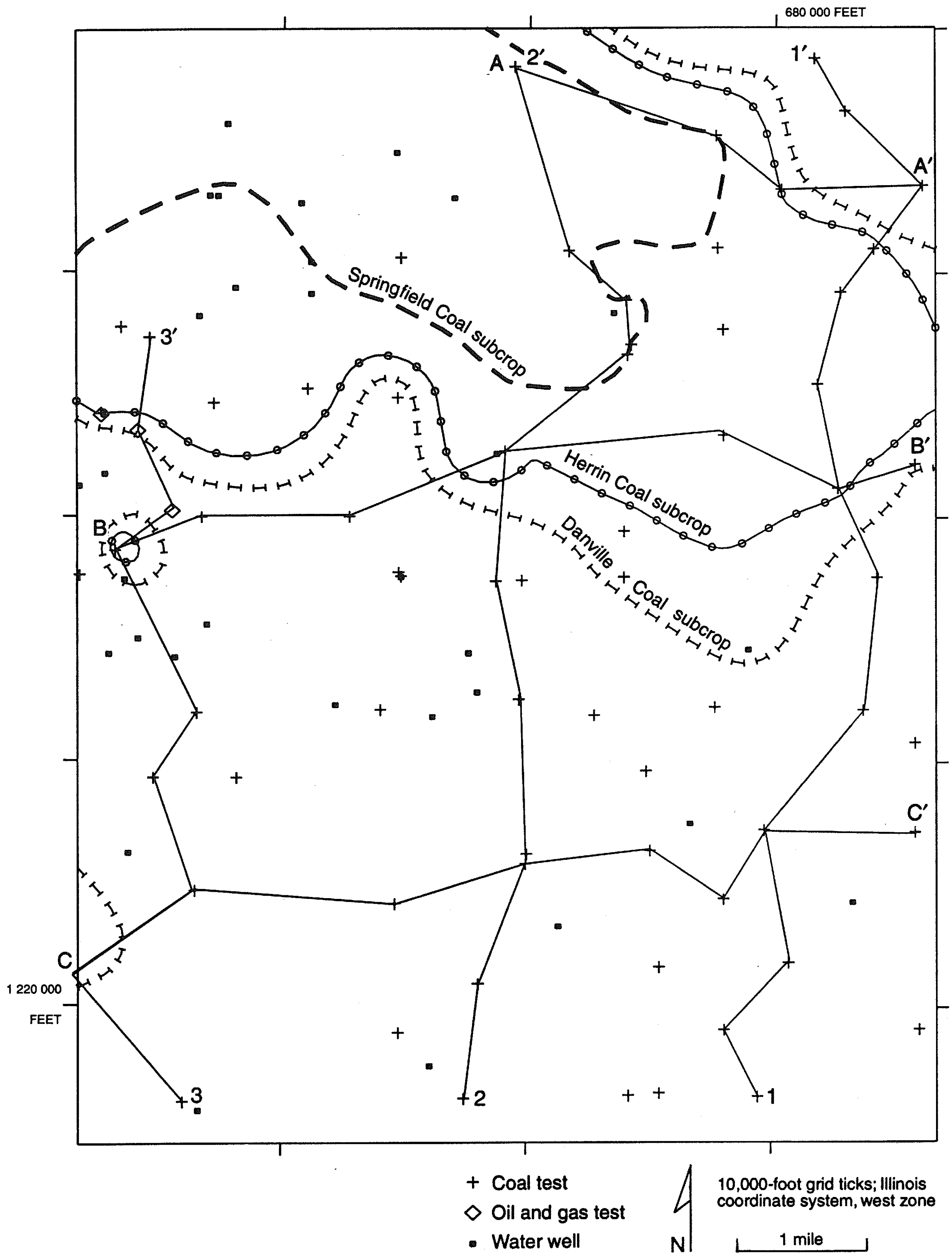


Figure 10 Distribution of data points and cross section lines used in this study.

GEOLOGY OF THE MIDDLETOWN QUADRANGLE

The subsurface geology of the Middletown Quadrangle was mapped using data from 311 boreholes in the study area and a 4-mile zone surrounding it (fig. 10). The 4-mile buffer was used because the ISGS definition of inferred coal resources allows resources to be projected up to 4 miles from a datum point (Cady 1952). The top of the bedrock was penetrated by 272 holes and the Springfield Coal by 223 holes. The deepest were oil test holes that penetrated the entire succession of Pennsylvanian strata (figs. 11 and 12).

Glacial Deposits

Deposits of clay, silt, sand, and gravel cover the entire quadrangle. The thickness of these glacial sediments is directly related to the topography of the concealed, preglacial land surface. A large bedrock valley extends from northwest to southeast across the north half of the quadrangle (figs. 13–17). A tributary to this valley extends southward along the east side of the quadrangle (fig. 18), and another minor valley extends east to west across the southwest quarter (fig. 19). Glacial sediments fill these buried bedrock valleys and form the relatively level land surface now present. Glacial sediments are more than 250 feet thick in the main valley to the north and well over 100 feet thick in the other valleys (fig. 20).

Bedrock Stratigraphy

The uppermost bedrock in the Middletown Quadrangle comprises approximately 400 to 600 feet of Pennsylvanian strata consisting primarily of shale, siltstone, sandstone, and some thin limestones and coals (fig. 11). Eight coals or coal horizons are present. These are, in descending stratigraphic order, the Chapel, Danville, Herrin, Springfield, Houchin Creek, Survant, Colchester, and "Seahorne" Coals. Bedrock units above the Houchin Creek Coal have been eroded across much of the northern half of the quadrangle. They crop out at the bedrock surface beneath the glacial sediments filling the major bedrock valley that crosses the quadrangle.

Chapel Coal In the Middletown Quadrangle, the uppermost named unit is also the uppermost coal. It is thin and widespread in areas to the south and has been mined in areas around Springfield. It is eroded throughout the quadrangle, except for small areas where bedrock is near the surface (fig. 21). The Chapel Coal is 1 to 1.5 feet thick and lies 60 to 85 feet deep.

West Franklin Limestone Although this limestone was deposited throughout the quadrangle, it has been eroded in the bedrock valleys (fig. 22). It ranges from less than 5 feet to more than 20 feet thick.

Danville Coal In areas away from the main bedrock valley, the Danville Coal is present. It is not known to exceed 2.5 feet in thickness (fig. 23). The overburden above the coal ranges from less than 50 feet to almost 200 feet thick (fig. 24).

Anvil Rock Sandstone This zone of sandstone, siltstone, and sandy to silty shale is found 12 to 25 feet below the Danville Coal. In places, the zone contacts the Herrin Coal, and in other places, it lies as much as 15

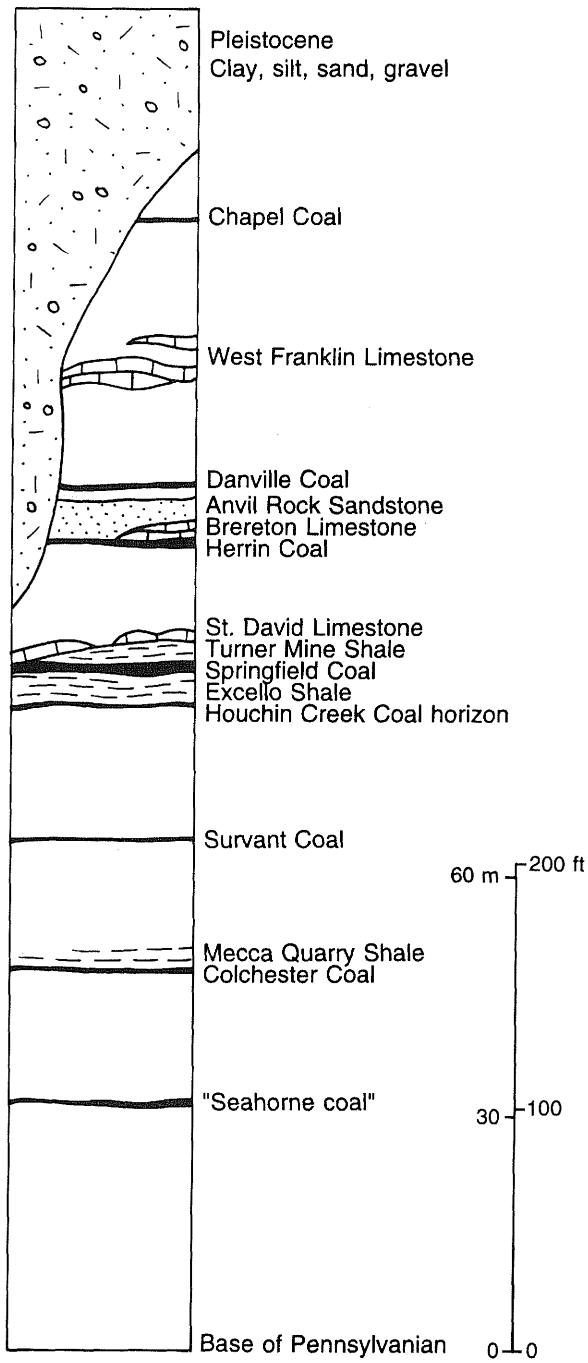


Figure 11 Selected stratigraphic units present in the Middletown Quadrangle. Vertical scale: 1 inch equals approximately 70 feet.

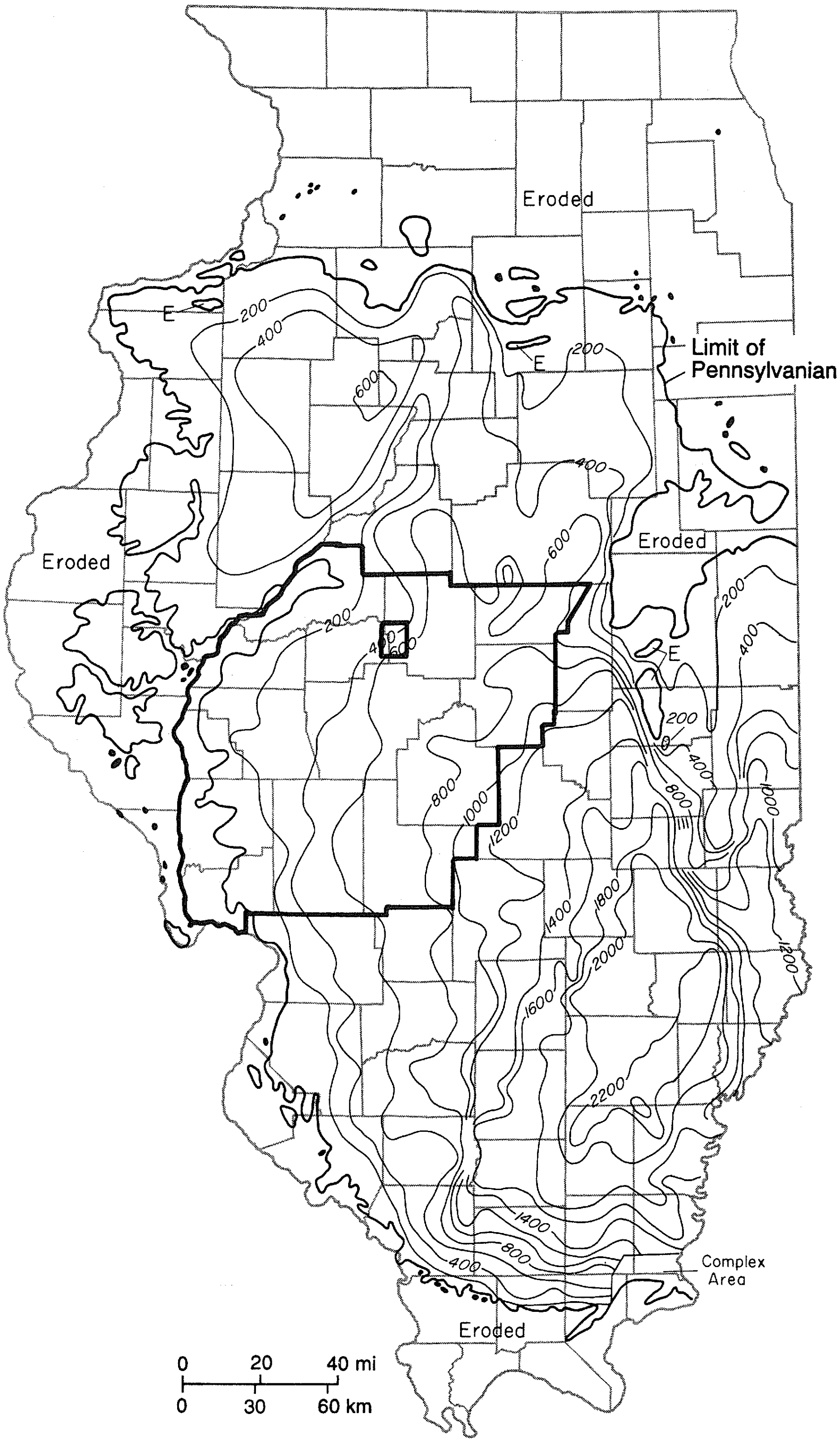


Figure 12 Thickness of Pennsylvanian System in Illinois (from Willman et al. 1975). Contour interval is 200 feet. Region 3 and the Middletown Quadrangle are outlined.

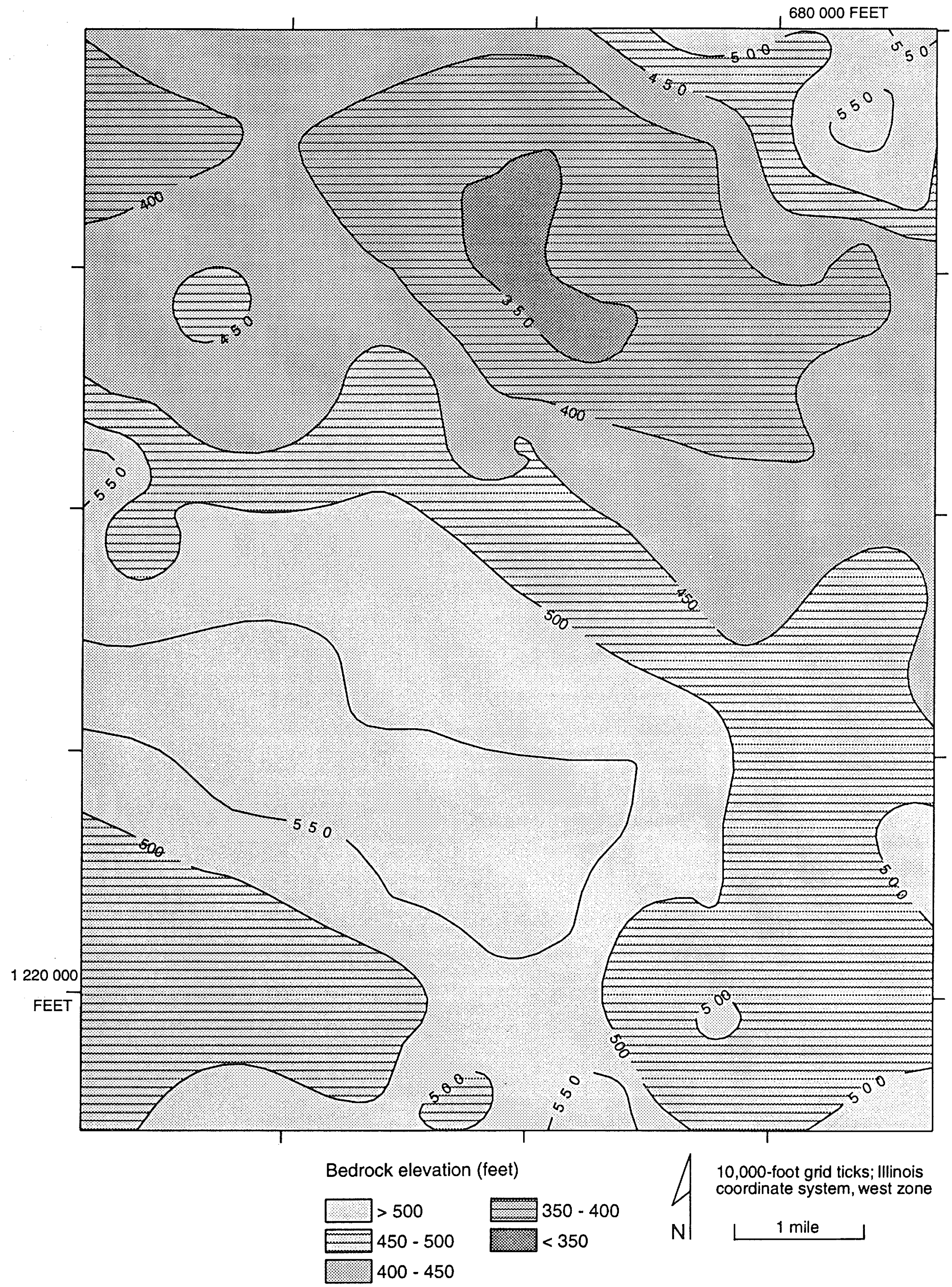


Figure 13 Elevation of the bedrock surface in the Middletown Quadrangle. Contour interval is 50 feet.

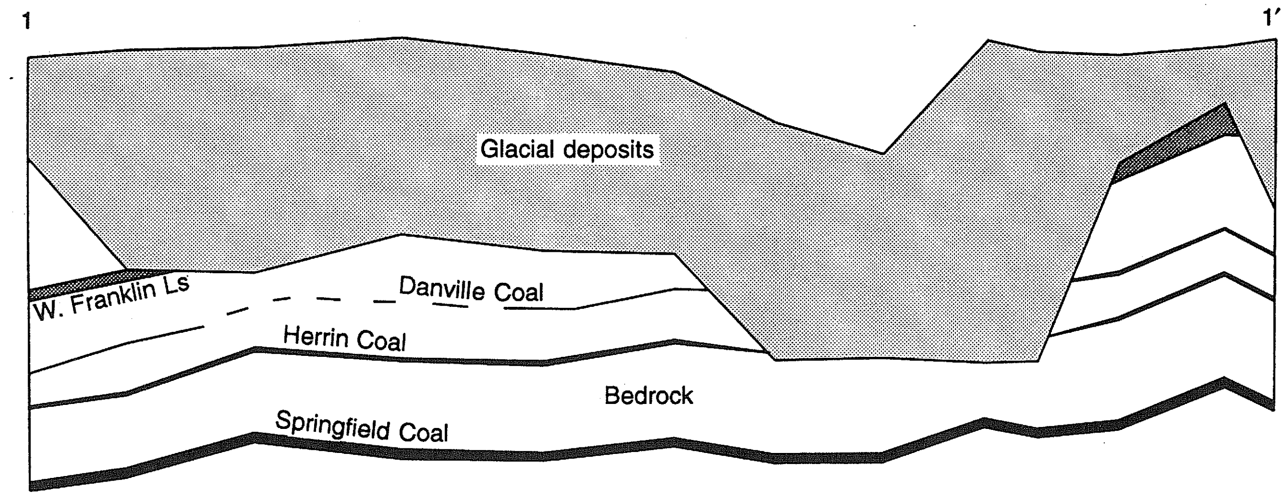


Figure 14 Cross section 1–1′. See figure 10 for location.

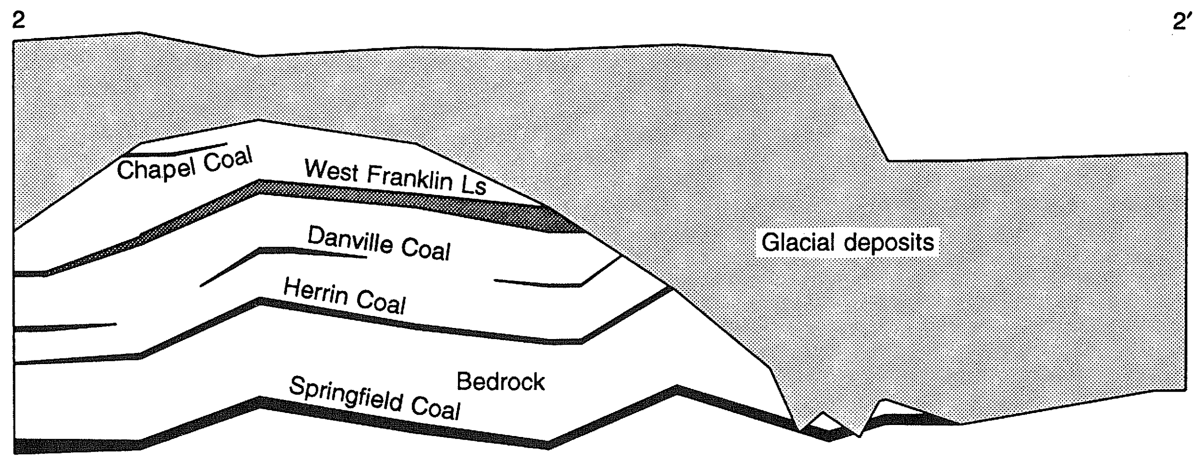


Figure 15 Cross section 2–2′.

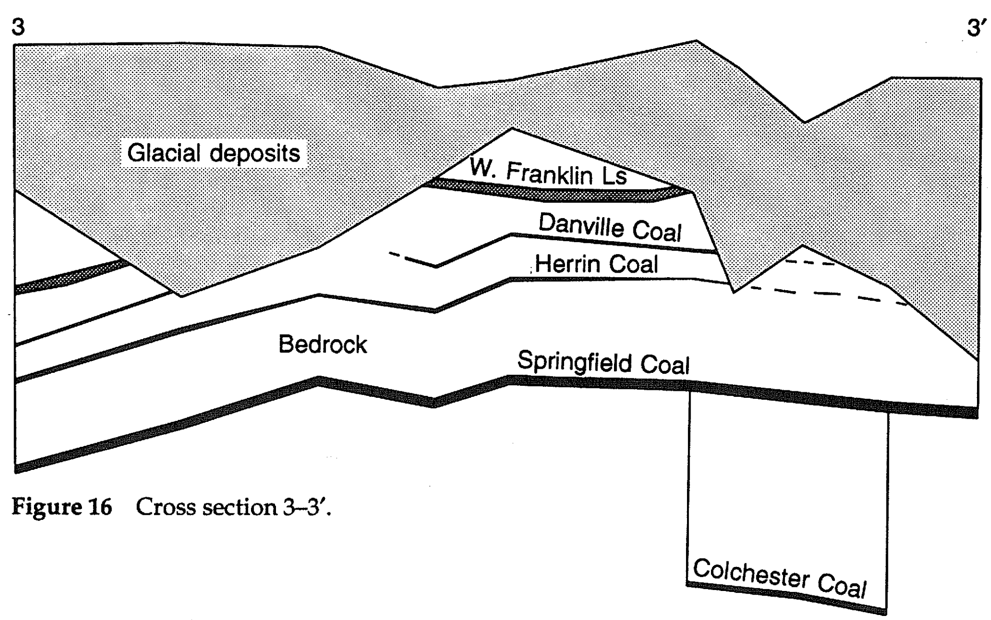


Figure 16 Cross section 3–3′.

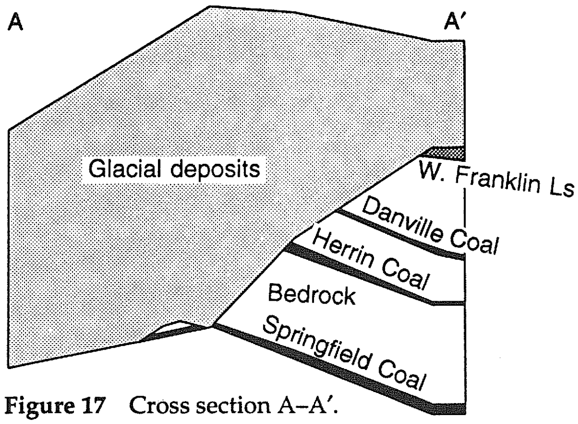
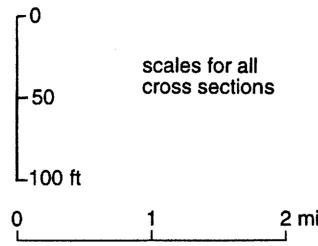


Figure 17 Cross section A–A′.



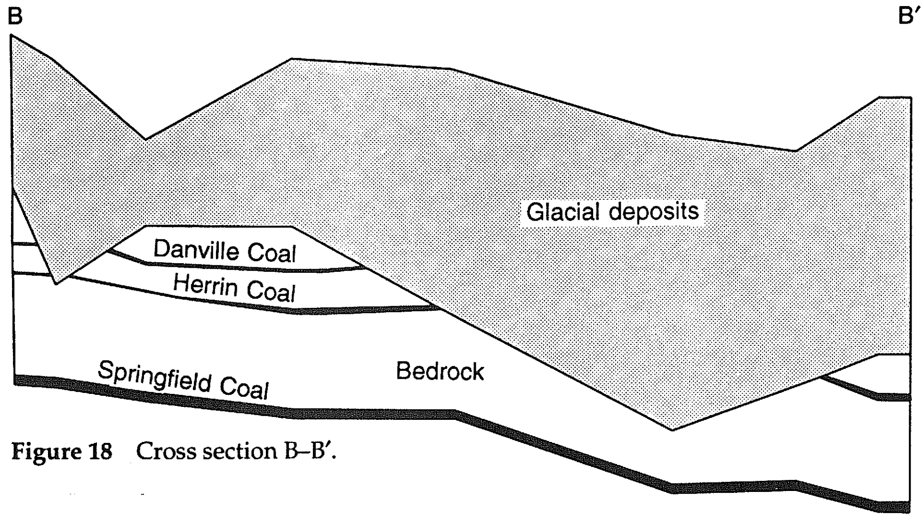


Figure 18 Cross section B–B′.

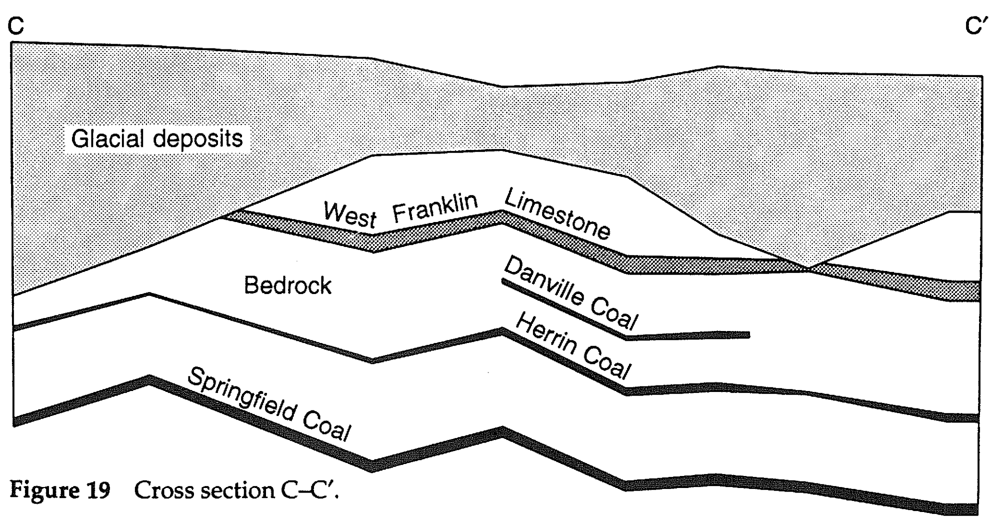


Figure 19 Cross section C–C′.

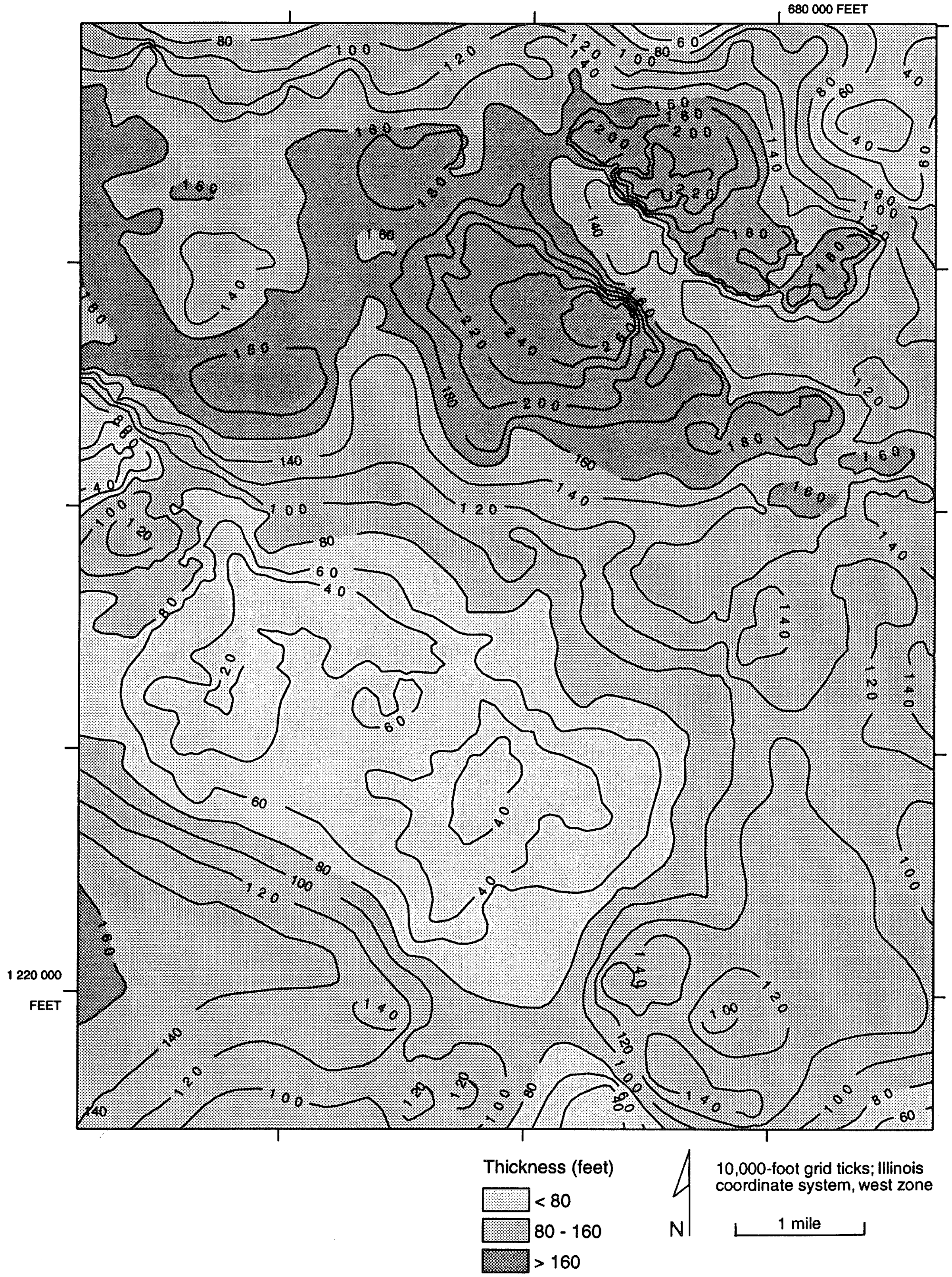


Figure 20 Thickness of glacial sediments in the Middletown Quadrangle. Contour interval is 20 feet.

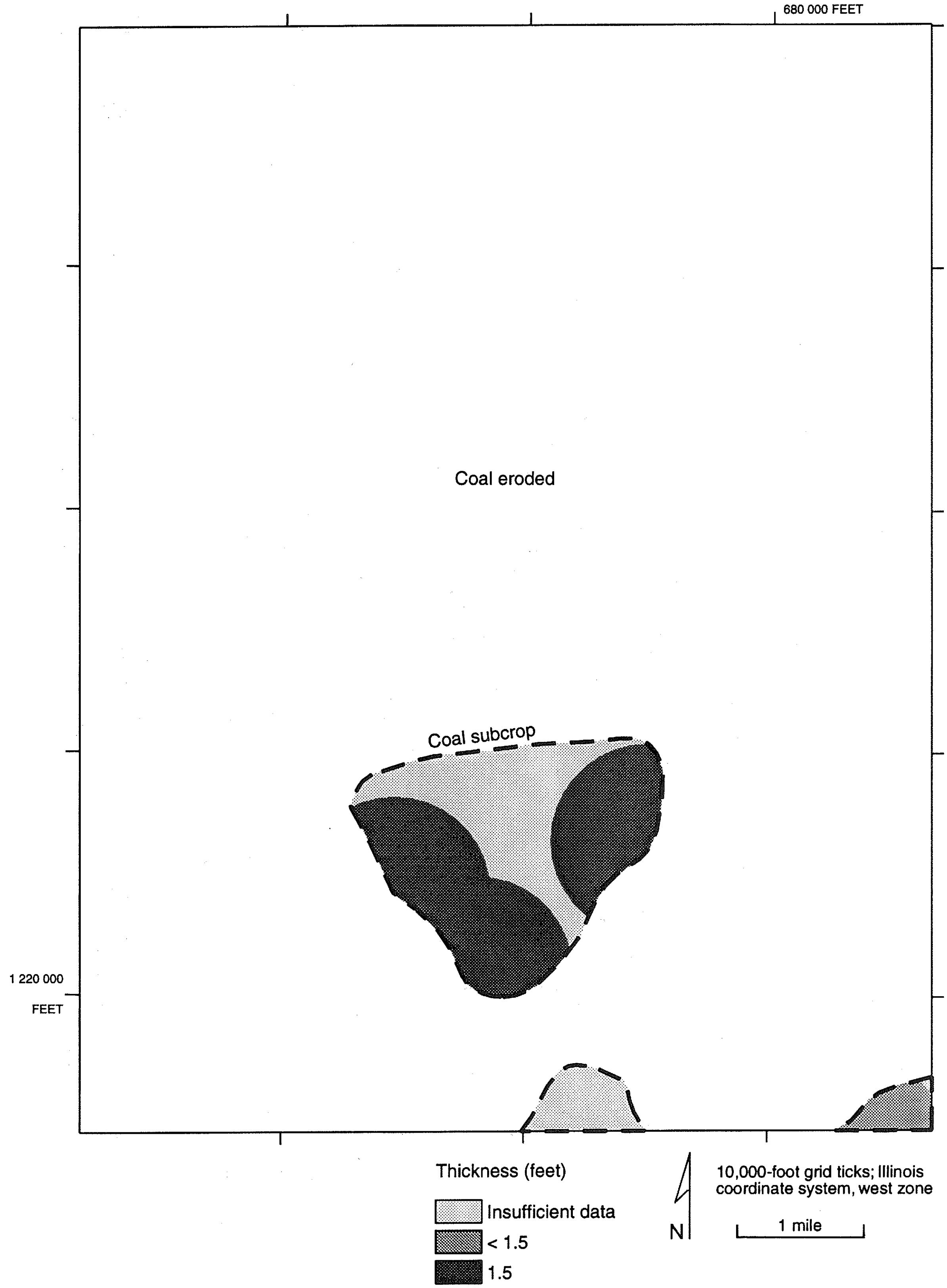


Figure 21 Thickness of the Chapel Coal in the Middletown Quadrangle.

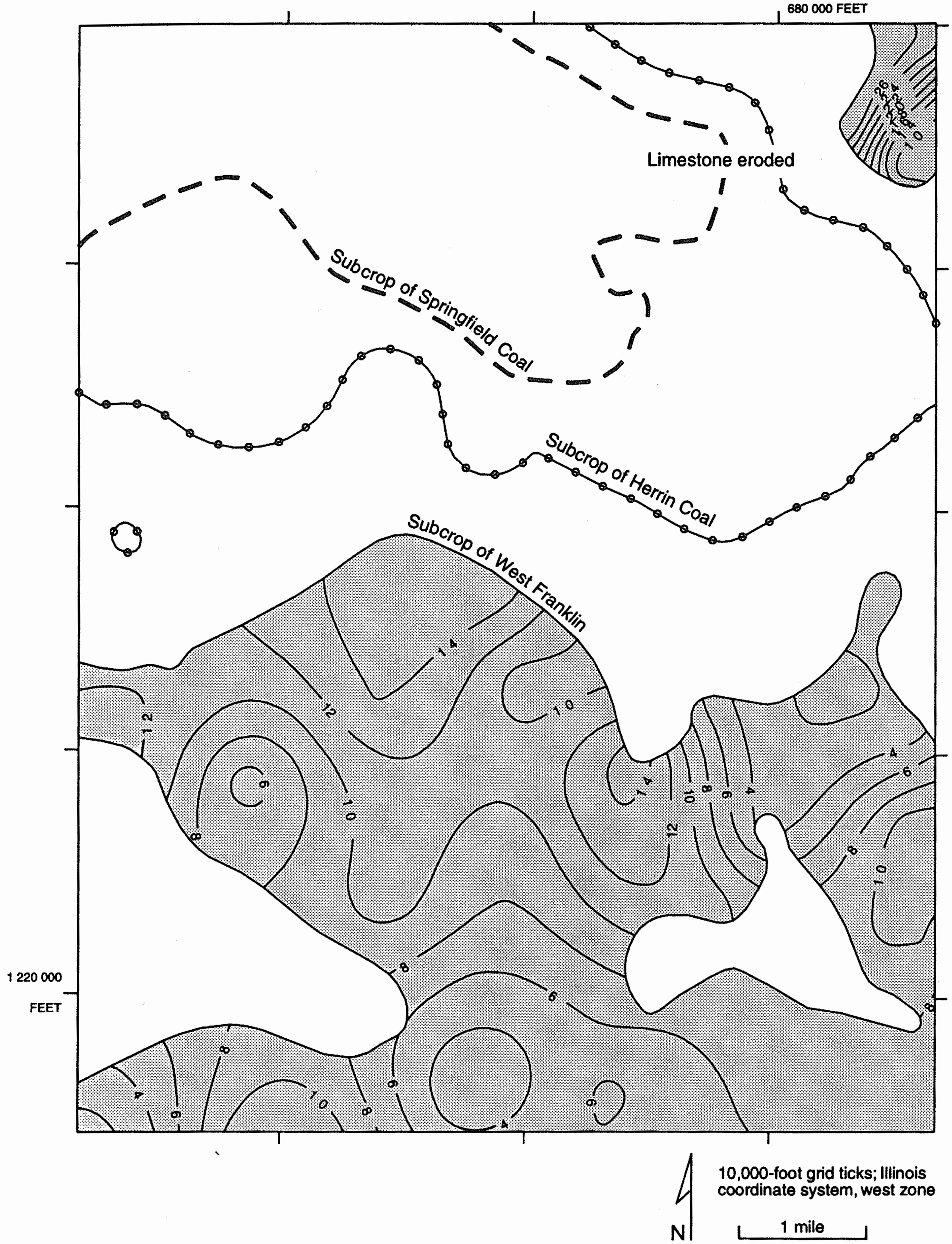


Figure 22 Thickness of the West Franklin Limestone in the Middletown Quadrangle. Contour interval is 2 feet.

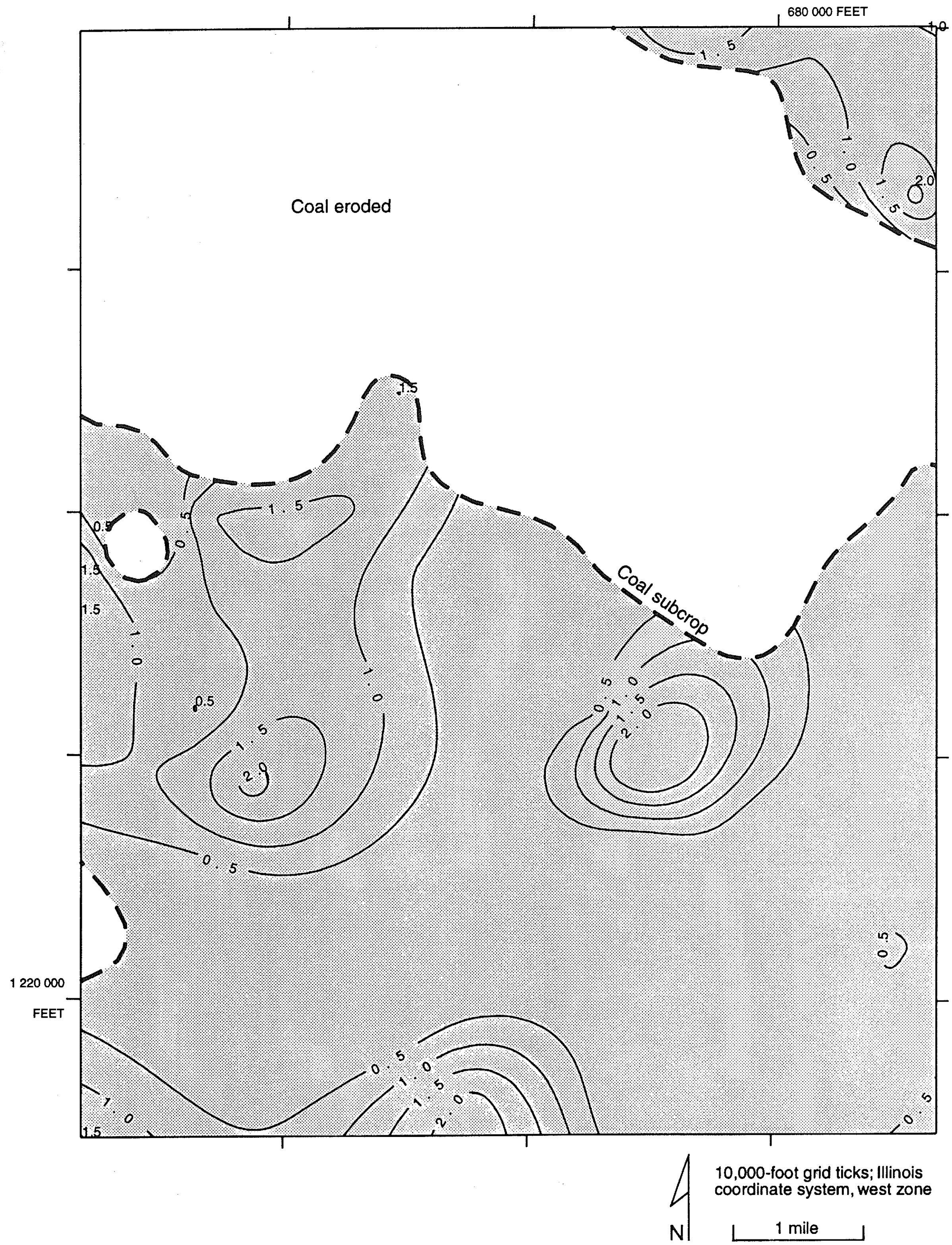


Figure 23 Thickness of the Danville Coal in the Middletown Quadrangle. Contour interval is 0.5 feet.

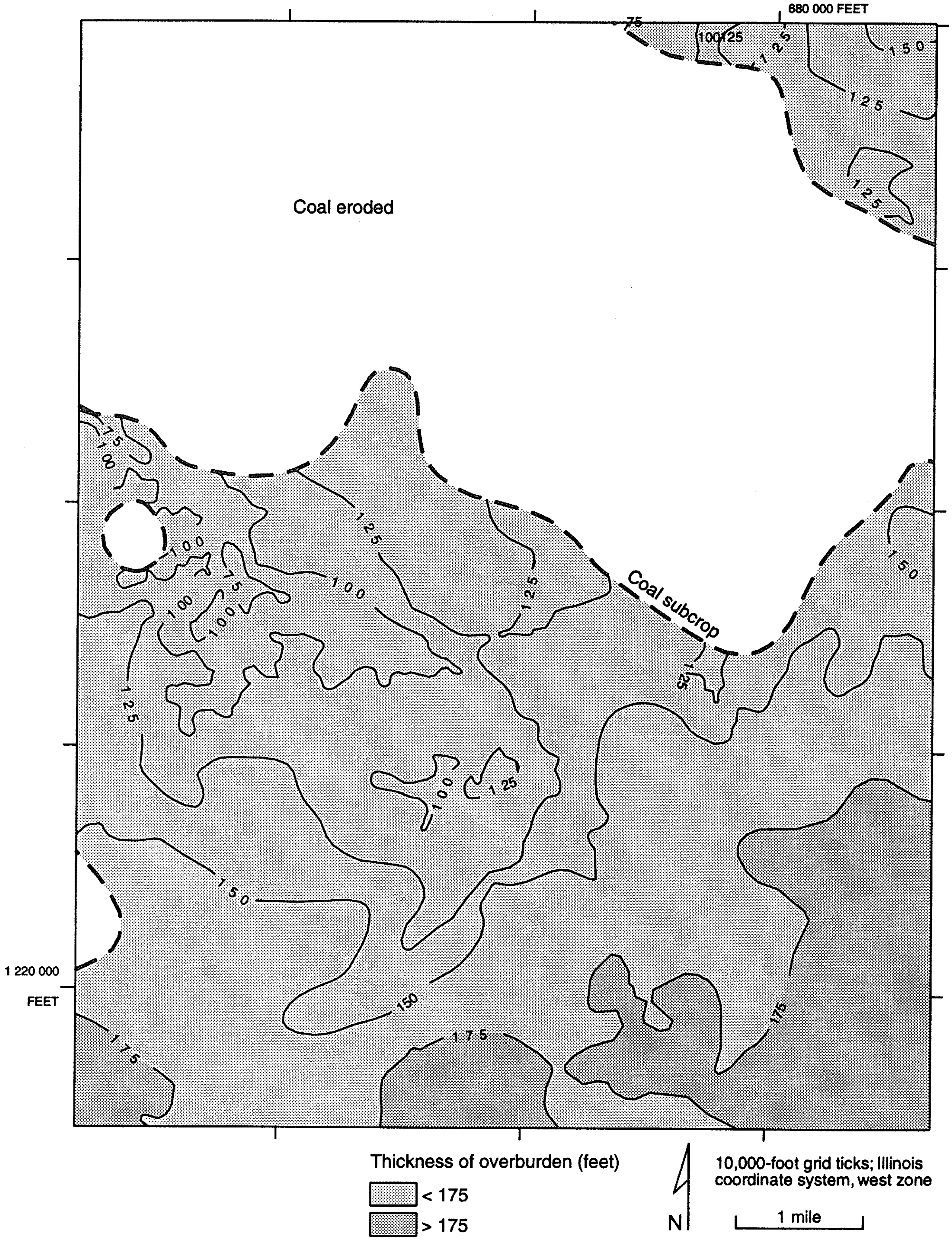


Figure 24 Thickness of overburden of the Danville Coal in the Middletown Quadrangle. Contour interval is 25 feet.

feet above the Herrin. The unit is highly variable in thickness and occurrence, and it is interpreted to be part of an ancient channel system (Nelson 1987, DeMaris and Nelson 1990). In some areas of central Illinois, these channels have eroded into and through the Herrin Coal. The Anvil Rock has also been known to contain water that may seep into a mine through roof bolt holes, natural rock fractures, and roof falls (Cartwright and Hunt 1978). In the Middletown Quadrangle, the Anvil Rock Sandstone ranges from a few feet to 25 feet in thickness. Where it is thick, it lies just above or directly on the Herrin Coal. No areas of ancient erosion, indicated by Anvil Rock sandstone replacing part or all of the Herrin Coal seam, were found. These channels are typically only a few hundred feet wide, however, and could easily be missed by the relatively widely spaced drill holes.

Brereton Limestone Where present, the Brereton Limestone ranges up to 8 feet thick, lying directly on or a few feet above the Herrin Coal. Detailed mapping of the unit in mines in central Illinois shows the Brereton deposited in irregularly shaped lenses (Krause et al. 1979). In the Middletown Quadrangle, the Brereton was present in less than 25% of the holes. This limestone is important for roof control in mines in the Herrin Coal. Where the limestone is about 2 feet thick or more, it provides an anchor for roof bolts and can form a cap on minor roof falls.

Herrin Coal The most abundant coal resource in Illinois, the Herrin Coal, is best developed in the south-central, southern, and northwestern parts of the state (fig. 9). In the area of the Middletown Quadrangle, the Herrin Coal varies in thickness, reaching a maximum of slightly more than 4 feet (fig. 25). Because of the nature of many geophysical logs from this area, coal is generally not detectable where it is less than about 1 foot thick. Consequently, it was not possible to determine whether the coal is absent in some areas or merely very thin. The coal crops out beneath the glacial sediments along the main buried bedrock valley in the northern part of the quadrangle and around a small bedrock low along the west-central edge of the quadrangle. The thickness of its overburden ranges from more than 50 feet along stream valleys in the northwest to more than 200 feet in the southeast (fig. 26).

St. David Limestone This unit is found directly on or a few feet above the Springfield Coal. It is recorded as more than 9 feet thick on a few logs, but it was 3 feet thick or less on about 85% of them. The St. David, which provides an important anchor for roof bolts, was present in most holes in this area.

Turner Mine Shale This black, marine shale directly overlies the Springfield Coal. It is present throughout the quadrangle and ranges in thickness from a few inches to several feet. Where the shale has been mapped in nearby underground mines, it has been found to be deposited in lenticular bodies that vary extremely in thickness within a distance of a few tens of feet. Drill holes spaced no more than a few hundred feet apart are needed to adequately map the thickness of this unit.

Springfield Coal The second most abundant coal resource in Illinois, the Springfield Coal, is relatively thick and continuous over large areas of central and southeastern Illinois. The Springfield is 4.5 to 6 feet thick throughout the Middletown Quadrangle, except where it has been removed by Pleistocene erosion (fig. 27). It crops out beneath the glacial sediments along the western portion of the main bedrock valley in the quadrangle. The thickness of the overburden over the coal ranges from more than 125 feet along stream valleys in the north and west to more than 250 feet in the southern areas of the quadrangle (fig. 28).

Excello Shale/Houchin Creek Coal Formerly the Summum (No. 4) Coal, the Houchin Creek is found 15 to 20 feet below the Springfield Coal. All available data indicate that the coal is less than 2.5 feet thick throughout the quadrangle. The position of the coal horizon is easily identifiable on gamma logs by reference to the overlying Excello Shale, a black marine shale.

Survant Coal Formerly the Shawneetown (No. 2A) Coal, this unit occurs about 75 feet below the Springfield Coal and 50 feet above the Colchester Coal. The Survant was less than 2.5 feet thick in all the holes that penetrated this horizon in this quadrangle, although it is as much as 3 feet thick in adjacent quadrangles.

Colchester Coal This unit lies about 125 feet below the Springfield Coal. In this quadrangle, only five holes penetrated the Colchester horizon; the coal was 2 to 3 feet thick in three of the holes, but thin or absent in the other two (fig. 29). In some areas north of the quadrangle, the Colchester Coal is of interest because of its low to moderate sulfur content. In this area, however, the coal is overlain by a marine black shale (Mecca Quarry Shale Member) and thus may have a high sulfur content.

"Seahorne coal" On several logs, a coal was noted at a position 60 to 70 feet below the Colchester Coal. The coal is below what is interpreted to be the Carrier Mills Shale Member and above the Stonefort Limestone. Smith (1958) described a coal in about this position in southern Illinois and referred to it informally as the "Seahorne coal." This coal was 3 to 4 feet thick in nine holes within the study area (fig. 30). Only two holes penetrated this horizon within the quadrangle. The coal was absent in one hole, but was approximately 4 feet thick in the other.

Structure

No major geologic structures have been found in this quadrangle. The bedrock strata dip gently to the east and south at rates generally less than 30 feet per mile

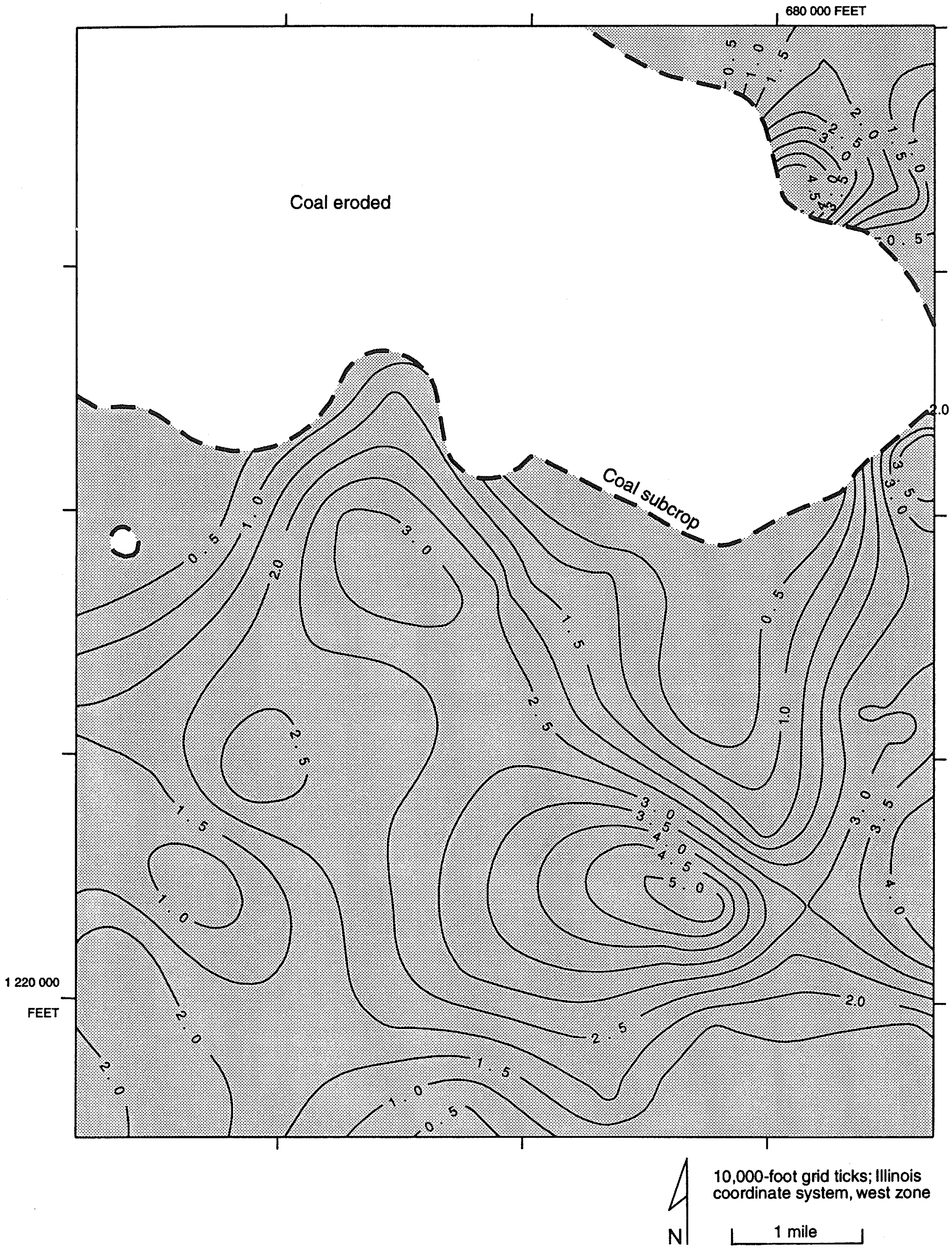


Figure 25 Thickness of the Herrin Coal in the Middletown Quadrangle. Contour interval is 0.5 feet.

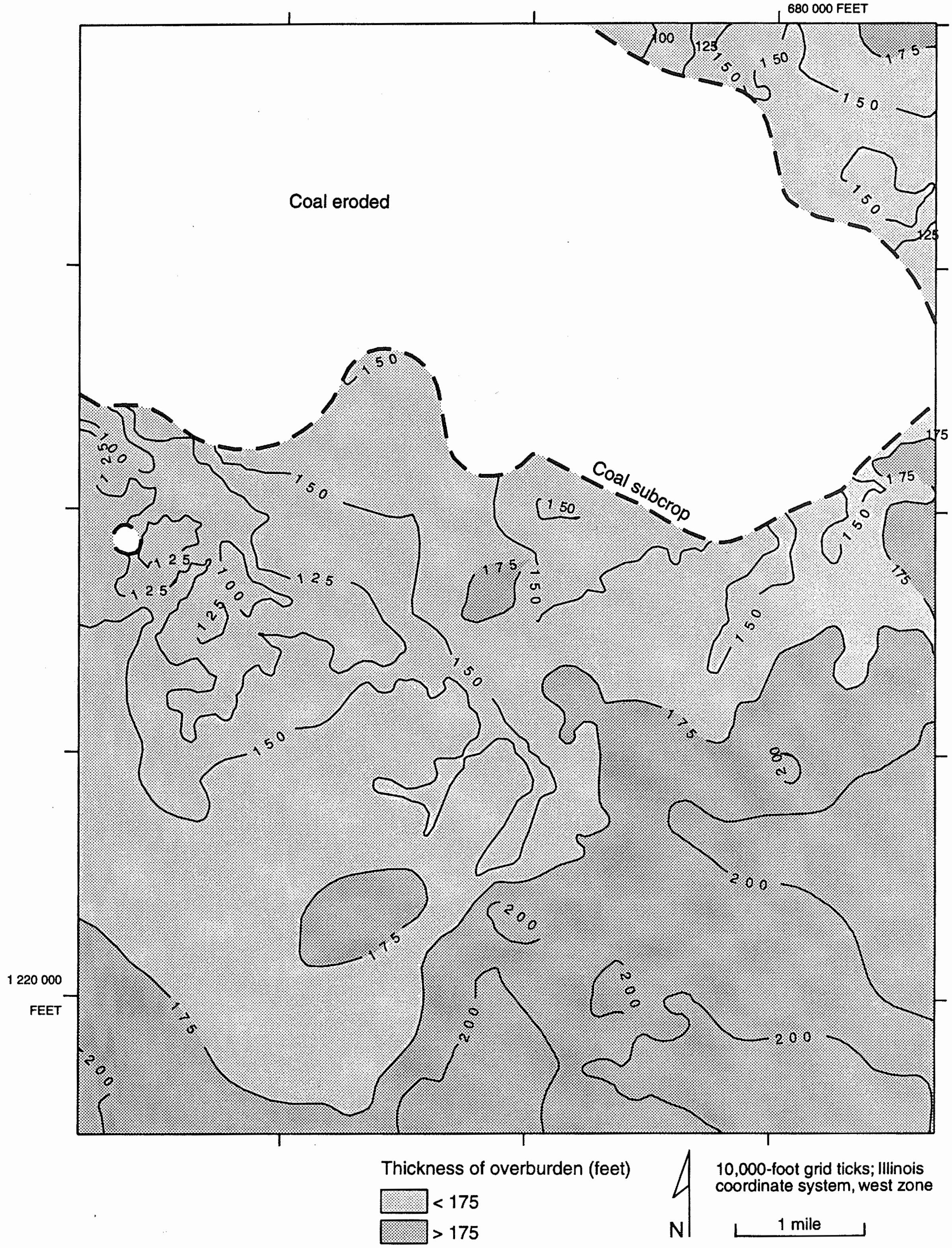


Figure 26 Thickness of overburden of the Herrin Coal in the Middletown Quadrangle. Contour interval is 25 feet.

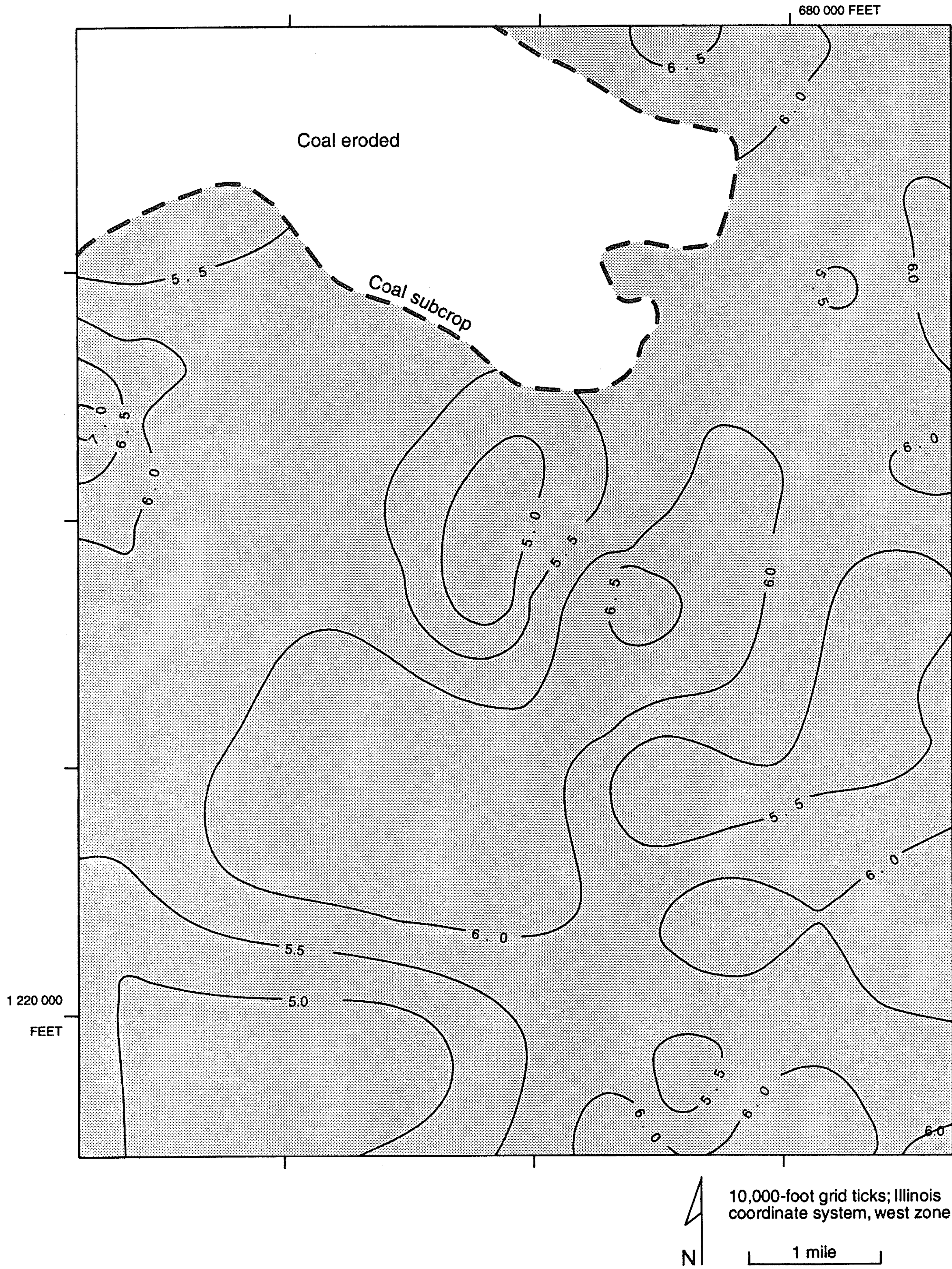


Figure 27 Thickness of the Springfield Coal in the Middletown Quadrangle. Contour interval is 0.5 feet.

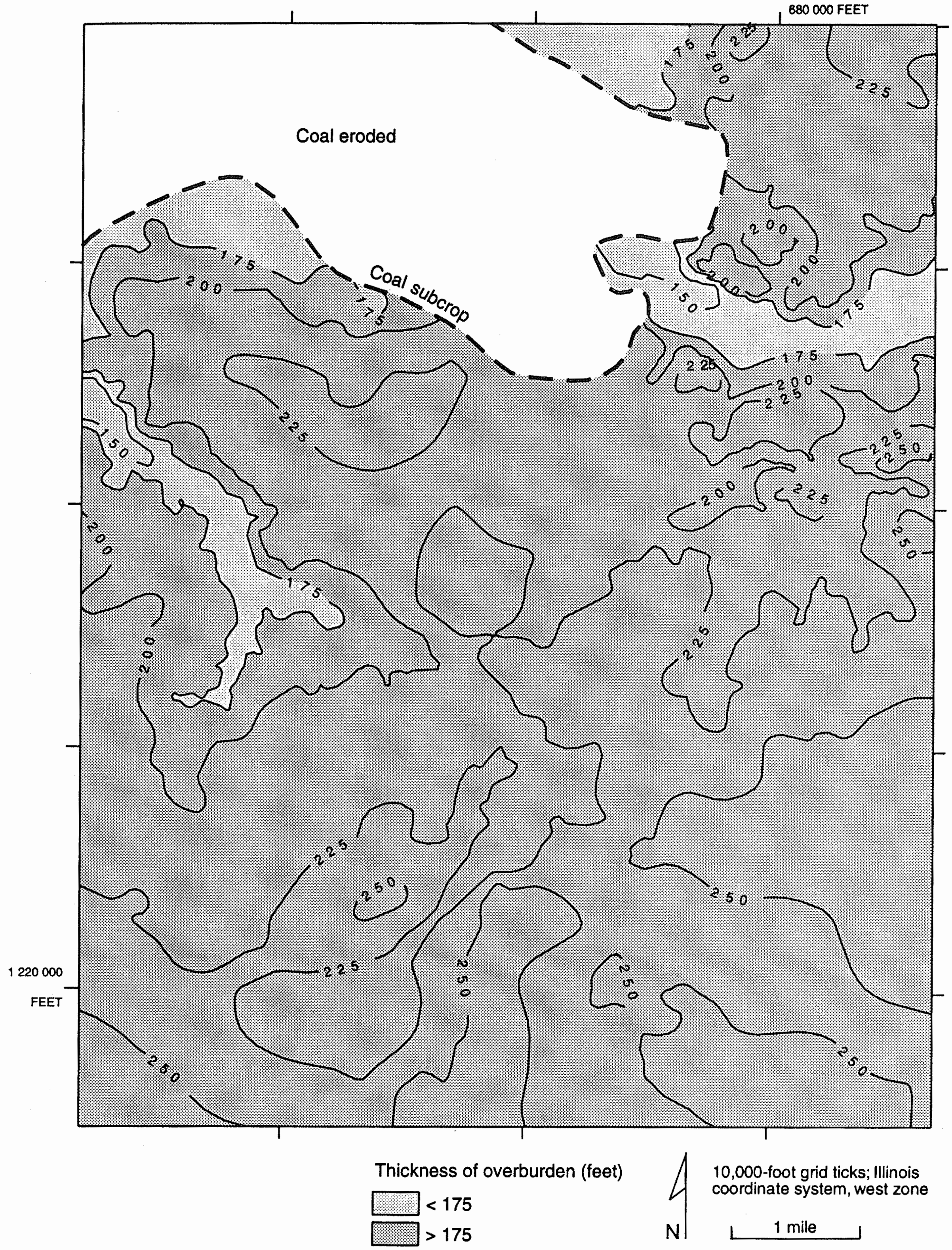


Figure 28 Thickness of overburden of the Springfield Coal in the Middletown Quadrangle. Contour interval is 25 feet.

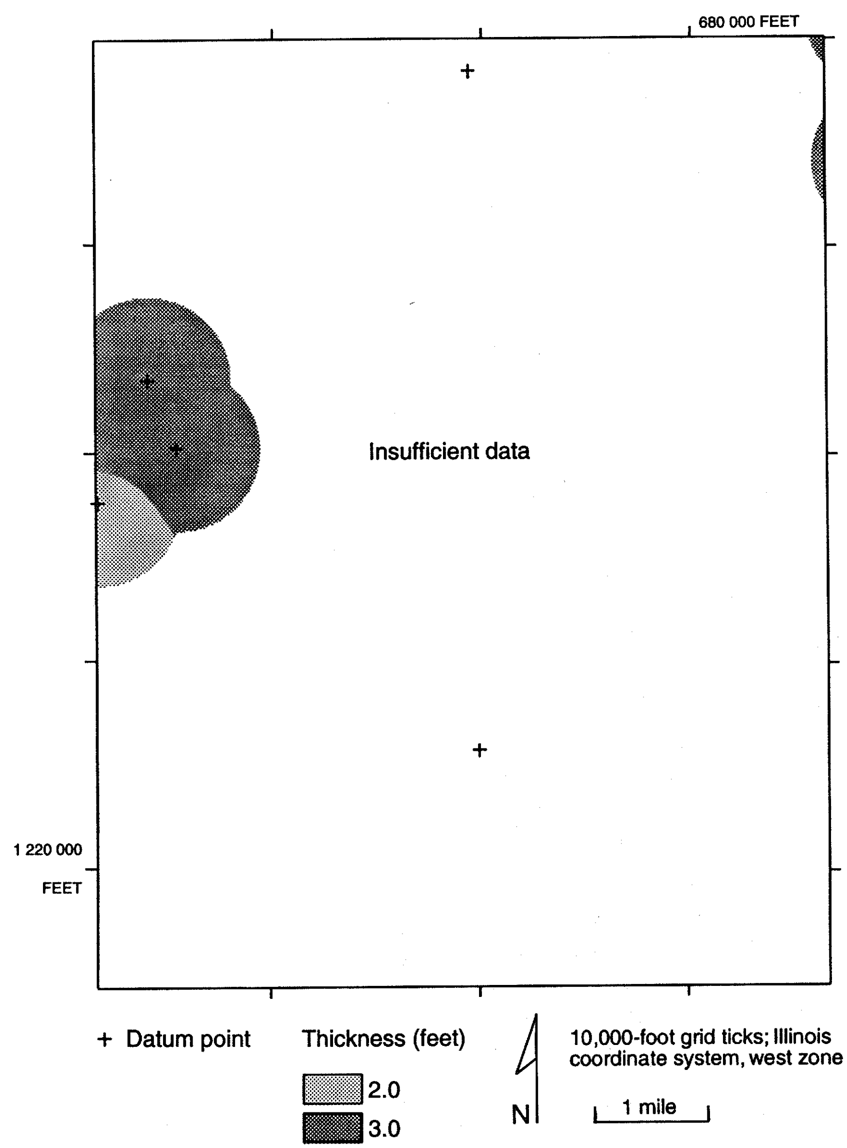


Figure 29 Thickness of the Colchester Coal in the Middletown Quadrangle.

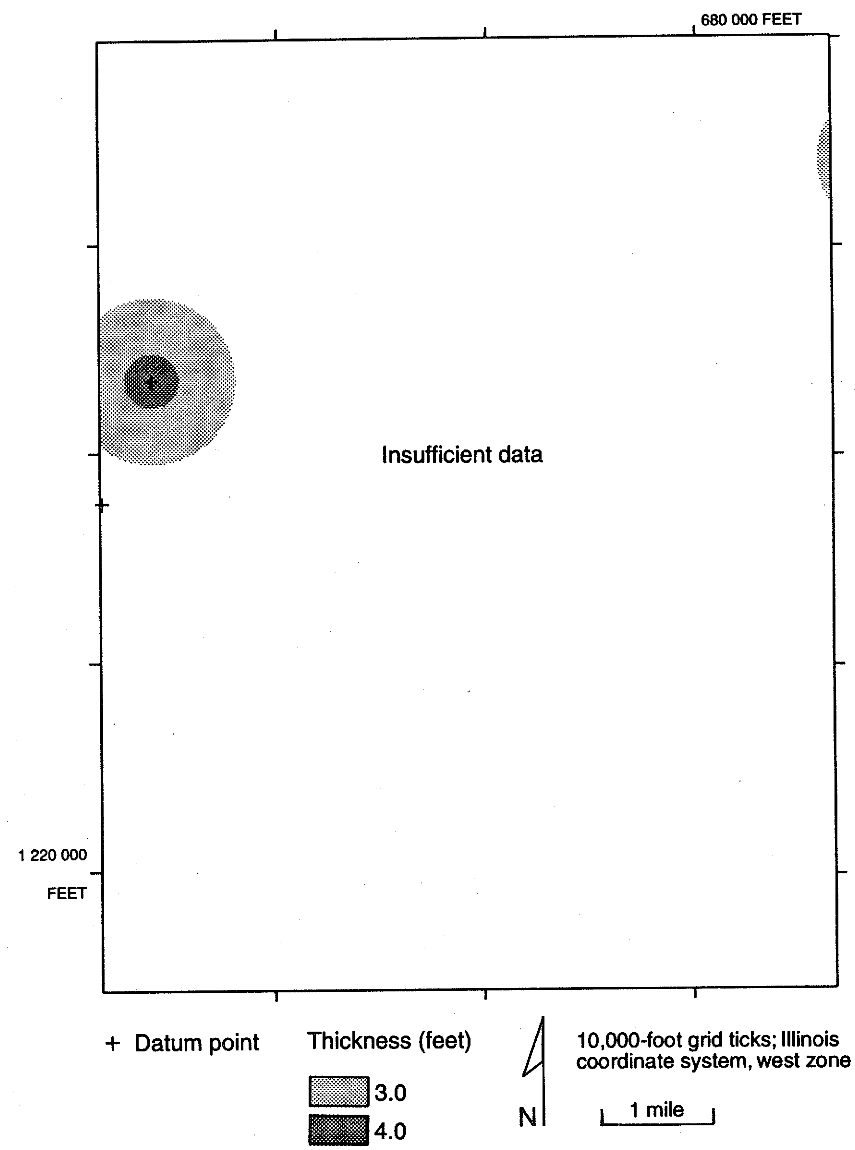


Figure 30 Thickness of the "Seahorne coal" in the Middletown Quadrangle.

(fig. 31). There is evidence of a small dome or ridge in the northeastern corner of the quadrangle. This feature may be related to the Lincoln Dome located a few miles to the northeast.

The clastic dikes (also called horsebacks or clay dikes) and associated faults commonly found in the Herrin and Springfield Coals in central Illinois are believed to be abundant in this quadrangle as well. Clastic dikes were noted in the Springfield Coal in two of the drill holes in the study area. They also were reported in the two mines in this quadrangle. Complete descriptions of clastic dikes and the mining problems associated with them can be found in Damberger (1970), Krause et al. (1979), and Nelson (1983).

LAND COVER AND OTHER FEATURES OF THE MIDDLETOWN QUADRANGLE

The Middletown Quadrangle is a rural area used primarily for row crops and pasture. The small community of Middletown, located in the northwest quarter of the quadrangle, is the only town in the study area (fig. 32). Interstate 55 and tracks of the Illinois Central Railroad cross the southeast corner of the quadrangle. Several large diameter pipelines and a high-voltage transmission line cross the entire quadrangle from north to south. The only major water body is Salt Creek, which traverses the northern quarter of the quadrangle. The river channel of Salt Creek is 100 to 200 feet wide and its floodplain is more than 1 mile wide in some places.

With the exception of several small knobs deposited by glaciers, the land surface in much of the southern part of the quadrangle is essentially flat and has poorly developed drainage. The central and northern areas of the quadrangle have gently rolling topography and well developed drainage.

MINING HISTORY

Two underground mines, both in the Springfield Coal, have operated in the Middletown Quadrangle (fig. 32). They are now abandoned. The mining conditions in these mines were probably typical of the area.

The Johnson Mine, active from 1903 to 1947, produced a reported total of 690,856 tons. The coal was 180 feet deep at the main shaft, which was located near the northeast corner of the mine. Poor roof conditions, encountered immediately to the north and east of the shaft, were probably due to the thin bedrock cover overlain by a thick layer of glacial sediments. (See the discussion of bedrock cover in the section, "Thickness and Composition of Bedrock Overburden.") Mining to the west and south was under thicker bedrock cover and apparently encountered few roof control problems. Clastic dikes were also common throughout the mine.

The Middletown Mine, active from 1903 to 1912, produced a reported total of 474,724 tons. The coal was 210 feet deep at the main shaft. The mine operated under 25 to 100 feet of bedrock cover overlain by 120 to 200 feet of glacial drift. Under such conditions, supporting the roof would have been difficult. Although little is known about actual conditions in the mine, the irregular pattern of room development suggests that problems were encountered, particularly to the west and north of the shaft. Numerous clay veins were reportedly present throughout the mine.

FACTORS AFFECTING THE AVAILABILITY OF COAL

The availability of coal for future mining in the Middletown Quadrangle is limited by several factors. These were identified through interviews with mining engineers and geologists from three coal companies that have mines in geologic and physiographic settings similar to those found in the quadrangle. Staff members of the Illinois Department of Mines and Minerals (IDMM), the state agency responsible for permitting and inspecting mines, also were interviewed. Although this sampling of experts probably does not represent the views of all mining companies, it provides a reasonable basis for estimating the available coal resources in the Middletown Quadrangle.

Past experience has shown that more complete and accurate information on restrictions to mining is obtained when questions are based on specific tracts of land (Treworgy 1991). For this reason, discussion in the interviews was limited to the geology and coal resources of the Middletown Quadrangle. Although this approach helped to focus on the details of restrictions to coal availability in the area, factors not well represented by the particular combination of conditions found in this quadrangle may not have been well represented in the discussions. Care should be taken when extrapolating the findings of this study to other areas.

Availability of coal must be evaluated with respect to the mining method that will most likely be used to recover the coal. In Illinois, coal is mined by both surface and underground methods. The equipment and procedures used in each method change in response to economic pressures, new technologies, and legal restrictions. This evaluation of coal availability is based

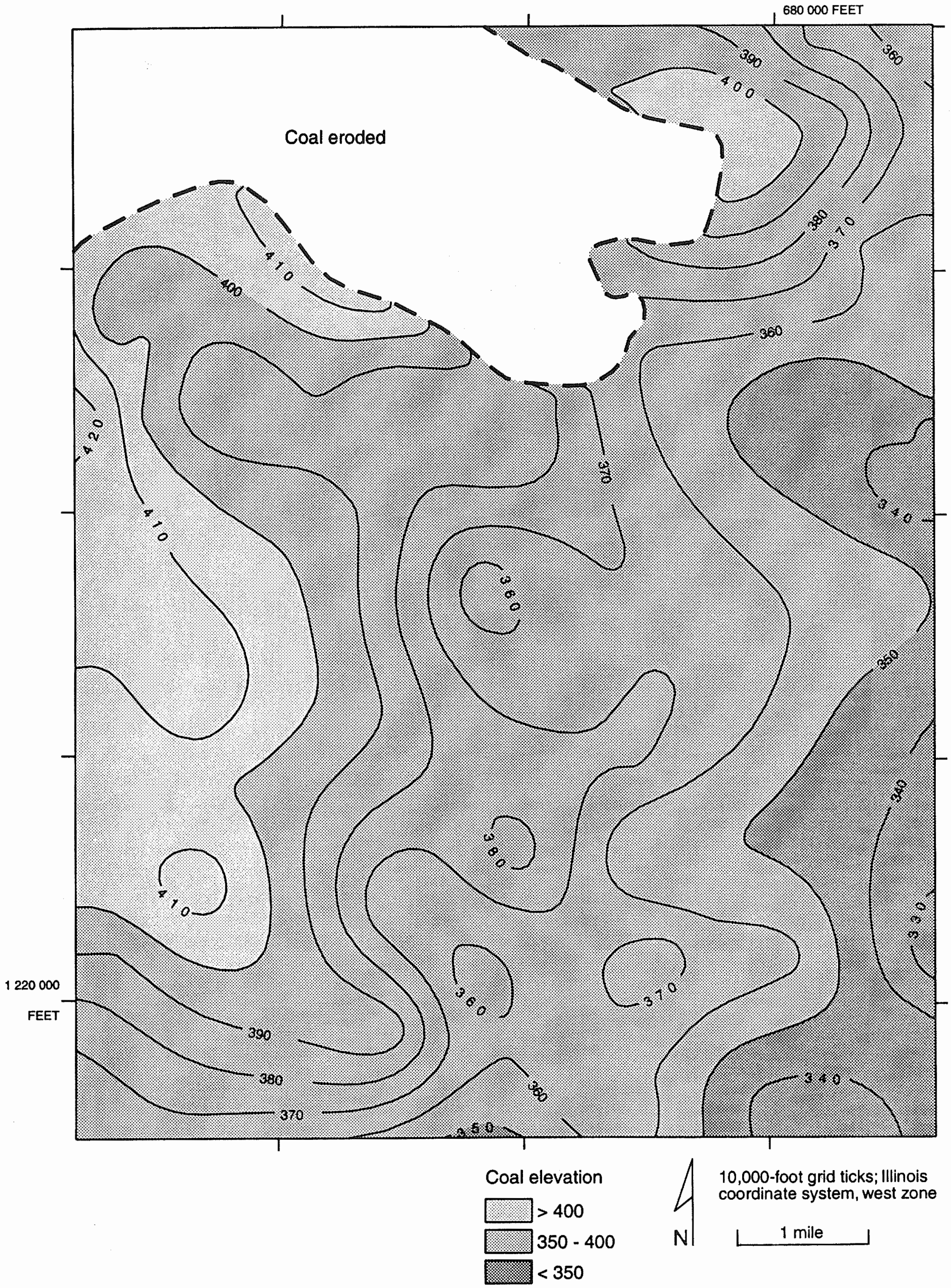


Figure 31 Elevation of the top of the Springfield Coal in the Middletown Quadrangle. Contour interval is 10 feet.

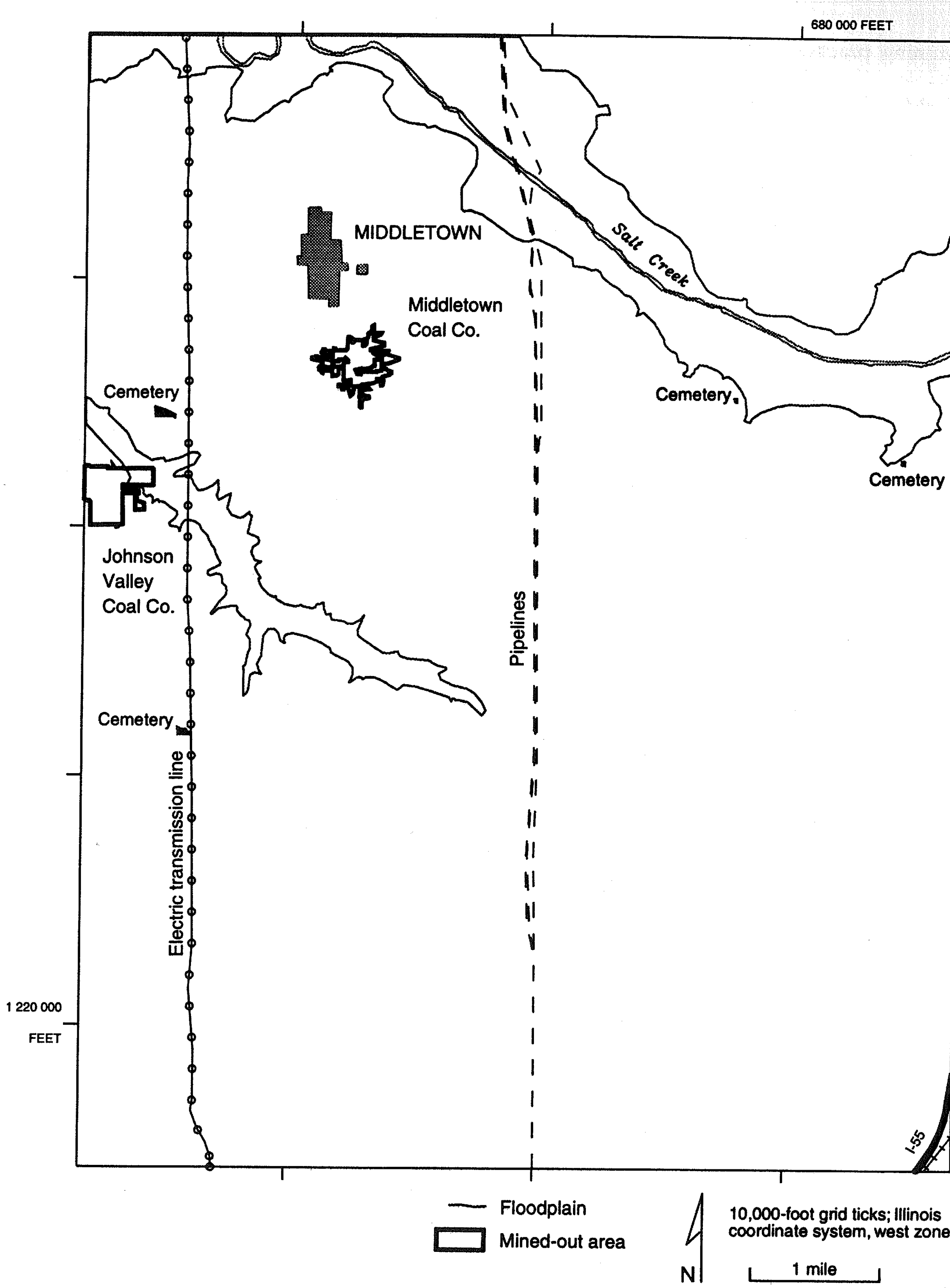


Figure 32 Selected features of the Middletown Quadrangle.

on current mining practices of companies active in Illinois.

In a few cases, the values of factors that limit the availability of coal for mining are specified by law (e.g. the width of unmined coal to be left between underground mines). In most cases, however, the limits are based on a general consensus of mining experts on minimum coal thickness, maximum coal depth, minimum bedrock cover, and minimum size of mining block. The experts generally agreed on most criteria for defining available coal. Where they differed, the range of values has been given and the rationale described.

Surface Minable Coal

Shallow coal deposits are mined by open pit or surface operations whenever possible. Generally, more of the deposit can be recovered by a surface mine than by an underground mine. Surface mines can also be cheaper to operate. The cost of a surface operation is directly related to the thickness of the overburden that must be removed. When overburden thickness exceeds 175 feet, economic factors generally favor underground mining methods. Where overburden thicknesses are between 75 and 175 feet, either surface or underground mining methods may be economical, depending on the thickness of the coal and the composition of the overburden. The method used to recover coal with an overburden in the range of 75 to 175 feet thick may not only depend on a combination of these factors, but on other factors such as surface ownership or land cover.

Factors that affect the availability of coal for surface mining in the Middletown Quadrangle are thickness of the coal and overburden, stripping ratio, land cover, and size of the mining block. The following section is a description of these factors as they relate to the availability of coal in this quadrangle.

Thickness of coal The use of large excavating equipment for removal of overburden and loading of coal results in the unavoidable loss of several inches of coal from the top and bottom of the seam. Additional coal is lost in transporting and washing the coal. These losses are higher as a percentage of the original coal in-place when the seam is thin. Seams less than a certain minimum thickness are impractical to mine because too much of the seam is lost.

The USGS generally considers 14 inches to be the minimum seam thickness for surface minable coal, but acknowledges that this minimum may vary from one region to another (Wood et al. 1983). The ISGS has traditionally used 18 inches as the minimum thickness for defining surface minable coal resources in Illinois (Smith 1957), and this thickness was used in this study. The thin seams in this quadrangle are so unattractive for mining (unfavorable stripping ratios, small mining blocks, high sulfur contents), however, that the issue of minimum thickness did not receive consideration in any of the interviews.

Thickness of overburden Most surface mines in Illinois utilize large draglines, shovels, or wheel excavators to remove overburden from the coal. A combination of small shovels and trucks is used in some mines. According to the engineers interviewed, these methods currently have an effective limit of 150 to 175 feet of overburden. Although small areas of thicker overburden, such as a small ridge dividing a property, can be surface mined, underground mining methods are more economical for recovering large contiguous blocks of coal at depths greater than 175 feet.The composition of the overburden does not directly affect the availability of coal. Mining equipment and procedures are selected to suit the overburden conditions at a particular site. The presence of water-bearing zones within the overburden, for example, may add to mining costs and cause companies to favor mining other areas. However, these conditions alone do not seriously limit the availability of coal. Composition of the overburden also affects the angle of repose required for a stable highwall and spoil bank. Although this has the effect of increasing the stripping ratio (see below) in areas of thick unconsolidated materials, the engineers and geologists interviewed did not view this as a significant consideration.

Stripping ratio The stripping ratio is the number of cubic yards of overburden that must be removed to recover 1 ton of coal. Whereas the minimum thickness of coal and maximum thickness of overburden that can be mined are values controlled in part by technical factors such as mining equipment and procedures, the maximum stripping ratio is strictly an economic limit. Coals with high stripping ratios may be more economical to mine by underground methods or may be unminable until the market price for coal rises relative to production costs.

Under present economic conditions, the maximum average stripping ratio for a deposit must be less than 20 to 1. The incremental stripping ratio may exceed 20 to 1 for portions of a mine block, but the average stripping ratio for the entire block must not exceed 20 to 1. If two or more coals are present within the maximum overburden limit of 175 feet, their combined thickness may be used in calculating the stripping ratio. Although there are four coals with surface minable resources in this quadrangle, there are no prospects for multiseam surface mining because the areas where successive seams are both thick and shallow do not overlap.

Land cover State laws do not specifically prohibit surface mining of any area; however, rules governing the mining of certain features have the effect of prohibiting or severely restricting the mining of these areas. Cemeteries cannot be mined, for example, unless all surviving family members give permission to move the graves of their ancestors. It is usually so time-consuming and expensive to fulfill this requirement that most cemeteries are avoided.

Mining through towns or other large developed areas is also impractical because the cost of purchasing the surface property is likely to exceed the value of the coal. Although laws do not prohibit mining up to the edge of a town, companies are required to control dust levels and vibrations from blasting. These restrictions make it difficult to mine near towns. During the interviews with the mining experts, those who had the most experience with surface mining said they avoid mining within 1 to 2 miles of towns.

Surface mining through roads, railroads, pipelines, or transmission lines requires permission from the owners or governing authorities. Generally, it is less expensive to avoid all but minor roads and pipelines. Coal deposits underlying interstate highways are considered to be inaccessable by surface mining.

For engineering, environmental, and safety reasons, companies generally leave a buffer of unmined coal (usually 200 feet wide) around underground mine workings. In some cases, however, mining through a small abandoned underground mine may be necessary to access adjacent areas of unmined coal.

Environmentally sensitive areas, such as the floodplain along Salt Creek, are potential restrictions to surface mining. Although regulators at the Illinois Department of Mines and Minerals (IDMM) would not rule out mining in the floodplain, they said that applications for mining permits in that area would be carefully scrutinized to ensure that environmental damage would not occur. The coal companies representatives interviewed said that they would avoid areas such as the Salt Creek floodplain because of the potential for extra expense and regulatory delays.

Size and configuration of mining block Opening a surface mine of any size entails certain fixed costs for exploration, land acquisition, mine planning, permitting, and construction of offices, facilities for equipment maintenance, coal cleaning, storage, and transportation. If a mine is to be profitable, the block of coal to be mined must contain more than enough tonnage to recover these fixed costs. In the Middletown Quadrangle and wherever the coal is buried by a thick layer of glacial deposits, the excavation and construction required to open a mine will be significant in scope and cost.

According to the experts interviewed for this study, a mine block of 30 million tons of recoverable coal is needed to justify the construction of a preparation plant and a rail link. Assuming that 65% of the coal can be recovered after mining, cleaning, and loading, a block of about 46 million tons of in-place coal is the minimum requirement.

Smaller mining blocks may be feasible for mining under certain conditions; for example, a modern preparation plant and rail-loading facility is currently located within a few miles of the quadrangle. Coal can be hauled to this facility for cleaning and then loaded onto railcars or trucked directly to customers in central Illinois. If the cost of constructing a preparation plant and rail link need not be recovered, the minimum block size is 10 million tons of clean, saleable coal. Assuming that 65% of the coal can be recovered after mining, cleaning, and loading, a block of about 15 million tons of in-place coal is the minimum requirement in this case.

A mining block for a surface mine does not have to be a contiguous deposit of coal; it may consist of two or more smaller blocks relatively near one another and not separated by barriers such as a river that impedes the movement of equipment. Blocks must also have a configuration suitable for the mining methods anticipated.

Deep Minable Coal

Where the thickness of overburden or the stripping ratio is too great, coal must be mined by underground methods. Under these conditions, it is classified as a deep minable resource. As noted previously, there is no definite boundary between surface minable and deep minable deposits. Rather, there is a range of depths where either method is technically feasible.

Two mining methods are commonly utilized in underground mines in Illinois: room and pillar and longwall. Although many of the factors that affect the availability of coal are independent of the mining method, some factors such as roof and floor conditions depend on the mining method used.

Thickness of coal The thickness of the seam controls the amount of coal that can be produced per acre and the ease of moving miners and machinery within the mine. Thin seams are more costly to mine because of the amount of roof control and longer haulage per ton mined. Also, miners work more efficiently when they can move freely and the working face is fully visible.

As noted earlier, the USGS considers all coals 14 inches or greater in thickness to be resources (Wood et al. 1983). The ISGS has traditionally used 28 inches (about 2.3 feet) as the minimum seam thickness for deep minable resources in Illinois (Cady 1952). These thicknesses are far less than the minimum thickness that companies consider minable in Illinois. The average thickness of coal mined in the state is about 6 feet. According to the experts interviewed, the costs of mining coal less than 4 feet thick are prohibitively high, although short spans of thinner coal and even rock may be mined to gain access to thicker coal. In this study, 4 feet was used as the minimum thickness for available coal.

Depth of coal A major cost in opening an underground mine is the cost of constructing slopes or shafts for ventilation and the movement of miners, materials, and coal. The deeper the coal, the more expensive it is to construct these facilities and extract the coal. All the coals in the Middletown Quadrangle are less than 400 feet deep, which is comparatively shallow and does not limit the availability of coal for deep mining.

Thickness and composition of bedrock overburden A minimal amount of bedrock cover is needed to support the mine roof and seal the mine from water seeping down from the surface. If the bedrock is too thin, the mine roof may be unstable; fractures resulting from any failure of the mine roof may propagate to the bedrock surface and allow water to enter the mine.

The minimum thickness of bedrock overburden needed above a mine depends on the composition of the bedrock and the thickness of unconsolidated sediments (glacial deposits) overlying the bedrock. Thick, continuous limestone or sandstone beds and thin overlying unconsolidated sediments are the most suitable geologic conditions. The bedrock overburden must be proportionately thicker for support in areas overlain by thick glacial deposits. The mining experts interviewed considered the minimum thickness of bedrock in this study area to be 75 feet. If the bedrock is less than 75 feet thick, severe roof problems may be encountered. There is also a risk that water in the glacial deposits will enter the mine through fractures from roof falls. In the Middletown Quadrangle, extensive areas of both the Herrin and Springfield Coals are overlain by less than 75 feet of bedrock overburden (figs. 33 and 34).

Because of the thickness of the glacial sediments in this quadrangle, the size of pillars must be increased in areas where the bedrock is less than 100 feet thick. Also, the main entries, shafts, and other areas of the mine that will be used for a long period of time should be overlain by 100 feet or more of bedrock. Mine panels should be laid out so that areas under thin bedrock can be easily abandoned if problems are encountered.

For the assessment of this quadrangle, an assumption has been made that longwall mining will not be attempted in areas overlain by less than 100 feet of bedrock cover. Available resources in areas with less than 100 feet of bedrock cover have been reduced by 1% to account for the larger pillar sizes required. This reduction is based on the pillar sizes used by mines operating under similar conditions. Tonnage of coal restricted by these conditions is listed in table 4b under the category, "Roof conditions due to thin bedrock cover."

Some companies also consider the ratio of the thickness of the bedrock overburden to the thickness of the glacial overburden. Studies in other areas of the state have shown that when this ratio is less than 1:1, the incidence of roof falls and floor squeezes increases (Treworgy and Bargh 1982). One expert interviewed said his company would not mine coal with a bedrock to glacial overburden ratio of less than 1:1. An expert from the company with the most experience in this area said, however, that some coal in areas with a ratio of less than 1:1 can be recovered by adjusting room and pillar sizes and designing the mine layout so that the rooms need to be held open for only a relatively short period of time and can be quickly abandoned without disrupting access or ventilation to other parts of the mine.

Floor conditions The character of the rock underlying a coal seam affects the design of a mine, method of mining, and percentage of coal that can be recovered. In Illinois, the rock directly under coal is almost always claystone (underclay) a few inches to several feet thick. The claystone may be underlain by limestone (generally thin, commonly lenticular), shale, and in some areas, sandstone or coal. Thick, weak underclay may squeeze from under pillars and obstruct access rooms or cause roof falls. Underclay must be protected from water seeping from bedrock aquifers in the mine roof or fractures created by roof falls that extend to the bedrock surface. Water may decrease the bearing capacity of the underclay, cause swelling, and reduce the traction of mine equipment.

Although additional data are needed to fully evaluate floor conditions, the underclay of the Springfield Coal is known to be thick and relatively weak in this area. The underclay is generally underlain by shale, although a thin (less than 1 foot) limestone may be present in some areas. To compensate for these floor conditions, the mining operation must leave pillars that are larger than normal along main entries and other parts of the mine that require long term support. The suitability of the underclay for supporting longwall shields has not been evaluated. For this study, the assumption was made that floor conditions do not restrict the use of longwall methods.

Specific areas of Springfield Coal have not been excluded from estimates of available resources because of unsuitable floor conditions. Estimates were made, however, of the amount of Springfield Coal that cannot be mined because large pillars are necessary for the main entries and panel areas of room and pillar mines, and the main entries of longwall mines. The estimates are based on room and pillar sizes used by mines operating under similar conditions. In areas that can be longwall mined (i.e., areas overlain by more than 100 feet of bedrock cover), 5% of the coal may be left unmined because of the use of large pillars. In areas that can only be mined by room and pillar methods (i.e., areas overlain by less than 100 feet of bedrock cover), an additional 5% of the coal may be unavailable because large pillars are likely to be left in panel areas. The tonnage of coal restricted by these conditions is given in table 4b under the category, "Weak floor."

The characteristics of the underclays of other coals in this quadrangle are not known and thus not considered as factors influencing the availability of these resources.

Roof conditions An unstable mine roof creates dangerous working conditions for miners, slows the rate of advance, and requires additional materials and extra procedures for roof control. An area with an exceptionally unstable roof may be so costly to mine that it is avoided entirely, if it can be identified prior to mining. The effect of roof conditions due to the thickness of bedrock overburden or the presence of clastic dikes is considered separately in this report. This section

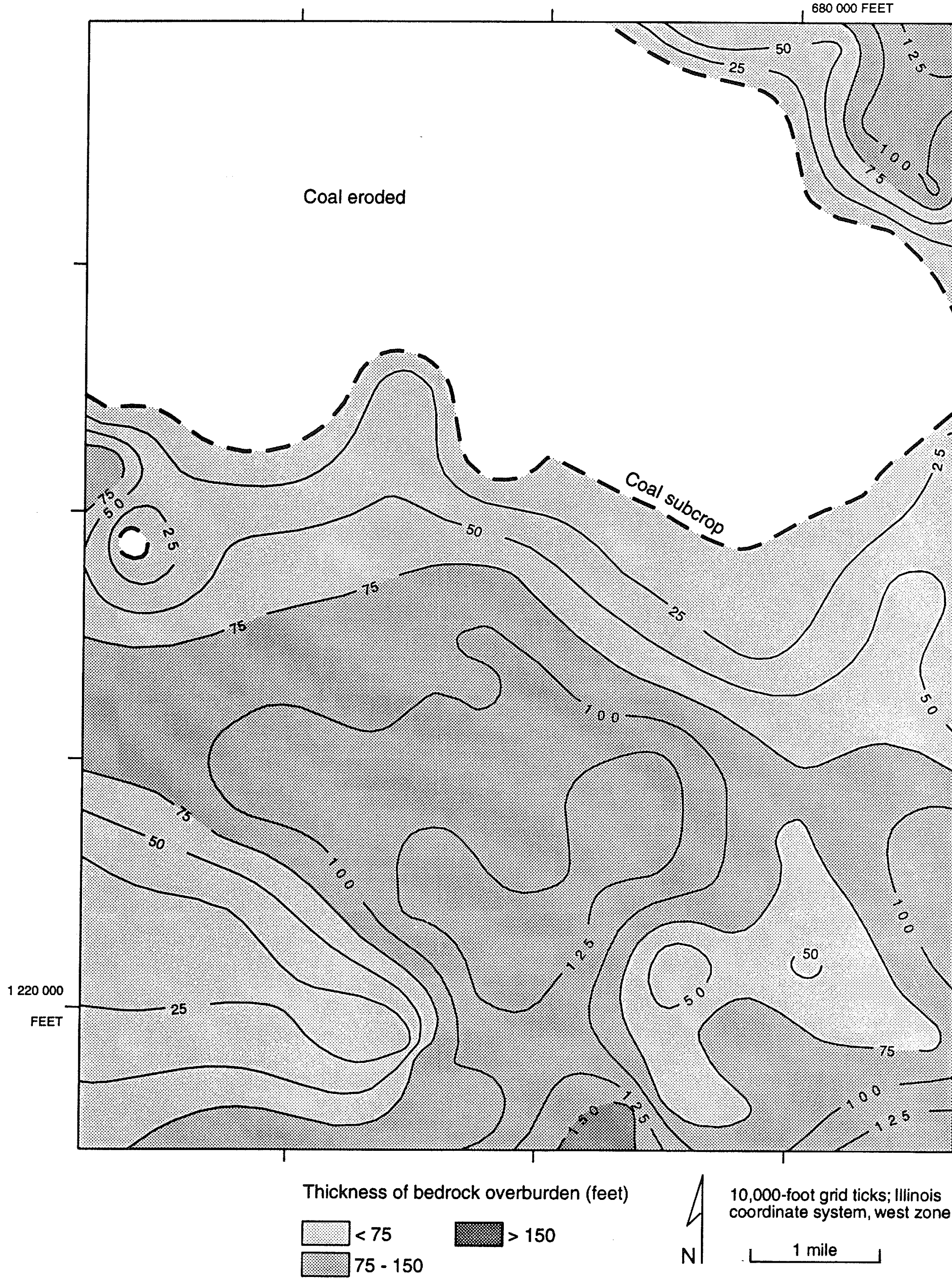


Figure 33 Thickness of bedrock cover over the Herrin Coal in the Middletown Quadrangle. Contour interval is 25 feet.

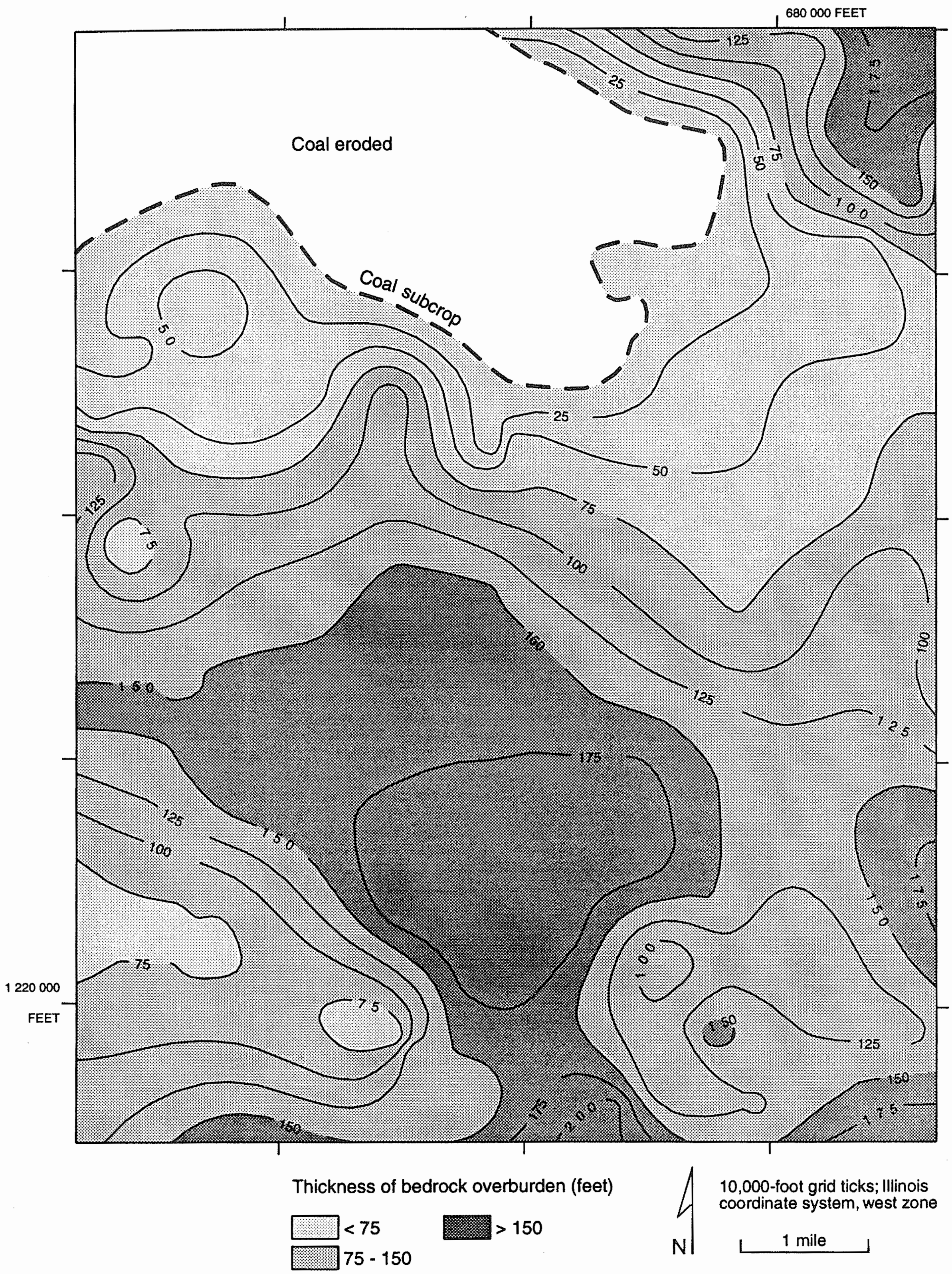


Figure 34 Thickness of bedrock cover over the Springfield Coal in the Middletown Quadrangle. Contour interval is 25 feet.

discusses how the geology of the immediate mine roof could restrict the availability of coal.

The effects that strata immediately overlying the coal have on roof conditions (and consequently, on the availability of coal) are difficult to quantify without data from closely spaced drill holes and a record of extensive experience in mines with identical geology. In the study area, something is known about roof conditions in only two seams, the Herrin and Springfield Coals. Each mining method has a different effect on roof conditions. Roof strata that are prohibitively expensive to support in a room and pillar mine may be of little or no consequence in a longwall operation.

The roof of the Herrin Coal is most stable where the Brereton Limestone is thick and near enough to the coal to serve as an anchor for roof bolts. From detailed mapping in mines in west-central Illinois, the Brereton is known to be deposited in lenticular bodies of variable thickness (Krause et al. 1979, Nelson and Nance 1981). Closely spaced drilling is needed to accurately map these deposits, although more widely spaced exploratory drilling, such as that available for the study area, can be used as a sample of the relative frequency of occurrence and thickness of the limestone. Of the 60 holes that reported a measurable thickness of Herrin Coal, only 22 holes reported the presence of the Brereton Limestone. The limestone was greater than 2 feet thick in about half of these holes. Absence of the Brereton Limestone does not necessarily mean that the roof will be unstable; however, the roof strata in these areas should be carefully evaluated. Also, problems due to thickness of bedrock or the ratio of bedrock to glacial overburden may be more severe in areas where the Brereton is absent.

Another potential roof problem for the Herrin Coal is caused by the Anvil Rock Sandstone. In other areas of west-central Illinois, this unit is known to fill channels that have eroded part or all of the Herrin Coal. The sandstone can also be a source of water leakage into a mine, if the rock is penetrated by roof bolts or fractures (Cartwright and Hunt 1978).

Data are insufficient to determine whether any portion of the Herrin Coal is unavailable due to roof conditions. However, the presence of Anvil Rock Sandstone in some drill holes and the absence of thick Brereton Limestone in the majority of drill holes indicate that unstable roof conditions may be encountered. More drilling is necessary to fully assess the availability of these resources.

The St. David Limestone overlies the Springfield Coal and, where thick enough, makes a good anchor for roof bolting (fig. 11). The St. David, present in nearly all holes in the study area, was generally 1 to 3 feet thick. Unfortunately, the Turner Mine Shale (which lies between the St. David and the coal) tends to fall out around roof bolts in areas where it is 3 feet or more in thickness. Where the shale is 4.5 feet thick or greater, roof control is so expensive that companies try to design the mine layout to avoid areas of thick Turner Mine Shale as much as possible.

Areas of thick Turner Mine Shale occur in linear bands a few hundred feet wide. Holes drilled on 350-foot centers or less are needed to map these zones. Because data from closely spaced drill holes do not exist for the Middletown Quadrangle, areas affected by Turner Mine Shale are assumed to be equally distributed throughout the quadrangle and to cover acreages comparable to adjacent quadrangles. It is also assumed that the shale does not affect longwall mining and therefore only restricts the availability of coal in areas that must be mined by room and pillar methods (i.e. areas where the bedrock cover is less than 100 feet thick). Estimates based on data from other mines indicate that occurrences of thick Turner Mine Shale reduce the available resources in these areas by 4%.

Clastic dikes Clastic dikes, observed in two drill holes in the study area, are common in underground mines in and adjacent to this quadrangle. It is likely that clastic dikes are common in all coals in the quadrangle (Damberger 1970 and 1973). Because of their relatively small size and irregular pattern of distribution, clastic dikes cannot be avoided. According to mining experts familiar with this area, however, their effect is only to increase the cost of roof control and coal cleaning by a few percentage points. Although this will reduce the profitability of mining in the area, the experts interviewed did not consider clastic dikes, as an isolated factor, to be a limitation on the availability of coal.

Size and configuration of mining block The development of an underground mine entails fixed costs for exploration, land acquisition, mine planning, permitting, and construction of facilities including mine shafts and a preparation plant. The block of coal to be mined must contain enough recoverable tonnage so that the return from selling the coal exceeds the cost of investing in the mine. Thirty million tons of recoverable coal are needed to support the operation of an underground mine that includes a preparation plant and rail loading facilities. If 50% of the coal can be recovered after mining, cleaning, and loading, then a mine block of 60 million tons in-place is the minimum needed.

Smaller blocks are feasible for mining under certain conditions. For example, if the seam can be reached through a highwall (which requires that the coal be within about 200 feet of the surface), and if existing preparation and rail loading facilities can be used, a block of only 20 million tons of in-place coal is needed. This is equivalent to a block of 10 million tons of recoverable coal.

As with surface minable coal, the minimum block size can be achieved by mining multiple seams from a single shaft, drift, or highwall. In this quadrangle, the only multiseam operation that has some potential is mining the small areas of thick Herrin Coal in combination with the underlying Springfield Coal. However, the experts interviewed were uncertain whether they would attempt to mine the Herrin Coal along with the Springfield Coal because of the Herrin's marginally suitable characteristics (minimal seam thickness, thin bedrock cover, unfavorable bedrock to glacial overburden ratio, uncertain roof geology, and clastic dikes).

Thickness of the interval between seams Where two or more seams of minable thickness are present, both seams cannot be mined unless the strata between them (interburden) are sufficiently thick and competent (Chekan et al. 1986). If the interburden is too thin, ground control problems may occur in both the upper and lower seams. The thickness of interburden required depends on several geologic and engineering parameters, including the method and sequence of mining the seams (Hsiung and Peng 1987a, 1987b). According to the experts interviewed, the interburden between the two minable seams is sufficient to permit mining both.

Destruction of resources by order of mining Coal mining causes fracturing and subsidence of overlying strata and can render the resources in overlying coal seams unminable. The amount of destruction of resources depends on several variables, including the thickness and competency of the interburden and the mining method. Because the most attractive seam for mining in the study area is the Springfield Coal, the deep minable resources of the overlying Herrin Coal could possibly be destroyed. The surface minable Chapel, Danville, and Herrin coal resources would not be affected. None of the experts interviewed would consider underground mining of the Herrin Coal, if the Springfield Coal had already been mined by the longwall method.

Land cover Except for requiring a 200-foot buffer between underground mines, state laws do not specifically prohibit underground mining of any area. Rules governing the mining of certain features have the effect, however, of prohibiting or severely restricting the mining of these areas. For example, damage caused by mine subsidence must be repaired, even if the companies have subsidence rights. Consequently, it is generally not economical to mine under towns. Also, the regulations controlling the disturbance of cemeteries (as discussed previously in the section on surface mining) must be adhered to by underground mines.

Mining is feasible under most roads, railroads, pipelines, and transmission lines, but mine layouts are generally planned to keep mining under these features to a minimum. Because of the costs of mitigation, should subsidence occur, the undermining of interstate highways or main railroad lines is avoided, except where necessary for main entries to gain access to coal. The cost of constructing rail links to mines in this quadrangle may also be prohibitively high because the only railroad in the vicinity lies on the east side of the interstate highway (fig. 32).

Buffers must be left around oil wells unless they are abandoned and known to be adequately plugged. Although large concentrations of wells can be a significant obstruction to mining, there is no measurable effect on the availability of coal in areas such as the Middletown Quadrangle, where oil wells are few. Mines can be designed so that most of the wells are within the regular mine pillars.

Environmentally sensitive areas, such as the floodplain along Salt Creek, are potential restrictions to underground mining. To receive a permit to mine, companies must demonstrate that mining will not cause flooding or environmental damage. The Illinois Department of Mines and Minerals does not consider any of the coal resources in the quadrangle to be currently unavailable for underground mining because of environmental restrictions.

Coal Quality

Data on quality are available only for the Springfield Coal (table 1). All the coals in this quadrangle are expected to have sulfur contents of 2% to 6% and heating values of 9,500 to 11,000 Btu/lb (as-received basis). Although the demand for high sulfur coals such as these has been sharply reduced as a result of recent federal regulations, these resources cannot be considered unavailable on the basis of their sulfur content.

Table 1 Range of typical analyses of the Springfield Coal on an as-received basis (based on 47 samples from cores).

	Average	Minimum	Maximum
Moisture (%)	15.0	12.5	17.5
Ash (%)	11.0	7.4	16.1
Volatile matter (%)	33.7	31.8	37.3
Fixed carbon (%)	40.3	37.2	42.2
Sulfur (%)	3.7	2.1	5.9
Heating value (Btu/lb)	10,462	9,741	10,885

COAL RESOURCES AND AVAILABLE COAL IN THE MIDDLETOWN QUADRANGLE

The coal *resources* of the Middletown Quadrangle were calculated using the standard ISGS classifications for surface minable and deep minable coal. Surface minable resources must be 1.5 feet or greater in thickness and less than 150 feet deep. Deep minable resources must be 2.3 feet (28 inches) or greater in thickness and greater than 150 feet deep.

The amount of *available* coal was calculated on the basis of criteria derived from the interviews with mining experts (table 2). Note that according to these criteria, the range of depth for surface and deep minable coals overlap one another and differ from the depth limits used for the standard definition of resources in the ISGS coal resource classification system. The maximum depth for surface mining is 175 feet, but the minimum depth of deep minable coal can be as shallow as 75 feet, given the requirement that the minimum thickness of bedrock cover for underground mining is 75 feet. Because of these definitions, some coal deposits are potentially both surface and deep minable.

Table 2 Criteria used to define available coal resources in the Middletown Quadrangle.

Underground Mining

Minimum seam thickness
- 4 feet

Minimum depth
- 75 feet

Minimum bedrock cover
- 75 feet
- only room and pillars panels may be developed under <100 feet of bedrock; no main entries; no longwall mining; available tonnage reduced in these areas by 1% because of larger pillar size required.

Minimum block size
- 60 million tons in-place for a shaft or slope mine with preparation plant and rail facilities;
- 20 million tons in-place for a highwall mine without preparation plant or rail facilities.

Roof conditions: Springfield Coal
- avoid room and pillar mining where the Turner Mine Shale is >4.5 feet thick; tonnage reduced by 4% in areas that cannot be mined by longwall method.

Floor conditions: Springfield Coal
- reduced recovery due to thick, weak underclay; tonnage reduced by 5%, or by 10% in areas that can only be mined by room and pillar method.

Exclusion zone
- 200 feet around cemeteries, interstate highways, railroads, towns, and other mines.

Surface Mining

Minimum seam thickness
- 1.5 feet

Maximum depth
- 175 feet

Maximum average stripping ratio
- 20 cubic yds/1 ton

Minimum block size
- 15 million tons in-place (assumes use of existing preparation and rail-loading facilities)

Exclusion zones
- 200 feet around cemeteries, interstate highways, railroads, and other mines;
- 1 mile around towns;
- no mining in Salt Creek floodplain.

Total original resources for the six seams underlying the quadrangle are 385 million tons; 383 million tons remain in place and 211 million tons are estimated to be available for mining (table 3). None of the surface minable resources are available, and only 58% of the original deep minable resources (55% of the total original resources) are available—all in the Springfield Coal. Technological factors (e.g seam thickness, bedrock thickness, stripping ratio) account for 168 million tons (97%) of the excluded tonnage (fig. 35). Land use restrictions (proximity to towns, interstate highways, other mines) account for 6 million tons (less than 2%) of the excluded resources.

Of the 22 million tons of surface minable resources and 47 million tons of deep minable resources that are potentially surface minable (less than 175 feet deep), none are actually available for surface mining. Eighty-eight percent of the excluded tonnage has an average stripping ratio of greater than 20:1; 6% is restricted by land use factors; 4% is in blocks of less than 15 million tons; and less than 1% of the resources has been removed by mining or left as pillars (fig. 36, table 4a).

Of the 362 million tons of deep minable resources originally in the quadrangle, 58% are available for mining. None of the 5 million tons of surface minable resources that are potentially deep minable (more than 75 feet of bedrock cover) are available for underground mining. The factors restricting availability of potentially deep minable coal are, in order of significance, bedrock cover less than 75 feet thick (58% of the excluded tonnage), coal thickness less than 4 feet (23%), weak floor (9%), mining block less than 60 million tons in place (5%), coal mined out or left as pillars (2%), land use restrictions (about 1%), thick Turner Mine Shale (1%), and bedrock cover 75 to 100 feet thick (less than 1%) (fig. 37, table 4b).

Common Resource/Reserve Classifications and Available Coal

Federal and state agencies responsible for estimating coal resources and reserves use special terms to describe the relative degree of geologic certainty and economic minability of deposits. Two widely reported categories are *identified resources* and *demonstrated reserve base.* Since the 1970s, the ISGS has reported a category of resources called *high development potential.*

Identified resources In the USGS resource classification system, this category is generally used to report resources of coal. It represents resources for which "the location, rank, quality, and quantity are known or estimated from specific geologic evidence" (Wood et al. 1983). All remaining resources in the Middletown Quadrangle (384 million tons) are considered *identified resources.* Of these, 55% is available for mining.

Demonstrated reserve base The Energy Information Administration of the U.S. Department of Energy (US DOE) maintains estimates of the demonstrated reserve base (DRB) of coal in the United States. The DRB repre-

Table 3 Original and remaining resources and available coal in the Middletown Quadrangle (thousands of tons).

	Surface minable		Exclusions from available surface minable resources		Deep minable	
	Resources	Available	Land use	Technological	Resources	Available
Remaining resources						
Chapel	3,490	0		3,490	0	0
Danville	2,984	0		2,984	0	0
Herrin	13,082	0	47	13,037	34,381	0
Springfield	2,681	0	215	2,465	311,726	211,077
Colchester	0	0			8,456	0
"Seahorne coal"	0	0			5,751	0
Total remaining	22,237	0	262	21,974	360,314	211,077
Mined or left as pillars						
Springfield Coal	132*		132*		1,959	
Original resources						
Total	22,369	0	394	21,974	362,273	211,077

* Although this coal was mined by underground mines, it was less than 150 feet deep.
Note: totals may not add up exactly because the subtotals are rounded off.

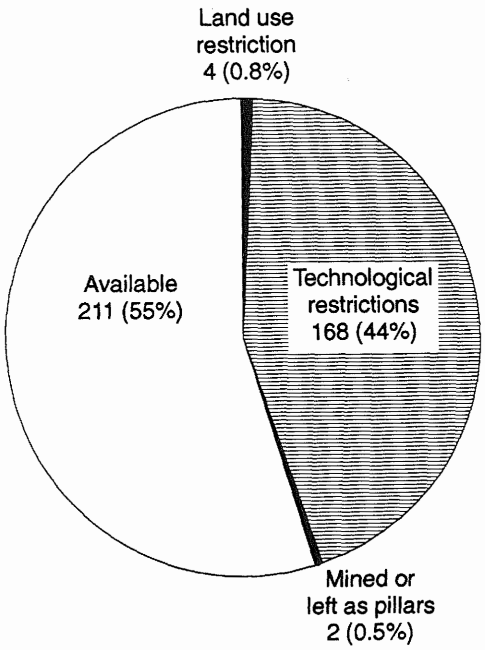


Figure 35 Availability of coal resources in the Middletown Quadrangle (millions of tons and percentage of original resources).

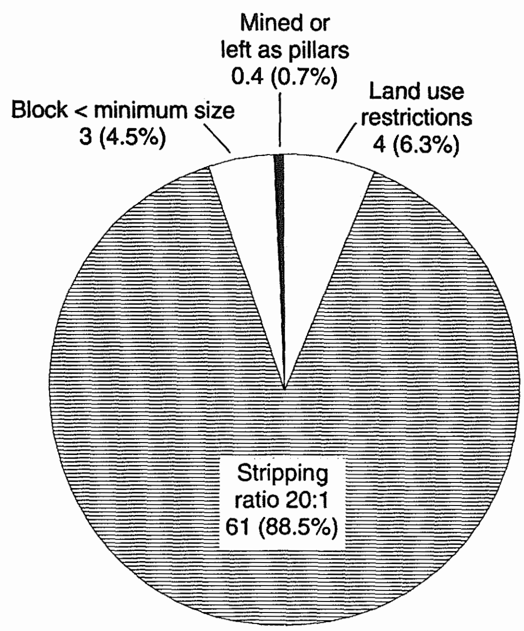


Figure 36 Factors restricting the availability of surface minable coal in the Middletown Quadrangle (millions of tons and percentage of original resources that are surface minable).

sents coal resources with a high degree of geologic assurance and some degree of economic minability. DRB figures are commonly used for purposes of planning, particularly for forecasting the source, characteristics, and price of future coal supplies.

For Illinois, the DRB consists of resources in the "proved" and "probable" categories of geologic assurance. The coal may be 18 or more inches thick and less than 150 feet deep, or 28 or more inches thick and less than 1,000 feet deep. About 96% or 368 million tons of the identified resources in the Middletown Quadrangle

Table 3 *continued*

Exclusions from available deep minable resources: Land use	Exclusions from available deep minable resources: Technological	Total: Resources	Total: Available	Exclusions from total available resources: Land use	Exclusions from total available resources: Technological
Remaining resources *continued*					
		3,490	0		3,490
		2,984	0		2,984
3	34,378	47,463	0	50	47,415
3,200	97,448	314,407	211,077	3,415	99,913
105	8,351	8,456	0	105	8,351
122	5,630	5,751	0	122	5,630
3,430	145,807	382,550	211,077	3,692	167,783
Mined or left as pillars *continued*					
1,959		2,092		2,092	
Original resources *continued*					
5,389	145,807	384,642	211,077	5,784	167,783

are classified as part of the *demonstrated reserve base,* of which 57% is available for mining.

High development potential Since the late 1970s, the ISGS has used the classification, high development potential (HDP), for resources that are equivalent in thickness and depth to those currently mined and are not restricted from development by other land uses (Treworgy et al. 1978, Treworgy and Bargh 1982). The definition for surface minable resources with a high potential for development also included a minimum size for mining blocks (Treworgy et al. 1978). In the study by Treworgy et al. (1978), the most attractive deposits for mining were referred to as *reserves.* The category has been renamed *high development potential* to make it consistent with Treworgy and Bargh (1982) and to avoid confusion with the term, reserves, as defined by Wood et al. (1983).

About 85% or 326 million tons of the identified resources in the Middletown Quadrangle are classified as having a high development potential; only 68% is available for mining.

Chapel Coal

The total resources of the Chapel Coal in the quadrangle are 3.5 million tons (table 3), all less than 150 feet deep and classified as surface minable. None of the Chapel Coal resources are available for mining because the average stripping ratio is well in excess of 20:1, and the total amount is less than the minimum block size (table 4a). Even if mined together with underlying coals, the combined resources would not have a favorable stripping ratio.

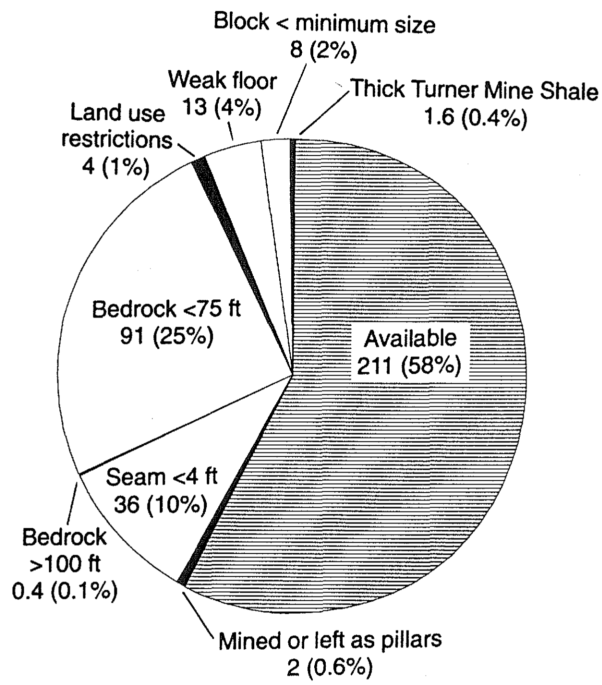


Figure 37 Factors restricting the availability of deep minable coal in the Middletown Quadrangle (millions of tons and percentage of original resources that are deep minable).

Danville Coal

The 3 million tons of Danville coal resources in the quadrangle are all surface minable (table 3). None are

Table 4a Available surface minable resources (thousands of tons), according to type of restriction, in the Middletown Quadrangle.

	Chapel	Danville	Herrin	Springfield	Total
Original surface minable resources (coal ≥1.5 ft thick and <150 ft deep)	3,490	2,984 (1,246)*	13,082 (23,114)	2,813 (22,372)	22,369 (46,732)
Exclusions					
Stripping ratio > 20:1	3,490	2,984 (1,246)	13,037 (23,086)	1,692 (15,582)	21,203 (39,914)
Mining block <15 million tons in place				773 (2,356)	773 (2,356)
Mined or left as pillars				132 (337)	132 (337)
Within 200 ft of					
mine				65 (255)	65 (255)
cemetery			47 (3)	0 (51)	47 (54)
interstate highway					
railroad			0 (25)	150 (3,791)	150 (3,816)
Total exclusions	3,490	2,984 (1,246)	13,082 (23,114)	2,813 (22,372)	22,369 (46,732)
Available surface minable resources	0	0	0	0	0

* Numbers in parentheses represent additional tonnages of deep minable resources that are shallow enough to surface mine.

available for mining because the average stripping ratio is well in excess of 20:1, and the total amount is less than the minimum block size (table 4a). Even if mined together with overlying and/or underlying coals, the combined resources would not have a favorable stripping ratio.

Herrin Coal

There are 47 million tons of Herrin Coal in the quadrangle (table 3). Of these resources, 13 million tons are classified as surface minable and 34 million tons are deep minable; none are available for mining (figs. 38 and 39). For the surface minable resources, the average stripping ratio is well in excess of 20:1, even if the Herrin were to be mined in combination with underlying and overlying coals (table 4a). The deep minable resources are ranked as unavailable primarily because of their unfavorable thickness, thin bedrock cover, and small block size (table 4b).

The Herrin coal deposits most suitable for mining are located in the south-central part of the quadrangle where the coal is greater than 4 feet thick and overlain by more than 75 feet of bedrock. The coal in this area is shallow enough that it can be mined as a highwall operation (a relatively inexpensive design for developing an underground mine), or it can be recovered in conjunction with the underlying Springfield Coal. The mining block contains only 6 million tons, however, and a portion of this is overlain by less than 100 feet of bedrock, and relatively thick unconsolidated sediments. Only one of the mining experts interviewed thought this block had even a remote chance of being mined.

Springfield Coal

The original resources of the Springfield Coal in the Middletown Quadrangle are just under 317 million tons, of which 2 million tons have been mined or left as pillars (table 3). Of the remaining 314 million tons of resources, less than 3 million are surface minable and about 312 million are deep minable. None of the resources are available for surface mining because of the thick overburden, unfavorable stripping ratio, and small block sizes (fig. 40, table 4a). Of the deep minable resources, 211 million tons (about 68%) are available for underground mining (fig. 41, table 4b). Resources that are unavailable for underground mining have bedrock cover of less than 75 feet, weak floor conditions, poor roof geology, land use restrictions, or small block sizes.

Colchester Coal

About 8 million tons of deep minable Colchester coal resources occur in this quadrangle (table 3). All of the resources are less than 4 feet thick and thus unavailable for mining (table 4b).

"Seahorne Coal"

There are 6 million tons of deep minable resources in the "Seahorne coal" (table 3). Of these, only 0.9 million tons are 4 feet or greater in thickness, which constitutes a block too small to be mined economically (table 4b).

Effect of Mining Method on Availability of Coal

As noted previously, all of the Springfield Coal in this area is thought to have a weak underclay that requires pillars larger than the average. Also, an estimated 4% of the Springfield Coal has roof (thick Turner Mine Shale) that is difficult to support with roof bolts. Because these factors have the greatest impact on room and pillar mining, they have been fully incorporated into the estimate of available coal only for areas unlikely to be mined by longwall methods. In these areas, which have less than 100 feet of bedrock cover, 10% of the Springfield Coal is unavailable because of floor conditions; 4% is unavailable because of roof condi-

Table 4b Available deep minable resources (thousands of tons), according to type of restriction, in the Middletown Quadrangle.

	Herrin	Springfield	Colchester	"Seahorne coal"	Total
Original deep minable resources (coal ≥2.3 ft thick and >150 ft deep)	34,381 (4,141)*	313,685 (432)	8,456	5,751	362,273 (4,573)
Exclusions					
Less than 75 ft of bedrock	9,300	81,663			90,963
Roof conditions due to thin bedrock cover (75 – 100 ft thick)	17	403			420
Weak floor		13,338**			13,338**
Thick Turner Mine Shale		1,613**			1,613**
Seam <4 ft thick	18,582 (4,141)		8,351	4,795	31,728 (4,141)
Mining block <60 million tons in place	6,479	431 (234)		835	7,746 (234)
Mined out		1,959 (132)			1,959 (132)
Within 200 ft of					
mine		1,356 (65)			1,356 (65)
cemetery	3	503	105	122	733
interstate highway		475			475
railroad		100			100
town		766			766
Total exclusions	34,381 (4,141)	102,609 (432)	8,456	5,751	151,197 (4,573)
Available deep minable resources	0	211,077**	0	0	211,077**

* Numbers in parentheses represent additional tonnages of surface minable resources that have sufficient bedrock cover to mine with underground methods.
** These exclusions assume that longwall mining will be used in areas with at least 100 feet of bedrock. If only room and pillar mining is used, the amount excluded because of weak floor conditions increases to 22,643 thousand tons; the exclusion for thick Turner Shale increases to 9,057 thousand tons; and the available coal decreases to 195,338 thousand tons.
Note: totals may not add up exactly because the subtotals are rounded off.

tions associated with thick Turner Mine Shale; and 1% is unavailable because of thin bedrock cover. In areas with more than 100 feet of bedrock, an estimated 5% of the coal is unavailable as a result of weak floor conditions.

These coal availability estimates are based on the assumption that longwall mining will be feasible in areas with more than 100 feet of bedrock overburden and that longwall mining will not be affected by the roof and floor conditions. According to the experts interviewed, longwall mining may not be feasible in much of this quadrangle because fractures from subsidence over longwall panels may allow water to enter the mine and further weaken the underclay. If it is assumed that only room and pillar methods can be used in this area, additional tonnage will be unavailable because of weak floor and unstable roof conditions. Available coal resources should be reduced by an additional 17 million tons, which leaves a total of 195 million tons of available coal (about 51% of the total original resources in the quadrangle).

Note that these are estimates of coal in the ground. The actual amount of coal recovered by mining will be substantially less than the amount available, depending on the mining method: about 50% recoverable for room and pillar, and 75% recoverable for longwall.

IMPLICATIONS FOR THE AVAILABILITY OF COAL RESOURCES IN REGION 3

The findings from careful study of a single quadrangle are not sufficient to identify and quantify factors that restrict the resources of region 3, let alone the entire Illinois Basin coal field. However, this assessment of the Middletown Quadrangle supports some of the findings of previous statewide evaluations, shows a need to modify some of the criteria used in past evaluations, and identifies and quantifies significant factors that impact the availability of coal resources. Studies of additional quadrangles in region 3 are needed to provide a complete perspective on the availability of coal resources in this region.

Surface Minable Resources

The experts interviewed for this study all expressed the opinion that the proximity of towns is a more significant restriction on availability of surface minable resources than previously recognized. Past estimates have excluded only the surface minable resources directly under towns (Treworgy et al. 1978). If the 1-mile buffer used around towns in this study is applied statewide, then available resources of surface minable coal in the state may be significantly less than estimated previously.

The impact of environmentally sensitive areas, such as the Salt Creek floodplain in this quadrangle, is difficult to assess. In this example, the IDMM would not declare the area off limits to mining, but the companies involved in the interviews did not consider the resources in the floodplain to be attractive enough to offset the probable difficulties in obtaining a permit and mining. Other environmentally sensitive areas should be evaluated to fully determine the impact on the availability of resources.

Past statewide evaluations of surface minable resources have used 6 million tons in-place as a minimum block size (Treworgy et al. 1978). Although this size (and perhaps smaller block sizes) may be appropriate for conditions in some regions of the state, a larger block of coal is needed to justify the higher initial costs of opening a mine in west-central Illinois. Most of the resources in this area are covered by relatively thick glacial sediments. Opening a surface mine under these conditions requires extensive drilling to delineate the subcrop and considerable time and investment to excavate a highwall. In addition, the presence of clastic dikes and the high sulfur content of the coals make it probable that a preparation plant will be needed for coal cleaning.

The maximum thickness of overburden used in this study (175 feet) is greater than that used in earlier studies. This higher limit may add significantly to the total of surface minable coal resources. In the case of the Middletown Quadrangle, however, none of the additional coal proved to be available for mining because of the high stripping ratios. The maximum average stripping ratio used in this study is also generally higher than the ratios used 15 years ago by Treworgy et al. (1978). It is not clear from this one study how these refinements in defining available surface minable deposits will change estimates of these resources in region 3.

Deep Minable Resources

Treworgy and Bargh (1982) based their ranking of all deep minable coal resources in the state on the potential for development of each deposit. As this study of the Middletown Quadrangle shows, some factors not considered by Treworgy and Bargh can have a significant impact on the availability of deep minable coal, and consequently, on its potential for development.

Given the ISGS system for ranking development potential, most of the Springfield Coal in the Middletown Quadrangle has a high potential for development, and most of the Herrin Coal has a moderate potential. Results of the study in this quadrangle indicate that less than 60% of the resources originally ranked with a high or moderate potential for development is actually available for mining. It is doubtful that the estimates of high and moderate potential coal in region 3 will be found to include such a low percentage of available coal; however, more quadrangles must be evaluated in region 3 to confirm the findings of the Middletown Quadrangle study.

Treworgy and Bargh (1982) estimated that surface land use restricts the development of approximately 5% of the deep minable coal in the state. As would be expected for a rural area, restrictions due to surface land use in the Middletown Quadrangle are considerably less than the state average. Only about 1% of the deep minable resources in the Middletown Quadrangle are unavailable because of surface land use (table 4b). Pipelines and transmission lines, factors that had not been considered in previous statewide studies, do not appear to have a measurable impact on the availability of deep minable resources.

Although the size of mining block was a factor in eliminating the availability of resources for three of the seams, the tonnage affected was only 2% of the potentially deep minable coal in the quadrangle (table 4b). It is not clear from this one study whether the size of blocks will be a significant limitation on the availability of deep minable resources.

Roof and floor conditions were found to be significant factors affecting the availability of coal in this quadrangle. Minimum bedrock cover, the single most important factor in reducing coal availability, restricted 25% of the potentially deep minable coal (table 4b). Weak floor conditions associated with the Springfield Coal restricted availability of 4% of these resources. A key assumption in making these estimates is that longwall mining is feasible and will be less susceptible to poor roof and floor conditions. If longwall mining proves to be technically, socially, or environmentally unacceptable in this region, available resources will be reduced by an additional 5%.

Minimum bedrock cover probably is a significant restriction in about 25% of region 3 as well as in portions of regions 1, 2, and 5. The restrictions due to floor conditions probably can be applied to the Springfield Coal in all of region 3. The extent of problems caused by the presense of thick Turner Mine Shale is not known at this time.

As noted earlier in the report, several potential roof problems associated with the Herrin Coal could not be evaluated in this study. Other study areas identified in the region will be more suitable for evaluating these factors (fig. 1).

Minimum seam thickness was a key factor in restricting the availability of 10% of the deep minable coal. This factor can easily be applied to regional resource estimates. A point to be considered in future studies is whether the minimum seam thickness can be reduced for lower sulfur coals or deposits accessible from surface mine highwalls.

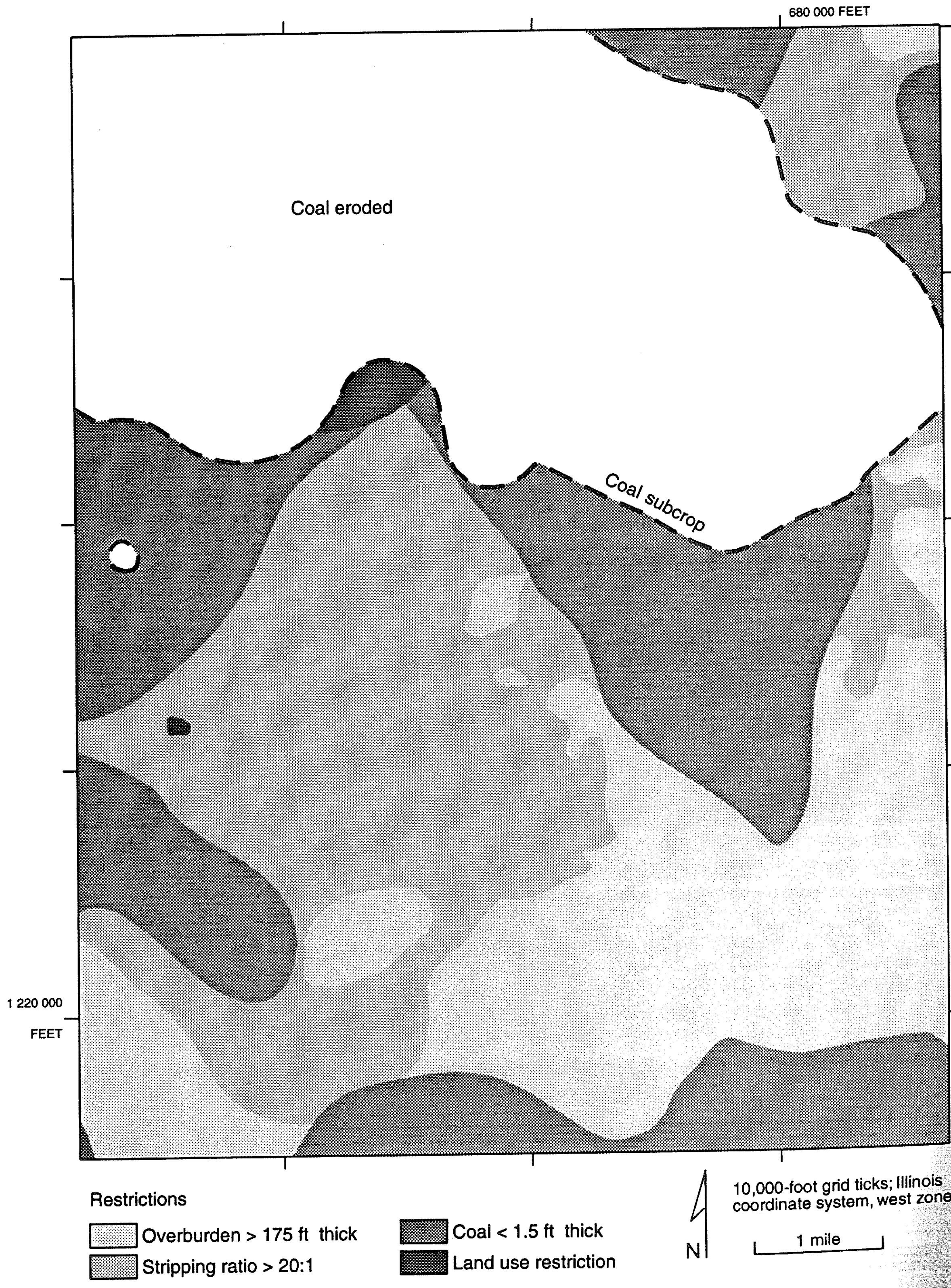


Figure 38 Availability of Herrin Coal resources for surface mining.

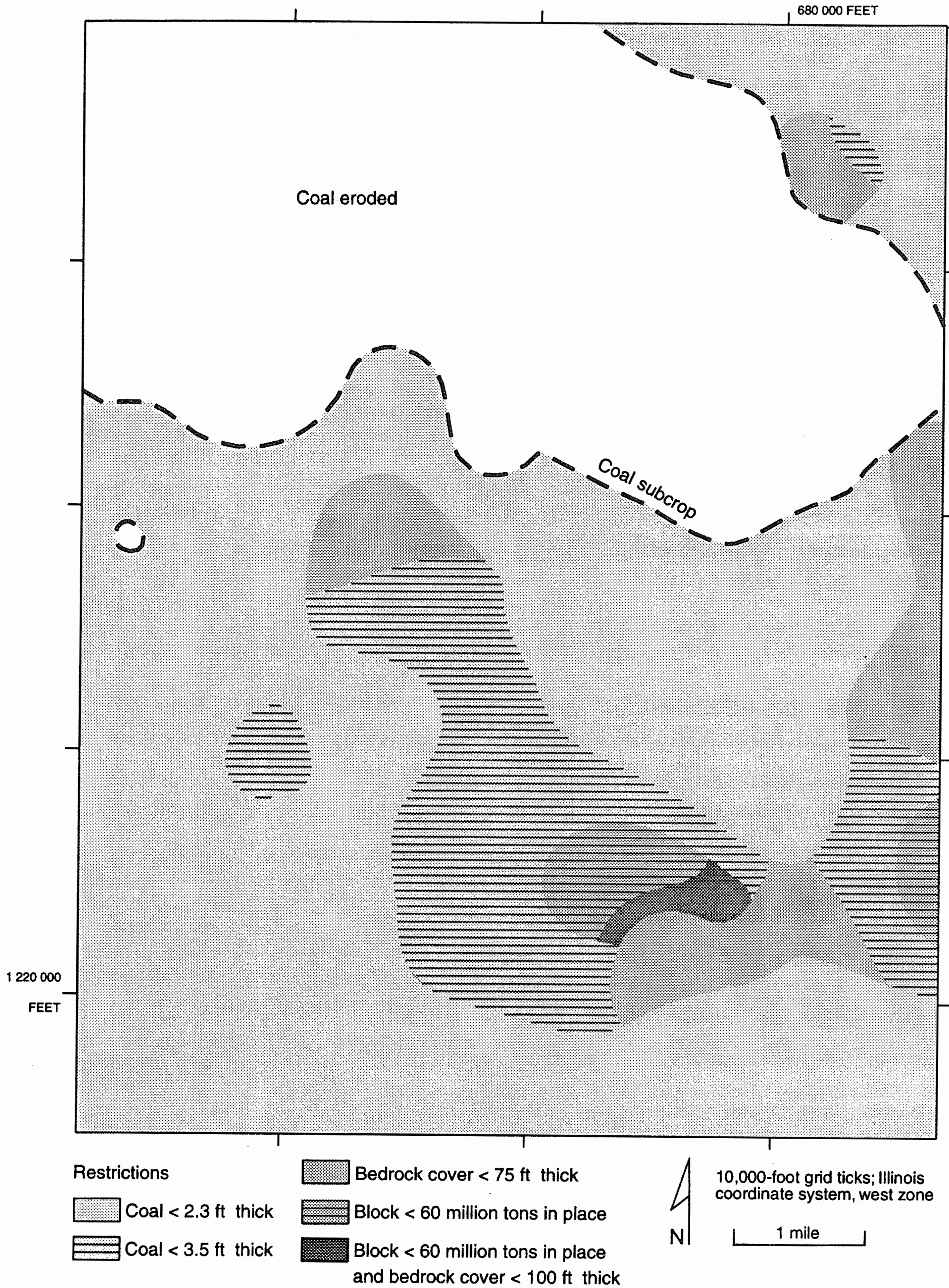


Figure 39 Availability of Herrin Coal resources for deep mining.

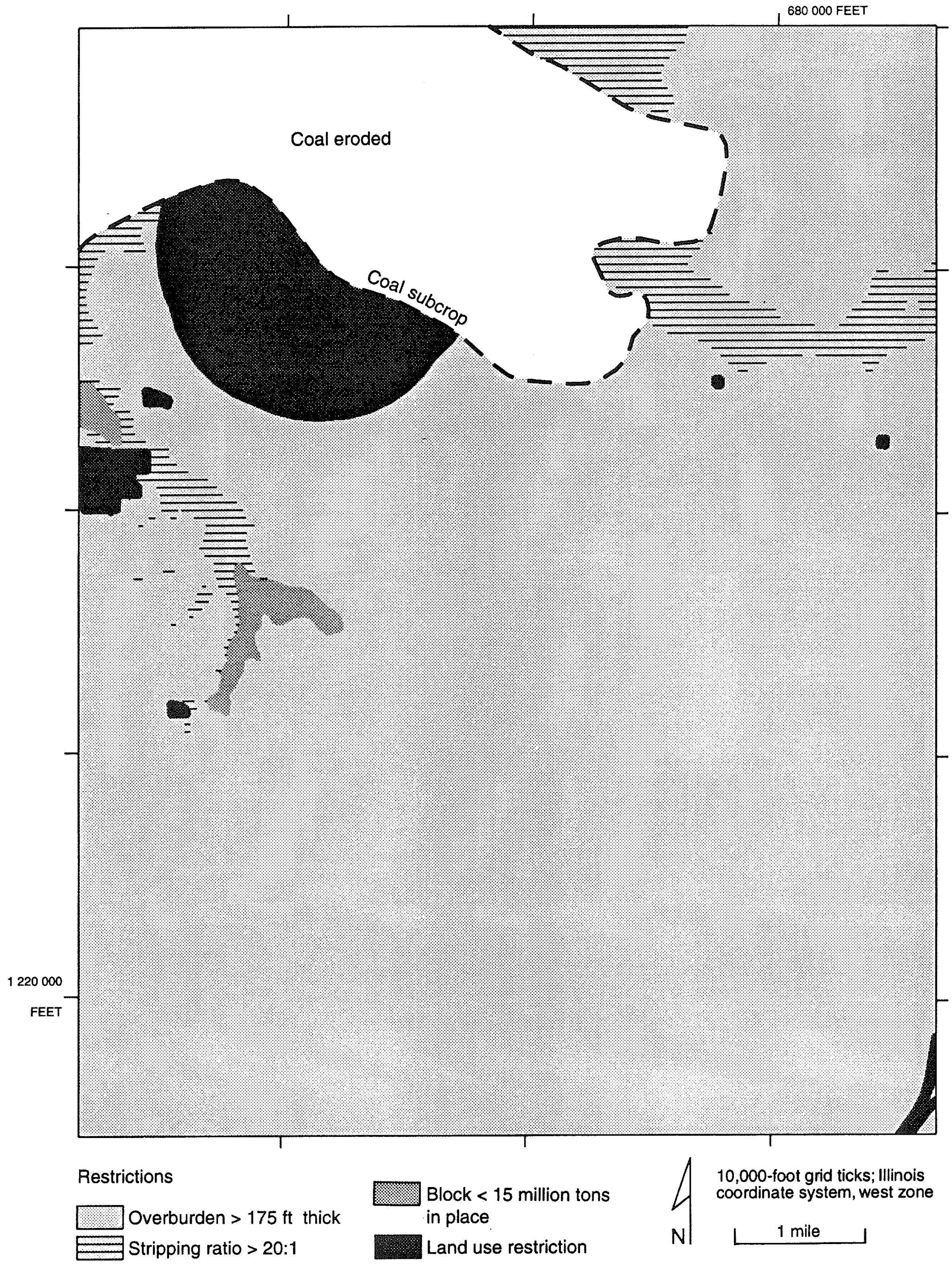


Figure 40 Availability of Springfield Coal resources for surface mining.

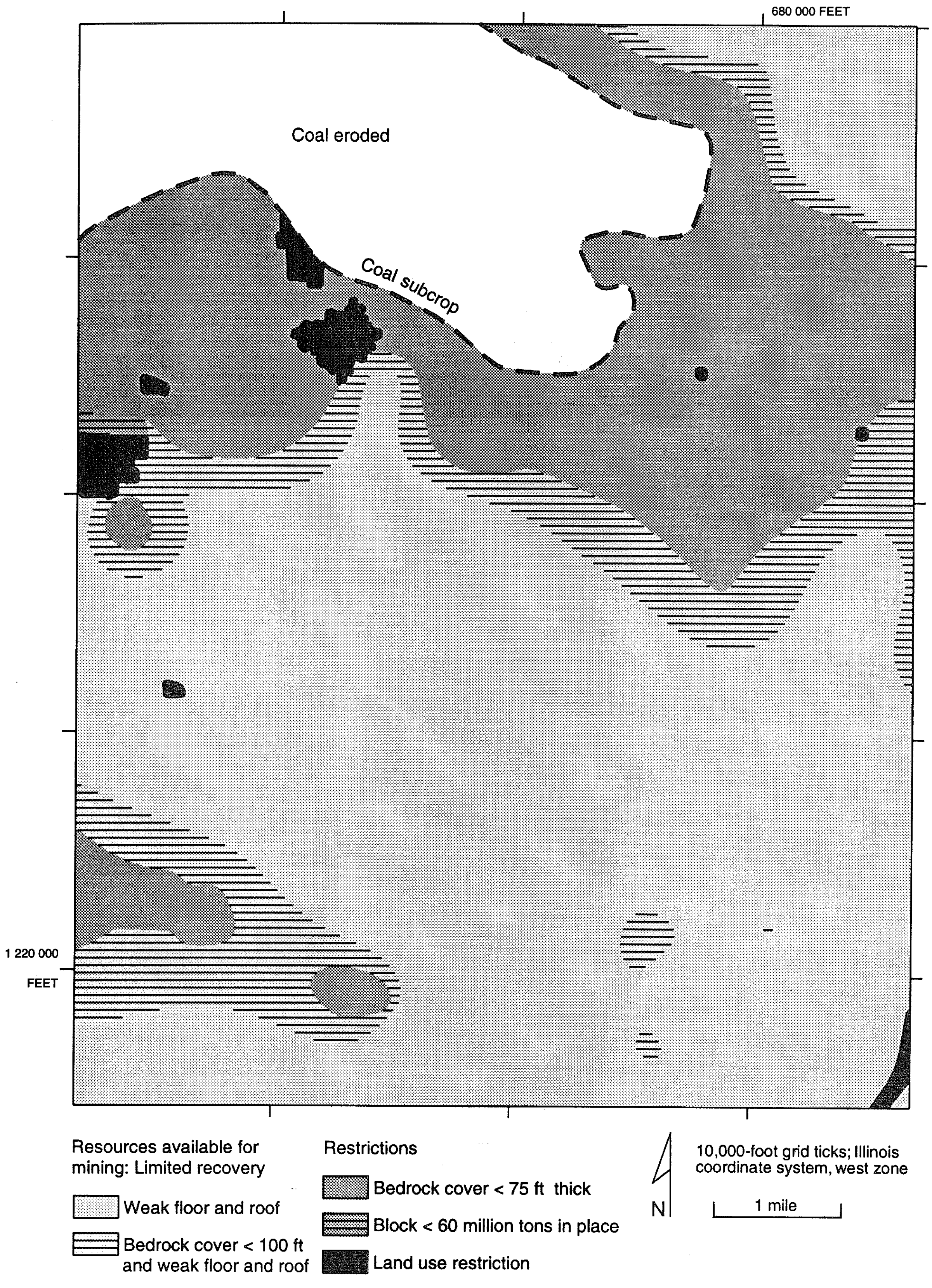


Figure 41 Availability of Springfield Coal resources for deep mining.

CONCLUSIONS

Of the 385 million tons of original coal resources in the Middletown Quadrangle, only 211 million tons (55%) is available for mining under current technical, legal, and environmental restrictions; none is available for surface mining. The 211 million tons of available resources represents 58% of the original deep minable resources. Factors that restrict availability of coal for deep mining are thin bedrock cover (25% of the original deep minable resources), thin seam thickness (10%), poor floor conditions (4%), small mining blocks (2%), proximity to cemeteries, interstate highways, and railroads (1%), and unfavorable roof conditions (<1%); less than 1% has been mined. Factors that restrict the availability of coal for surface mining include unfavorable stripping ratios (88% of the original surface minable resources), proximity to towns, cemeteries, and other mines (6%), and small mining blocks (5%); less than 1% has been mined.

As indicated by the evidence in this study, these factors are likely to affect the availability of coal in a significant part of the west-central Illinois region as well as other regions of the state. Factors such as thickness of bedrock strata and roof and floor conditions have not been considered in previous assessments of resources. Some factors that were considered in past studies require revision; for example, the minimum block size for surface mines should be larger for areas that are covered by thick glacial deposits. Also, the unavailability of surface minable resources because of their proximity to towns may be greater than previously estimated. Additional studies are planned to more completely assess the effects of these factors on availability of coal and to identify other factors that limit the availability of coal.

The results of this study show that the classifications of *identified resources* (USGS), *demonstrated reserve base* (USDOE), and *high development potential* (ISGS) commonly used for reporting coal resources should be supplemented by assessments of the availability of resources. In this study, only 55% of the identified resources, 57% of the demonstrated reserves, and 68% of the resources with a high development potential are available for mining.

ACKNOWLEDGMENTS

The organizations and individuals who have supported or contributed to this study are gratefully acknowledged. Financial support was provided by the U.S. Geological Survey, Branch of Coal Resources, through the U.S. Department of the Interior (grants 14-08-0001-A0773, 14-08-0001-A0841, and 1434-92-A-0940. We thank Harold J. Gluskoter and M. Devereux Carter of the USGS for their guidance and support.

Many ISGS staff contributed to aspects of the study: Steven D. Sroka assisted in compilation of stratigraphic data and cross sections; Carol A. Hindman assisted in data compilation and field reconnaissance; and Heinz H. Damberger, Jonathan H. Goodwin, Subhash B. Bhagwat, and Russell J. Jacobson reviewed the report and provided useful comments and suggestions.

We especially appreciate the support received from the mining companies and the Illinois Department of Mines and Minerals. Important information on the factors that limit the availability of coal was provided by Roger Nance of the Freeman United Coal Mining Company; Scott Fowler and Guy Hunt of the Turris Coal Company; Manny Efraimian, David Johnson, Tom McCarthy, George Martin, James Niemeyer, Mona Nemecek, and Marvin Thompson of the AMAX Coal Company; and Dan Barkley and Dean Spindler of the Illinois Department of Mines and Minerals.

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