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# COORDINATED STUDY OF THE DEVONIAN BLACK SHALE IN THE ILLINOIS BASIN: ILLINOIS, INDIANA, AND WESTERN KENTUCKY

*Final report : December 31, 1980*

ILLINOIS STATE GEOLOGICAL SURVEY
Champaign, IL 61820
*Principal investigator*
JERRY A. LINEBACK


Prepared for the U. S. DEPARTMENT OF ENERGY, Morgantown Energy Technology Center, Morgantown, WV 26505 Contract: U.S. Department of Energy DE-AS21-78MC08214

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*Jerry A. Lineback, Principal Investigator*

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Natural Resources Building
615 East Peabody Drive
Champaign, Illinois 61820

*31 December 1980*

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CONTENTS



*(continued)*

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Coordination of the study of the Devonian Shale in the Illinois Basin was under the general direction of Jerry A. Lineback, Principal Investigator. This study was conducted in conjunction with studies of the geology and geochemistry of the Devonian Shale directed by Robert E. Bergstrom and Neil F. Shimp, Illinois State Geological Survey; John B. Patton, Indiana Geological Survey; and Howard R. Schwalb, Kentucky Geological Survey, as a part of the U.S. Department of Energy's Eastern Gas Shales Project.

Individual research projects reported on in the coordination study were organized and directed as follows.

Geologic projects

1. *Stratigraphy, structure, and evaluation of hydrocarbon potential:* Jerry A. Lineback, Mark L. Reinbold, David L. Stevenson, Robert M. Cluff, and Jerry T. Wickham, Illinois State Geological Survey; Nancy R. Hasenmueller, John L. Bassett, and Donald D. Carr, Indiana Geological Survey; Howard R. Schwalb and Ronald L. Norris, Kentucky Geological Survey.

2. *Mineralogic and petrographic characterization:* Robert M. Cluff, Richard D. Harvey, Mary H. Barrows, and W. Arthur White, Illinois State Geological Survey; Nelson R. Shaffer and Pei-Yuan Chen, Indiana Geological Survey; Ronald E. Zielinski, Monsanto Research Corporation-Mound Laboratory.

3. *Physical Properties:* Paul B. DuMontelle and Stephen R. Hunt, Illinois State Geological Survey, Robert F. Blakely, Indiana Geological Survey.

Geochemical projects

1. *Major, minor, and trace elements:* Joyce K. Frost and R. R. Ruch, Illinois State Geological Survey; Richard K. Leininger, Indiana Geological Survey; Ronald E. Zielinski, Monsanto Research Corporation-Mound Laboratory.

2. *Hydrocarbon phases and gas content:* Donald R. Dickerson and Dennis D. Coleman, Illinois State Geological Survey; Warren G. Meinschein, Indiana University; Ronald E. Zielinski, Monsanto Research Corporation-Mound Laboratory.

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# COORDINATED STUDY OF THE DEVONIAN BLACK SHALE IN THE ILLINOIS BASIN: ILLINOIS, INDIANA, AND WESTERN KENTUCKY

*Jerry A. Lineback, Principal Investigator*

## INTRODUCTION

Production of gas from Devonian shales in the United States began in 1821 with the drilling of a well near Fredonia, New York. Since then, an estimated 2.5 trillion cubic feet (TCF) of gas has been produced from Devonian shale in the Appalachian, Michigan, and Illinois Basin. Most of this gas (2 TCF) has come from the Big Sandy Field in eastern Kentucky (Hunter and Young, 1953). Gas production from the other scattered fields has generally been small.

Devonian shales are distributed across more than 10 states from Illinois to Pennsylvania and Michigan to Mississippi. Large areas of the shale, mainly where it is relatively deep, have not been adequately explored. While gas production from individual wells may generally be small, the total potential reserves may be large. Therefore, the Devonian shales of the eastern United States may represent an important potential natural gas resource.

The United States Department of Energy (DOE) has undertaken an evaluation of the resource potential of the Devonian shales called the Eastern Gas Shales Project (ESGP). A study of the stratigraphy, structure, composition, and gas content of the Devonian shale in the Illinois Basin was undertaken by the State Geological Surveys of Illinois, Indiana, and Kentucky, under contract to the U.S. DOE as a part of the EGSP. Certain additional data were also developed by other research organizations (including Monsanto Research Corporation-Mound Facility and Battelle-Columbus Laboratory) on cores taken from the Illinois Basin.

This report, an overview of geological data on the Illinois Basin and interpretations of this data resulting from the EGSP, highlights areas of potential interest as exploration targets for possible natural gas resources in the Devonian shale of the basin.

The information in this report was compiled during the EGSP from open file data available at the three State Geological Surveys and from new data developed on cores taken by the DOE from the basin specifically for the EGSP. Specific items are taken from the final EGSP reports made by the Illinois, Indiana, and Kentucky Geological Surveys to DOE (Bergstrom, Shimp, and Cluff, 1980; Schwalb and Norris, 1980; and Indiana Geological Survey Final Report, 1981), from Cluff and Dickerson (1980), from Cluff, Reinbold, and Lineback (in preparation), and other materials as cited.

The Illinois State Geological Survey coordinated the collection, organization, storage of data, and evaluation of results in the EGSP in the Illinois Basin, involving the states of Illinois, Indiana, and Kentucky. Such coordination is necessary because a variety of geological and geochemical tasks were carried on more or less independently, and a large volume of data was generated by a number of contractors, some of whom had relatively narrow assignments and little opportunity to share in the broad implications of the research.

This coordinated study has resulted in the creation of a data base for the Devonian shale in the Illinois Basin and the integration of analyses and results into this final report. More detailed information is available in final reports prepared by the various State Surveys and other contractors; open-file information is also available at the State Geological Surveys.

## STRATIGRAPHY OF THE NEW ALBANY SHALE IN THE ILLINOIS BASIN: AN OVERVIEW

The name New Albany Shale (or New Albany Group) in the Illinois Basin designates a body of rock that is mostly shale and that ranges from brownish-black and black organic-rich shale to gray or greenish-gray organic-poor shale. The shale may be calcareous or dolomitic. Also present are relatively lesser amounts of sandstone, siltstone, limestone, and dolomite. Detailed stratigraphic correlations based on cores, geophysical logs, and sample studies indicate that these lithologies grade vertically and laterally into one another with complex intertonguing relationships (fig. 1).

The New Albany is considered a formation in Indiana and Kentucky (fig. 2) where it has previously been studied by Campbell (1946); Lineback (1968, 1970); Bassett and Hasenmueller (1978); Hasenmueller and Bassett *in* Indiana Geological Survey Final Report (1981); and Schwalb and Norris (1980). The New Albany has been assigned group status in Illinois (Collinson and Atherton, 1975). Major subdivisions of the New Albany are considered members in Indiana and Kentucky and formations in Illinois (fig. 2). Previous important studies in Illinois were conducted by Workman and Gillette (1956); Collinson et al. (1967); North (1969); and Reinbold (1978). A geological report providing complete details on the stratigraphy of the New Albany Shale Group in Illinois is now in preparation (Cluff, Reinbold, and Lineback).

The New Albany Shale Group ranges in age from middle Devonian to early Mississippian (Kinderhookian). It occurs widely in the subsurface of the Illinois Basin in Illinois, southwestern Indiana, and western Kentucky. The New Albany reaches a maximum thickness of more than 460 feet (140 m) in an area some 20 miles south of the tri-state junction (fig. 3). An area of thick New Albany extends eastward into Kentucky along the Moorman Syncline, a structure active during New Albany Shale deposition. The area of thick shale in the central part of the Illinois Basin is referred to as the southern depocenter. Laminated black shale is the predominant lithology in the southern depocenter, which was apparently the depositional center of the ancestral Illinois Basin during the middle and late Devonian.

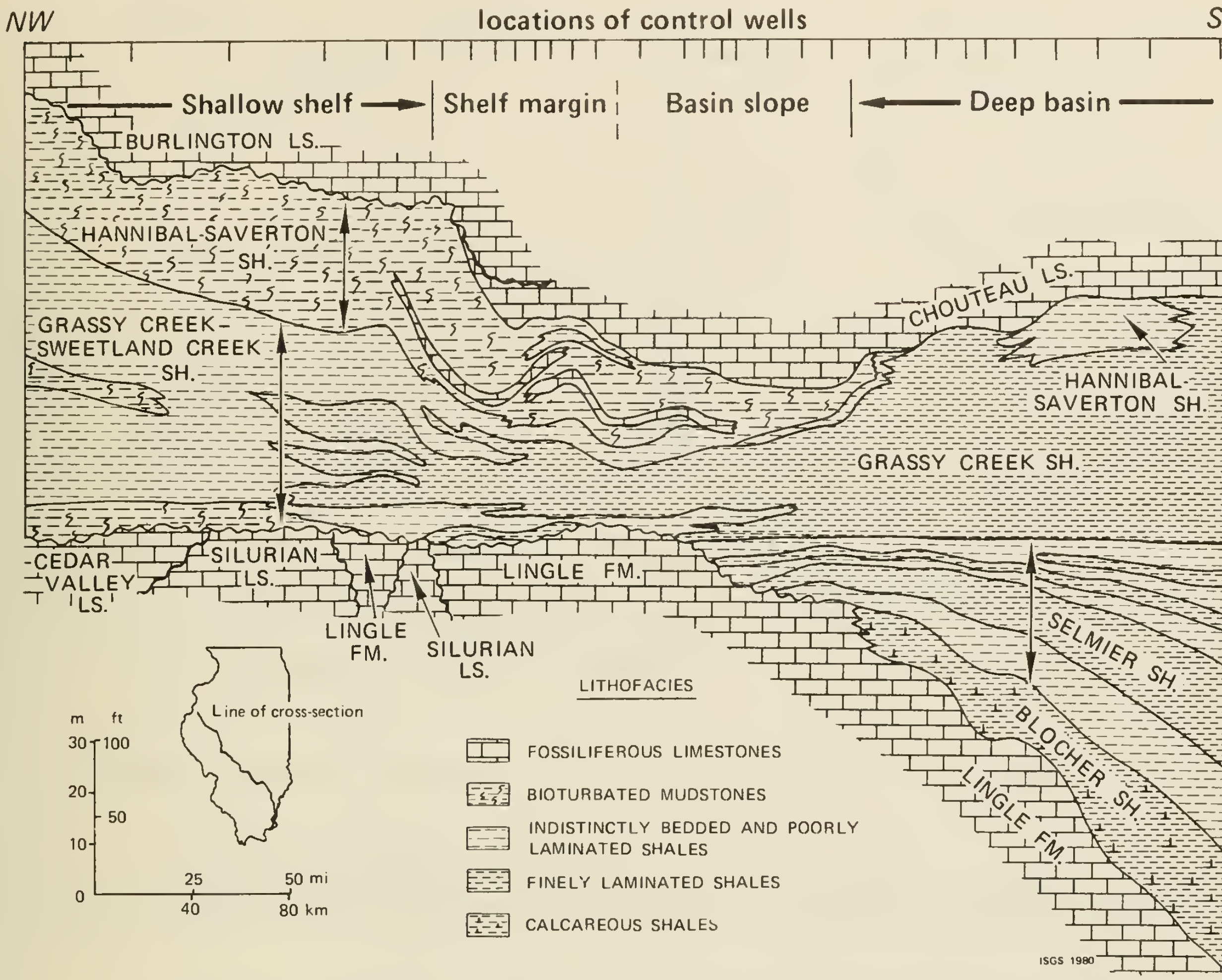


Figure 1. Diagrammatic cross section through the New Albany Shale Group in Illinois, illustrating broad lateral facies changes from shelf to slope to basin environments. (From Cluff, 1980)

A second depositional center known as the western depocenter lies in southeastern Iowa and adjacent west central Illinois, where the shales are late Devonian and Kinderhookian. Thicknesses of more than 300 feet (90 m) are attained in the western depocenter located in Henderson and Hancock Counties, Illinois, and adjacent Iowa. Bioturbated olive-gray and greenish gray shales are the predominant lithologies in this region.

The two depositional centers are separated by a northeast-southwest trending area of thin New Albany strata in central Illinois. Gray and black shales interfinger in this area called the central thin (fig. 3). The central thin area is continuous with a broad area of thin—100 ft (30 m) or less—New Albany that extends along the Indiana and Kentucky outcrop belt, an area dominated by black shale with some gray shale interbedded.

The New Albany Shale conformably overlies Middle Devonian limestone belonging to the Hunton Limestone Megagroup in Indiana, Kentucky, and southeastern Illinois. The lowest New Albany unit, the Blocher Shale, grades laterally westward into the Lingle Formation of the Hunton (figs. 1, 2).

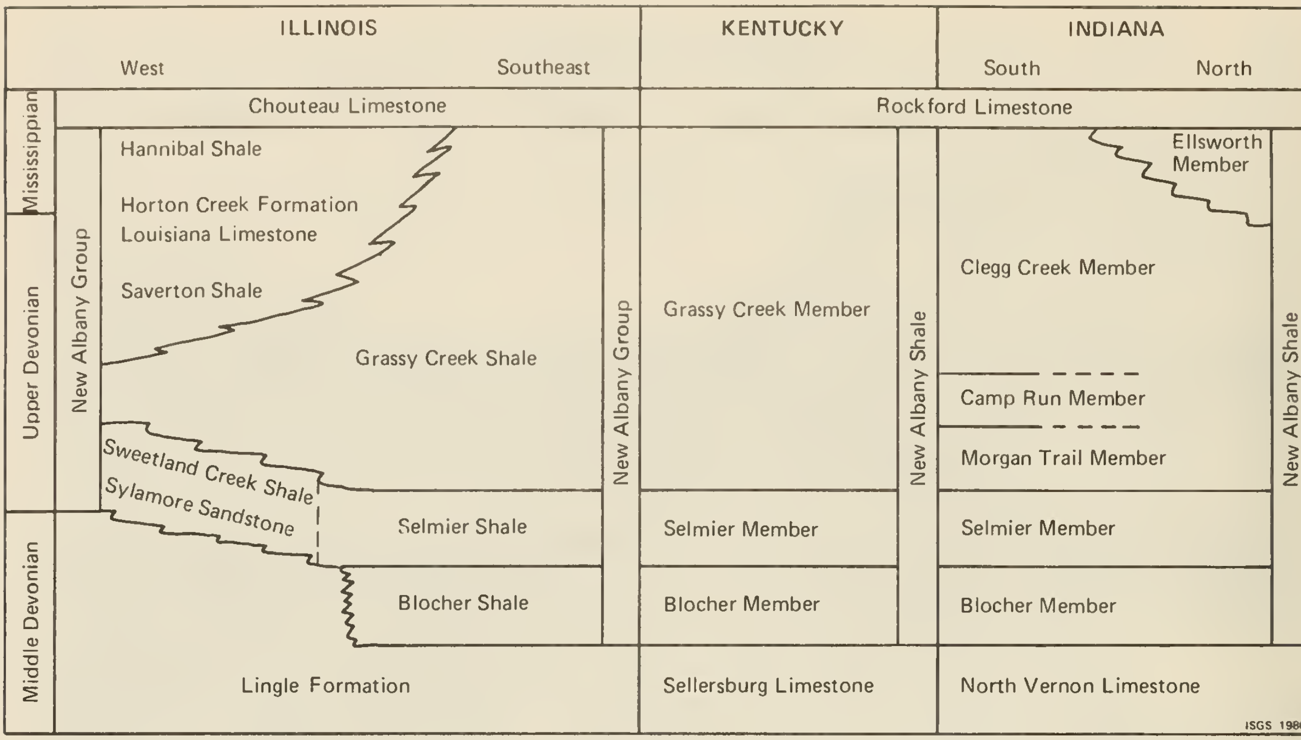


Figure 2. Stratigraphic nomenclature of the New Albany Shale Group in the Illinois Basin.

Beyond the limit of the Blocher Shale, the Sylamore Sandstone marks the base of the New Albany and the basal New Albany strata unconformably overlap the Hunton Limestone Megagroup toward the northwest.

The New Albany is conformably overlain by a thin limestone called the Chouteau Limestone in Illinois and the Rockford Limestone in Indiana and Kentucky. The Chouteau-Rockford is locally absent in Indiana and Illinois and is present at only a few places in Kentucky. In extreme western Illinois, the McCraney Limestone partially occupies the position of the Chouteau. Across most of western Illinois, an erosional unconformity separates the New Albany from overlying Valmeyeran strata.

The use of geophysical logs contributed greatly to the study of the New Albany in the basin. Most of the available logs are electrical resistivity-spontaneous potential logs, but a few gamma-ray, neutron, bulk density, and sonic velocity logs are available. Each major lithology in the New Albany can be characterized by its appearance on geophysical logs (table 1). Important marker horizons can be correlated and traced on geophysical log cross sections, and accurate measurements of the thickness of units can be made.

## Blocher Shale

The Blocher Shale (Blocher Member in Indiana and Kentucky), as used in the Eastern Gas Shales Project reports, is distinguished on the basis of its calcareous and dolomitic black shale. It is the only shale unit in the New Albany that is significantly calcareous. The high carbonate content of the Blocher imparts distinctive geophysical characteristics that permit it to be traced throughout most of the southern Illinois portion of the Illinois Basin (table 1).

Lineback (1968, 1970) included some black shale above the calcareous shale in the Blocher on the Indiana outcrop. As a result of correlations between the outcrop and the subsurface of the Illinois Basin, Cluff, Reinbold, and Lineback (in preparation) and Hasenmueller and Bassett (*in* Indiana Geological Survey Final Report (1981) revised the Blocher by restricting it to calcareous shale on the outcrop in Indiana, thus making the definition and identification consistent between the subsurface and outcrops. Maps prepared by Schwalb and Norris (1980) however, included poorly calcareous black shale now considered to be stratigraphically above the Blocher in that unit. The thickness of the Blocher in places in Kentucky has been revised downward in this report to match revised usage in Illinois and Indiana (fig. 4).

The Blocher is a brownish-black to grayish-black, finely laminated, carbonaceous, calcareous, and dolomitic shale. Thin beds of finegrained limestone, dolomite, calcareous sandstone, and phosphatic sandstone are also present in the Blocher. In central Indiana, a distinctive dark gray, laminated,

TABLE 1. Typical geophysical characteristics of major lithologies of the New Albany Shale Group.

| | Electrical resistivity | | | | | Spontaneous potential | Gamma ray | | | | | Neutron | | | | | Bulk density | | | | | Sonic velocity | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lithology | Very low | Low | Moderate | High | Very high | − ←→ + | Very Low | Low | Moderate | High | Very high | Very low | Low | Moderate | High | Very high | Very low | Low | Moderate | High | Very high | Very low | Low | Moderate | High | Very high |
| Limestone & dolomite | | | X | X | X | X | X | X | | | | | | | X | | | | | X | | | | | X | |
| Shale organic-poor (gray) | | X | | | | X | | X | X | | | | X | X | | | | | X | X | | | | X | X | |
| Shale organic-rich (black) | | | X | X | X | X X X | | | | X | X | | X | | | | | X | | | | | X | | | |
| Shale calcareous or dolomitic | | | X | X | | X | | X | X | | | | | X | X | | | | X | X | | | | X | X | |
| Siltstone | | X | X | | | X | | X | X | | | | | X | X | | | | X | X | | | | X | X | |

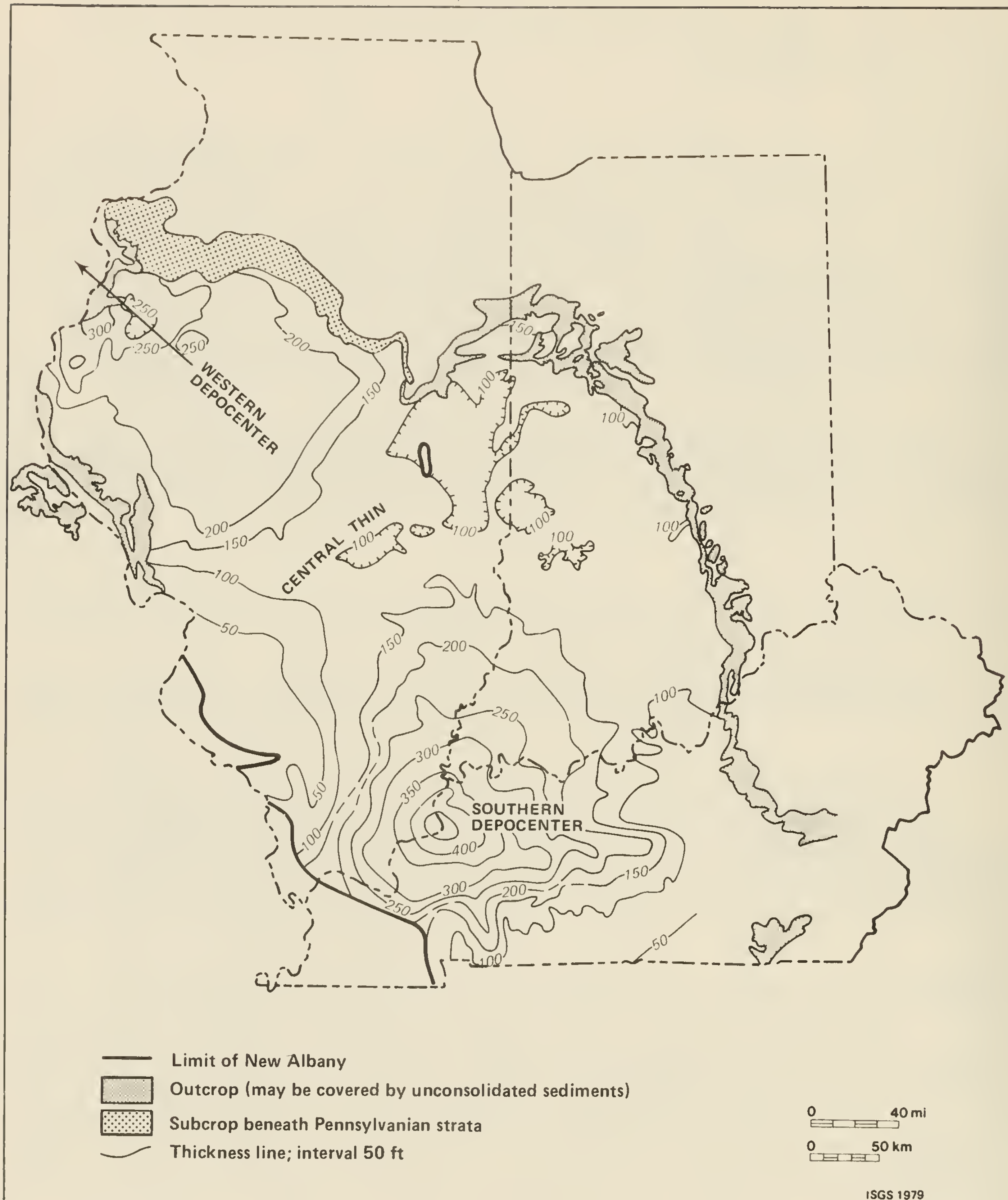


Figure 3. Total thickness of the New Albany Shale Group in the Illinois Basin.

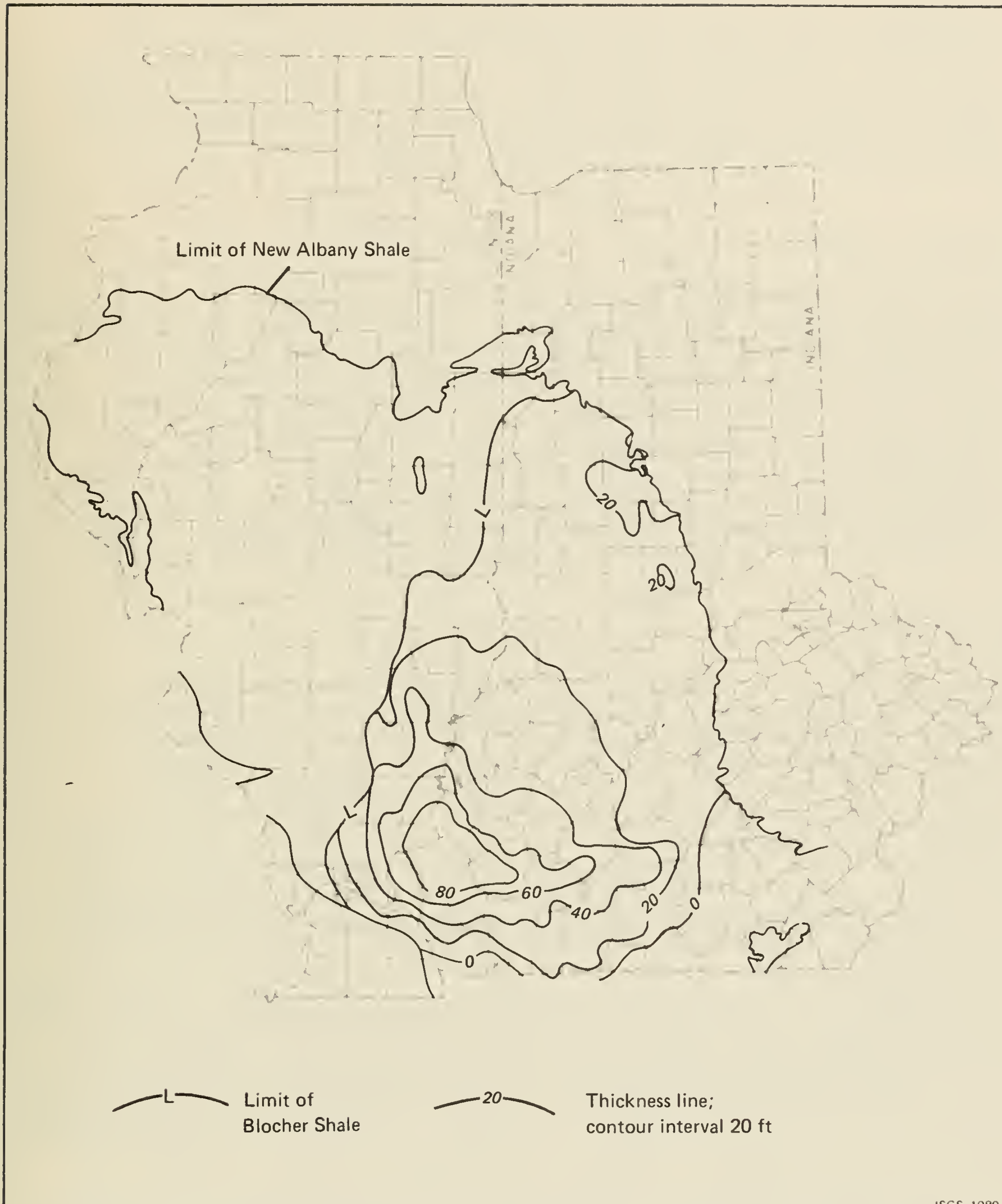


Figure 4. Thickness of the Blocher Shale in the Illinois Basin.

argillaceous limestone occurs in the basal part of the Blocher Member. The Blocher is more than 80 feet (24 m) thick in extreme southeastern Illinois and adjacent Kentucky (fig. 4). Eastward it thins to less than three feet (1 m) on the Indiana outcrop and may be absent on parts of the Kentucky outcrop. The Blocher grades westward into the Lingle Formation and an arbitrary vertical cutoff is used to step the base of the New Albany up to units overlying the Blocher (fig. 2).

### Sylamore Sandstone

The Sylamore Sandstone is the basal Upper Devonian formation in parts of central and western Illinois (Workman and Gillette, 1956). The Sylamore is rarely more than 3 feet (1 m) thick; more commonly it is only a few centimeters thick, and sometimes it is only a thin, sandy, or pyritic layer at the base of the Sweetland Creek or Grassy Creek Shales. The formation is typically a thin bed of rounded to subrounded, medium- to fine-grained quartz sand cemented by calcite, dolomite, or pyrite. The bed may be silty or shaly and is very commonly phosphatic. Although thin, the Sylamore marks the basal unconformity of the New Albany over a wide area (fig. 5) and rests on rocks of different ages. The Sylamore itself is apparently time transgressive, becoming younger westward in Illinois.

### Selmier Shale

Cluff, Reinbold, and Lineback (in preparation) and Hasenmueller and Bassett *in* Indiana Geological Survey Final Report (1981) redefined the base of the Selmier Member (Selmier Shale in Illinois) in the Indiana type section and moved it down to the top of the calcareous Blocher Shale. In so doing, they restricted the Blocher to black calcareous shale and assigned the black dolomitic shale between the restricted Blocher and the greenish-gray shale of the original Selmier to the Selmier. Subsurface correlation shows that the dolomitic black shale at the base of the outcrop Selmier extends westward and forms the middle black shale unit in a succession dominated by greenish-gray shale formerly called Sweetland Creek Shale in Illinois and Kentucky (Collinson et al., 1967; North, 1969; and Schwalb and Norris, 1980). Cluff, Reinbold, and Lineback (in preparation), however, show that the type Sweetland Creek is largely a facies of the Grassy Creek Shale and is for the most part stratigraphically higher than the Sweetland Creek in the deeper part of the Illinois Basin. Therefore the interbedded greenish-gray and black shales in southeastern Illinois that correlate with the expanded outcrop Selmier are now assigned to the Selmier Shale in Illinois and Kentucky. In Illinois, the Selmier is separated from the Sweetland Creek by an arbitrary vertical cutoff (figs. 2, 6) that precludes the two formations from being identified at the same location.

The Selmier Shale consists of alternating beds of brownish-black grayish-black, and olive-gray to olive-black shales and mudstones. The dark shale of the Selmier is generally thickly to poorly laminated. The greenish-gray mudstone is intensly bioturbated. Silt beds of micritic dolomite are present in places. The top of the Selmier is marked by a widespread geophysical

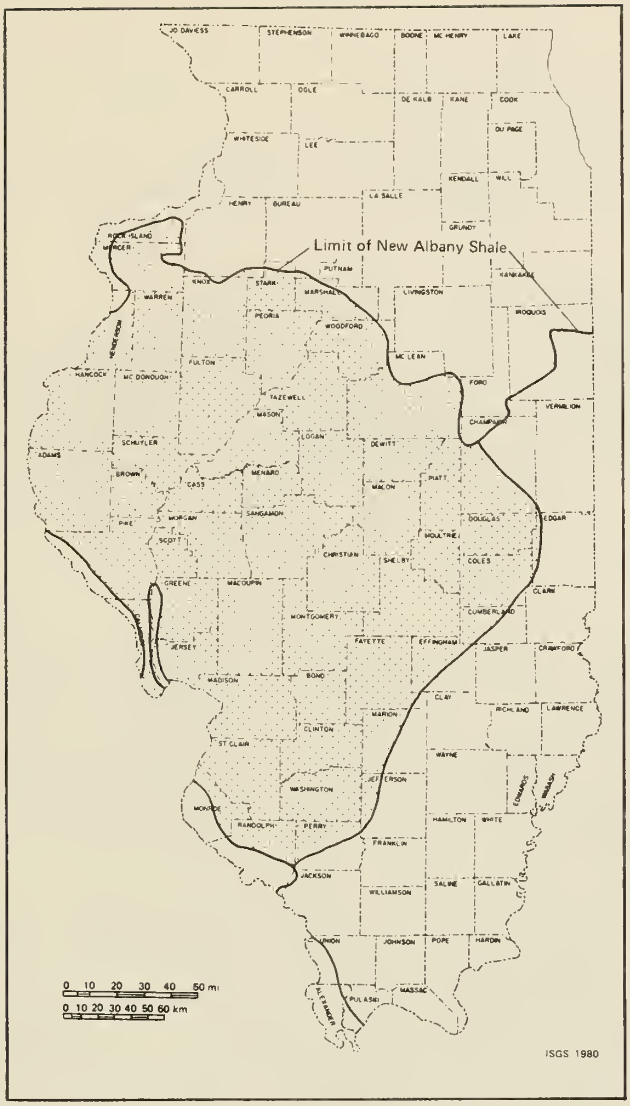


Figure 5. Approximate extent of the Sylamore Sandstone. (After Workman and Gillette, 1956; W. F. Meents, personal communication, 1979; and core descriptions in ISGS files)

marker horizon. The Selmier is more than 200 feet (62 m) thick in extreme southeastern Illinois and adjacent Kentucky (fig. 6); it is only 20 to 40 feet (6 to 12 m) thick over most of Indiana and may pinch out southward along the Indiana-Kentucky outcrop belt. In northwestern Indiana, the Selmier may include some shale assigned to the Sweetland Creek Shale in adjacent Illinois.

The thickness of the Selmier in Kentucky is increased from that shown on the 1980 Schwalb and Norris maps of the Sweetland Creek Shale because of the previously mentioned revisions in the Selmier and Blocher. The Selmier thins to about 20 feet (6 m) in central Illinois where it is separated from partially equivalent Sweetland Creek Shale by an arbitrary vertical cutoff. In southeastern Illinois and Kentucky, the Selmier underlies the Grassy Creek Shale; in Indiana it underlies the Morgan Trail Member or the Morgan Trail, Camp Run, and Clegg Creek Members undifferentiated.

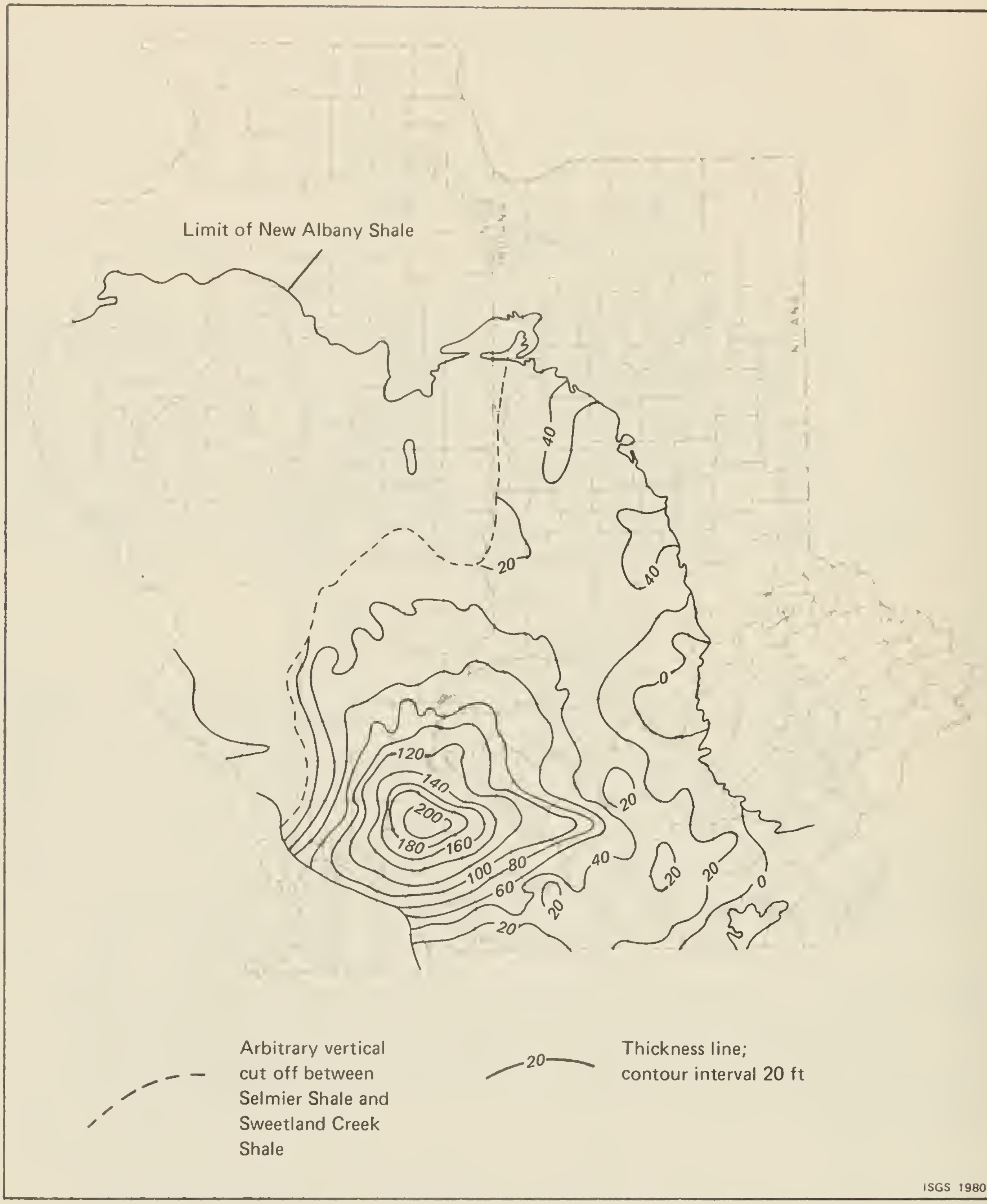


Figure 6. Thickness of the Selmier Shale in the Illinois Basin.

## Sweetland Creek Shale

Cluff, Reinbold, and Lineback (in preparation) restrict the use of Sweetland Creek to areas west and north of the deeper parts of the basin. The Sweetland Creek Member was used in Kentucky by Schwalb and Norris (1980) in a sense similar to the name Selmier as now applied there. Only the uppermost part of the Selmier Shale is equivalent to the Sweetland Creek and most of the Sweetland Creek is a lateral facies of the lower part of the Grassy Creek Shale.

The Sweetland Creek Shale consists of alternating beds of dark greenish-gray, greenish-gray, and grayish-green shales with minor amounts of olive-gray or olive-black shale. The dominant lithofacies is indistinctly bedded, moderately bioturbated shale. Pronounced interbedding of this lithofacies with thickly laminated olive-black shales is common. The Sweetland Creek cannot be easily differentiated from the Grassy Creek in many places and is not mapped separately in this report.

## Grassy Creek Shale

The Grassy Creek Shale includes the dominantly black shale interval of the middle and upper part of the New Albany Group. It is mostly brownish-black to grayish-black, finely laminated, pyritic, carbonaceous shale. The organic carbon content of these shales is among the highest in the New Albany. The Grassy Creek grades northwestward into less carbonaceous olive black to olive gray shale with interbeds of olive-gray to grayish-green mudstone (fig. 1).

The thick, dominantly black shales which characterize the Grassy Creek Shale are found primarily in the central part of the Illinois Basin in southeastern Illinois. To the north and west, the black shale interfingers with gray shales and becomes difficult to distinguish from the underlying Sweetland Creek Shale. The upper part of the Grassy Creek and its Indiana equivalents (the combined Morgan Trail, Camp Run, and Clegg Creek Members) grades laterally northwestward into a thickening wedge of greenish-gray shale and siltstone, the Saverton and Hannibal Shales in Illinois, the Ellsworth Member in Indiana (fig. 2). The Grassy Creek attains its maximum thickness, about 160 feet (50 m), in eastern Hardin County, Illinois, and adjacent Kentucky (fig. 7); it is also more than 130 feet (40 m) thick in Wayne, Edwards, and Wabash Counties, Illinois. Undifferentiated Grassy Creek-Sweetland Creek Shale attains a thickness of 140 feet (43 m) in western Illinois.

## Morgan Trail, Camp Run, and Clegg Creek Members undifferentiated (Indiana)

The Grassy Creek in southeastern Illinois is equivalent to the Morgan Trail, Camp Run, and Clegg Creek Members of the New Albany in Indiana (fig. 2). Combined, these members are 120 to 140 feet (37 to 43 m) in southwestern Indiana and thin northward as the overlying Ellsworth Member thickens. Like the Grassy Creek, the three members are predominantly black shale. They can be separated on the outcrop, but differentiation in the subsurface is difficult; for this reason the units are mapped together in Indiana (fig. 7).

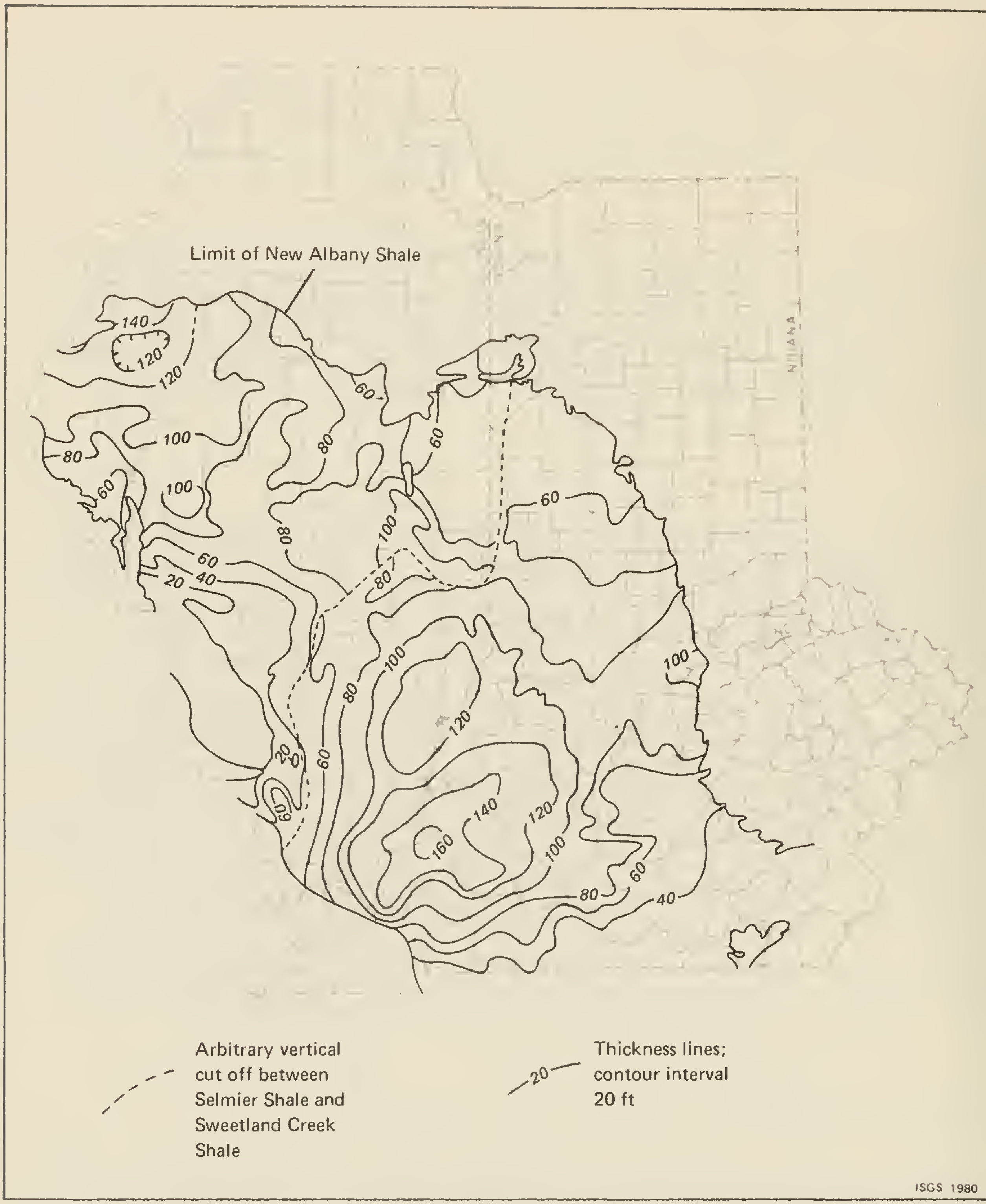


Figure 7. Thickness of the Sweetland Creek and Grassy Creek Shales undifferentiated beyond the limit of the Selmier Shale; thickness of Grassy Creek only where Selmier recognized in Illinois and Kentucky; and thickness of Morgan Trail, Camp Run, and Clegg Creek Members combined in Indiana.

The Morgan Trail Member is characterized by brownish-black, fissile, siliceous, pyritic shale. The Camp Run contains several thin (1 to 10 cm) beds of bioturbated olive gray mudstone and shale interbedded with brownish-black, organic-rich, pyritic, fissile shale. The Clegg Creek Member is predominantly a brownish-black, fissile, silty, pyritic shale. A thin phosphatic nodular zone and a few thin greenish-gray shale and mudstone beds at the top of the New Albany Shale are also included in the Clegg Creek Member.

## Saverton Shale

The Saverton Shale consists of interbedded greenish-gray, dark greenish-gray and olive-black shale. The organic carbon content of this shale is low. The Saverton overlies and grades laterally southeastward into the Grassy Creek Shale; it is overlain by the Louisiana Limestone or Horton Creek Formation, and where these distinctive units are absent, by the Hannibal Shale. The Hannibal is very similar lithologically to the Saverton; it is almost impossible to separate the two units in the absence of the Louisiana or Horton Creek. Therefore, we have mapped the combined thickness of the Saverton, Louisiana, Horton Creek, and Hannibal (fig. 8). Where separable from adjacent units, the Saverton reaches a maximum thickness of 120 feet (37 m) in northwestern Illinois and thins towards the south and east as it grades laterally into the Grassy Creek.

## Louisiana Limestone

The Louisiana Limestone is a light gray to tan, wavy-bedded, micritic limestone with thin shale and dolomite interbeds. In surface exposures it is often very pure carbonate with minor clay and quartz, and it is texturally very homogeneous (almost lithographic). Dolomite interbeds are often laminated, and in many areas the limestone appears faintly burrow mottled. Subsurface samples of the Louisiana are also micritic limestone, but are often argillaceous and extensively bioturbated.

A wide variety of invertebrate fossils is found in the Louisiana, although fossils are not abundant. The fauna is dominated by small brachiopods and dwarf crinoids. Bryozoans, ostracodes, sponges, corals, mollusks, trilobites, and conodonts are also found, but are rare (Williams, 1943). The Louisiana is thick (70 feet; 21 m) only in a small area near Hannibal and Louisiana, Missouri, and 30 feet (9 m) immediately east across the Mississippi River, in Illinois. An east-west elongated tongue of Louisiana, less than 10 feet (3 m) thick extends across the southwest-central part of the state (fig. 9).

## Horton Creek Formation

The Horton Creek is a complex unit consisting of siltstone, shale, sandy limestone, micritic limestone and dolomite, limestone conglomerates, and oolitic limestone. The most widespread carbonate lithology in the Horton Creek is a gray to tan, argillaceous, sparsely fossiliferous, micritic limestone and dolomite lithologically similar to the Louisiana Limestone.

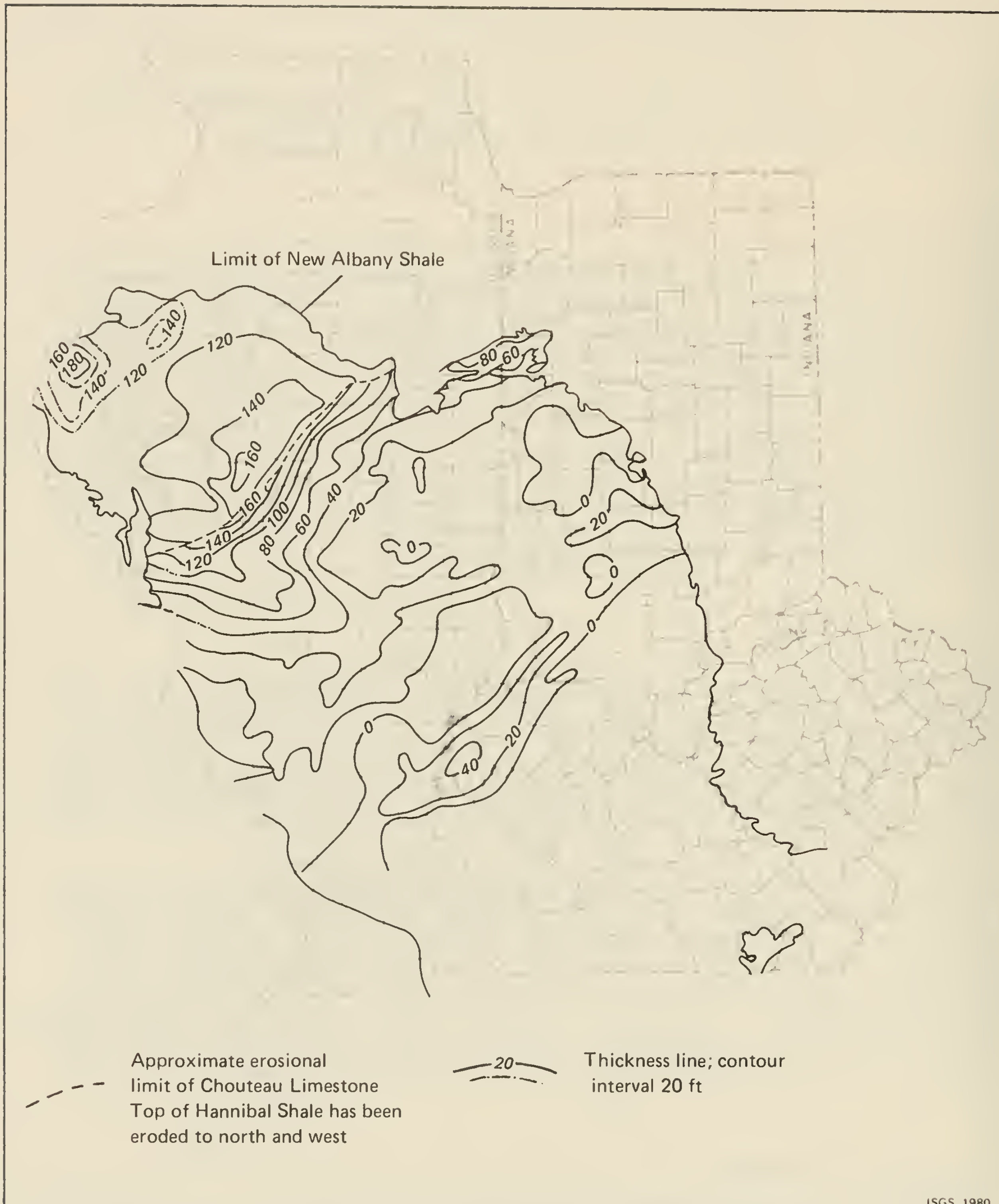


Figure 8. Thickness of the Saverton/Louisiana/Horton Creek/Hannibal in Illinois and the Ellsworth Member in Indiana.

These carbonate mudstones and wackestones are present throughout the extent of the Horton Creek and are the only carbonate lithologies observed towards the southern and eastern limits of the formation (fig. 9).

The Hamburg Oolite Bed lies in the upper part of the Horton Creek and is not present everywhere; it has been used to differentiate limestones in the Horton Creek from the Louisiana Limestone in the subsurface. The oolitic limestone is mainly present in a northeast-southwest trending belt across the northern part of the Horton Creek. The Horton Creek is 60 feet (18 m) thick in Macoupin County, where it consists mostly of siltstone. The Horton Creek includes shales and siltstones between the thin tongues of the Hamburg Oolite Bed and Louisiana Limestone; the shale and siltstone is otherwise indistinguishable from the Hannibal and Saverton Shales. The shaly Horton Creek is included in the Saverton where the Louisiana is absent and in the Hannibal where limestone lithologies do not exist in the Horton Creek to separate it from the Hannibal. Where both distinctive Louisiana and Horton

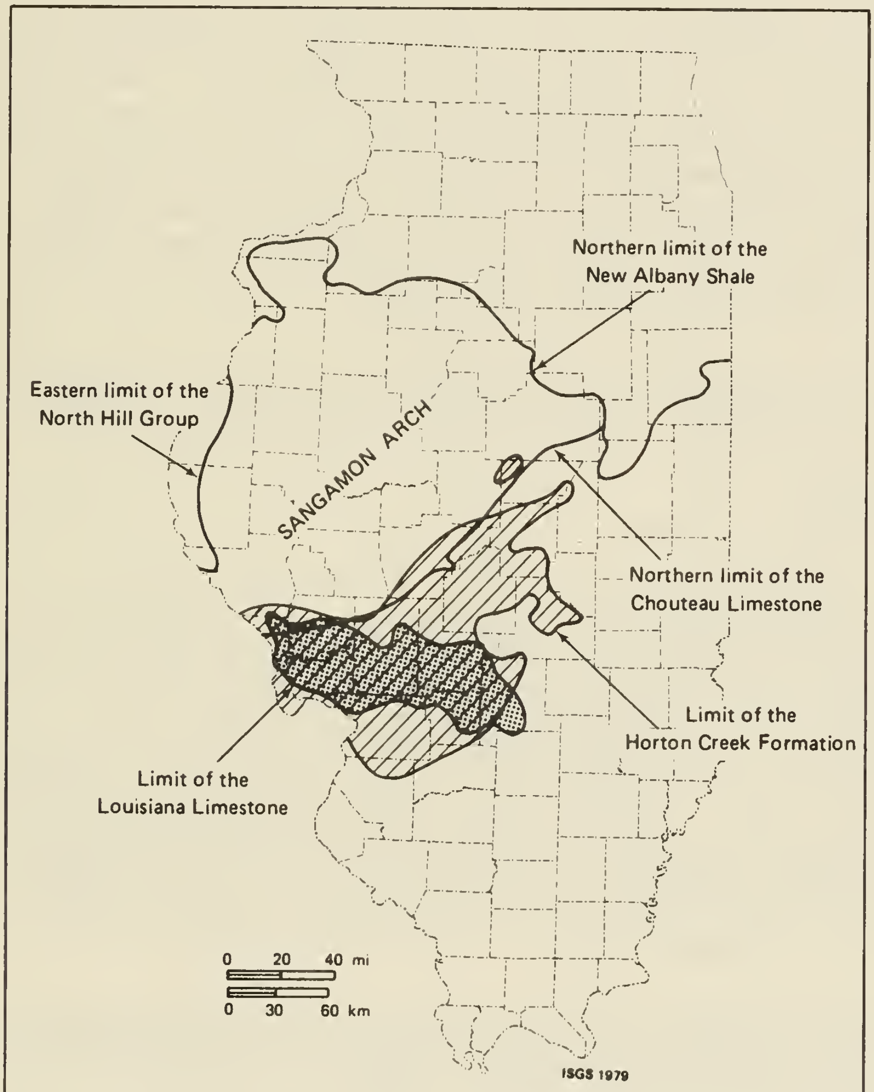


Figure 9. Extent of carbonate beds in the New Albany Shale of Illinois.

Creek carbonate lithologies are absent, the Hannibal and Saverton are undifferentiated.

The development of shoal and lagoonal carbonates in western Illinois and northeastern Missouri indicates a brief interlude in mud sediment deposition which allowed the development of shelf carbonate deposition. Calcareous fossils are found in black and greenish-gray shales at this stratigraphic position as far as southern Indiana (Campbell, 1946; Lineback, 1970), indicating the widespread nature of this brief depositional event.

## Hannibal Shale

The Hannibal Shale consists of dark greenish-gray, greenish-gray, grayish olive-green, and dusky yellow-green mudstone and shale; its organic carbon content is usually very low (<1%). Silty clay shales and argillaceous siltstones are present in places, particularly in the upper part of the formation. Mudstones of the Hannibal are highly bioturbated. A thin olive-black fissile shale called the Nutwood Member is locally present in western Illinois. In southeastern Illinois the Hannibal-Saverton is present in places between the Chouteau and Grassy Creek. In these localities a thin, black fissile shale may be present just below the Chouteau; this is believed to be the Henryville Bed of Indiana. Also present in cores and in outcrops in extreme southern Illinois are the very thin Jacobs Chapel Bed above the Henryville and the Falling Run Nodule Bed below the Henryville. These names are used in Illinois as beds in the Hannibal if greenish-gray shale is present below, or in the Grassy Creek if black shale underlies the beds.

The Hannibal is more than 110 feet (34 m) thick in west central Illinois (fig. 8); it is truncated by erosion below the Burlington Limestone in western Illinois and grades laterally into the Grassy Creek to the southeast.

## Ellsworth Member (in Indiana)

Greenish-gray shale in the Illinois Basin in the northwestern part of Indiana was called the Ellsworth Member by Lineback (1968). The term Ellsworth Member is currently used in Indiana for the combined Hannibal-Saverton interval. The same lateral gradation between black and gray shales noted in Illinois takes place in Indiana in the northeastern part of the Illinois Basin. The Ellsworth is more than 80 feet (24 m) thick there (fig. 8). A similar gradation between the Ellsworth Shale and the black Antrim Shale is present in the Michigan Basin (Lineback, 1970). Tongues of the Ellsworth Member, up to 40 feet (12 m) thick, extend into southwestern Indiana (fig. 8). The thin greenish shale beds of the Jacobs Chapel Bed and the Underwood Bed are probably tongues equivalent to the Ellsworth. The Ellsworth is predominantly a greenish-gray, intensely bioturbated, non-calcareous shale.

In Kentucky, greenish-gray shale at the top of the New Albany was not deposited or is generally too thin to be recognized and is not separated from the Grassy Creek Member there (Schwalb and Norris, 1980).

## ILLINOIS BASIN STRUCTURE

The Illinois Basin is a roughly oval structural depression centered in southeastern Illinois (fig. 10). It includes most of central and southern Illinois, southwestern Indiana, and western Kentucky. Detailed structure maps on the base of the New Albany have been compiled for the EGSP project (Schwalb and Potter, 1978; Bassett and Hasenmueller, in preparation, and Cluff, Reinbold, and Lineback, in preparation).


Figure 10. Geologic structure on the base of the New Albany Shale. (After Stevenson and Whiting, 1967; Bassett and Hasenmueller, in preparation; and Schwalb and Potter, 1978)

The depositional thickness of the New Albany was strongly affected by regional downwarping in extreme southeastern Illinois, somewhat south of the present structural center of the basin. Thickness of the New Albany is also greater in the Moorman Syncline in Kentucky, a structure active during the Devonian. The structural elevation of the base of the New Albany is affected by the major fault and anticlinal systems and also by minor compactional structures over Silurian reefs.

A structure map of the top of the New Albany Group is essentially the same as that of the base, but the top of the New Albany is not easily recognized where the overlying Chouteau-Rockford Limestone is absent.

Natural fractures have been major pathways for gas migration and accumulation in Appalachian gas fields (Hunter and Young, 1953). Although their exact relationship and importance to production are debatable, it seems likely that extensive fracturing aids the flow of gas into wells and increases the volume of shale drained by a single well bore. Most of the major fault systems in Illinois (including the Wabash Valley, Cottage Grove, and Rend Lake Fault systems, and the Shawneetown Fault Zone) and the Rough Creek and other fault zones in Kentucky occur in southern and southeastern Illinois and western Kentucky. Extensive fracturing of rocks in these areas is known to exist, as indicated by observations in coal mines, cores, and by significant production of oil from fractured reservoirs in the New Harmony Field, White County, Illinois. Mineralization along fracture systems is common in the Fluorspar District in extreme southeastern Illinois.

Linear features visible on LANDSAT images of Illinois have been mapped in Indiana and Illinois. Linears associated with known faults occur only beyond the limit of continental glaciation. Linear features in Illinois may have a variety of origins (Stevenson et al.), *in* Bergstrom, Shimp, and Cluff, 1980). It is generally impossible on the basis of remote sensing techniques alone, to discriminate between linears that are bedrock controlled and linears formed by glacial processes. This determination can be made only when the regional geology of the area is well understood and the linears have been field investigated. Linear features can be useful only when the particular causes of their development are understood.

Almost all of Illinois, except for the southern and northwestern tips, is blanketed by glacial drift derived from multiple glaciations during the Pleistocene (Lineback, 1979). The drift is more than 50 feet (15 m) thick over large areas of the state and is more than 400 feet (122 m) in places (Piskin and Bergstrom, 1975). This cover of glacial drift and other Pleistocene deposits may effectively mask underlying bedrock structural features in places.

A number of linears in western Illinois were field investigated. The linears proved to be related to linear glacial landforms such as drumlins and glacial flutes.

Somewhat in contrast to the results of studies of linear features in Illinois, results from Indiana show similar pronounced orientations of linear features in glaciated areas and areas with thin or no glacial deposits (Carr, *in* Indiana Geological Survey Final Report, 1981). The linear features are oriented approximately NE-SW and NW-SE, about 90° apart. They appear to be unrelated to joint patterns, faulting, or the location of gas fields in the New Albany. They may be related to narrow linear fracture zones in the bedrock that have propagated through overlying cover.

## PETROGRAPHY AND DEPOSITIONAL ENVIRONMENT

Petrographic studies of the New Albany Shale Group were carried out at the Illinois and Indiana Geological Surveys. The results of these studies were largely in agreement and have been reported in detail by Harvey et al. (1978); Cluff (1980); Shaffer and Chen, *in* Indiana Geological Survey Final Report (1981); and Cluff and others, *in* Bergstrom, Shimp, and Cluff (1980). Although petrographic descriptions of selected samples were made by the other contractors, no substantive conclusions or generalizations were made in their reports.

In general, the Illinois petrographic studies of the New Albany Shale Group have identified and characterized five major lithofacies: (1) limestones and dolomites; (2) highly bioturbated mudstones; (3) indistinctly bedded shales; (4) thickly laminated shales; and (5) finely laminated shales (table 2). The distribution of these lithofacies—the basis for the major stratigraphic subdivisions of the New Albany Group—is shown to have been determined by the depositional environment of the shale, especially wave energy, bottom oxygenation, and bottom topography. A transect from the margin to the center of the

TABLE 2. Lithofacies characteristics of the New Albany Shale Group.

| | Color | | | | | Bedding & lamination | | | | Bioturbation | | | | Pyrite | | | | Organic Carbon | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lithofacies | Gray or brownish gray | Greenish gray | Olive gray | Olive black | Brownish black | Massive | Indistinctly bedded | Thickly or poorly laminated | Finely laminated | Very extensive or total | Extensive | Moderate | Sporadic | Fine hairlike features (burrows) | Burrow fillings | Nodules | Laminae | <1% | 1 to 5% | 5 to 10% | >10% |
| Fossiliferous limestones and dolomites | A | | | | | A | R | | | A | R | | | | R | | | A | | | |
| Highly bioturbated mudstones | R | A | | | | A | | | | A | | | | A | A | | | A | | | |
| Indistinctly bedded shales | | | A | R | | | A | R | | | A | A | | A | A | R | | | A | | |
| Thickly laminated shales | | | | A | R | | | A | R | | | R | A | | R | A | A | | R | A | |
| Finely laminated shales | | | | | A | | | | A | | | | | | | A | A | | R | A | A |

A = major or common
R = minor or rare

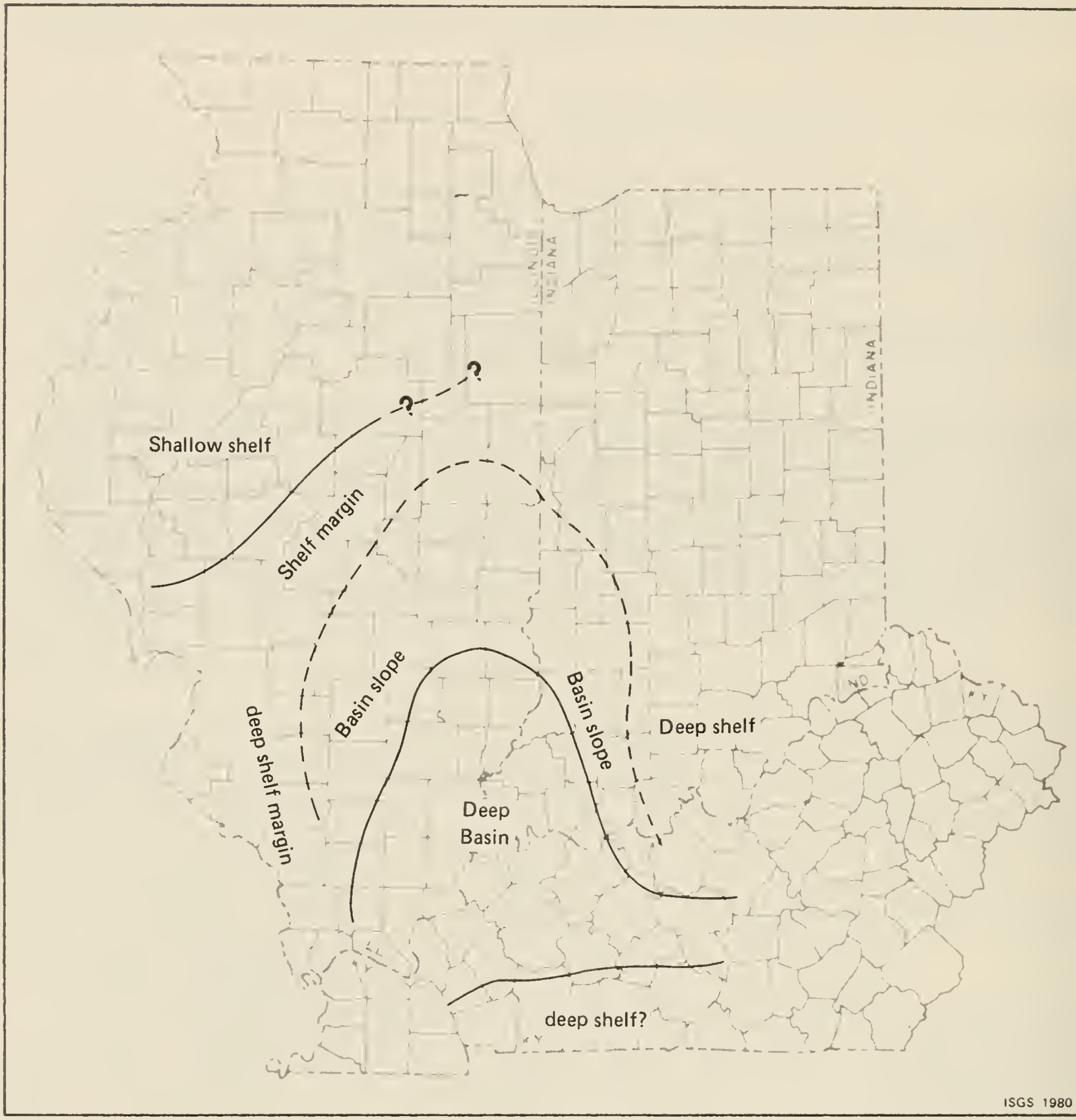


Figure 11. Generalized paleogeography of the Illinois Basin during New Albany deposition.

Illinois Basin reveals a complete transition from high energy, aerobic, shallow-water environments to quiet, anaerobic, deep-water environments (fig. 11).

Shallow areas at the margin of the basin are characterized by rapid facies transitions over short distances. High-energy, very shallow conditions are recorded by oolitic-skeletal limestones with abundant calcified marine invertebrate fossils (fig. 9). Offshore, less agitated areas are represented by highly bioturbated carbonate wackestones, argillaceous quartz siltstones, and greenish-gray mudstones. Calcified invertebrates are generally rare in these facies, indicating deposition in dysaerobic conditions. Basinward, slope areas are characterized by olive-gray to black, weakly bioturbated shales commonly interbedded with thickly laminated black shales. Anaerobic conditions prevailed during most of New Albany time in the deepest areas of the basin, and finely laminated, undisturbed, pelagic black shales were deposited.

## MINERALOGY OF THE NEW ALBANY SHALE

Petrographic and lithologic examinations of the New Albany Shale in Illinois and Kentucky were made by Harvey et al. (*in* Bergstrom, Shimp, and Cluff, 1980) and in Indiana by Shaffer and Chen (*in* Indiana Geological Survey Final Report (1981). Shales of the New Albany are composed of about 80 to 90 volume percent of grains and flakes <2 μm in size. The remaining fraction is composed almost entirely of silt-sized grains (2-62 μm). The New Albany is composed mainly of quartz, clay minerals, feldspars, pyrite, marcasite, dolomite and calcite mixed with fine carbonaceous material. Small mica flakes, rutile, and zircon are present in many samples. Apatite (mainly fluorapatite) occurs as pellets or conodonts. Trace minerals observed in few samples include rhodochrosite, siderite, gypsum, fluorite, glauconite, barite, tourmaline, sphalerite, amphibole, and pyroxene.

Quartz constitutes up to 25 percent of the shale. Illite predominates in the clay mineral suite, increasing slightly southward at the expense of chlorite. Minor amounts of mixed-layer expandable clay minerals were present in nearly all samples.

Calcite and dolomite are most abundant in the Blocher Shale but occur in variable abundance through the New Albany as scattered grains and in laminar bands. Some ferroan dolomite was noted. Pyrite and marcasite are the most abundant accessory minerals. Pyrite is more abundant and occurs in widely variable forms such as silt-sized framboids, nodules of various sizes, lenticular forms along bedding planes and burrow fillings, cementing material in coarser beds, and as isolated euhedral crystals. All these forms probably grew in place, near the sediment-water interface, in response to bacterial activity. The more organic-rich phases of the shale contain the most pyrite.

## PETROGRAPHIC CHARACTERIZATION OF ORGANIC MATTER

Petroleum geologists regard most dark, fine-grained, sedimentary rocks in which abundant organic matter has been preserved as probable petroleum source rocks. As the thickest and most continuous black shale in the Illinois Basin, the New Albany Shale Group is suspected of having played a major role in petroleum generation throughout the basin (Stevenson and Dickerson, 1969). Petrographic studies of the organic matter in the New Albany Shale Group have been carried out by the Illinois Geological Survey and the Mound Facility of Monsanto Research Corporation in an attempt to evaluate the quality of the source beds in this group and their maturity with respect to oil and gas generation. Researchers at the Mound Facility concluded that the organic matter in the New Albany Shale is thermally too immature to have generated significant hydrocarbons (Nance and Zielinski, 1979). However, the Illinois Survey indicated areas in the basin in which significant quantities of petroleum were likely to have been generated (Barrows, Cluff, and Harvey, 1979, and *in* Bergstrom, Shimp, and Cluff,

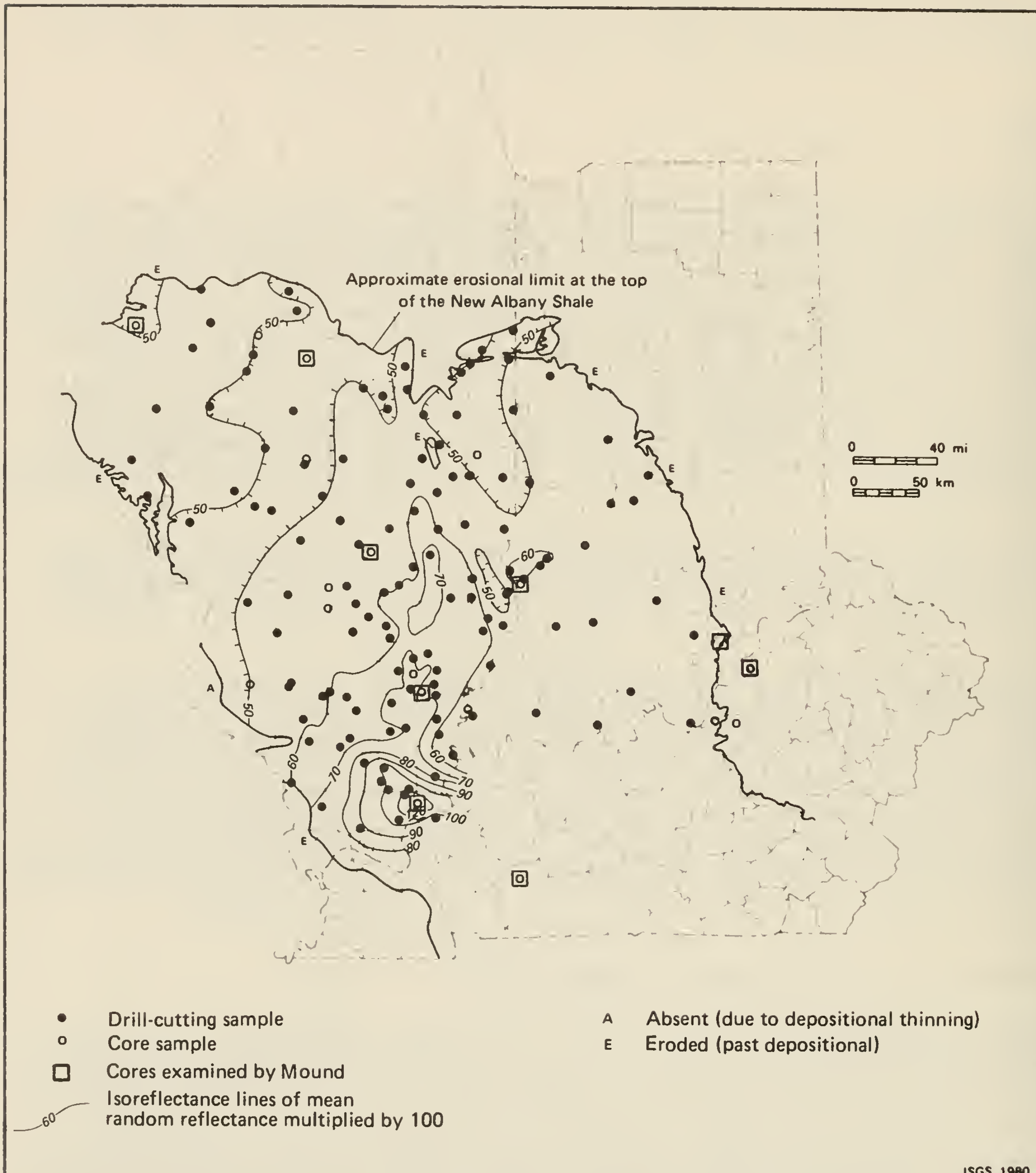


Figure 12. Mean random reflectance of vitrinite in the New Albany Shale ($R_o$ % x 100). (After Barrows, Cluff, and Harvey, *in* Bergstrom, Shimp, and Cluff, 1980)

1980). These differences in interpretation result from differing observations of the relative amounts of terrestrial and marine derived organic matter and by the greater number (148 wells) and broader geographic distribution of data points developed by the Illinois Survey as compared to the eight cores examined by Mound (fig. 12).

Work by both groups indicates that shale color is generally indicative of the organic matter content (Harvey et al., 1978; Zielinski and Nance, 1979; Illinois Geological Survey DOE Quarterly Report January-March 1980). The black shales are relatively rich in organic matter; the greenish shales have little organic matter and are, therefore, lighter in color.

The carbonaceous material (kerogen) in the shales is composed of varying amounts of very finely divided organic matter with no distinct form (amorphous organic matter) and recognizable plant fragments from the morphologically distinct maceral groups (liptinite, vitrinite, and inertinite) defined by coal petrographers.

Work done at the Illinois Survey indicates that in thin sections of black shales perpendicular to bedding, the amorphous organic matter is closely associated with the clay minerals and occurs as discontinuous streaks, curved laminae, and patches. These discontinuous streaks of amorphous organic matter are much less common or are absent in the gray to greenish-gray shales. Distribution of recognizable plant fragments is variable. In the black shale facies, amber yellow to brownish-yellow spores are common; these spores are much less common in the greenish shales. Vitrinite and inertinite fragments may also be observed in thin section, but their distribution is variable.

Studies of organic matter separated and concentrated from the shale matrix by an acid maceration process were conducted by both Illinois Survey and Mound Facility groups to determine the relative abundance of the different types of organic matter and to evaluate their thermal maturuation.

Reflected light studies carried out by the Illinois Survey indicate that the occurrence and abundance of the organic matter types are facies dependent. In the organic-lean greenish-gray shales, only vitrinite and inertinite are commonly observed. The predominance of these fragments corresponds to the type III kerogen of Tissot and Welte (1978), which is said to be gas prone. In or the organic-rich brownish-black shales, amorphous organic matter believed to be derived primarily from marine algae accounts for 90-95 percent of the kerogen. The appearance of the amorphous organic matter changes toward the center of the basin. In shale samples from most of the basin, the amorphous organic matter occurs as an interconnected network of dark gray material. However, near the center of the basin, the network-like structure is less common and is replaced by a lighter gray hash of unidentifiable fragments. Surrounding this region is an area in which both the network and the hash of unidentifiable fragments are observed.

The remaining 5 to 10 percent of the kerogen is composed of fragments of liptinite, vitrinite and inertinite. The mixed assemblage of amorphous organic matter and macerals corresponds to the type II kerogen of Tissot and Welte (1978). Studies have shown that type II kerogen is capable of generating large quantities of oil and gas and therefore is a favorable source rock material.

Although consistently reporting higher amounts of terrestrial organic material Mound Facility researchers working on detailed palynological studies (transmitted light) are in reasonable agreement with the reflected light work done by the Illinois Survey. Mound research findings indicate that the organic-rich shales in the New Albany Group contained varying amounts of marine and terrestrial organic matter (Nance and Zielinski, 1979).

However, there is disagreement on the types of organic matter found in the Hardin County Illinois core. Studies at the Illinois Survey indicate that, for the most part, the organic matter is composed of a finely divided hash of unrecognizable fragments (fig. VIII-d, Barrows, Cluff, and Harvey, *in* Bergstrom, Shimp, and Cluff, 1980) presumed to be the result of alteration of the amorphous organic matter during the maturation process. Some of the larger, angular fragments (fig. VIII-f, Bergstrom, Shimp, and Cluff, 1980) may be angular solid hydrocarbons produced during petroleum generation. Studies at Mound, on the other hand, concluded that most of the organic matter in the Hardin County well was very mature, terrestrially derived plant debris (Nance and Zielinski, 1979). It seems unlikely that samples from Hardin County would consist predominately of terrestrial organic matter, since petrographic studies of samples from adjoining counties conducted by the Illinois Survey indicate that the samples consist largely of amorphous organic matter. Reasons for the discrepancies in interpretation are currently being investigated. Mound researchers did present geochemical data (H/C plotted against O/C atomic ratios, Zielinski and Nance, 1979, April to June Quarterly Status Report) which suggest that the material is terrestrial in origin. However, if the levels of vitrinite reflectance ($R_o$ values ranging from 1.36 to 1.55) determined by both groups are correct, then there are some questions regarding the interpretation of this data. Atomic ratio diagrams presented in two separate publications (Tissot and Welte, 1978, and Durand, 1980) indicate that for reflectance values of 1.0 percent and greater, O/C values should be less than about 0.125. Mound's calculated mean O/C values for 8 samples is 0.24. According to the published diagrams and accompanying information cited above, at that level of reflectance, kerogen types cannot be easily identified using the H/C and O/C ratios because the overall chemical structure of the three kerogen types is very similar.

In recent years it has been recognized that oil is generated within a relatively narrow maturation range and that oil and gas are formed over a much broader range. The relative thermal maturity of organic material in a potential source rock can be measured using a variety of techniques. In this project the well established tool of vitrinite reflectance was used by both groups. Other less precise measures such as the Thermal Alteration Index used by Mound and the observations of liptinite fluorescence under blue light used by the Illinois Survey may also be used as indicators of the level of maturity. The levels of maturation determined with these techniques are in general agreement with the reflectance data.

Vitrinite reflectance measurements indicate that much of the New Albany Shale Group in the Basin is in the immature stage. With the exception of the Hardin County, Illinois core, all the samples examined by Mound using vitrinite reflectance were taken from areas where organic matter is in this stage. The areas (fig. 12) where reflectance values fall within the oil generation zone ($\bar{R}_o$ values of 0.50 to 1.30) lie near the center of the basin where the New Albany Shale is most deeply buried and type II kerogen is dominant. Peak oil generation is believed to occur when vitrinite reflectance values are above 0.70 percent. A considerable amount of gas may also be generated with the oil (Harwood, 1977).

Although vitrinite reflectance values for the Hardin County core on Hicks Dome range from 1.36 to 1.55 percent (indicating that organic matter has just reached the mature stage) nowhere in the Illinois Basin are levels of maturation known to reach the main zone of gas generation. No major gas fields are known to be present in the Illinois Basin parts of Indiana and Illinois. Gas fields in western Kentucky may be related to possible higher maturation levels in the Moorman Syncline area, but we do not have enough data to be certain of this.

*Conclusions.* Considerations of (1) the occurrence and abundance of type II kerogen as determined by reflected and transmitted light studies; (2) the thermal maturation as determined by vitrinite reflectance, the thermal alteration index, and the character of liptinite fluorescence; and (3) the occurrence of solid hydrocarbon pore fillings and isolated fragments, strongly suggest that active petroleum generation and expulsion occurred within the New Albany Shale in southern and southeastern Illinois. Nowhere within the Illinois Basin is the thermal maturation known to reach the main zone of gas generation. Gas within the New Albany Shale is thought to be gas produced during oil generation, possibly diluted by small amounts of biogenic gas.

## PHYSICAL PROPERTIES OF THE NEW ALBANY SHALE

Several thousand tests were performed to characterize the physical properties of six oriented cores from the New Albany Shale in the Illinois Basin. Details of these tests were reported by Miller, Bauer, and Johnson, *in* Bergstrom, Shimp, and Cluff (1980); and Blakely, *in* Indiana Geological Survey Final Report (1981).

Each core was reoriented and a north direction indicated. The core was divided into 10-foot long data sets and fractures and other visible features were then logged. A point-load test was used to determine the preferred weakness orientations in the direction normal to bedding. The test is also an index of rock strength. A "Brazilian" indirect tensile strength test was run on selected samples or oriented core. Triaxial compression tests were conducted on small (3/4 inch, 19 mm) diameter cores cut from the larger core pieces, both parallel and perpendicular to bedding.

Directional acoustic velocity measurements were performed using an acoustic bench with a direct pulse transmission technique. Compressional wave velocities transmitted through shale samples were measured parallel to the bedding at six orientations in order to investigate the transverse directional nature of the acoustic fabric and elastic properties.

Shore hardness tests were obtained at intervals on the core. Moisture content and specific gravity measurements were made. Drilling penetration rates from drillers' logs were also analyzed. Inconclusive results were determined for clay particle orientation by x-ray diffraction methods.

Natural fractures with a consistent orientation were noted in the Christian County, Kentucky core. Point load tests also show a strong orientation parallel to the natural fractures in that core. The Kentucky core lies in an area of intense faulting. Tests performed in cores in Indiana and Illinois were less conclusive in indicating relationships between test results and known geologic structure. Test variations between lithologies were noted in cores from Illinois. Samples of greenish-gray bioturbated shale are the least strong and samples of laminated black shale and limestone are the strongest lithologies tested from the New Albany.

## CHEMICAL ANALYSIS OF THE SHALE

### Organic Carbon

Organic carbon determinations were made on core samples and drill cuttings from the Illinois Basin (Frost, *in* Bergstrom, Shimp, and Cluff, 1980; Meinschein, *in* Indiana Geological Survey Final Report, 1981). High organic content of the shale generally correlated directly with high gamma-ray intensities recorded on radioactivity logs of boreholes and with high gas release values for the cores tested. Black shale lithofacies III and IV have the highest organic content (2.5 to 9 weight percent); greenish-gray shale lithofacies I and II average only 1 to 2 weight percent organic carbon. Stratigraphically, the Blocher Shale averages 4 to 9 weight percent, the black shale lithofacies of the Selmier Shale 2.5 to 6.5 weight percent, and the Grassy Creek Shale (and its Indiana equivalents) average 5 to 9 weight percent organic carbon. Individual beds and samples may exceed 15 weight percent organic carbon.

Organic carbon content averages for black shales in the Grassy Creek Shale show no systematic variation within the slope and basin environments. Values of organic carbon in the Grassy Creek in the shelf area of western Illinois are lower, and lower gamma-ray values are also recorded on nuclear logs of boreholes in western Illinois. Plots of organic carbon determinations for the Sweetland Creek and Selmier Shales show a similar random distribution in central and southeastern Illinois and generally lower values on the western shelf.

Previous maps of the organic carbon in the lower 50 feet of the New Albany Group in Illinois (Stevenson and Dickerson, 1969) included shale from the Blocher, Selmier, Sweetland Creek, and lower part of the Grassy Creek Shales, and for that reason do not show a geologically significant regional trend.

### Major, minor, and trace elements

The study of the major, minor, and trace element content of the inorganic fraction of the New Albany Shale in Illinois and Kentucky has not been completed yet. (This part of the study will be completed by the end of 1980.) Leininger, *in* Indiana Geological Survey Final Report (1981) reports that the major element composition of the New Albany is normal for Paleozoic shales in the basin. Composition is uniform between samples and locations. Trace element content of Indiana samples is generally predictable in regard to those elements associated with clays, feldspars, carbonates, phosphates and accessory minerals. The top organic-rich unit of the New Albany, the Henryville Bed, is enriched in several trace elements (Zn, Cd, Mo, V, Pb, Ni, Cu). The phosphatic nodule zone (Falling Run Bed) at the base of the Henryville is enriched in uranium and rare earths.

## ANALYSIS OF GAS RELEASED BY SHALE SAMPLES

Samples were taken from each coring site and sealed in airtight canisters to permit released gas analysis. A certain variable length of time (4 to 6 hours) elapsed between the cutting of the core and its placement in the canister. Thus the gas content determined represents minimal values because an appreciable amount of the indigenous gas was probably lost during the coring operation and the removal of the core from the well (Dickerson and Chou, *in* Bergstrom, Shimp, and Cluff, 1980).

The canisters were stored at a constant temperature, and headspace pressure was monitored weekly until a relatively constant equilibrium pressure was attained. The quantity of gas released by each sample was then calculated. A small sample of gas was removed periodically and analyzed by gas chromatography. Adjustments were made for the original headspace gas composition.

Released gas values from cores in western Illinois were very low, less than 0.05 $m^3/m^3$ shale (Dickerson and Chou, *in* Bergstrom, Shimp, and Cluff, 1980). Black shale with high gamma-ray readings and high organic content in the west released a little gas and the organic-poor greenish-gray shale that predominates in this area released practically no gas.

A core drilled in Hardin County in extreme southern Illinois did not yield much gas because of surface exposure and metamorphism due to local igneous intrusions. Samples of cores in Sullivan County, Indiana, and Christian County, Kentucky, released moderate amounts of gas (0.5 $m^3/m^3$ shale). A core from Effingham County, Illinois, released moderate amounts of gas, too; but the composition of the gas there indicated that some of it may come from lower horizons. With the exception of the altered core from Hardin County, all the previously mentioned tests fall outside the deeper part of the Illinois Basin where the New Albany is deeply buried, thick, and mostly black shale. Only one partial core and one complete core were taken from this deep and favorably located area; these two cores were from locations in Wayne County, Illinois. These cores yielded the largest volumes of released gas found thus far in the basin (as high as 2.4 $m^3/m^3$ shale). In the Wayne County cores, as with all the others tested, the quantity of gas released was highest in zones of radioactive (high gamma-ray readings) black shale and lowest in greenish-gray shale and in the calcareous Blocher Shale. Zones of high gas release were generally the highly radioactive intervals of the Grassy Creek Shale and the middle black shale interval of the Selmier Shale.

On the average, the hydrocarbon composition of the released gas was 70 percent methane, 19 percent ethane, 8 percent propane, 2 percent butane, and 1 percent heavier hydrocarbons (Dickerson and Chou, *in* Bergstrom, Shimp, and Cluff, 1980). This gas is richer in heavier hydrocarbons than typical pipeline gas. The calculated heat content value for this hydrocarbon composition is 46,200 $kJ/m^3$ (1240 Btu/cubic foot). The actual heat content will be less because any carbon dioxide and nitrogen present in the gas was not taken into account in the calculation.

Off-gas content and composition of cores in Indiana (Meinschein, *in* Indiana Geological Survey Final Report (1981) and unpublished data provided by Monsanto Research Corporation-Mounds Facility, are similar to results determined for the Christian County, Kentucky core. Mounds researchers also analyzed samples from the same Illinois and Kentucky cores studied by Dickerson and Chou. The values determined by Mound are generally similar to those obtained by Dickerson and Chou for adjacent samples (*in* Bergstrom, Shimp, and Cluff, 1980).

## CHEMICAL CHARACTERIZATION OF ORGANIC MATTER IN SHALE

Stepwise pyrolysis-gas chromatography of the organic matter in the New Albany Shale provided a simple and direct method for qualitatively characterizing the chemical properties of organic matter contained in the shale (Dickerson and Chou, *in* Bergstrom, Shimp, and Cluff, 1980; Meinschein, *in* Indiana Geological Survey Final Report, 1981).

In the work in Illinois by Dickerson and Chou, heating the shale to 250°C and 350°C yielded the highly volatile and medium volatile hydrocarbons; heating to 550°C and 750°C produced the less volatile hydrocarbons. A sample of shale was pre-extracted with benzene-methanol and heated to 250°C. No volatile hydrocarbons evolved, indicating that the more volatile components are also extractable with benzene-methanol.

The amount of non-condensable hydrocarbons produced by pyrolysis increased with the increasing organic carbon content of the shale and also with higher temperatures. The non-condensable hydrocarbons ($C_1$ to $C_5$) arising from the thermal degradation of the New Albany black shale contained both saturated and unsaturated n-paraffins.

Pyrolysis in the presence of molecular oxygen produced more hydrocarbons per unit carbon up to about 10 percent oxygen. These studies show that pyrolysis may produce gas at lower temperatures in the presence of oxygen, a fact that may be helpful for designing models for in situ retorting of the shale for gas production.

Pyrolysis produces a complex mixture of hydrocarbons in which it is virtually impossible to identify individual components. In contrast, solvent extraction yields a smaller and more select number of compounds. Although this does not give a complete picture of the organic matter present, it makes identification of individual compounds less complicated, and thus more useful, specific information can be obtained. Benzene:methanol mixed or benzene alone were used as

TABLE 3. Content of the bitumens from benzene and benzene-methanol extraction of Sample 01KY03C2.

| | Extract (benzene) | Extract (benzene-methanol) |
|---|---|---|
| Extractability | 3.9% | 6.0% |
| Aliphatic | 41.9% | 29.0% |
| Aromatic | 29.0% | 27.6% |
| Asphaltene | 21.7% | 44.1% |
| Nitrogen/Carbon ratio | 0.0071 | 0.0167 |
| Sulfur/Carbon ratio | 0.0044 | 0.0065 |

extraction solvents. The extracts were divided into aliphatic, aromatic, and asphaltene groups by liquid column chromatography (table 3).

The aliphatic fraction was further separated into n-paraffins and into branched and cyclic aliphatics. The distribution of n-paraffins from the shale was compared to their distribution in the Silurian-Devonian crude oils in the Illinois Basin. Both show a carbon preference index of about 1, indicating that the New Albany may have been the source rock for much crude oil in the basin.

The aromatic fractions contain mainly 2-ring and 3-ring aromatics substituted with combinations of 1, 2, 3, or 4 methyl, ethyl, or propyl side chains.

The asphaltene fractions had an average molecular weight ranging from 400 to 1,400.

Meinschein's studies in Indiana indicate that the kerogen is the source of organic compounds produced during pyrolysis. In Indiana, hydrocarbon production on pyrolysis was expressed as amounts of oil and gas per weight of shale. These values fall within the range determined for cores in similar stratigraphic position elsewhere in the Illinois Basin. Unpublished data provided by Mound shows values similar to those produced in Illinois; but Mound did not attempt to synthesize the data in the fashion of Dickerson and Chou.

## CARBON ISOTOPE ANALYSIS OF OFF-GASES

Interpretations based on the analyses of off-gases from shale cores require the assumption that the off-gas that collects in the canister has the same composition as the gas originally present in the shale (Coleman, *in* Bergstrom, Shimp, and Cluff, 1980; Meinschein, *in* Indiana Geological Survey Final Report, 1981). To test the validity of this assumption, a laboratory study was conducted to evaluate the extent of isotope fractionation which occurs during the outgassing of shale. Shale samples were degassed, pressurized with natural gas of known composition, and allowed to equilibrate. The samples were degassed under controlled conditions and variations in the composition of the released gas were monitored. Study results suggest that although isotopic fractionation does occur, the effects will probably not be significant if the core samples are sealed in canisters very quickly after they are collected and then outgassed until the outgassing rate becomes negligible.

The carbon isotopic composition of methane from four New Albany Shale cores was determined. Results indicate that the gases are of low-grade thermal origin with no significant contribution of bacterial gas. Comparison of the isotopic composition with other data available on the core samples adds information about the origin and history of the gas in the shale.

## GAS PRODUCTION AND POTENTIAL OF DEVONIAN SHALE IN THE ILLINOIS BASIN

Gas has been produced from several small fields, most of them now abandoned, along the eastern side of the Illinois Basin in Indiana and Kentucky. Minor


Figure 13. Cumulative thickness of "radioactive" black shale (gamma-ray log values more than 60 API units above a normal shale baseline value) in the New Albany Shale Group of the Illinois Basin. Contours in northern Illinois, Indiana, and Kentucky are based on comparative thickness of units and are only approximate because of lack of gamma-ray log control.

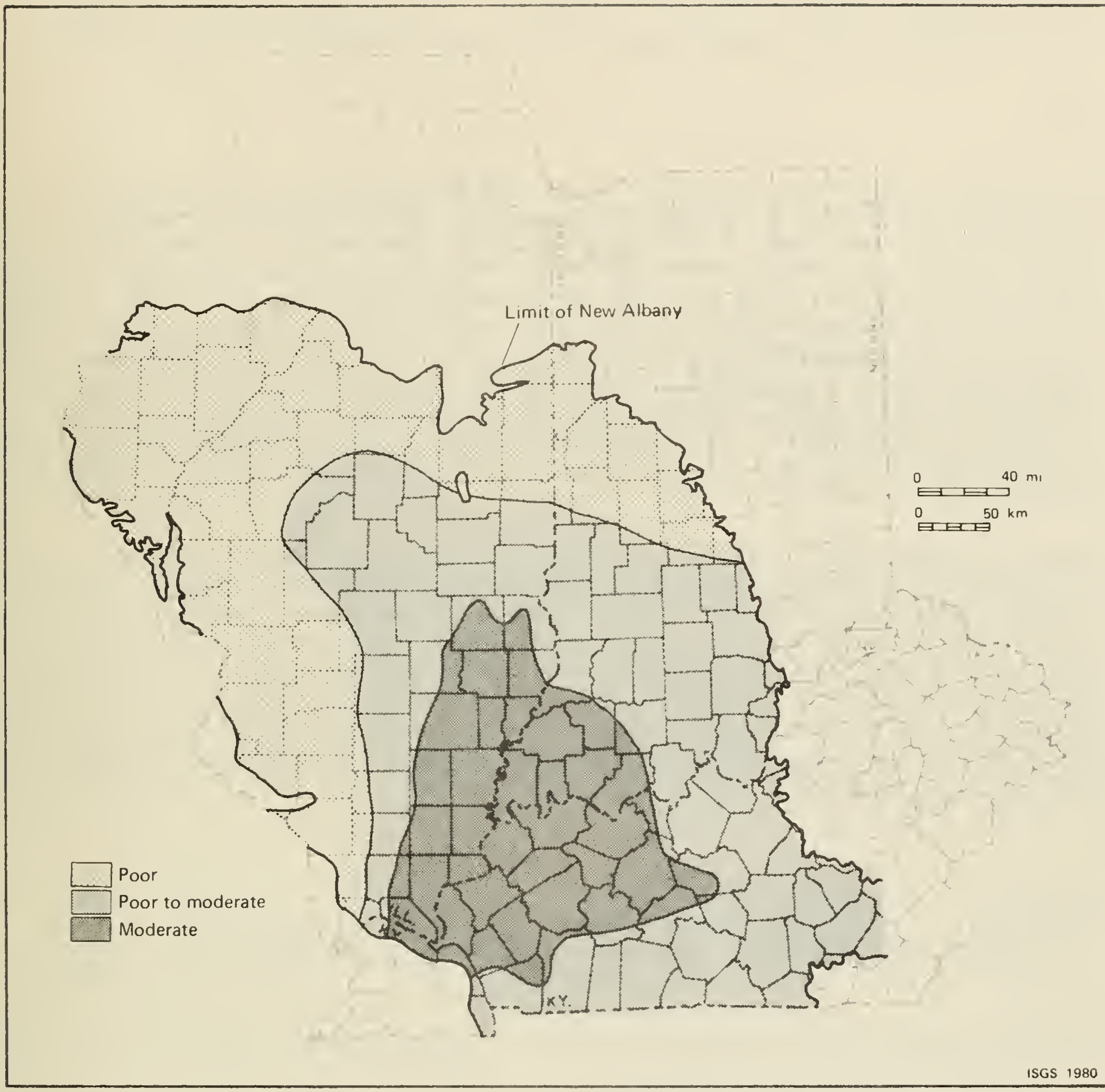


Figure 14. Natural gas potential of the New Albany Shale Group in the Illinois Basin.

production has recently been developed in Kentucky along the southeastern side of the Illinois Basin (Schwalb and Norris, 1980; Hasenmueller and Bassett, *in* Indiana Geological Survey Final Report, 1981; Cluff and Dickerson, 1980).

## Indiana

Gas has been commercially produced from the New Albany Shale in 10 fields, now largely abandoned, in southeastern Indiana (Hasenmueller and Bassett, *in* Indiana Geological Survey Final Report, 1981). Most of the production has been from Harrison County, where 186 wells have produced an estimated 5 billion cubic feet (Sorgenfrei, 1952). Most drilling took place between 1885 and 1925, and few geologic and production data have been preserved. Rock pressures were low (48 to 169 psi) and open flow rates were small (27 to 1361 MCF) (Sorgenfrei, 1952). The best production was developed 15 to 30 feet below the top of the shale in an organic rich zone of the Clegg Creek Member. Another producing horizon may correspond to the Morgan Trail Member. A significant characteristic of New Albany gas wells is their longevity; some have produced gas for 20 or more years.

Structure maps indicate that some structural doming or flattening is imposed on the general westward dip of the sediments in the Harrison County fields. Organic content does not appear to be higher in the productive area than in nearby nonproductive areas. Other fields do not appear to be related to structural features. The limited geologic data suggest that structural traps are not necessary for shale gas production. Hasenmueller and Bassett (*in* Indiana Geological Survey Final Report, 1981) suggested that natural fracturing may be the most critical factor in gas accumulation. Presence of geologic structure may enable gas to displace saltwater, commonly present in shale fractures, that otherwise would kill the gas release.

## Kentucky

Several small gas producing areas were discovered in Kentucky south of the producing areas in Indiana. The production history of these areas is probably similar to that found in the Indiana areas; but data were not kept in Kentucky, and production history cannot be reconstructed accurately. Much of the drilling was accomplished prior to 1925.

In more recent years, many gas shows have been reported from the New Albany. Some small production has been realized from an area in Christian County, Kentucky, in the southeastern part of the basin; production there appears to be related to fracturing near major faults. Production is economically encouraged by proximity to existing gas pipelines.

## Illinois

To date there has been no production of gas from the New Albany Shale in Illinois. Only a few shows have been reported in the southeastern part of the state. However, large areas have been inadequately explored.

## CONCLUSIONS

Potential natural gas resources in the New Albany Shale of the Illinois Basin may be related to four key factors:

- Organic content of the shale
- Thickness of the organic-rich shale
- Thermal maturity as related to depth of burial
- Presence of natural fractures

The organically richest shale is found in southeastern Illinois and in most of the Indiana and Kentucky portions of the Illinois Basin. The low organic content of the dominantly greenish-gray shale that constitutes most of the New Albany in western Illinois and the northern part of the Illinois Basin indicates that those areas should be considered of poor potential, even where the shale is thick.

The organic-rich shales in the New Albany are thickest near the center of the basin in southeastern Illinois, southwestern Indiana, and adjacent parts of Kentucky (fig. 13). The area of thick (more than 100 [30 m] ft) shale with high organic content near the center of the basin is also the area most deeply buried by younger rocks and the area with the highest thermal maturity of the organic matter. Thus the area near the basin center has at least a moderate potential for natural gas resources. The eastern side of the basin, where the shale is thin but organic-rich, may contain poor to moderate possibilities for additional discoveries of small gas fields that would be similar to those found in the past.

Natural fractures in the shale may aid in collecting gas from a larger volume of shale. These fractures may be more abundant and interconnected to a greater degree in the vicinity of major faults. Major faults along the Rough Creek Lineament and Wabash Valley Fault System cross the deeper part of the basin (fig. 10).

The results of the EGSP study in the Illinois Basin indicate that the part of the basin with the highest potential for shale gas resources lies in southeastern Illinois and adjacent parts of Indiana and Kentucky, where organic-rich shale is thick and fault-induced fractures may be present (fig. 14). This area is relatively unexplored, and more drilling will be required for a proper evaluation of potential resources of natural gas that may exist in the New Albany Shale.

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