UPPER SILURIAN AND LOWER DEVONIAN STRATIGRAPHY OF THE CENTRAL ILLINOIS BASIN

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Upper Silurian and Lower Devonian Stratigraphy of the Central Illinois Basin

By JOHN B. DROSTE *and* ROBERT H. SHAVER

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By John B. Droste and Robert H. Shaver

ABSTRACT

The little-studied thick rock sequence of the middle and upper parts of the Bainbridge Group (Upper Silurian) and of the New Harmony Group (Lower Devonian) in the tristate central Illinois Basin is dominated by four kinds of carbonate rocks. (1) Reef rocks, fringing the deeper basin area and as thick as 900 feet, consist of light-colored, poorly sorted, skeletally derived materials that range from within the St. Clair Limestone (lower part of the Bainbridge Group) to the uppermost part of the Bailey Limestone (upper Bainbridge). (2) Very light colored, fairly well sorted high-purity bioclastic carbonate rocks, nearing 300 feet in thickness, are distinguished genetically from reef rocks by their principal distribution in thick, areally broad piles that make up especially the Backbone Limestone (lower and middle parts of the New Harmony Group) and that are concentrated along the eastern margin of the central basin. (3) Variably colored fine-grained impure noncherty to very cherty carbonate rocks make up most of the Moccasin Springs Formation and the Bailey Limestone (Upper Silurian), whose nonreef facies are more than 600 feet thick in places. (4) Light-colored fine- to medium-grained carbonate rocks that are as thick as 1,000 feet and are characterized by replacement chert and a speckled appearance dominate the Grassy Knob and Clear Creek Cherts (lower and upper New Harmony).

The Silurian reefs belong to two principal generations, beginning during St. Clair and Moccasin Springs deposition respectively. Undiscovered, probably smaller reefs in the deeper basin are a distinct possibility. Distributions of the Backbone type of sediment and of the chertier New Harmony facies attest to asymmetrical sedimentational development of the deeper basin during Early Devonian time.

INTRODUCTION

BACKGROUND FOR THE REPORT

This report represents one of a series of investigations of middle Paleozoic rocks in southwestern Indiana and environs that have been undertaken or sponsored in part by the Indiana Geological Survey since 1970: Becker (1974), Droste and Shaver (1975, 1980, and the present report), Ault and others (1976), Becker and Keller (1976), Becker and Droste (1978), and Noel (1979). These investigations of the relatively poorly known Bainbridge Group and equivalent Silurian rocks and the New Harmony Group (Devonian) (fig. 1), deep within the Illinois Basin, were carried on during the time when world oil prices reached unprecedented heights and encouraged renewed interest in developing hydrocarbon production from the Illinois Basin. The reports and maps listed above were at once intended to answer increasing numbers of requests of the Indiana Geological Survey for geologic information and to facilitate particularly new exploration below the long-exploited productive horizons in Mississippian rocks.

The present report continues in that mode, and at the time of its preparation one of the more interesting new Indiana discoveries that had been made in several years was by the Petro Union No. 1 Kenneth Beasley well in Spencer County. Initial production, reported to be 120 barrels of oil per day untreated, was variably said to be from a Silurian reef or from the Backbone Limestone (Lower Devonian). Both types of potential reservoirs in that part of the basin and in adjacent parts are focal points of the present report.

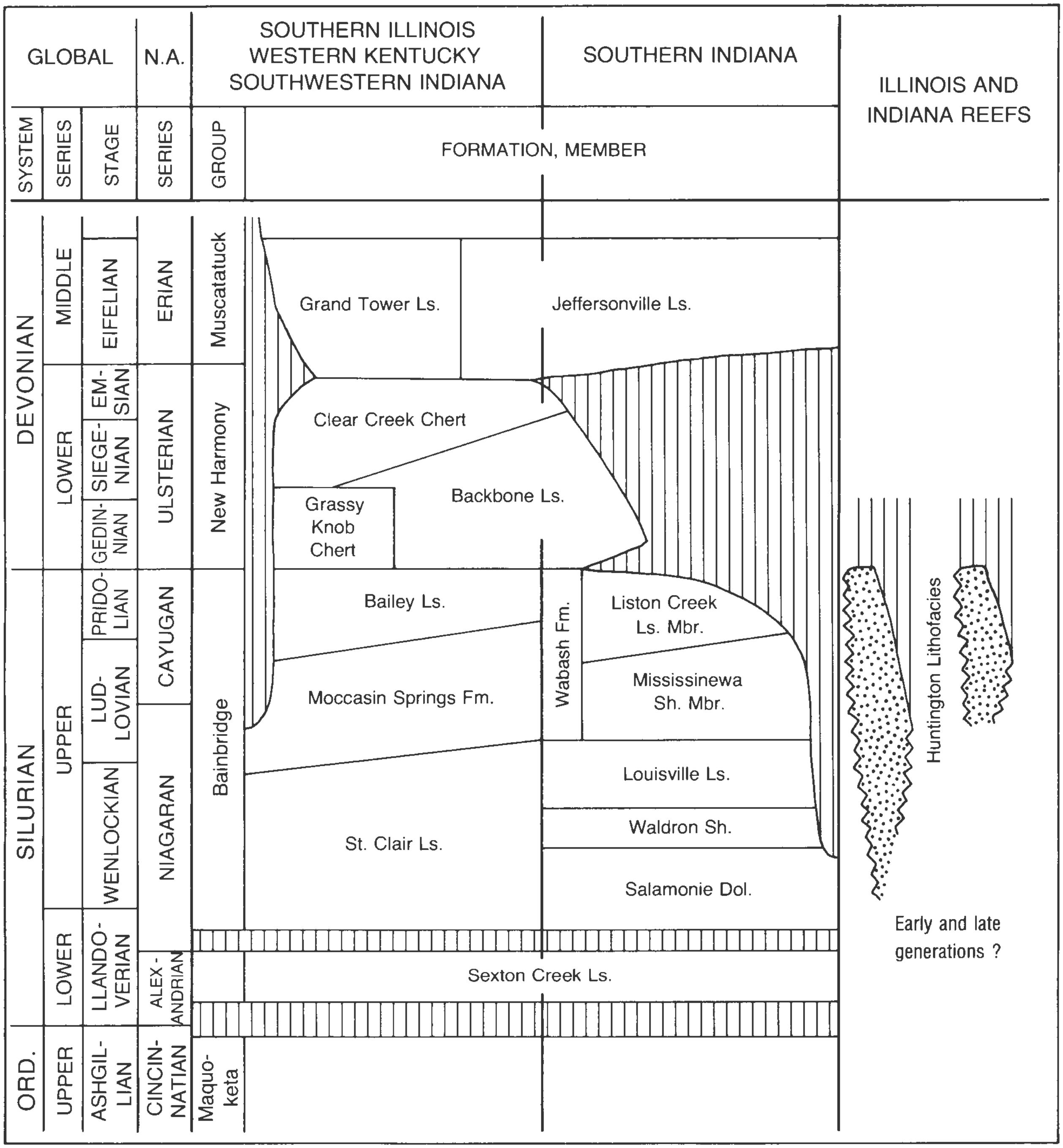


Figure 1. Chart showing nomenclature and correlation of the stratigraphic section in Illinois, Indiana, and Kentucky that is the basis for this report.

The study area consists of what may be considered as the proto-Illinois Basin, or what was named the Vincennes Basin by Droste, Shaver, and Lazor (1975) as a middle Paleozoic feature to distinguish it from what is commonly thought of today as the Illinois Basin. In its middle Paleozoic connotation, the term is not synonymous with the term

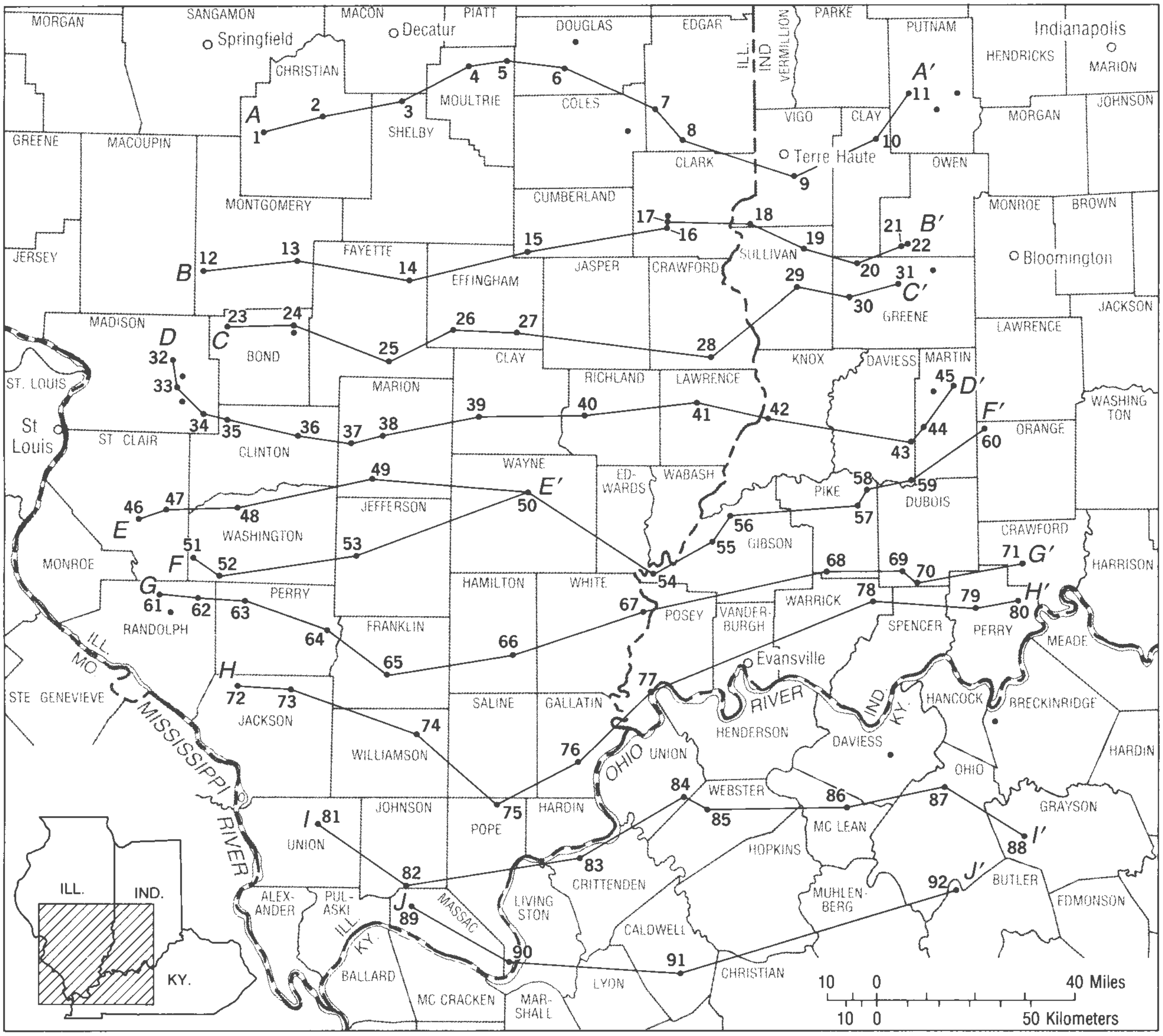


Figure 2. Map of the study area showing locations of wells and cross sections AA′ through JJ′. See the appendix for precise locations and identifications of wells.

"Fairfield Basin," which is applied to a limited part of the present Illinois Basin. The study area also includes what was once the immediately peripheral shelf area and what is called the Wabash Platform, a middle Paleozoic feature. Therefore, part of southern Illinois, southwestern Indiana, and part of western Kentucky are included (fig. 2). The limits of the study area and the middle Paleozoic basin-shelf margin in Illinois and Indiana are defined further especially by a linear carbonate buildup that includes broadly massive to more pinnaclelike reefs of Late Silurian age (the Terre Haute Bank of fig. 3) and by the shelfward thinning to zero thickness of a thick basin sequence of Lower Devonian carbonate rocks. (See figures farther on in this report and Droste and Shaver, 1980.)

Stratigraphically, the scope of this report ranges from the Moccasin Springs Formation (upper part of the Bainbridge Group) to the Clear Creek Chert (upper part of the New Harmony Group) inclusively. Description of

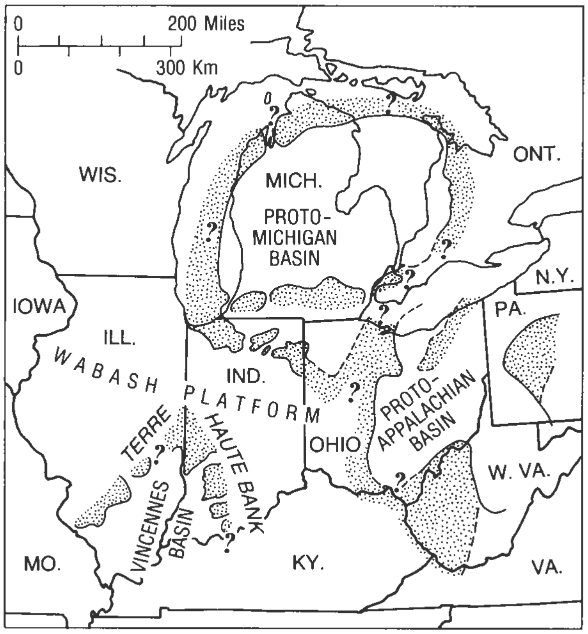


Figure 3. Map of part of the Midwest showing locations of three intracratonic Silurian basins, the intervening platform, and surrounding carbonate bank and reef systems (stipple). Hundreds of known discrete-reef locations are not shown. From Droste and Shaver (1980).

the factual circumstances of these rocks is a principal objective. Another objective is to add paleoenvironmental and sedimentational interpretation to the basis that has already been set forth, especially by Becker and Droste (1978).

NEW AND OLD WORK

Much of the investigative work on which this report is based was completed for some of the above-mentioned reports and maps and includes some work for Illinois and Kentucky and extends to laboratory-based sedimentological research. Most of the new work was undertaken to examine well cuttings and logs on file at the Illinois State Geological Survey, Champaign. Virtually all the pertinent Illinois wells were considered, that is, all those wells in the area described that penetrate the entire Silurian section, that are represented by both logs and samples, and that are not essentially repetitive because of close proximity to one another. (The locations of these 105 wells are shown in figures 5-10.) Cross-section construction (fig. 4), interpretation, and preparation of this report followed. (The precise locations of the 92 wells used in the cross sections, together with depths to stratigraphic tops, are given in the appendix.)

This report builds especially on the 1978 report by Becker and Droste, which was mostly restricted to Indiana-based observations. The geologic setting, stratigraphy, and some petrographic understanding most pertinent to this report have been described in varying amounts of detail in that report and in others by Becker and Keller (1976), Bristol (1974), Droste and Shaver (1980), and Lowenstam (1949). A useful summary for western Kentucky was made by Seale (1985), and the subsurface study of Butler County reported by Schwalb (1975) has some application. Also, standard stratigraphic details, including original-source information, for all the named rock units treated here can be found in two handbooks (Shaver and others, 1986, for Indiana and Willman and others, 1975, for Illinois).

We emphasize that in those places where this report deviates from previously published correlations and definitions of rock units in one state or another, the deviations are deliberate. Most notably, the Bailey Limestone, here recognized to exclude the Backbone-like rocks above it that are Early Devonian in age and that are sometimes called the Ozora in Illinois subsurface terminology, is considered to be Silurian in age and to correlate most closely with the Liston Creek Limestone Member of the Wabash Formation in Indiana (fig. 1). This understanding extends to the Butler County, Ky., use of the name "Bailey," where it was once said to include Devonian rocks. (See explanations and the resulting implications in Becker and Droste, 1978, p. 4; Droste and Shaver, 1980, p. 569; and Shaver and others, 1985, wherein only a small upper part of the Bailey as defined by the Illinois State Geological Survey is assigned to the Devonian System.)

Further, the so-called unnamed shale in the basal part of the Bailey of common Illinois usage has here been assigned, where recognized, to the Moccasin Springs Formation.

Also, the Backbone Limestone (Lower Devonian) as recognized here includes several so-called strays of Grassy Knob lithology, and the reverse is true in lesser degree for Backbone lithology within the Grassy Knob Chert (fig. 4). We have used arbitrary definitions of each unit in accord with the principles established by Becker and Droste (1978, p. 4-5).

These stratigraphic definitions, together with our use of datum points in three different states, account for some differences in our maps in comparison with those of William North (unpublished manuscript, Illinois State Geological Survey) and, to a lesser extent, with those of Becker and Droste (1978).

In all these ways, therefore, the present report both borrows from and extends well beyond earlier reports in its application. It has a distinct advantage in its consideration of a sedimentational province without regard to state boundaries, and it is not handicapped by two differing sets of stratigraphic classification.

ACKNOWLEDGMENTS

We are indebted to Curtis H. Ault, Edwin J. Hartke, Nancy R. Hasenmueller, and John A. Rupp, the Indiana Geological Survey reviewers of the manuscript for this report, and to Wayne F. Meents, Askum, Ill., and formerly of the Illinois State Geological Survey, through whose auspices we were able to compare our maps with those of William North in an unpublished manuscript at the Illinois State Geological Survey. The illustrations were prepared by the Drafting and Photography Section, which is staffed jointly by the Indiana Geological Survey and the Department of Geology, Indiana University, Bloomington.

We are also appreciative for the financial support provided by the Ceja Corp. of Tulsa, Okla., for that part of our work that was performed at Champaign, Ill.

STRATIGRAPHY

CROSS SECTIONS

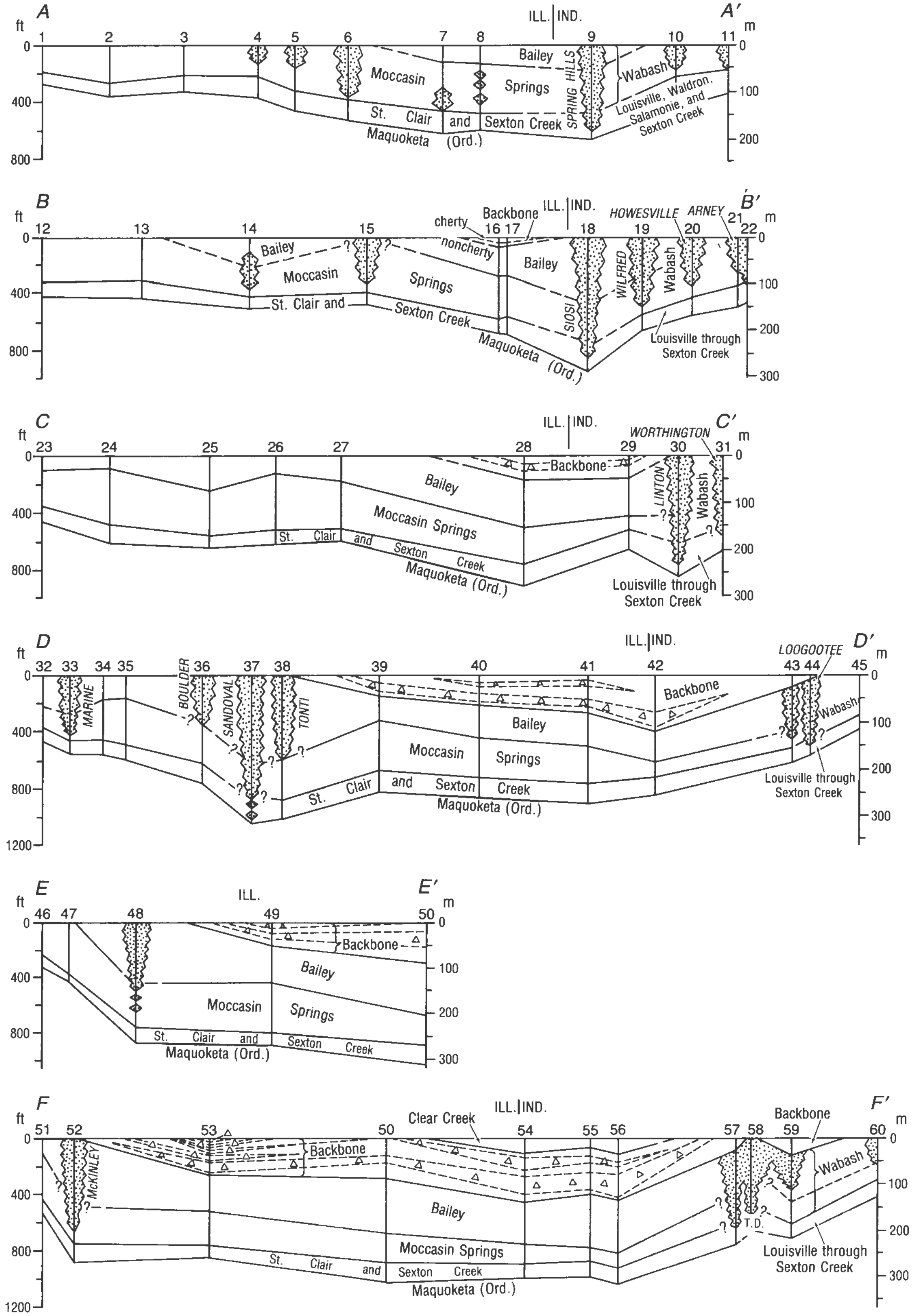
Our basic findings are presented in 10 cross sections (fig. 4) that begin north, west, and south of the basin-fringing trend of Silurian carbonate buildups in Illinois, extend eastward along the edge of or across the basin, and end east of the same fringing feature (the Terre Haute Bank, fig. 3) in Indiana and its potential Kentucky projection (this feature has not been positively identified in Kentucky). The zero datum is the base of the Muscatatuck Group (Middle Devonian) or, where that unit is absent from western Illinois, the base of the New Albany Group (Upper Devonian). Although this report does not deal fundamentally with Lower Silurian rocks, these are shown in the cross sections, which bottom, therefore, within the Maquoketa Group (Ordovician).

Formation tops and some nonformational lithologic tops are recorded in the appendix.

THICKNESS AND AREAL DISTRIBUTION

UPPER PART OF THE BAINBRIDGE GROUP

The upper part of the Bainbridge Group (Silurian), consisting of the Moccasin Springs Formation and the Bailey Limestone (Upper Silurian), has two general loci of greatest thickness (fig. 5). One is adjacent to and within the major reef trend along the basin-shelf edge. There two separate thickest piles, as much as 750 and 925 feet thick, correspond to major parts of the Terre Haute Bank and its far western Illinois projection (fig. 3). These thicknesses are less, however, than the thickest reefs, because some of the reefs have their origins within the St. Clair Limestone, below the Moccasin Springs (fig. 1). Along the major reef trend, the greater part of the thickness is in the Bailey Limestone and the Wabash equivalent, and it is reef related (cross sections BB′ through FF′, fig. 4).


A
A′
ft
m
ILL.
IND.
Bailey
Moccasin
Springs
SPRING HILLS
Wabash
Louisville, Waldron, Salamonie, and Sexton Creek
St. Clair and Sexton Creek
Maquoketa (Ord.)
B
B′
cherty
noncherty
Backbone
HOWESVILLE
ARNEY
WILFRED
SIOSI
St. Clair and
Sexton Creek
Louisville through Sexton Creek
C
C′
WORTHINGTON
LINTON
Moccasin Springs
D
D′
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Clear Creek
McKINLEY
T.D.

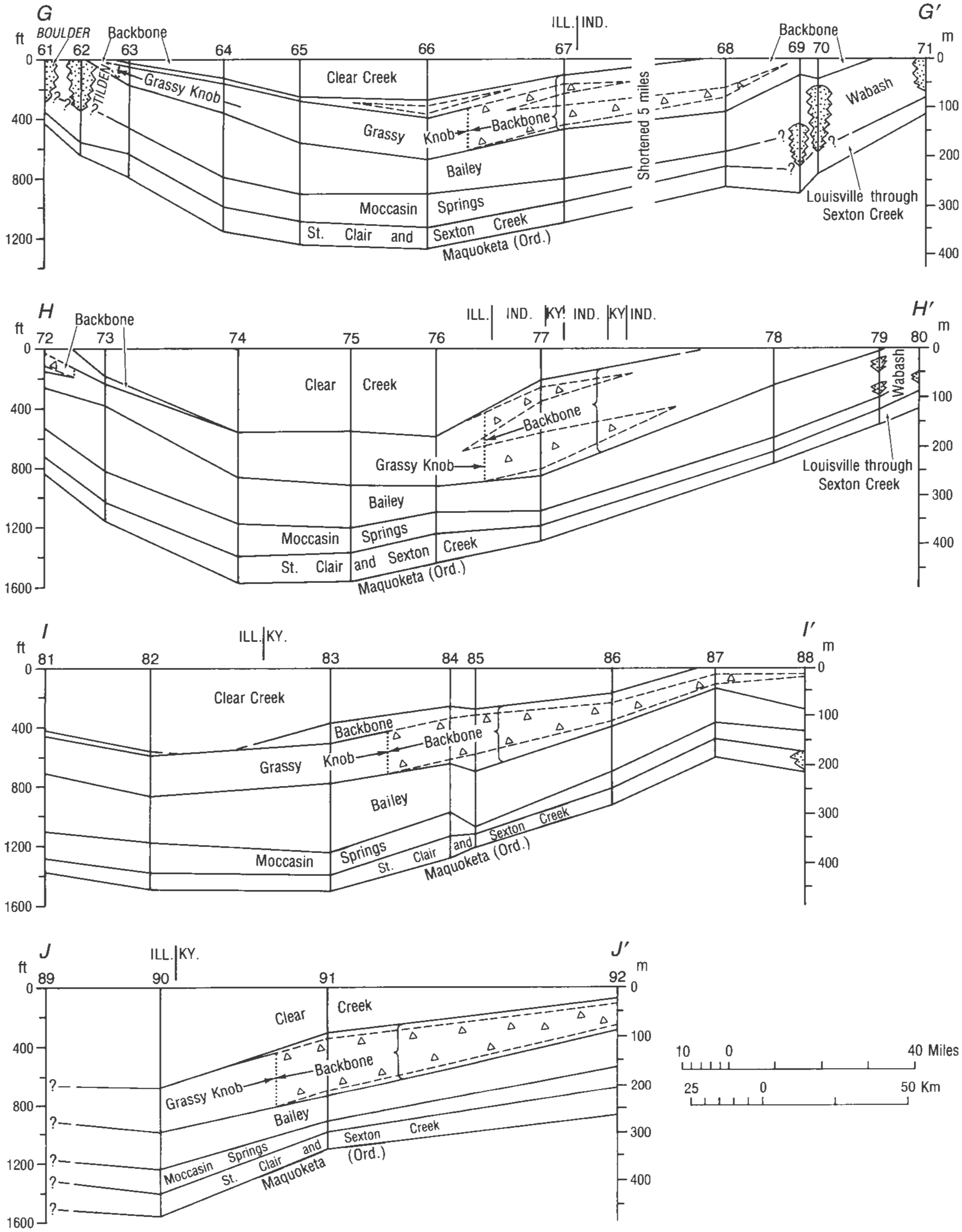

Figure 4. Cross sections AA′ through DD′, EE′ through GG′, and HH′ through JJ′ of Lower Silurian through Lower Devonian rocks of the central Illinois Basin along the alignments shown in figure 2 and in accord with the record of stratigraphic tops in the appendix. The reef symbols used in figure 4 have been idealized; the placement of symbols on well centers does not at all mean that all wells are reef-center wells.

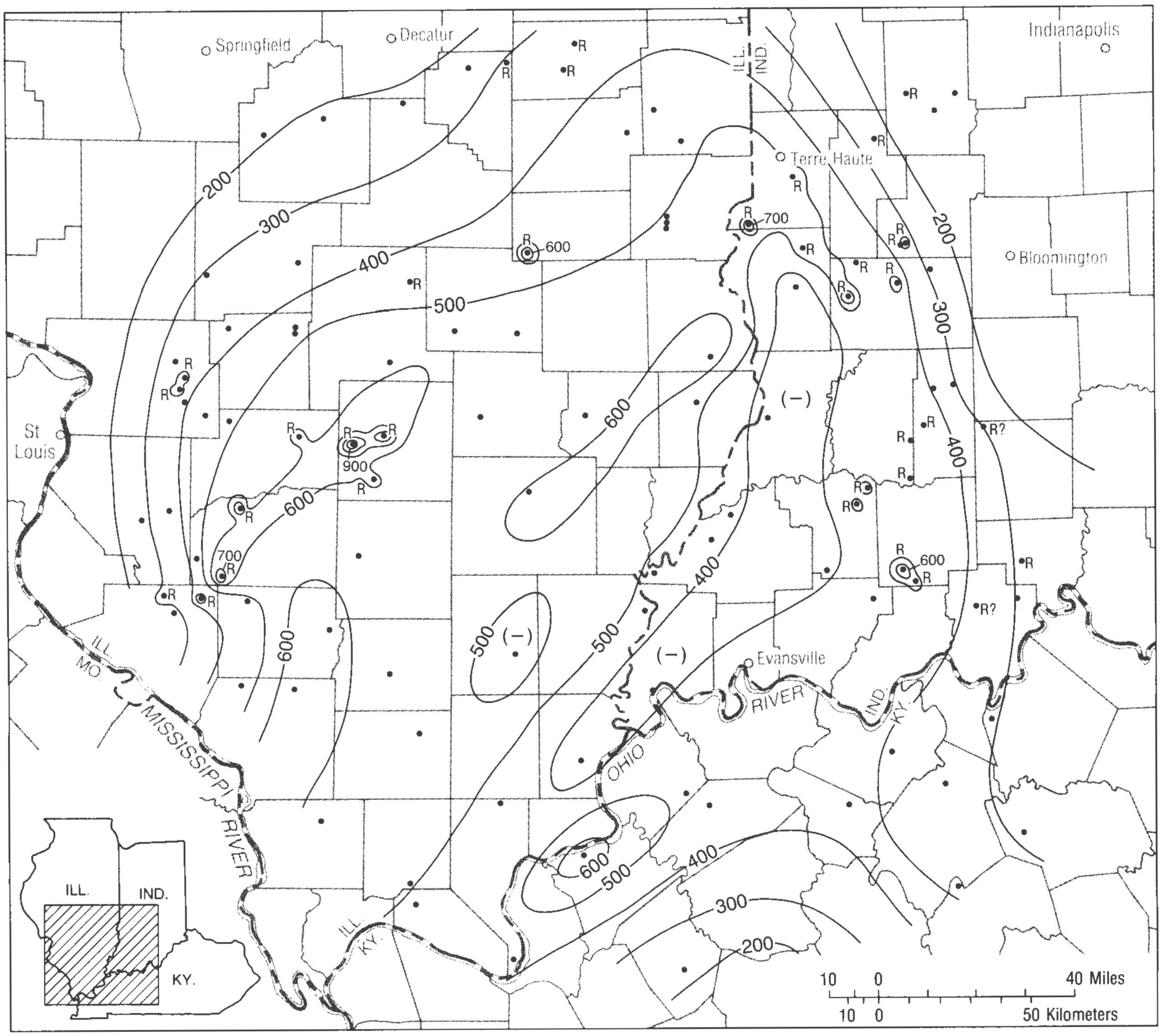

Figure 5. Map of the study area showing thickness of the Moccasin Springs Formation and the Bailey Limestone. R indicates wells that penetrate reefs and that may yield thicknesses greater than regional thickness. Contour interval is 100 feet. Data used in figures 5-10 are recorded in the appendix.

The other general area of greatest Moccasin Springs and Bailey thickness is in the deep basin and is there found in three separated areas of thicknesses greater than 600 feet, even though no reefs are known to add to the thickness. As suggested through contouring (fig. 5), these three areas may have linear trends, all roughly parallel. Although these areas may represent some kind of growth structure controlled by the basement, such an interpretation is highly speculative because so few data exist. Also, the pattern apparently has little relation to later sedimentational events.

The basin area seems to be asymmetrical with respect to Moccasin Springs and Bailey thickness, since a conspicuous linear area of thinning, to less than 350 feet, is immediately east of the Illinois-Indiana state line. This thinning relates especially to the Moccasin Springs, which thins from west to east by more than 200 feet within its basin, nonreef facies (cross sections CC′ through HH′, fig. 4). Again we note a linear trend, which in this observation does seem to have enough datum points for verification of a northeast-southwest alignment.

Shelfward at the basin margin and on the shelf itself a major erosional unconformity separates the Bainbridge Group from the Muscatatuck Group (Middle Devonian) and in part from the New Harmony Group (Lower Devonian). This erosional unconformity accounts for much of the marked shelfward thinning of the Moccasin Springs-Bailey interval.

NEW HARMONY GROUP

The New Harmony Group (Lower Devonian), consisting of the Backbone Limestone and the Grassy Knob and Clear Creek Cherts, thickens fairly regularly toward the basin center to its greatest thickness of about 1,000 feet in southeastern Illinois (fig. 6). The zero thickness line of figure 6 probably everywhere represents pre-Middle Devonian erosional truncation, but thickness in the central-basin area is probably erosionally unaffected.[1]

Because of erosional truncation and structural attitude, the lower New Harmony rocks, made up jointly of the Grassy Knob Chert and the Backbone Limestone, or in places of either formation alone, have the widest distribution (fig. 7), whereas the youngest formation, the Clear Creek Chert, is restricted to the central part of the study area (fig. 8; cross sections FF′ through II′, fig. 4).

The New Harmony Group, considered petrographically, has two basic carbonate-rock types that are not separately restricted to named formations. (See the section on types of carbonate rocks.) The aggregate thickness of rather coarse grained bioclastic carbonate rocks (type 2 carbonate) reaches 300 feet in far southwestern Indiana (fig. 9). These rocks reach zero thickness where the entire New Harmony Group reaches zero thickness except in southeastern Illinois, where zero thickness is complementary with the greatest thickness of the New Harmony Group. Like the Moccasin Springs, type 2 carbonate rocks are asymmetrically distributed with respect to thickness and have their major development just off the Terre Haute Bank in the eastern basin area.

The aggregate thickness of rather fine grained cherty New Harmony rocks (type 3 carbonate) makes up the entire New Harmony thickness in southeastern Illinois but is partly complementary with the thickness of the coarse carbonate rocks (type 2) elsewhere (fig. 10).

UNDERLYING ROCKS

Each of the cross sections (fig. 4) bottoms in the Maquoketa Group (Upper Ordovician). Lying above these dominantly soft gray shaly rocks and below the Moccasin Springs Formation is an approximately 125-foot sequence of Silurian limestones and dolomitic limestones that change little in thickness and lithology within most of the study area.

The lower part of this sequence, making up the Sexton Creek Limestone (Lower Silurian) and possibly older Silurian rocks in places, changes downward from cream-colored fine-grained cherty carbonate rocks to tan fine-grained, mostly chert free carbonate rocks (for example, well nos. 3 and 26 in the appendix). The upper part of this sequence is the mostly chert free St. Clair Limestone (Lower and Upper Silurian), which generally changes color vertically in either direction from whitish and other very light shades to strikingly splotchy pinkish white and salmon red to, less commonly, yellowish (for

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[1] In Indiana, especially the zero isopach lines of figures 6, 7, and 10 differ from the zero isopach lines shown by Becker and Droste (1978, figs. 4A and C), even though the same data in part were used. Most of the more peripheral Indiana datum points used in the present study are at reef locales, where local highs resulted in total removal by erosion (pre-Middle Devonian) of the overlying Lower Devonian rocks. The contouring done here is strictly faithful to the data in the appendix and does not reflect the greater number of Indiana wells, both reef and nonreef, used by Becker and Droste.

Other departures from the 1978 maps (Becker and Droste, figs. 4A-D) relate to the use of additional wells here in the bordering Kentucky and Illinois region.

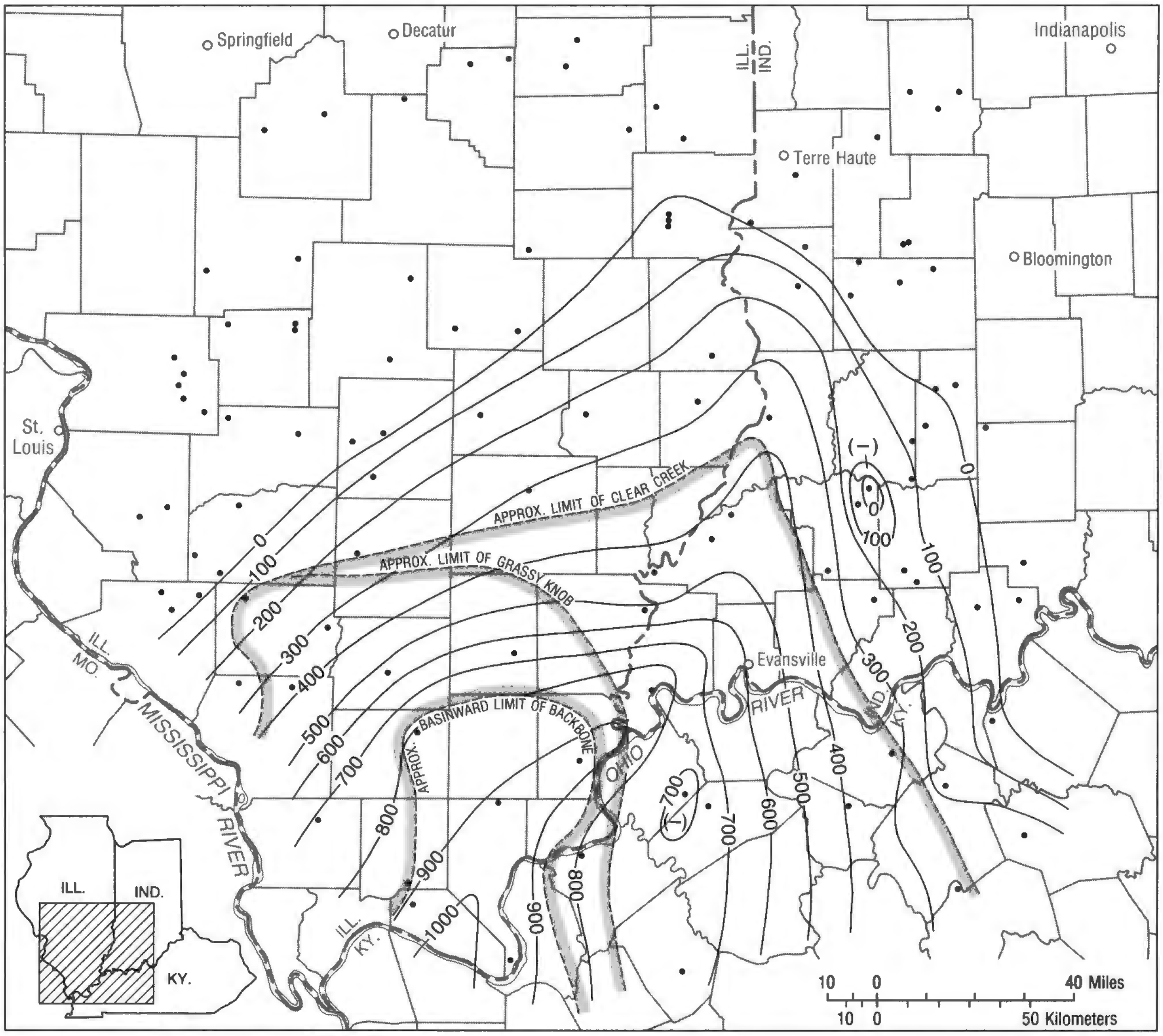


Figure 6. Map of the study area showing thickness of the New Harmony Group. Contour interval is 100 feet.

example, well nos. 26 and 33). The whitish material is very fine grained matrix, whereas coarse bioclasts make up the brightly colored material.

The St. Clair-Moccasin Springs contact may be time transgressive. The upper St. Clair becomes younger shelfward and has equivalency with the Louisville Limestone of Indiana and the lower part of the Racine Formation of central and northern Illinois. (See relations of these formations shown by Shaver and others, 1985.)

OVERLYING ROCKS

The upper contact of the Upper Silurian-Lower Devonian sequence of concern here ranges from a surface of erosional truncation around the central-basin margin to probably a conformable surface in the centralmost study area. In the deep-basin tristate area and shelfward in Indiana and Kentucky, light-colored, generally bioclastic Middle Devonian carbonate rocks of the Grand Tower and Jeffersonville Limestones overlie the Lower

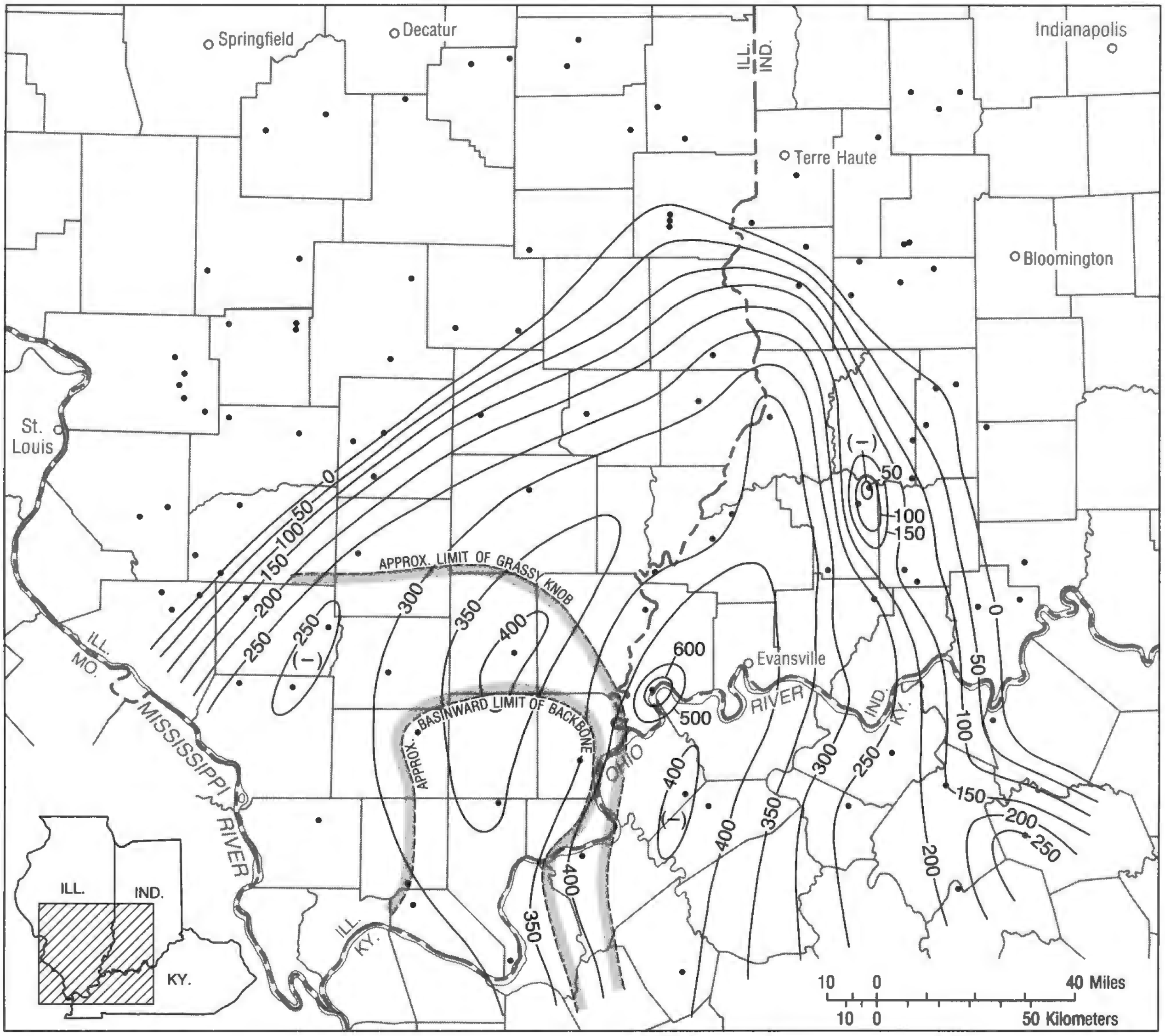


Figure 7. Map of the study area showing thickness of the Backbone Limestone and the Grassy Knob Chert and their respective areal distributions. Contour interval is 50 feet but changes to 100 feet in a small area of southwestern-most Indiana.

Devonian-Upper Silurian sequence. In many places well-sorted quartz sand or sandy carbonate rocks mark the unconformity (for example, well no. 14) and, where abundant, are called the Dutch Creek Sandstone Member (Grand Tower and Jeffersonville). Northward the distinctive brown bioclastic vuggy rocks of the Geneva Dolomite Member (Grand Tower and Jeffersonville), commonly sandy in their basal part, also overlie the Upper Silurian-Lower Devonian sequence (for example, well no. 14).

In southwestern Illinois the time value of the unconformity increases markedly, and tan and gray fine-grained impure carbonate rocks of the Lingle Limestone (upper Middle Devonian) and blackish carbonaceous shale of the New Albany Group (Upper Devonian) also overlie the Upper Silurian-Lower Devonian sequence.

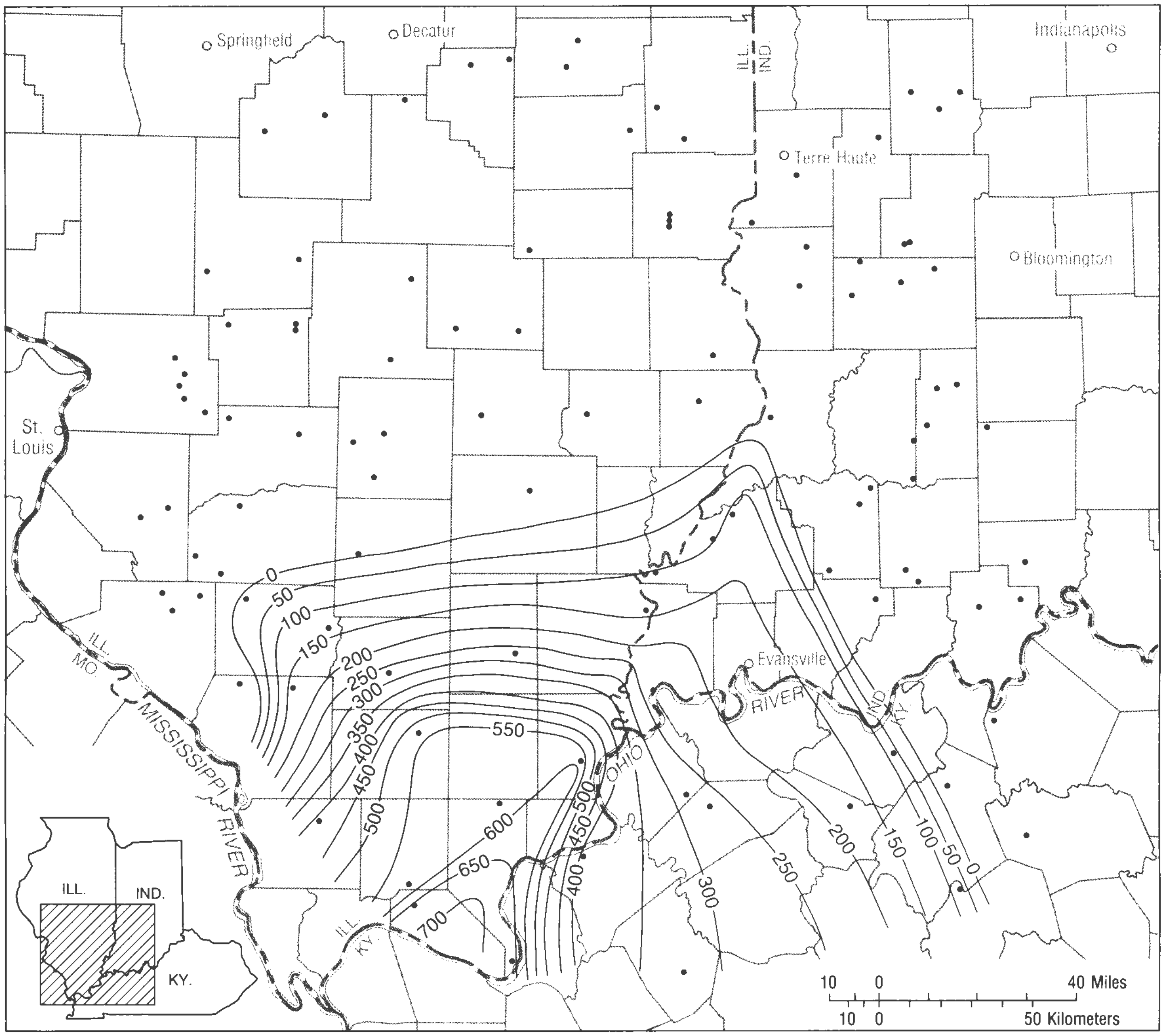


Figure 8. Map of the study area showing thickness of the Clear Creek Chert. Contour interval is 50 feet.

CARBONATE BUILDUPS

Scores of individually recognized carbonate buildups (generally termed "reefs") of modest to very large size were already known within the study area. The present study has resulted in better understanding of the sedimentational relationships of reefs but has not resulted in new discoveries. In the defined sense of carbonate buildups having localized topographic relief, all those buildups identified in the study area and within the pertinent stratigraphic section are confined to the Silurian System.[2] They range from within the

[2]The buildups as portrayed in figure 4 are idealized, and the wells shown penetrating the buildups are actually not necessarily centered in the buildups. Considering Silurian reef geometry, therefore, the stratigraphic levels of the bottoms of the buildups are not all accurately shown. Silurian reef geometry and petrography are described especially by Lowenstam (1950), Textoris and Carozzi (1964), Shaver (1977), Shaver and others (1978), Indiana University Paleontology Seminar (1980), and Droste and Shaver (1980); poorly understood linear complexes fringing Silurian basins are discussed especially by Droste and Shaver (1980 and 1982, figs. 5-7).

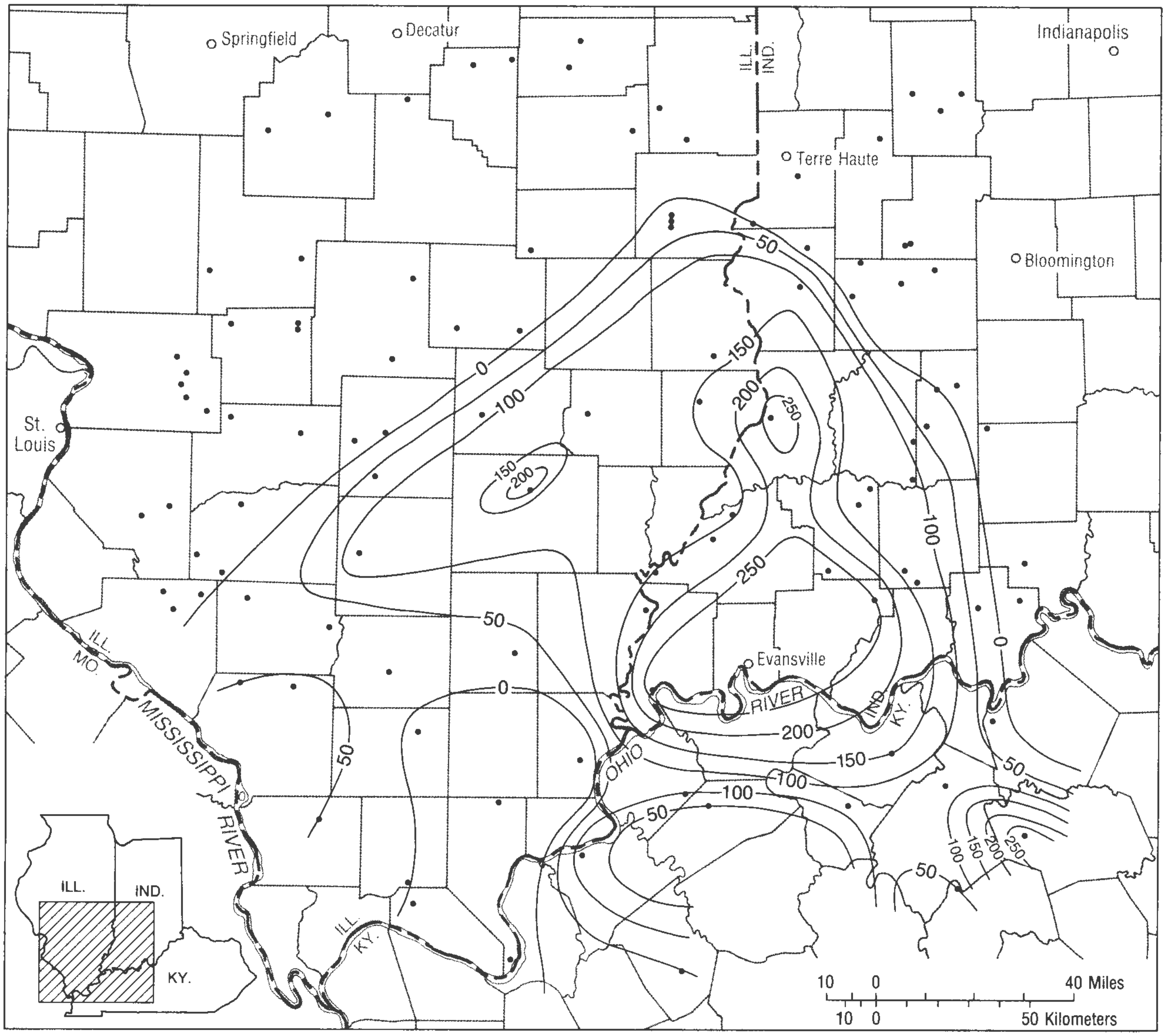


Figure 9. Map of the study area showing aggregate thickness of type 2 carbonate rocks, which are assigned mostly to the Backbone Limestone and in subordinate amount to the Grassy Knob Chert. Contour interval is 50 feet.

St. Clair Limestone through the Bailey Limestone and their shelf equivalents. The lithologic type made up of Silurian reefs in general and at any stratigraphic level has been called the Huntington Lithofacies (fig. 1 and Pinsak and Shaver, 1964). The Backbone Limestone of Early Devonian age is characterized by thick accumulations that on casual inspection of well cuttings therefrom closely resemble Silurian reef-carbonate rocks. These Devonian deposits, so far lacking identification with internal quaquaversal reef structure, are noted in the next section as type 2 carbonate.

Petrographically, the Silurian buildups of the Illinois Basin consist of very light (mostly whitish to light-tan, gray, and bluish-gray), rather pure limestones, dolomitic limestones, and dolomites that both make up boundstone and have poorly sorted but mostly fine grained matrices supporting much coarser bioclastic carbonate sediments (for example, well no. 37). Such lithology has been called the Huntington Lithofacies (fig. 1).

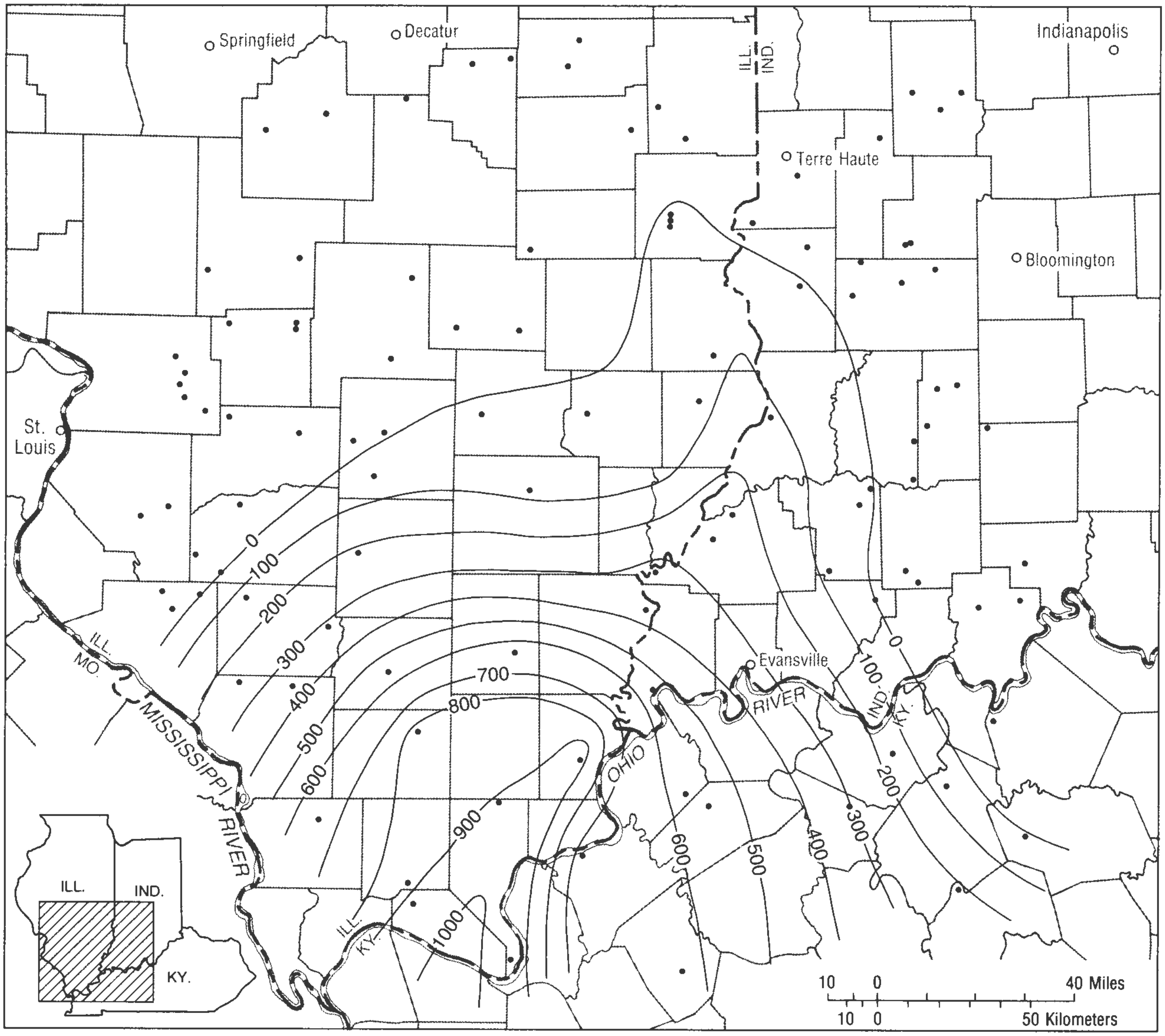


Figure 10. Map of the study area showing aggregate thickness of type 3 carbonate rocks, which are assigned in order of decreasing amounts to the Clear Creek Chert, the Grassy Knob Chert, and the Backbone Limestone. Contour interval is 100 feet.

As far as can be determined from well cuttings, the dolomites are much more vuggy and, therefore, possibly more permeable than are the limestones. A given buildup may be mostly or wholly limestone as it appears in a single well section, it may be mostly dolomite, or it may be an intimate mixture having no readily apparent explanation for such mixing (for example, wells nos. 5, 33, 36, and 59).

The subtle differences in coloration relate simultaneously to small amounts of impurities, to stratigraphic position, and to ecologic maturity of the observed part of the buildup. These differences also go hand in hand with changes in granularity and with position within the core-to-far-flank (proximal-to-distal) arrangements of beds. Bluish-gray, very fine grained dense carbonate rock characterizes structurally defined core rock, if not also ecologically defined core rock, and is observed in the lower, immature parts of many buildups. The lighter colored and more coarsely granular fractions generally relate to mature core rock, including ecologically defined core rock consisting in part of framework rock, and to proximal flank rock in the mature parts of buildups. It follows, therefore, that the lower intervals (within the Moccasin Springs) of given buildups can be identified separately from the upper, Bailey intervals, especially in those buildups for which a number of wells provide a geometric perspective. Indeed, such differentiation is reflected in geophysical logs (for example, well no. 37).

Flank rocks within the buildups are wholly gradational with the surrounding rocks of nonbuildup origin (for example, well no. 37), and they take on the character of interbuildup rocks. Distal flank rocks, then, may appear as whitish, uniformly fine grained chert-free carbonate rock that is essentially identical (except for chert) to the surrounding chert-bearing interbuildup carbonate rock. In fact, these two carbonate types are intimately interbedded, which suggests at once that the lateral boundaries of buildups are digitate and that the buildups contributed much sediment to the interbuildup strata, possibly to distances of several miles as noted long ago by Lowenstam (1949). Also, strict differentiation between buildup and nonbuildup is an arbitrary procedure. All this is to say that type 1 and type 2 carbonates, which are defined below for convenience of description of nonbuildup rocks, are also found within the main body of buildups and that reeflike rocks, petrographically considered, occur beyond the limits of definable buildups.

TYPES 1, 2, AND 3 CARBONATE ROCKS

In accord with the interpretation of Becker and Droste (1978, p. 5-10), we note that three basic types of carbonate lithologies dominate the nonreef upper Bainbridge rocks and the New Harmony rocks. As defined for convenience of reference, type 1 carbonate consists of very fine grained to fine-grained argillaceous to silty (quartz), modestly cherty to noncherty limestones and dolomitic limestones.

Type 2 carbonate consists of very light colored medium- to coarse-grained high-purity bioclastic limestones and some dolomitic limestones that have little or no chert. As applied by Becker and Droste (1978), however, type 2 carbonate did not include Silurian reef rocks.

Type 3 carbonate consists of fine- to medium-grained dolomites and dolomitic limestones that commonly have a speckled appearance and have been moderately to completely replaced by chert. The speckled appearance is due variably to the nearly ubiquitous dolomite rhombs enclosed in a fine-grained matrix and, in lesser degree, to chitinozoans and glauconite. Even the chert is commonly speckled, as the dolomite-rhomb and fossil fabrics were generally preserved during the replacement process.

As will be noted, each of these types has its own nuances on a formation-by-formation basis. Further, especially large Silurian reefs brought about sedimentational modification of their own.

MOCCASIN SPRINGS FORMATION

Except for rocks of reef origin, the Moccasin Springs is dominated by type 1 carbonate. These rocks become very silty and shaly in places (for example, well no. 59) and, as defined here, include a dark-gray so-called unnamed shale (and shaly carbonate) (Collinson and others, 1967) as its topmost interval (for example, well no. 74). The shale is not present everywhere, but we recognize no Moccasin Springs-Bailey unconformity. One outstanding characteristic lithology is very fine grained, modestly argillaceous carbonate rock that is colored in pastel shades of pink, green, yellow, tan, and gray (for example, well nos. 57 and 59). More intense coloring also prevails in places, and dark red particularly marks the lower few tens of feet of the Moccasin Springs overlying the St. Clair (for example, well nos. 24 and 57).

The Moccasin Springs, having a reef facies (for example, well nos. 9 and 15), shows such an influence even in nonreef sections by resembling the Liston Creek Limestone Member of the Wabash Formation of Indiana (light-colored fine- to medium-grained, fairly pure carbonate rocks partly of reef derivation; for example, well no. 26).

The Moccasin Springs correlates mostly with the Mississinewa Shale Member (Wabash Formation) of Indiana and the lower part of the Racine Formation of northern Illinois but probably also has some equivalency with the Louisville Limestone of Indiana.

BAILEY LIMESTONE

The Bailey Limestone, like the Moccasin Springs, is dominated by type 1 carbonate, but it is generally chertier than the Moccasin Springs (for example, well no. 14), has purer carbonate rocks, and has less distinctive coloring. Whitish to pale neutral coloration characterizes the upper part, and increasingly darker coloration, even near black, dominates downward (for example, well nos. 73 and 77). This downward darkening relates to increasing impurities (Becker and Droste, 1978, fig. 3).

Like the Moccasin Springs, the Bailey has a reef facies (for example, well nos. 18 and 37), and in near-reef localities the Bailey exhibits the coarser aspects of type 1 carbonate. Here it is whitish, light-gray, or tan medium-grained, rather pure, chert-scarce limestone and dolomitic limestone (for example, well no. 26). This facies was probably considerably reef influenced during deposition, and in its lithology and probable derivation it very much resembles the Liston Creek Limestone Member (upper part of the Wabash Formation) of Indiana. Indeed, the Liston Creek is the principal Bailey correlative in central and northern Indiana as are upper Racine rocks in central and northern Illinois.

This special Bailey lithology, together with similar Moccasin Springs lithology, helps to make up the feature that has previously been called the Terre Haute Bank in Indiana and Illinois.

BACKBONE LIMESTONE

Nearly all the type 2 carbonate (excludes Silurian reefs as applied here) is found in the Backbone Limestone, but as the Backbone is defined here as a consistently mappable rock unit, it contains much type 3 carbonate material as interfingerings from the main body of Grassy Knob rocks (for example, well nos. 53 and 67, cross sections FF′ and GG′). In this definition the Backbone, although dominantly a basinward prograding deposit, is distributed more peripherally and asymmetrically (to the east) in the Illinois Basin than are the more centrally distributed and depositionally complementary Grassy Knob type 3 carbonate rocks (figs. 7 and 9). An anomalously thick interval of type 2 carbonate, however, is within the Backbone well toward the center of the basin in Wayne County, Ill. (for example, well no. 50 and fig. 9).

A type 2 carbonate unit lying just above the main body of Bailey rocks in some places and often called the Ozora or the Beaucoup in driller's terminology (Collinson and others, 1967, p. 940) is included here in the Backbone (for example, well nos. 16 and 41). In all these understandings and employing the principle of arbitrary cutoff (Becker and Droste, 1978, fig. 5), the Backbone is lowermost in the New Harmony Group and shares that position with the Grassy Knob Chert (cross sections GG′ through JJ′) if type 2 carbonate is present immediately above the Bailey (for example, well nos. 40, 50, and 85). If, however, type 2 carbonate is present only above the lowest type 3 carbonate in supra-Bailey positions, the Backbone is assigned an intermediate New Harmony position between the Grassy Knob and Clear Creek Cherts. (See well nos. 63, 73, and 83 and cross sections GG′ through II′.)

These two dispositions relate respectively to positions on the margins and in the center of the study area. Further, the type 2 carbonate phase of the Backbone was largely an eastern development, at least as far as the preserved section within the study area permits assessment. (See well nos. 42, 68, and 78, cross sections DD′, GG′, and HH′, and the section on distribution of type 2 carbonate.)

GRASSY KNOB CHERT

The Grassy Knob Chert is dominated by type 3 carbonate rocks (for example, well nos. 73 and 76), including in some places and intervals carbonate that has been completely replaced by chert. It also includes type 2 carbonate in the complementary interfingering and classificatory arrangements that have been noted above in the Backbone discussion. (This is suggested by cross sections HH′ and JJ′ as constructed, but no single well among those recorded in the appendix gives such arrangements.) Because of its particular sedimentational relationship with the Backbone and the resulting arbitrary definition of the formations, the Grassy Knob Chert is restricted to the southeastern part of the study area (figs. 5 and 6).

Much of the Grassy Knob is dolomitic limestone; that is, it is characterized by dolomitic rhombs in a fine-grained limestone matrix as is type 3 carbonate in general, but in some intervals dolomitization has been so pervasive that the speckled appearance becomes minimal.

In contrast to the overlying carbonate and cherty rocks in the Clear Creek Chert, Grassy Knob carbonate and chert tend to be darker, including hues of brown, gray, and blue. These colors are associated with greater impurity of the Grassy Knob, which grades upward into the lighter colored and less cherty Clear Creek Chert.

CLEAR CREEK CHERT

The Clear Creek Chert of the study area, although consisting dominantly of type 3 carbonate and being very cherty in places (for example, well no. 89), becomes only moderately cherty, light colored, even whitish, and medium grained to even coarse grained over some of its area of distribution (for example, well nos. 66 and 75). The thickest Clear Creek rocks, possibly 700 feet thick (area between wells 89 and 90, cross section JJ′), are in southernmost Illinois (fig. 8) and there make up 70 percent of the New Harmony thickness, sharing the New Harmony interval only with the Grassy Knob to the exclusion of the Backbone (fig. 6).

DISCUSSION

GENESIS OF CARBONATE BUILDUPS

In one of the discussions of lithology under the heading "Stratigraphy," we used the unbiased, nongenetic term "carbonate buildup" in place of the ecologically directed term "reef." The reason is that little opportunity is afforded in subsurface Illinois Basin study to prove the ecologic framework requirement of a properly designated reef. Even core samples from a large buildup may have remarkably little easily discerned evidence of framework, but this observation also extends to core samples of exposed reefs in northern Illinois and Indiana that are known to have central framework as well as a predictable biotic and lithologic zonation in general. There is little doubt that the buried Illinois Basin buildups are also properly called reefs.

Further parallels may be drawn. It is theoretically possible that large single, apparently well-integrated reef masses, such as the Linton Reef in Greene County, Ind. (well no. 30), were generated from essentially single point sources and grew both upward and outward to become circular, elliptical, or even atoll like in plan view. (See diagrams by Indiana University Paleontology Seminar, 1980, fig. 8.) More likely, however, large reefs, their regular external appearances notwithstanding, have internal coalesced structures that partake of multiple isochronous point sources or of these and of later generated satellite reefs as well.

Coalescence may have been an early event for a given reef mass, so that no external proof exists at mature size, and it could also be a late event, so that telltale suprareef drape structure has two or more areas of closure (for example, the Marine Reef in southwestern Illinois, well no. 33, and the Worthington Reef in southwestern Indiana, well no. 31). These considerations bear on diagenetic history (for example, dolomitization) and on distribution of porosity and permeability within reef masses; also, on the discovery of buried reefs and their induced drape structures in that drape structure directly relates to reef geometry, both external and internal.

Few wells in the Illinois Basin were deliberately drilled entirely through the Silurian carbonate buildups. Also, the particular geometry of the buildups does not lend itself to accurate assessment of stratigraphic range. For example, nearly all the Silurian reefs for which control exists are known not to have flat bottoms. That is, interreef sedimentation proceeded somewhat more slowly than upward reef growth, so that reefs spread laterally onto ever-accumulating substrate as they grew upward. For these reasons, one cannot often be sure of the times of initiation and abortion of reef growth or that the reefs are assignable to one, two, or more principal generations. A single well, for example, can penetrate a single limited interval of reef rock at any Lower to Upper Silurian level, whatever the actual reef ranges. Do such limited penetrations of reef rock suggest that only random stratigraphic distribution of reefs applies, or could they relate mostly to the chance placement of wells in relation to complications in reef geometry?

The answer is certainly a complex one. This latest study only adds nuances to previously reached interpretations. Probably not more than two principal reef generations can be identified. This is attributable to greater environmental stability in the Illinois Basin than in the more northern and eastern parts of the Great Lakes area, where several generations relate to the cyclic salt-carbonate depositional episodes. (See Shaver, Sunderman, and others, 1983, and Droste and Shaver, 1977 and 1985.) The earliest generation in the Illinois Basin was founded within the early part of the St. Clair depositional regime (for example, well nos. 30 and 37), and the latest was a Moccasin Springs event (for example, well nos. 33 and 48).

The first generation was not a single, everywhere-isochronous event; it may have been a longer continuing happening than had previously been thought, although much of this generation seems to be associated in some limiting way with the possibly time-transgressive St. Clair-Moccasin Springs boundary. One of the earliest known reef starts in the study area is in Grayson County, Ky. (well no. 88, cross section II′), where well cuttings strongly suggest that the entire St. Clair interval, lying above a thin Sexton Creek section, belongs entirely to the Huntington Lithofacies (fig. 1). The Sandoval Reef (well no. 37, Marion County, Ill.) also gives evidence of even earlier initiation in the St. Clair than was depicted by Lowenstam (1949). Also, this reef section (well no. 37) suggests either a start-and-stop beginning, or it shows very interdigitate geometry in relation to complementary interreef rocks. Given these conditions, we further expect some basin-to-shelf progression in the positions of reef sites that relate to the early generation. Such a geographic shift should accord predictably with stratigraphic positions of individual reef starts.

The generation arising within the Moccasin Springs seems to accord with the relatively late generation of hundreds or thousands of reefs in northern Indiana beginning at and near the base of the Mississinewa Shale Member of the Wabash Formation (Droste and Shaver, 1977 and 1985; Shaver and others, 1978). The timings of the two groups are close, and, for example, the succession of interbedded organic-reef and shaly nonreef rocks in well no. 48 (fig. 4, cross section EE′) at the base of a Mocassin Springs-originated reef in Illinois is reminiscent of the basal part of the Georgetown Reef in Cass County, northern Indiana. A distinctly Moccasin Springs generation may, like the St. Clair generation, have its own special geographic relations.

We know that many reefs continued to grow until the end of Silurian time; also, that some, beginning either in deeper water or on a more rapidly subsiding sea floor, attained great thicknesses but comparatively modest areal sizes (for example, well no. 30); and also, that some, beginning in more shelfward locales, attained more modest thicknesses in relation to great laterally spreading coalescent masses (for example, well nos. 31 and 33). But the question of intra-Silurian reef abortion in the Illinois Basin has hardly been considered. Probably it should have happened, and the most likely locales are basinward and in association with the St. Clair generation. Such reefs may be modest in size and require more careful interpretation of the usual subtlety of the discovery evidences. The subtler evidences could include geographically restricted lithologies in younger Paleozoic strata that indicate shallowing waters (for example, in Lower Devonian formations) and that could relate to reef-induced drape structure.

AGE OF THE BAILEY LIMESTONE

Understanding of the Bailey Limestone, of the nature of Silurian reefs and a proposed carbonate-bank system (Terre Haute Bank) in the Illinois Basin, and of the basin itself has been handicapped by the traditional assignment of a Devonian age to this formation. Such understanding has its practical side. Was there truly great topographic relief around 500- to 900-foot reefs as they grew? How deep did the water have to be to accommodate such reefs? And was there actually a linearly trending, prominently steep fronted bank along the west side of the reef trend in southwestern Indiana that would have certain implications for development of overlying hydrocarbon reservoirs?

These suppositions probably continue to be greatly exaggerated in the minds of some basin stratigraphers. Much of the answer rests with the age of the Bailey. We do not repeat here the evidence for a Silurian age as such but add perspective, both as to evidence and application. (See further discussion of suprareef drape under "Postreef depositional and diagenetic effects.")

There are striking similarities between the Moccasin Springs-Bailey section of the Illinois Basin and the Wabash section (entirely Silurian in age) of central and northern Indiana. The intimacy of typical Moccasin Springs and Bailey lithologies, seemingly juxtaposed in unpredictable order in some areas and so apparently related to reef development, could hardly have greater parallel than within the Wabash Formation. The typical Mississinewa and Liston Creek lithologies within the Wabash also have seemingly unpredicatable relations in association with massive reef development, and they could be transplanted, so to speak, into the Moccasin Springs-Bailey rocks and wholly escape detection as foreign material. This observation, together with what was already known, reinforces the conclusion that the Bailey is Late Silurian in age, and it adds refinement to the interpretation of a Silurian linear basin-fringing buildup that is called the Terre Haute Bank. Much of the typical Moccasin Springs and Bailey lithologies appears to consist of very fine reef-derived sediments (so-called reef milk) and coarser sediments that found their way to locales not only in immediately interreef areas (for example, as part of the Terre Haute Bank) but also in areas many miles distant into the basin proper. Although not included in this study, the subsurface Racine rocks of central and northern Illinois, like the Wabash rocks, should suggest similar ideas on the age and makeup of the Bailey Limestone.

If these basic interpretations are correct, even the largest reefs were surrounded by only modest topographic relief at the time of their growth, because interreef strata accreted simultaneously, were partly derived from reef-shed debris, and became interdigitate with laterally and upward expanding reef-flank strata. It follows that water was much shallower in the immediate reef vicinities than was once supposed. For example, water depths probably were less than thought by as much as the Bailey and part of the Moccasin Springs are thick. Further, reefs did not have to grow up from especially deep water, a concept that has generally prevailed to this time; rather, a general history of basin subsidence (sea-level rise?) would have accommodated such great reef thicknesses.

In their denial of the concept of great topographic relief, these ideas do not at all deny the existence of reef-drape structure, but they give added import to the diagenetic processes causing the differential volumetric changes that largely accounted for suprareef drape and for significant structural adjustments within the reefs. Obviously, there is a practical lesson to be derived here from a proper Bailey age assignment and to be applied to the recognition of buried reefs.

DISTRIBUTION OF TYPE 2 CARBONATE

As interpreted by Becker and Droste (1978), type 2 carbonate, which in its nonreef context is confined mostly to the Backbone, represents shallower water than do other New Harmony carbonate types. Further, westward (basinward) progradation from the Indiana side was proposed, which would not have been a simple progradation to judge from the eastward interfingered deeper water carbonate rocks (type 3 and as in the Grassy Knob) within the Backbone. The present study has not revealed a basin symmetry in this respect, as type 2 carbonate accumulations are only moderately thick in the lower New Harmony rocks in southwestern Illinois (fig. 9; fig. 4, cross sections EE′ through HH′). If thicker type 2 carbonate rocks were once present in western locales, they were eroded. Greater Devonian tectonism (epeirogenesis?) may be the cause and has already been indicated for that area, since the pre-Muscatatuck unconformity becomes a pre-New Albany unconformity in western Illinois.

POSTREEF DEPOSITIONAL AND DIAGENETIC EFFECTS

Previously published papers have emphasized the effects that buried Silurian reefs have on the structural attitude of younger Paleozoic rocks as high as the Pennsylvanian System. This emphasis has extended to reef-induced attributes of hydrocarbon reservoirs. Considering suprareef drape that may extend in effective amounts as high as a few thousand feet above the thickest reefs, the reef relation to the structural attributes of overlying reservoirs seems obvious.

Application of Silurian reef effects to deposition and to diagenesis of younger Paleozoic rocks, however, is not so obvious, although there surely is application whose degree is not fully understood. Our latest study, based specifically on many Illinois wells, does not reveal new truths, at least not that we have been able to sift out. We make the following exemplary observations that in themselves should encourage further investigation.

The Plummer Reef site in Greene County, Ind., has apparently drape-controlled solution features in Upper Mississippian limestone (Noel, 1979). The Rockford Limestone (Lower Mississippian) and the New Albany Shale (Devonian and Mississippian) in some southwestern Indiana locales are known to have been depositionally affected at the sites of then well-buried Silurian reefs (Hasenmueller and Bassett, 1979). Selective deposition and dolomitization of Devonian rocks over the major Silurian reef trend in southern Indiana have been proposed previously (Droste and Shaver, 1975). Also, preferred siting of younger Silurian reefs over older aborted Silurian reefs and separated from the older reefs by nonreef strata has been observed.

Given these effects, shallowing in many younger depositional regimes succeeding the reefs may have resulted in localized increased permeabilities, such as in localized coarse bioclastic accumulations and in oolite shoals. These effects could have begun as early as during Backbone deposition.

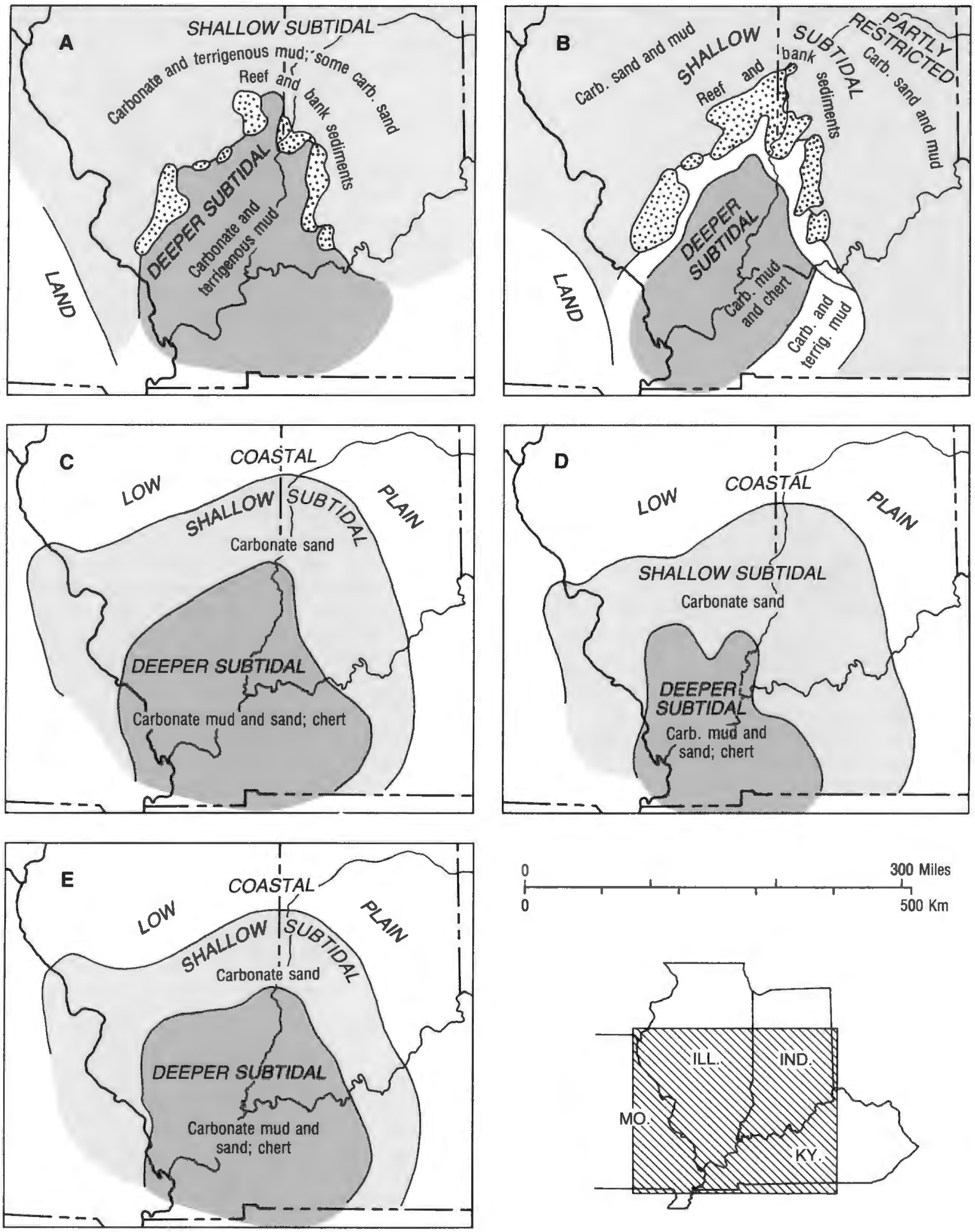
Most of the hydrocarbon-producing fields in the Illinois Basin are in post-Devonian reservoir rocks. Some of these are known to relate to buried Silurian reefs in some way; many others probably do, but the facts have not yet been established.

PALEOENVIRONMENT AND SEDIMENTATION

Systematic summary statements on the paleoenvironmental and sedimentational history of Upper Silurian and Lower Devonian rocks in far southwestern Indiana have been presented (Becker and Droste, 1978; Droste and Shaver, 1980). Further, parts of the discussion and of the descriptive treatment above have been couched in historical, interpretative language. A set of paleoenvironmental maps (fig. 11) has been added here as expansion to such maps as were presented by Droste and Shaver (1982 and 1985) and were made for longer averaged periods of time.

The Silurian maps (figs. 11A and B) represent one of the great marine invasions of

Figure 11 (*on facing page*). Five maps showing the paleoenvironmental and sedimentational history of the study area. A, Moccasin Springs (Ludlovian) deposition; B, Bailey (Pridolian) deposition; C, Grassy Knob and early Backbone (Gedinnian) deposition; D, late Backbone (Siegennian) deposition; and E, Clear Creek (Emsian) deposition.


A
SHALLOW SUBTIDAL
Carbonate and terrigenous mud; some carb. sand
Reef and bank sediments
DEEPER SUBTIDAL
Carbonate and terrigenous mud
LAND
B
Carb. sand and mud
SHALLOW SUBTIDAL
PARTLY RESTRICTED
Carb. sand and mud
Reef and bank sediments
DEEPER SUBTIDAL
Carb. mud and chert
Carb. and terrig. mud
LAND
C
LOW COASTAL PLAIN
SHALLOW SUBTIDAL
Carbonate sand
DEEPER SUBTIDAL
Carbonate mud and sand; chert
D
LOW COASTAL PLAIN
SHALLOW SUBTIDAL
Carbonate sand
DEEPER SUBTIDAL
Carb. mud and sand; chert
E
LOW COASTAL PLAIN
SHALLOW SUBTIDAL
Carbonate sand
DEEPER SUBTIDAL
Carbonate mud and sand; chert
0
300 Miles
0
500 Km
ILL.
IND.
MO.
KY.

the continent and present the idea that reef complexes in the study area did not reach their greatest sizes until latest Silurian time, an observation that is contrary to the traditional interpretation of the ages of Silurian reefs. The Silurian time interval represented probably entirely postdates the first three major salts (A-1, A-2, and B) of the Salina Group that were deposited in the Michigan Basin. Moreover, growth of the proposed Moccasin Springs generation of Illinois Basin reefs probably awaited the end of such restricted circulation conditions northward that led to salt deposition and to the abortion of many previously established reefs on the Wabash Platform. The upper parts of the reef system portrayed in figure 11 probably correspond, therefore, to the classically studied Silurian reefs that are exposed in the upper Wabash Valley of Indiana but in that area have eroded tops.

Although reef growth in the Illinois Basin was probably influenced by the more northerly focused regional events of restriction and nonrestriction, no evaporites seem to have been deposited. This suggests that the basin was never closed off from circulation southward with a major seaway. Lacking such rapidly deposited sediments as evaporites and also lacking overwhelming siliciclastic sediments, the central Illinois Basin was likely characterized by considerably deeper water for much of Silurian time than were the Michigan and Appalachian Basins.

The Silurian reefs of the Illinois Basin seem not to have survived the lowering of sea level that attended the inception of Devonian time and caused the locus of shallow-water skeletal-carbonate-dominated sedimentation to shift basinward. There these Early Devonian (Backbone) sediments accumulated, nevertheless, over the basinward facies of the Silurian carbonate bank. The apparently basinward progradation of these Backbone sediments suggests very shallow water and rapid carbonate production, a continued lowering of sea level, or both. Because of the thickness of this pile of type 2 carbonate sediments immediately west of the Terre Haute Bank (fig. 9), as observed from some wells, no structure definable as a Devonian reef is proved. If such a reef exists, it might be discernible from underlying Silurian reef rock below only with the greatest difficulty.

The interdigitation of type 3 carbonate rocks (Grassy Knob-like) with type 2 rocks suggests a certain amount of instability that could have inhibited growth of buildups prominent enough to be called reefs. Such interdigitation and the distribution of the Backbone Limestone and the Grassy Knob Chert (figs. 7 and 9) show the contemporaneity of the two kinds of sedimentation and relatively deep water in the centralmost basin (fig. 11C).

Whatever the number of more modest fluctuations in rate of basin subsidence, sea-level change, rate of carbonate production, or some combination that accounts for the type 2 and type 3 carbonate interdigitations (see cross sections), the more shallow shelflike environment prograded farthest toward the center of the basin during the Siegenian Age (figs. 1 and 11D). This general Early Devonian trend was reversed by Emsian time, when cherty Clear Creek (type-3) sediments and deeper water advanced shelfward over the former shallow-water Backbone domain (fig. 11E).

Although no Silurian-Devonian unconformity appears to have developed in the centralmost part of the basin, the complexities of Early Devonian history proposed above suggest that some more shelfward Silurian reefs could have been eroded more than once before their ultimate burial by Middle Devonian sediments of the Muscatatuck Group. Further, the more shelfward reefs were more severely eroded.

APPLICATION

This setting forth, partly interpretative, of the physical circumstances of this middle Paleozoic sedimentational province, such as it is presently known, should enhance future economic exploration. As both Becker and Droste (1978, p. 11) and Droste and Shaver (1980, p. 585) have noted, perhaps the most significant conclusion that can be reached is that the history of Silurian reef growth, diagenesis, burial, and erosion is not a simple one, and neither is the Backbone depositional episode a simple one. The different factors discussed here have differentially affected the prospects for favorable reservoir development. Each stratigraphic level, each geographic locale, and each part of regional structure surely has its own subtly changing set of evidences that should lead most directly to future discovery and exploitation.

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APPENDIX – REGISTER OF WELLS USED IN THIS STUDY AND TOPS OF STRATIGRAPHIC UNITS

Well no. and location	Elevation in feet	Tops of stratigraphic units in feet									
		Clear Creek	Backbone type 2 carbonate	Backbone type 3 carbonate	Grassy Knob	Bailey[1]	Moccasin Springs	St. Clair[2]	Sexton Creek	Maquoketa (Ordovician)	Total depth
Cross section AA′:											
1. Christian County, Ill., 32-13N-3W Nat. Assoc. Petrol. No. 1 Peabody	617						1,950	2,140	2,210	2,230	2,618
2. Christian County, Ill., 9-13N-1E Nat. Assoc. Petrol. No. 34 Lawrence	620						2,330	2,600	2,670	2,695	3,021
3. Shelby County, Ill., 19-14N-2E NEA Yes No. 1 Stoggsdill	632						2,460	2,670	2,760	2,790	4,500
4. Moultrie County, Ill., 22-15N-5E Sanders No. 1 Harrison	686						2,910	3,130	3,260	3,295	6,525
5. Moultrie County, Ill., 13-15N-6E Continental No. 1 Beachy	665						2,840	3,160	3,280	3,310	3,681
6. Douglas County, Ill., 23-15N-8E Richardson No. 1 Cole	645						440	830	950	970	1,276
7. Edgar County, Ill., 1-13N-14W Poppas No. 1 Hannold	676					1,290	1,410	1,770	1,910	1,930	2,205
8. Edgar County, Ill., 4-12N-13W Livingood No. 1 Babcock	795					1,740	1,870	2,230	2,330	2,350	2,694
9. Vigo County, Ind., 15-11N-9W Princeton No. 1 Smith	497					1,845	2,020	2,440	2,480	2,515	2,933
10. Clay County, Ind., 4-12N-6W Carter No. 1 Longshore	668						1,450	1,660	1,870	1,900	1,962
11. Putnam County, Ind., 15-14N-5W Stanolind No. 1 Wells et al.	755						1,215	1,390	1,520	1,555	2,829
Cross section BB′:											
12. Montgomery County, Ill., 20-8N-5W Seaboard No. 1 Lay	673						1,820	2,140	2,220	2,240	2,577
13. Montgomery County, Ill., 3-8N-2W Superior No. 1 Singler	671						2,520	2,830	2,920	2,960	3,249
14. Fayette County, Ill., 28-8N-3E Humble No. 1 Unit Weaber Horn	563					3,095	3,310	3,510	3,570	3,600	8,616
15. Cumberland County, Ill., 28-9N-7E Texaco No. 10A Willenborg	622						3,925	4,530	4,590	4,620	6,410
16. Clark County, Ill., 31-10N-13W Athena No. 1 Pence	591		1,800	1,750		1,820	2,040	2,350	2,440	2,460	2,731
17. Clark County, Ill., 30-10N-13W Trenton No. 13 Cooper	599		1,810	1,765		1,835	2,050	2,335	2,430	2,455	3,150
18. Vigo County, Ind., 32-10N-10W Siosi No. 18 Riggs	450					2,250	2,740	3,010	3,090	3,110	3,534
19. Sullivan County, Ind., 30-9N-8W Texas No. 1 Unit McAnally	533					2,260	?	2,800	2,870	2,920	3,440
20. Greene County, Ind., 1-8N-7W Citizens No. 1 Rowe	540					1,900	2,290	2,330	2,440	2,465	3,527
21. Owen County, Ind., 21-9N-5W Schwartz No. 1 Everhart	670					1,600	1,910	1,955	2,085	2,120	2,578
22. Owen County, Ind., 15-9N-5W White No. 1 Burge	643					1,545	?	1,950	2,010	2,050	2,469

APPENDIX – REGISTER OF WELLS USED IN THIS STUDY AND TOPS OF STRATIGRAPHIC UNITS—Continued

Well no. and location	Elevation in feet	Tops of stratigraphic units in feet									
		Clear Creek	Backbone type 2 carbonate	Backbone type 3 carbonate	Grassy Knob	Bailey[1]	Moccasin Springs	St. Clair[2]	Sexton Creek	Maquoketa (Ordovician)	Total depth
Cross section CC′:											
23. Bond County, Ill., 7-6N-4W Sun No. 1 Young	589					1,995	2,100	2,360	2,420	2,470	2,958
24. Bond County, Ill., 9-6N-2W Goose Creek No. 1 Jackson	581					2,395	2,485	2,890	2,965	3,015	3,244
25. Fayette County, Ill., 13-15N-2E Kewanee No. 1 Gehle	582					3,540	3,790	4,110	4,175	4,200	4,527
26. Effingham County, Ill., 12-6N-4E Henderson No. 1 Koss	565					4,010	4,130	4,535	4,610	4,640	4,704
27. Effingham County, Ill., 18-7N-6E Wiggins No. 1 Genault	578					4,050	4,230	4,570	4,630	4,660	5,000
28. Crawford County, Ill., 3-5N-12W Drake No. 1 Maxwell	587		3,100 3,210	3,170		3,260	3,620	3,890	4,000	4,040	4,600
29. Sullivan County, Ind., 36-8N-9W Filmont No. 1 Riggs	458		2,430 2,510	2,460		2,600	2,870	2,970	3,075	3,100	4,160
30. Greene County, Ind., 10-7N-7W Sun No. 1 Richardson	577					1,990	?	2,600	2,800	2,845	3,267
31. Greene County, Ind., 32-8N-5W Citizens No. 1 Newsom	532					1,510	1,780	2,090?	2,140	2,185	2,644
Cross section DD′:											
32. Madison County, Ill., 21-5N-6W Powers No. 1 Kaufman-Isenberg	546					1,810	2,040	2,180	2,230	2,275	2,590
33. Madison County, Ill., 15-4N-6W Eason No. 1 Mayer	535					1,745	2,040	2,180	2,230	2,275	2,590
34. Madison County, Ill., 10-3N-5W Magnolia No. 1 Plocker	509					2,030	2,200	2,490	2,560	2,595	2,815
35. Clinton County, Ill., 17-3N-4W Tatum No. 1 Schrage	510					2,175	2,330	2,670	2,725	2,775	3,550
36. Clinton County, Ill., 35-3N-2W Texas No. 1 Defend-Gray Comm.	434					2,610	2,955	3,245	3,320	3,375	3,812
37. Marion County, Ill., 4-2N-1E Martin No. 1 Robinson	532					2,990	3,620	3,925	4,005	4,055	5,023
38. Marion County, Ill., 33-3N-2E Harvey No. 11 Kazy	571					3,550	4,150	4,440	4,510	4,565	4,900
39. Clay County, Ill., 1-3N-5E HAVE No. 1 Sutton	582		4,660 4,780	4,720		4,810	4,980	5,340	5,440	5,500	6,048
40. Richland County, Ill., 4-3N-9E Pure No. 18B Montgomery	503		4,760 4,840 4,960	4,820 4,895		4,980	5,225	5,500	5,600	5,645	6,800
41. Lawrence County, Ill., 29-4N-12W Atlantic No. 1 Lewis	500		3,130 3,210 3,360	3,170 3,310		3,400	3,630	3,900	4,005	4,040	9,261
42. Knox County, Ind., 97-3N-10W Poe No. 1 Guerretaz	491		3,400 3,765	3,660		3,800	4,010	4,130	4,205	4,255	5,470
43. Daviess County, Ind., 2-2N-5W Midwest No. 1 Kiefner	510		1,955			2,040	2,410	2,460	2,535	2,570	3,129

44. Martin County, Ind., 20-3N-4W	459		1,720			1,730	?	2,220	2,250	2,280	2,807
McHale No. 1 Hart											
45. Martin County, Ind., 16-4N-3W	494		?			1,420	1,650	1,700	1,780	1,810	2,314
Wires No. 1 McBride											
Cross section EE′:											
46. St. Clair County, Ill, 32-1S-7W	475						1,440	1,680	1,735	1,770	2,010
McC&G No. 2 Stoneman											
47. St. Clair County, Ill., 20-1S-6W	460						1,760	2,150	2,180	2,215	2,415
Truitt No. 1 Moeller											
48. Washington County, Ill., 15-1S-4W	444					2,350	2,795	3,110	3,175	3,240	3,505
Obering No. 3 Baldwin											
49. Marion County, Ill., 5-1N-2E	520		3,440	3,400		3,555	3,840	4,205	4,275	4,300	5,655
Texas No. 21 Tate			3,510	3,475							
50. Wayne County, Ill., 27-1N-7E	446		5,020	5,140		5,320	5,700	5,920	5,970	6,060	7,207
Pure No. 3 Billington			5,200								
Cross section FF′:											
51. Washington County, Ill., 6-3S-5W	448					2,090	2,200	2,515	2,565	2,610	2,860
Horton No. 1 Metalman											
52. Washington County, Ill., 29-3S-4W	542					2,210	2,700?	2,980	3,040	3,110	3,984
McBride No. 1 Hunlith											
53. Jefferson County, Ill., 35-2S-1E	475		3,930	3,915		4,170	4,425	4,670	4,705	4,760	5,101
Magnolia No. 9 Eubanks			3,970	3,955							
			4,005	3,990							
			4,060	4,040							
			4,150	4,080							
54. Gibson County, Ind., 13-3S-14W	376	4,870	4,980	5,015		5,330	5,630	5,770	5,820	5,870	6,408
Continental No. 1-D Cooper			5,095	5,150							
			5,270								
55. Gibson County, Ind., 12-2S-12W	391	4,085	4,150	4,210		4,485	4,870	4,970	5,055	5,090	5,586
Skiles No. C-2 Sullivan			4,265	4,330							
			4,450								
56. Gibson County, Ind., 16-1S-11W	398	3,940	4,050	4,125		4,380	4,750	4,860	4,940	4,985	6,198
Brown No. 1 Bingham			4,145	4,200							
			4,365								
57. Pike County, Ind., 1-1S-7W	472		2,690			2,780	3,100	3,340	3,400	3,450	3,855
Union No. 1 Uppencamp											
58. Pike County, Ind., 30-1N-6W	506					2,490	2,650?	3,000?			3,050
R&V No. 1 Schnarr											
59. Daviess County, Ind., 15-1N-5W	505		2,090			2,205	2,550	2,700	2,770	2,805	3,250
Newton No. 1 Brittain											
60. Orange County, Ind., 29-3N-2W	798						1,660	1,960	2,055	2,080	3,226
Hays No. 1A Baker											
Cross section GG′:											
61. Randolph County, Ill., 7-4S-6W	486					1,545	1,800?	1,890	1,935	1,965	2,225
Jet No. 1 Guebert-Herbert											
62. Randolph County, Ill., 16-4S-5W	494					2,185	2,500	2,750	2,810	2,835	2,985
Jet No. 2 Easdale											
63. Perry County, Ill., 13-4S-4W	518	2,700	2,730		2,745	2,870	3,160	3,335	3,455	3,500	3,776
Pure No. 1 Schwartzkopf											
64. Perry County, Ill., 11-5S-1W	458	3,175	3,300		3,330	3,510	3,950	4,150	4,200	4,320	4,529
McBride No. 1 Heape											
65. Franklin County, Ill., 36-6S-2E	474	4,725	4,920		5,000	5,295	5,640	5,825	5,870	5,980	6,250
Shell No. 19 CW&F Coal											

APPENDIX — REGISTER OF WELLS USED IN THIS STUDY AND TOPS OF STRATIGRAPHIC UNITS—Continued

Well no. and location	Elevation in feet	Tops of stratigraphic units in feet									
		Clear Creek	Backbone type 2 carbonate	Backbone type 3 carbonate	Grassy Knob	Bailey[1]	Moccasin Springs	St. Clair[2]	Sexton Creek	Maquoketa (Ordovician)	Total depth
Cross section GG′—Continued											
66. Hamilton County, Ill., 6-6S-7E Texaco No. 1 Cuppy	393	5,170	5,455 5,550	5,500	5,575	5,860	6,090	6,320	6,400	6,470	13,051
67. White County, Ill., 27-4S-14W Superior No. C-17 Ford	384	4,990	5,100 5,235 5,460	5,170 5,315		5,480	5,810	5,970	6,065	6,120	7,682
68. Pike County, Ind., 14-3S-8W Miller No. 1 Dixon	458		3,240 3,500	3,440		3,600	3,875	3,970	4,055	4,110	4,650
69. Dubois County, Ind., 17-3S-5W Barrow No. 7 Schmett	496		2,390			2,500	2,900	3,140	3,275	3,310	3,398
70. Dubois County, Ind., 35-3S-5W Texas No. 1 Luebbenhuesen	568		2,400			2,540	2,700?	?	3,140	3,190	3,803
71. Crawford County, Ind., 9-3S-1W Atkins No. 2 Gray	811						1,800	2,080	2,155	2,190	3,025
Cross section HH′:											
72. Jackson County, Ill., 11-7S-4W Magnolia No. 1 Reuscher-Froemling	659		2,435 2,560	2,460	2,585	2,700	2,970	3,170	3,220	3,275	3,582
73. Jackson County, Ill., 11-7S-2W Texaco No. 1 Harsha	438	3,245	3,425		3,490	3,635	4,080	4,280	4,320	4,410	7,094
74. Williamson County, Ill., 25-8S-3E Brehm No. 1 Harris	532	4,700			5,270	5,570	5,895	6,115	6,220	6,310	8,500
75. Pope County, Ill., 2-11S-6E Texas Pacific No. 1 Streich	783	4,060			4,615	4,980	5,275	5,440	5,520	5,645	
76. Gallatin County, Ill., 29-9S-9E Texaco No. 1 Walters	355	4,685			5,280	5,620	5,790	5,940	6,045	6,140	7,688
77. Posey County, Ind., 19-7S-13W GE No. WD-2	395	5,160	5,370 5,515 5,980	5,420 5,730		6,020	6,260	6,360	6,410	6,465	7,980
78. Warrick County, Ind., 19-4S-6W Shenandoah No. 1 Zirkelback	487		2,980			3,240	3,590	3,680	2,740	3,760	4,000
79. Perry County, Ind., 25-4S-3W Central No. 1 Delaise	646		2,050			2,070	2,390	2,460	2,540	2,560	3,255
80. Perry County, Ind., 17-4S-1W Sun No. 1 Gibson	748						1,850	2,150	2,240	2,260	3,534
Cross section II′:											
81. Union County, Ill., 35-11S-1W Little Egypt No. 1 Baslaw	480	2,425	2,850		2,880	3,130	3,525	3,710	3,760	3,800	4,053
82. Johnson County, Ill., 34-13S-3E Texas Pacific No. 1 Farley et al.	594	2,510	3,080		3,100	3,370	3,680	3,890	3,965	4,010	14,284
83. Crittenden County, Ky., 17-L-16 Shell No. 1 Davis	373	1,730	2,110		2,240	2,520	3,000	3,150	3,230	3,260	8,821
84. Union County, Ky., 15-N-21 Union No. F-11 Breckenridge	496	5,020	5,280 5,640	5,360		5,655	5,990	6,150	6,265	6,305	8,620
85. Webster County, Ky., 5-M-22 Exxon No. 1 Choice Duncan	359	5,130	5,415 5,720	5,445		5,845	6,220	6,275	6,330	6,370	15,200

86. McLean County, Ky., 4-M-28	440	3,440	3,620	3,680		3,840	4,140	4,260	4,350	4,380	6,830
Texas Gas No. 1A Heirs			3,805								
87. Ohio County, Ky., 18-N-33	605		2,450	2,500		2,600	2,830	2,950	3,050	3,070	?
L&H No. 1 Marks			2,570								
88. Grayson County, Ky., 10-L-36	712		1,960	2,000		2,250	2,400	2,540	2,705	2,720	10,522
Texas Gas No. 1 Shain			2,020								
Cross section JJ′:											
89. Massac County, Ill., 23-14S-3E	345	1,870			2,540?	2,790?	3,060?	3,210?	3,340?	3,400?	
Kahle No. 1 Harvik											
90. Pope County, Ill., 18-16S-7E	347	1,890			2,570	2,880	3,140	3,300	3,370	3,450	4,104
Rigney No. 1 Lewis											
91. Caldwell County, Ky., 19-H-22	683	3,560	3,840	3,900		4,280	4,445	4,520	4,625	4,640	?
Ryan No. 5 Ryan			4,265								
92. Butler County, Ky., 3-J-33	415	3,110	3,190	3,220		3,380	3,635	3,780	3,920	3,975	5,711
Humphrey No. 1 Deweese			3,365								
Other wells used as datum points:											
Douglas County, Ill., 26-16N-8E	669					218	?	610	765	780	1,744
Illinois Power No. 1 Waltrip											
Coles County, Ill., FR30-13N-11E	?					1,265	1,340	1,750	1,875	1,895	2,314
Sanders No. 1B Childress											
Putnam County, Ind., 3-13N-4W	790						1,215?	1,360	1,530	1,560	2,072
Hayes No. 1 Zeiner											
Putnam County, Ind., 17-14N-3W	810					1,090	?	1,190	1,350	1,390	2,376
Hayes No. 1 Nichols											
Clark County, Ill., 19-10N-13W	571		1,770	1,750		1,800	2,020	2,325	2,410	2,440	3,370
Magnolia No. 1 Young											
Greene County, Ind., 10-8N-4W	539					1,400	1,550	1,690	1,810	1,840	2,394
Whitaker No. 1 Sharr											
Bond County, Ill., 16-6N-2W	566					2,360	2,430	2,840	2,920	2,965	2,291
Miami No. 1 Bresserman											
Madison County, Ill., 2-4N-6W	550					1,800	2,005?	2,250	2,300	2,350	2,619
Sloan & Ryan No. 1 Kisner											
Madison County, Ill., 36-4N-6W	510					1,910	2,025	2,310	2,380	2,415	2,685
Thompson No. 1 Reynolds											
Martin County, Ind., 34-4N-4W	650		1,845?			1,860	?	2,220	2,290	2,320	2,809
Lyons No. 1 Haines											
Randolph County, Ill., 33-4S-6W	458					1,625	1,730	1,870	1,945	1,970	2,230
Superior No. 1 Grass											
Daviess County, Ky., 15-O-30	388	3,290	3,390	3,425		3,625	3,825	4,020	4,115	4,165	?
M.S.E. No. 1 Fields			3,510								
Breckinridge County, Ky., 6-P-35	402		1,750			1,775	?	2,100	2,215	2,240	?
Langford No. 1 Knight											

[1] Same as Wabash top in eastern part of Indiana area.

[2] Same as top of Salamonie-Louisville section in eastern part of Indiana area.