SUBSURFACE STRATIGRAPHY OF THE SALEM LIMESTONE AND ASSOCIATED FORMATIONS IN INDIANA

by
ARTHUR P. PINSAK

Indiana Department of Conservation
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SUBSURFACE STRATIGRAPHY OF THE SALEM LIMESTONE AND ASSOCIATED FORMATIONS IN INDIANA

BY ARTHUR P. PINSAK

ABSTRACT

The Meramec series (middle Mississippian) in Indiana is composed of a virtually continuous sequence of shallow-water limestones that underlie the southwestern one-third of the State and thicken in a southwesterly direction to a maximum of nearly 1,000 feet. Formational boundaries can be defined throughout most of the areal extent but are vague and gradational in the extreme southwestern part of Indiana.

The Salem limestone (lower Meramec) is widely known because of its peculiar diminutive fauna and its extensive use as a building stone. The distinctive foraminiferal limestone is recognized easily on outcrop in the building stone district which extends from Washington County into Owen County, Ind. Except for local occurrences of the foraminiferal limestone, the formation is distinguished with some difficulty on outcrop around the remainder of the Illinois Basin.

Deposition of the Salem limestone was subject to three distinct environments. In the northern area of occurrence the formation is a near-shore (epineritic) deposit, in the central area it is a shelf (infraneritic) deposit, and in the extreme southwestern part of the State the sediments were deposited in a basin environment. In the area of shelf deposition, which is expressed at the surface in the building stone district, the Salem can be differentiated from overlying and underlying limestones. In the areas of near-shore and basin deposition, the Harrodsburg and Salem limestones are lithologically similar and formational boundaries are vague.

The Salem limestone in the shelf area was deposited in the same manner as a quartz sandstone and exhibits the characteristics of a well-sorted subareal sandstone. Local structural anomalies expressed at the top of the formation are due to localized bar development within the clastic part of the formation or to differential compaction of underlying sediments.

Oil which is produced from the Salem limestone in Indiana is restricted geographically to the shelf (infraneritic) area. Environmental conditions north and south of the shelf area apparently were not favorable for oil accumulation. The oil is present within a few feet of the top of the formation in the foraminiferal limestone. Mode of occurrence of the oil indicates that the rocks were tilted to the southwest after accumulation of the oil.

INTRODUCTION

PURPOSE OF STUDY

Oil has been produced from the Salem limestone in Indiana since 1937, but Salem production is not as extensive as that from other formations. As a result of interest in possible further oil production from this formation, a regional study of the Salem limestone in Indiana was undertaken. On the basis of available data an attempt has been made to better understand the formation, its relation to associated formations, its lateral continuity and correlation, and the geologic setting of the oil pools.

SCOPE OF STUDY

Before a subsurface study of the Salem limestone was begun, a regional surface reconnaissance was made during the summer of 1953 with Mr. Ned M. Smith of the Indiana Geological Survey. Mr. Smith is presently engaged in a detailed study of the Salem in its outcrop belt.

For the subsurface investigation, detailed studies were made of cuttings from 310 wells in Indiana, including all wells which penetrate the Salem limestone except those in Vigo and Sullivan Counties. These two counties have dense well control as a result of exploration for Silurian reef structures. In general, only 3 wells per township were studied in these 2 counties in order to maintain a well density pattern comparable to the rest of the State. The core from the Superior Oil Co. No. C-17 Ford well in White County, Ill., was studied at the Illinois Geological Survey in Urbana, and the Shell Oil Co. kindly permitted samples to be taken from cores in Crittenden County, Ky., and Hardin County, Ill.

Results of the study are presented in this report on maps and cross sections. Although detailed mineralogic analyses have not been made, spectrographic analyses were made of the Salem limestone and the upper part of the Harrodsburg limestone from a few selected wells in which the commonly encountered lithologic types were developed.

ACKNOWLEDGMENTS

The writer wishes to express appreciation to Mr. T. A. Dawson, Head of the Petroleum Section, Indiana Geological Survey, and to the members of his section for their aid, suggestions, and criticisms. Mr. R. K. Leininger, Head of the Geochemistry Section, Indiana Geological Survey, made the spectrographic analyses. Appreciation also is accorded Mr. Ned M. Smith for his suggestions concerning the outcrop belt of the Salem and to Dr. John B. Patton for his aid and his critical study of the manuscript.

PREVIOUS WORK

Most reports that have been written about the Salem limestone in Indiana are concerned with the building stone for which the formation is famous. Little material dealing with the Salem limestone and adjacent formations in the Indiana subsurface has been published. The extensive literature which discusses the formations on outcrop are not covered in detail in this report; however, a few of the more pertinent and comprehensive papers are reviewed briefly.

The first published reference to the Salem formation was by James Hall (1864, p. 1-36), who described the peculiar diminutive Spergen Hill (Salem) fauna. He redescribed the fauna in 1883 (p. 319-375) and included plates by R. P. Whitfield. T. C. Hopkins and C. E. Siebenthal (1897, p. 289-427) prepared the first detailed study of the formation on outcrop in relation to the building stone industry. E. R. Cumings, J. W. Beede, E. B. Branson, and E. A. Smith (1906, p. 1187-1479) described the paleontology and stratigraphy of the Salem in Indiana. The occurrence and stratigraphic relations of the Salem limestone on outcrop in western Illinois were discussed by Stuart Weller (1908, p. 81-102). Information on the occurrence of the Salem limestone and its equivalents was included in a reconnaissance study of western Kentucky by Charles Butts (1917, p. 32-33). E. R. Cumings thoroughly reviewed the pertinent literature and presented an excellent discussion of the formation, including the history of nomenclature and description, in the Handbook of Indiana geology (1922, p. 499-506).

J. M. Weller and A. H. Sutton (1940, p. 765-858) discussed the geology of all Mississippian rocks of the entire Illinois Basin in a paper that was the result of a cooperative study begun in 1913 in which numerous geologists and agencies throughout the basin area had participated. Much of the work on which the report was based was done or supervised by Stuart Weller, who was actively engaged for many years in a study of Mississippian fauna and strata.

J. N. Payne (1940, p. 225-236) reported on the Iowa series (Kinderhook, Osage, and Meramec) in the subsurface in Illinois. He included correlations and insoluble residue studies in his report.

METHODS USED IN PRESENT STUDY

Before the present study was begun, it was necessary to choose some persistent and easily recognizable marker bed for orientation in the stratigraphic column. The closest, most readily distinguished, and most persistent stratigraphic marker to the Salem limestone is the top of the Renault of Wabash Valley subsurface usage, which is equivalent to the top of the Paoli limestone of the

Indiana outcrop area. In studying well cuttings, the top of the Renault limestone was used as a datum or starting point. Stratigraphic interpretations have been derived from actual examination of samples; however, electric logs, when available, were used to augment information obtained from samples.

The correlations of the various units in this study are based on physical criteria. Faunal content was not a primary factor in correlation. Although much of the Salem is composed of fossils and fossil debris, they are regarded from a sedimentary aspect as clastic constituents of the limestone. Formational boundaries were ignored to a great extent in the preliminary work in an attempt to eliminate any influence they might have on the description and correlation of rock units.

The amount of lithologic detail that can be obtained from subsurface study is obviously dependent on the quality of samples taken during the drilling operation. Generally, the shallow holes have good samples, but exceptions are common. In the deep wells, cavings from higher in the hole commonly contaminate the samples and tend to obliterate details. Only the more apparent lithologic units can be noted in the subsurface.

Common methods of stratigraphic analysis were used. The physical characteristics of the rock units were described and compared in order that magnitude of change might be determined. Stratigraphic determinations and indices were plotted on base maps to show results graphically on a regional basis so that general conditions of sedimentation and environment might be made apparent.

NOMENCLATURE OF THE MISSISSIPPIAN SYSTEM

At the time the first detailed geological surveys were made in the Illinois Basin and the rock sequences were subdivided and classified, the geologic formations were compared on the basis of paleontologic evidence with the type geologic sections in the eastern part of the United States. Correlations were made and comparable stratigraphic successions were determined.

James Hall (Hall and Whitney, 1858, p. 92-120) divided the Carboniferous limestone, the strata lying between the time equivalent of the Chemung (Devonian) of New York and the "Coal Measures" (Pennsylvanian), into the following units from top to bottom: Kaskaskia limestone, "Ferruginous sandstone," and St. Louis, Warsaw, Keokuk, and Burlington limestones. He correlated the Spergen Hill beds near Salem, Ind., with the Warsaw limestone of western Illinois on the basis of faunal similarity.

A. H. Worthen (1866, p. 83-84) did not recognize a faunal difference between Hall's Warsaw limestone and the St. Louis group from which Hall had separated the Warsaw. Worthen included the Warsaw and consequently the Spergen Hill beds in the lower part of the St. Louis group. He apparently did not intend to exclude the name Warsaw completely because he used it after 1866.

D. D. Owen (1859, p. 20), in a report of a geological reconnaissance made in 1837, proposed the name Subcarboniferous for the rocks lying between the "Coal Measures" and the Devonian black slates. Alexander Winchell (1869, p. 79) proposed "Mississippi group" for the Subcarboniferous rocks. The name attracted little attention until H. S. Williams (1891, p. 135) proposed to revive the name as "Mississippian"; this name has been generally accepted in the United States, and the series of rocks is considered a system.

E. O. Ulrich (1904, p. 109-110), in his division of Mississippian rocks, proposed the name Meramec group to include the Warsaw limestone and the overlying Spergen (Salem)[1] and St. Louis limestones. He used the restricted "St. Louis limestone" (Ulrich and Smith, 1905, p. 36) and excluded the Ste. Genevieve from the Meramec.

The Mississippian system at present is generally subdivided into the following four groupings from the base: Kinderhook, Osage, Meramec, and Chester series. The boundaries of the Meramec have been changed by many workers subsequent to the original proposal by Ulrich. In 1937 the U. S. Geological Survey accepted "Meramec group," although the Meramec generally is considered a series, and included within its boundaries from top to bottom the Ste. Genevieve limestone as it is presently defined and the St. Louis, Spergen (Salem), and Warsaw limestones (Wilmarth, 1938, p. 1349). The Indiana Geological Survey uses the name Harrodsburg at present and includes only the upper part of the Harrodsburg (Warsaw) limestone in the Meramec series.

DESCRIPTION OF MIDDLE AND LOWER MISSISSIPPIAN FORMATIONS

The Paoli limestone (lower Chester) and the Meramec series form a virtually continuous carbonate rock sequence with only minor occurrences of quartz sandstone and shale. The Osage series varies in composition through its areal extent from sandstone, siltstone, and shale to a sequence composed almost entirely

[1] Formations considered to be equivalent to those used are included in parentheses.

of limestone. The Meramec series and the carbonate facies of the Osage series form a nearly continuous sequence of limestones in southwestern Indiana which locally attains a thickness of as much as 1,300 feet. A close relationship between the rock units that constitute the total sequence is indicated when individual units are traced laterally. Consequently, correlation of a given rock sequence within the carbonate series is virtually impossible if the study is not combined with observations concerning the associated strata.

The section of carbonate rocks in Indiana that extends down from the Paoli limestone through the Osage series was studied in some detail in order to obtain a better understanding of the Salem limestone. Regional descriptions of the Paoli limestone and the formations constituting the Meramec and Osage series are given below.

CROSS SECTIONS

Four stratigraphic cross sections (pl. 1) were prepared to illustrate correlations and lithologic associations of Osage and Meramec strata in Indiana. As the sections are stratigraphic rather than geologic, the vertical scale is exaggerated (158 times) in order to show relationships of thin lithologic units which could not be included otherwise. Two of the cross sections (A-A′ and D-D′) were drawn in the direction of dip, and two of them (B-B′ and C-C′) were drawn in the direction of strike of the Salem limestone. Position of the cross sections was determined by the amount of available well control as well as by location of areas in which significant lithologies might be shown.

The top of the Paoli limestone (top of Renault) in Indiana was used as datum in cross sections A-A′, B-B′, and D-D′. In section C-C′ the top of the lower part of the St. Louis limestone, one of the better markers in the Meramec series, was used as the datum; this datum was used primarily because the Paoli limestone is not present in every well. The pronounced local structures which are apparent on all the cross sections are reflections of underlying Silurian reefs. The structures, of course, are exaggerated because of the exaggerated vertical scale.

The Meramec and Osage strata illustrated on the cross sections include thin lithologic units and diverse lithologies. An attempt to include all detail in sections of this sort would entail use of a very large scale and would mask regional associations; therefore, only the major lithologic types are shown.

PAOLI LIMESTONE

The Paoli limestone (lower Chester) is a distinct and persistent stratigraphic marker in the subsurface. It lies directly below the Mooretown (Bethel) sandstone and rests unconformably on the Aux Vases formation or the Ste. Genevieve limestone of Indiana outcrop terminology. (The Aux Vases of Illinois Basin subsurface terminology lies within the Levias member of the Ste. Genevieve limestone.) The name Paoli was used originally by M. N. Elrod (1899, p. 258-267) for exposures at Paoli, Orange County, Ind. His lower boundary was at the top of the Lost River chert near the base of the Ste. Genevieve limestone as it is presently defined. E. R. Cumings (1922, p. 506-507) redefined the boundaries of the Paoli to include the rock sequence between the Mooretown sandstone and the top of the Ste. Genevieve limestone.

DISTRIBUTION

The northern limit of the formation in the subsurface coincides roughly with the northern boundaries of Clay and Vigo Counties, and it is present everywhere in the subsurface west of an irregular outcrop line that extends from western Putnam County through central Crawford County, Ind. (Counties in Indiana which are referred to in the text are shown in figure 1.) The formation does not vary in thickness to any great extent throughout the Indiana portion of the Illinois Basin. Near its northern boundary, the Paoli limestone is 15 to 20 feet thick. It thickens regionally to the southwest with local fluctuations, attaining a maximum thickness of about 65 feet in Posey County. Local variations in thickness of the formation appear to be influenced, at least in part, by the extent of erosion at the top of the Ste. Genevieve limestone; if the top of the Ste. Genevieve has been eroded locally, the Paoli limestone in most places is slightly thicker than normal.

LITHOLOGY

The Paoli limestone can be divided into three easily recognized members. Each of the three members is described separately below.

The uppermost member of the formation, 5 to 20 feet thick, is light-tan to tan fine- to medium-grained[2] dense locally oolitic limestone. This unit is the most persistent member of the Paoli limestone.

[2] Used in reference to a texture composed predominantly of detrital fragments which may be crystalline or irregular in outline; size is defined by the modal class.

Figure 1.—Index map showing counties in southwestern Indiana.

The middle member of the Paoli limestone has a variable lithology and ranges from a few inches to about 30 feet in thickness. The unit is present near the northern boundary of the Paoli limestone, appears to thin regionally in Greene, Martin, and Daviess Counties, and thickens in a southwesterly direction to about 30 feet in Posey County. This middle member is characteristically green fissile somewhat arenaceous shale. Fragments of dense brown limestone are found locally near the top, red shale is present locally, and traces of authigenic pyrite are common. The unit is composed predominantly of fine- to medium-grained subrounded quartz sand in the extreme southwestern part of Indiana. In a few cores a local unconformity is indicated at the top of the middle Paoli. The lower boundary of the midle Paoli limestone is not well defined. The member is transitional into the lower Paoli limestone, and the boundary between the two is generally placed where limestone becomes predominant.

The lower Paoli limestone is typically tan to gray-tan, medium crystalline,[3] and oolitic to suboolitic and ranges from a few feet to slightly more than 15 feet in thickness. The unit is interbedded with gray-green argillaceous limestone and green fissile shale, which becomes abundant in the basal few feet, and the limestone generally is transitional into green fissile shale and fine- to medium-grained subrounded quartz and limestone sand in a green argillaceous matrix which contains traces of authigenic pyrite (Aux Vases of Indiana outcrop terminology). The sandstone content of the basal few feet varies locally.

CORRELATION

The upper member of the Paoli limestone is equivalent to the upper Renault (Stuart Weller, 1913, p. 120) in the subsurface of the Illinois Basin and to the Downeys Bluff limestone (Atherton, 1947, p. 129), described by E. F. Tippie from an exposure on the bluffs of the Ohio River at Rosiclare, Ill.

The middle Paoli limestone is equivalent to the shale in the middle of the Renault of the Illinois Basin and to the shale member of the Shetlerville formation (Stuart Weller and others, 1920, p. 290).

The lower Paoli limestone, equivalent to the limestone member of the Shetlerville formation (Stuart Weller and others, 1920, p. 290), is the lower Renault of the outcrop belt in southeastern Illi-

[3] Used in reference to a texture in which adjacent mineral crystals have mutual boundaries; results from recrystallization or from precipitation of secondary solutions; individual mineral crystals may have a detrital grain as a nucleus.

nois, the area in which the Renault was first described. However, it is equivalent to only the upper part of the lower Renault of the subsurface in the Illinois Basin. Most subsurface geologists include the upper part of the Ste. Genevieve limestone (Indiana outcrop terminology) in the lower Renault and extend the basal contact of the lower Renault to the top of the first shale, sandstone, or dolomitic limestone unit ("basin Aux Vases") below the top of the Ste. Genevieve limestone.

The calcareous sandstone at the base of the lower Paoli limestone is the unit which has been correlated by C. A. Malott (1946, p. 325) with the Aux Vases sandstone (Keyes, 1892, p. 295) of southern Illinois and eastern Missouri.

STE. GENEVIEVE LIMESTONE

The Ste. Genevieve limestone was named by B. F. Shumard (1873, p. 293) for outcrops in the Mississippi River bluffs just south of Ste. Genevieve, Ste. Genevieve County, Mo. The Ste. Genevieve beds were included for many years, however, in the upper part of the St. Louis limestone throughout most of the Illinois Basin, and it was not until after 1900 that they were generally recognized as a distinct formation.

DISTRIBUTION

The Ste. Genevieve limestone is present in Indiana as far north as central Parke County and central Vermillion County. As a result of the Mississippian-Pennsylvanian erosional unconformity, a complete section does not exist north of Clay County (pl. 1). Where a complete section is present in this northern area, the average thickness of the Ste. Genevieve limestone is 50 to 60 feet. The formation is about 125 feet thick in northeastern Greene County and averages 100 to 125 feet thick immediately west of the outcrop belt southward to the Ohio River. The formation thickens in a southwesterly direction from the outcrop and attains an average thickness of 160 feet along the Wabash River in Gibson and Posey Counties. The thickness of the formation averages about 170 feet in Perry and Spencer Counties, and local thinning is evident in northwestern Pike County, where the Ste. Genevieve is less than 125 feet thick.

The Ste. Genevieve limestone is divided into the following three members from top to bottom: Levias limestone, Rosiclare sandstone, and Fredonia limestone. They are described here as defined in the outcrop area of Indiana. The Levias limestone member ranges from 30 to 75 feet in thickness; the average thickness is about 50 feet. The Rosiclare sandstone member ranges from a few feet to 30 feet in thickness; this thickness fluctuates locally. The Rosiclare member appears as discontinuous lenses in Posey and Vanderburgh Counties and in southern Warrick County and western Spencer County (pl. 1). The Fredonia limestone member ranges in thickness from about 30 feet at the northern and eastern occurrences to a maximum of 100 feet in Spencer and Warrick Counties and thins to about 75 feet in Posey County. The Fredonia appears to reflect the major fluctuations in thickness of the Ste. Genevieve limestone.

LITHOLOGY

Lithology of the Ste. Genevieve limestone is varied. The formation is composed of limestone with various textures, dolomite, shale, and calcareous sandstone. The three members of the formation as defined in the outcrop area of Indiana are described separately.

Levias member.—The Levias member of the Ste. Genevieve limestone consists predominantly of light-tan dense finely crystalline thin-bedded limestone and dense oolitic to suboolitic limestone. The oolitic limestone is most common near the base and at the top of the member. Rounded limestone grains rather than typical concentrically laminated oolites are common. Dolomite appears locally throughout the member. A laterally persistent light gray-tan saccharoidal dolomite, 5 to 10 feet thick and locally green and argillaceous, is present near the top of the Levias (pl. 1). The dolomite generally is overlain by finely crystalline dense limestone but is present locally at the top of the formation in places where the overlying limestone probably has been stripped off by erosion. A local unconformity is at the top of the dolomite.

Southwest of a line extending from western Knox County through eastern Perry County, an argillaceous unit is present in the middle of the Levias limestone (pl. 1). At its eastern limit this unit in the middle of the Levias consists of interbedded dolomite, green calcareous shale, and green argillaceous dolomite. As the unit is traced to the southwest, it grades into fine- to medium-grained quartz and limestone sand in a green argillaceous matrix. The unit is very similar in lithology to the Rosiclare sandstone member (Indiana outcrop).

Rosiclare member.—The Rosiclare sandstone member of the Ste. Genevieve limestone is generally a distinctive and readily recognized unit. Characteristically, the member is composed of fine- to medium-grained quartz and limestone sand in a green shale matrix which contains traces of authigenic pyrite. Any one of the three components may be locally predominant. Shale is most commonly the dominant lithology in the central area of occurrence. The member is generally bounded by tan very finely crystalline dense limestone.

Fredonia member.—The Fredonia limestone member consists of alternating beds of gray-tan to light-tan finely crystalline limestone and oolitic limestone. The oolitic limestones vary in composition from true oolites to rounded limestone grains and range in texture from dense limestone to true calcareous oolite with virtually no matrix. Light-tan granular dolomite appears locally, and the limestone locally exhibits varying degrees of dolomitization. The most persistent dolomite unit is at or near the base of the Fredonia and locally may contain gray to dark-blue chert. This chert unit is probably the subsurface equivalent of the Lost River chert.

The lower boundary of the Fredonia is vague. Apparently it was picked on the Indiana outcrop at a faunal change rather than at a distinct lithologic change. Generally, a dolomite unit separating tan oolitic limestone above and gray granular[4] finely crystalline dense thin-bedded limestone below can be recognized. In this report the base of the Ste. Genevieve limestone has been placed at the base of the dolomite or, in the absence of the dolomite, at the base of the oolitic limestone. Many people working in the subsurface pick the St. Louis-Ste. Genevieve contact at the place where chert first appears. Light-gray chert in the St. Louis is recognized easily and in most places is no more than a few feet below the contact. Lithologically the St. Louis limestone appears to be transitional into the base of the Ste. Genevieve limestone.

CORRELATION

E. O. Ulrich and W. S. T. Smith (1905, p. 38, 52-53) included the Ste. Genevieve formation in the Chester group and divided it into the following three members from top to bottom: Ohara limestone, Rosiclare sandstone, and Fredonia limestone. Stuart Weller (1907, p. 23, 26-27), in determining mappable units for a geologic map of Illinois, arbitrarily excluded the Ste. Genevieve limestone from both Chester and Meramec but in 1920 (p. 96-97) included the formation in the Meramec series. Weller contended that the upper part of the Ohara limestone is equivalent to the

[4] Used in reference to a texture in which grains are crystalline in outline and of approximately equal size.

Renault formation and excluded it from his Ste. Genevieve limestone. A. H. Sutton and J. M. Weller (1932, p. 430) adhered to the correlation of upper Ohara with the Renault formation and named the lower Ohara beds Levias, which is the name now used for the upper member of the Ste. Genevieve limestone. The U. S. Geological Survey in 1937 transferred the so-called "Upper Ohara" to the Renault formation of the "Chester group" and left the remainder of the Ste. Genevieve limestone in the Meramec series (Wilmarth, 1938, p. 1534). Th name "McClosky sand" has been applied to beds in the lower part of the Ste. Genevieve limestone and generally refers to any porous oolitic zone in the Fredonia that might act as an oil reservoir.

On the Indiana outcrop, the Ste. Genevieve limestone was included for many years in the Mitchell limestone, a name proposed by C. E. Siebenthal (Hopkins and Siebenthal, 1897, p. 298-299) to include all rocks between the Salem limestone and the lowest Chester sandstone. The fact that the unit included the Paoli, Ste. Genevieve, and St. Louis formations was recognized, but E. R. Cumings (1922, p. 506-507) was the first to subdivide formally the Mitchell limestone in Indiana to correlate with the standard stratigraphic column of the Illinois Basin. C. A. Malott (1946, p. 323-325) in his description of the strata at Cataract Falls, Owen County, Ind., divided the Ste. Genevieve limestone in Indiana into three members. On the basis of stratigraphic position he correlated the members with the Levias limestone, Rosiclare sandstone, and the Fredonia limestone of Illinois and western Kentucky and assigned the same names to them.

The type locality of the Rosiclare sandstone is on the Ohio River bluffs below Rosiclare, Hardin County, Ill. The northerly equivalent of the Rosiclare sandstone in the subsurface of southeastern Illinois apparently is the so-called "Aux Vases sandstone."

The Rosiclare sandstone as it is defined on Indiana outcrop can be traced in the subsurface toward western Indiana (pl. 1). A unit which is similar in lithology to the Rosiclare sandstone is present southwest of a line extending from western Knox County through eastern Spencer County (pl. 1); this unit appears above the Rosiclare at about the middle of the rock sequence that has been designated Levias limestone on the Indiana outcrop. The equivalent of the Indiana outcrop Rosiclare is present only locally in Posey and Vanderburgh Counties and in southern Warrick County and southern Spencer County, but the sandstone unit above it becomes prominent to the southwest and can readily be traced into Illinois (pl. 1). In western Posey County, this unit in the middle of the Indiana Levias lies within the stratigraphic interval called "basin Aux Vases" which correlates with the type section of the Rosiclare sandstone at Rosiclare, Ill. The Indiana outcrop Rosiclare, therefore, underlies the type Rosiclare sandstone and lies within the equivalent of the type Fredonia member of the Ste. Genevieve limestone.

The extensive arenaceous dolomite unit in the upper part of the Indiana Levias limestone is commonly an oil reservoir in Indiana and has been called "Aux Vases" or "basin Aux Vases" in subsurface work. This arenaceous dolomite unit is separated stratigraphically from the sandstone unit which is found in the middle of the Indiana Levias throughout a large portion of the southwestern part of the State. The two units coalesce, however, in western Posey County and the relationships become vague (pl. 1). More detailed work will have to be done in order to determine the exact relationship between the arenaceous dolomite in the upper Levias, the sandstone in the middle Levias, and the type Rosiclare sandstone ("basin Aux Vases") of Illinois.

ST. LOUIS LIMESTONE

The St. Louis limestone (middle Meramec) is a relatively thick unit which covers the part of Indiana that lies west of an irregular line extending southeastward from northern Parke County to the Ohio River along the east edge of Harrison County. George Engelmann (1847, p. 119-120) originally described the formation from exposures near St. Louis, Mo., but the boundaries as they are commonly accepted today were restricted in 1904 by E. O. Ulrich (p. 103).

DISTRIBUTION

The formation thickens regionally from its outcrop on the east toward the center of the Illinois Basin. The northernmost extent has been limited by the Mississippian-Pennsylvanian erosional unconformity. In Vermillion County, which is as far north as a complete section of St. Louis limestone can be observed, the formation is about 50 feet thick. It is between 50 and 70 feet thick southward through Vermillion and Parke Counties and thickens rapidly to about 200 feet in northern Clay County and northern Vigo County. The thickness is fairly uniform near the outcrop of the St. Louis limestone in the area from Clay County through Harrison County. The formation thickens rather uniformly toward the center of the Illinois Basin in the northern two thirds of its areal extent and is about 350 feet thick in western Knox County. In Crawford County and western Orange County the formation thickens westward in a few miles to slightly more than 300 feet. It continues to thicken westward to about 400 feet in western Posey County, except for a locally thin area which trends northward along the western boundary of Pike County, northeastern Warrick County, and central Spencer County.

The areas underlain by Silurian reefs are notable examples of local thinning of the St. Louis limestone. Most of the variation in thickness, however, appears to be in the lower part of the formation. The upper part of the St. Louis thickens from the north to about 100 feet in northern Clay County and appears to thicken only slightly in a southerly direction to about 150 feet in Spencer County and to about 125 feet in Posey and Perry Counties.

LITHOLOGY

The St. Louis limestone appears upon casual examination to be a heterogeneous mixture of varied lithologic types. The rocks can be divided on the basis of lithology, however, into two depositional or environmental units. Because they are distinctive, the two members are treated separately and are referred to as the upper St. Louis limestone and the lower St. Louis limestone. The upper St. Louis was deposited in an open-sea environment with relatively unrestricted circulation, and the lower St. Louis was deposited in a restricted shallow-water environment. As the contact between the two members is recognized easily, it is one of the better subsurface stratigraphic markers in the Meramec series. Division of the St. Louis into two members on outcrop is not feasible, however, because the lower St. Louis is in most places only a few feet thick and does not constitute a mappable unit.

Upper St. Louis.—The upper part of the formation is composed predominantly of tan to light-tan fine- to medium-granular dense thin-bedded limestone and contains abundant gray to light blue-gray vitreous chert. The unit is locally dolomitic, but occurrence of dolomite apparently is secondary and rather unpredictable. The limestone is finely granular at the base of the unit and grades to crystalline toward the top. The crystalline limestone is not common north of T. 5 N., but it becomes very common southward, constituting as much as half of the upper St. Louis in the extreme southern part of Indiana. Clastic oolitic limestone units are common at the top of the formation south of T. 5 N. The majority of the apparent "oolites" actually are rounded and spherical limestone grains rather than concentrically laminated concretions.

Lower St. Louis.—The lower part of the St. Louis is composed predominantly of dense brown carbonaceous limestone alternating with units of gypsum and anhydrite. These evaporites, which can be grouped into three separate units, are at the top, middle, and base of the lower St. Louis. Tan finely granular dolomite is associated with the evaporite units and is more persistent laterally than the gypsum and anhydrite. Green calcareous shale containing traces of authigenic pyrite is found locally in the upper evaporite unit. The upper unit appears most sporadically, and the lower unit most persistently. Thickness of the evaporite sequences varies laterally. Calcium sulphate is concentrated in what apparently were local, restricted basins at the time of deposition. This localized concentration is noted especially in the upper evaporite unit. The Silurian reefs probably had some influence on the concentration of the evaporites in that the progressively formed structures in the beds overlying the reefs (induced by progressive, differential compaction within the Silurian) probably were more or less continuous, positive topographic features on the sea floor during Mississippian deposition. These topographic highs impeded free circulation in early St. Louis shallow seas, and basins were formed in the interreef areas. The evaporites are not present north of Clay County or in most of the outcrop belt. In these areas, the equivalents of the evaporite units are thin-bedded calcareous shales or argillaceous dolomites; however, nodules of gypsum have been observed in the lower St. Louis on outcrop in Harrison County. The pronounced thickening of the St. Louis limestone a few miles away from outcrop occurs in the lower St. Louis and is due to development of the evaporite section (pl. 1).

The evaporite content of the lower St. Louis decreases toward southwestern Indiana, and brown crystalline clastic fossiliferous limestone, which is apparently a facies equivalent of the typical dense brown carbonaceous limestone, is common to the southwest (pl. 1).

The top of the lower St. Louis is brown dense crystalline to clastic oolitic limestone and can be differentiated easily from the upper part of the formation. A dark-gray to brown finely granular dense locally argillaceous limestone unit marks the lower limit of the formation and generally is recognized easily.

CORRELATION

The St. Louis limestone of Indiana was included originally in the Mitchell limestone, a name proposed by C. E. Siebenthal (Hopkins and Siebenthal, 1897, p. 298-299). He believed that the limestones between the Salem limestone and the lowest Chester sandstone could not be subdivided to correlate with the St. Louis and Ste. Genevieve limestones of eastern Missouri. Later workers noted that the equivalent of the St. Louis could be recognized in Indiana, but E. R. Cumings (1922, p. 507) first proposed that the Mitchell limestone be subdivided and correlated with the St. Louis limestone and overlying formations of the standard Meramec series.

SALEM LIMESTONE

The Salem limestone is described in detail in another section of this report. (See p. 33.) However, in order to maintain continuity, a brief description of the formation is included here.

A number of local names had been used for this famous building stone before E. R. Cumings (1901, p. 232-233) proposed Salem limestone, a name derived from the quarry district in Washington County, Ind. This name is used by the Indiana Geological Survey, although the U. S. Geological Survey (Wilmarth, 1938, p. 2039-2040) adopted "Spergen limestone," a name proposed by E. O. Ulrich (Ulrich and Smith, 1905, p. 30).

DISTRIBUTION

The distribution pattern of the Salem limestone is essentially the same as that of the overlying and underlying formations; the northern and eastern boundaries extend from Vermillion and Fountain Counties and southwestern Montgomery County southeastward to the Ohio River along the east edge of Harrison County. The northernmost extent is limited in part by the Mississippian-Pennsylvanian erosional unconformity and in part by a depositional pinchout of the formation.

The formation thickens regionally in a southwesterly direction to a maximum of slightly more than 360 feet in Posey County, Ind. Thickness fluctuates locally from 120 feet to 160 feet in the area between T. 13 N. and T. 1 S.

LITHOLOGY

The outstanding lithologic type in the Salem limestone is a gray-tan medium- to coarse-grained clastic limestone whose individual grains are composed of microfossils, macrofossil fragments, and whole diminutive macrofossils. This is the building stone type of limestone. Relative abundance of the components varies laterally. The limestone is referred to as a calcarenite as it was deposited in the same manner as a shallow-water quartz sandstone. The calcarenite is most common north of T. 1 S. South of this area, the formation is composed predominantly of brown dense argillaceous limestone interbedded with thin lenses of calcarenite (pl. 1). The calcarenite commonly is interbedded with tan finely granular dolomitic somewhat carbonaceous and argillaceous limestone. This dolomitic limestone is present most commonly at the top, middle, and base of the calcarenite.

Boundaries of the Salem limestone become indistinct south of T. 1 S., and near its northernmost extent the formation contains abundant crinoid columnals and macrofossil fragments, which make it difficult to distinguish from the underlying Harrodsburg limestone.

CORRELATION

The Salem limestone is distinguished easily in the area downdip from the building stone district which lies between Washington County and Owen County, Ind. (pl. 1). In other areas around the edge of the Illinois Basin the formation is distinguished with some difficulty and in many places is not differentiated from the underlying Warsaw limestone. Charles Butts (1922, p. 119-120) suggested that the Salem limestone be considered a member of the Warsaw limestone. This proposal seems reasonable in view of the intimate lithologic and faunal associations. However, because of the economic importance of the Salem limestone, the formational status is favored.

HARRODSBURG LIMESTONE

The Harrodsburg limestone was named and described by T. C. Hopkins and C. E. Siebenthal (1897, p. 296-298) for exposures near Harrodsburg, Monroe County, Ind. The formation can be divided readily into two parts; the upper is earliest Meramec in age, and the lower is late Osage in age. The 2 members can be separated on the basis of lithology and appear to represent 2 distinct depositional phases. In this report the upper part of the formation is referred to as the upper Harrodsburg limestone and the lower part as the lower Harrodsburg limestone.

DISTRIBUTION

In Indiana the Harrodsburg limestone underlies the Salem limestone and overlies the Borden group. The formation is limited northward, as are all other Mississippian formations, by the Mississippian-Pennsylvanian erosional unconformity. The Harrodsburg ranges from 60 to 90 feet in thickness in the subsurface between southern Fountain County and northern Clay County and ranges about the same thickness on outcrop. The formation increases in thickness southwestward from its outcrop between T. 12 N. and T. 2 N. to about 160 feet in western Knox County. Local variations in thickness, which commonly occur in this area, appear to be influenced, in part at least, by Silurian reefs. A complete summary of regional variations in thickness cannot be presented because the lower Harrodsburg varies markedly in thickness and is transitional into the top of the Borden group south of T. 2 N. (pl. 1) and in Sullivan County. The upper Harrodsburg can be traced throughout the areal extent of the formation in Indiana and is reasonably uniform in thickness, ranging from 35 to 110 feet with uniform increase from its northern and eastern boundaries toward the center of the Illinois Basin.

LITHOLOGY

The characteristic rock type in the Harrodsburg is light tan-gray medium fragmental to coarsely fragmental crinoidal limestone. The upper Harrodsburg is in most places relatively pure and contains abundant fenestellid bryozoan remains which locally form coquinas at the top of the formation. Minor amounts of milk-white to gray chert, much of which appears to be secondary, and traces of glauconite are present at the base of the unit and become progressively more common from north to south. This green glauconite, which has an earthy appearance, is present as coatings on limestone fragments and as interstitial fillings and commonly contains minor amounts of authigenic pyrite. X-ray diffraction patterns were made of a few selected samples in order to confirm the identification because green earthy material often is mistakenly identified as glauconite. Although the test samples were determined to be glauconite, inasmuch as the term "glauconite" includes a large number of mineral varieties, additional analyses of similar samples might indicate other minerals in addition to glauconite.

South of T. 1 N. dark-gray argillaceous limestone or calcareous siltstone appears at about the middle of the upper Harrodsburg.

This siltstone separates the upper pure crinoidal limestone from the basal part of the upper Harrodsburg, which contains minor amounts of chert and glauconite and a somewhat argillaceous matrix. This dark-gray argillaceous limestone unit in the middle of the upper Harrodsburg has been observed on outcrop in Harrison County.

The lower Harrodsburg also is light-gray coarse-grained crinoidal limestone, but the limestone fragments are typically embedded in a medium-gray argillaceous limestone matrix. Chert and glauconite are much more abundant in the lower than in the upper Harrodsburg. The chert, which appears to have the same texture as that in the upper Harrodsburg, ranges in color from white to dark gray, commonly is mottled, retains relict fossil structures, and commonly contains traces of authigenic pyrite. Thin siltstone or argillaceous limestone beds containing chert may be present throughout the lower Harrodsburg but are best developed at the top and in the middle of the member.

Generally, the upper and lower Harrodsburg limestones can be readily separated. The lower Harrodsburg is more argillaceous and cherty and has markedly less microfossils and bryozoans than the upper Harrodsburg. The contact between the two members is vague south of T. 1 N. and between T. 6 N. and T. 11 N. in Sullivan and Vigo Counties; however, chert, argillaceous content, and faunal difference of the lower Harrodsburg serve to distinguish it from the upper part of the formation.

CORRELATION

James Hall in 1857 (p. 191) named an 18-foot exposure at Warsaw, Ill., the Warsaw formation but later expanded the boundaries (Hall and Whitney, 1858, p. 97) to include 50 feet of strata lying between the so-called geode beds and the St. Louis limestone at the type locality. Stuart Weller (1908, p. 87) proved that the upper 8 feet of the Warsaw limestone was equivalent to the Salem limestone of Indiana.

In the meantime, the geode-bearing beds (Harrodsburg) of Indiana had been commonly correlated with the geode-bearing beds (Keokuk) of western Illinois, and the Salem limestone of Indiana had been correlated with the Warsaw formation of western Illinois. In view of the uncertain correlation of the geode-bearing beds of Indiana and western Illinois, T. C. Hopkins and C. E. Siebenthal (1897, p. 296) named the geode-bearing limestone beds below the Salem limestone in Indiana the Harrodsburg limestone and designated the type section at Harrodsburg, Monroe County, Ind.

Charles Butts (1915, p. 157), on the basis of regional studies, transferred the geode-bearing beds of the Keokuk formation to the Warsaw formation and correlated the Warsaw formation with the Harrodsburg limestone of Indiana. Stuart Weller (1920, p. 97), F. M. VanTuyl (1925, p. 185), and others agreed with this correlation, which is adhered to by the U. S. Geological Survey (Wilmarth, 1938, p. 2276). The Indiana Geological Survey uses "Harrodsburg" rather than Warsaw, however, inasmuch as the lower Harrodsburg seems more closely related to the Keokuk than to the Warsaw.

P. B. Stockdale (1929, p. 236), as a result of detailed work on the lower Mississippian rocks in southern Indiana, suggested that the Harrodsburg limestone be divided into two formations but did not propose new names. On the basis of further field evidence (1939, p. 72) he suggested that the basal Harrodsburg beds be placed in the top of the Borden group.

The lower Harrodsburg limestone and the carbonate phase at the top of the Borden group are lithologically inseparable in the extreme southern part of Indiana (pl. 1) and in Sullivan County. In view of the intimate lithologic relations in the subsurface, if lithology can be used as a criterion, the lower Harrodsburg forms the top of the Osage series and the upper Harrodsburg forms the base of the Meramec series; the upper Harrodsburg correlates with the Warsaw limestone and the lower Harrodsburg correlates with the upper part of the Keokuk limestone.

BORDEN GROUP

D. D. Owen (1856, p. 89-90) named the massive lower Mississippian siltstone and shale sequence "Knobstone" or "Knob sandstone" for outcrops in Kentucky. The name first appeared in his field notes in 1837. E. R. Cumings (1922, p. 487), realizing the necessity for a more appropriate name for this series of rocks, proposed the name Borden series from the town of Borden, Clark County, Ind. It is now considered a group in the Osage series. P. B. Stockdale (1931, p. 76-77), on the basis of work done in southern Indiana, subdivided the group on outcrop into 5 formations, 24 facies, and 9 members. He proposed the following formations from the base: New Providence, St. Joseph (later changed to Locust Point because of preoccupation), Carwood, Floyds Knob, and Edwardsville. The five formations are not defined in this report, as they cannot be recognized everywhere in the subsurface. A regional picture of the entire group is presented.

DISTRIBUTION

Plate 2 is a combined isopach-clastic ratio map prepared to illustrate the distribution and lithologic relations of Osage sediments in Indiana. The clastic ratio is the ratio of siltstone and shale to limestone. The boundaries on the map were established on the basis of a geometric progression in order to minimize the factor of error in calculating clastic ratios.

The isopach map shows the interval from the base of the Borden group to the top of the lower Harrodsburg limestone. These rocks are regarded as a continuous depositional sequence.

The Borden group, a complex series of gray to dark-gray argillaceous siltstones with interbedded limestones, constitutes most of the Osage series in Indiana. It is overlain by the Harrodsburg limestone and underlain by the Rockford limestone of Kinderhook age.

The Borden group attains a maximum thickness of slightly more than 700 feet in the area including the Putnam-Montgomery and Parke-Fountain county boundaries. Thinning of the Borden rocks north of this area apparently is a result of the Mississippian-Pennsylvanian erosional unconformity. The group thins regionally in a southerly direction to about 500 feet on outcrop along the Ohio River and in the subsurface in Posey County.

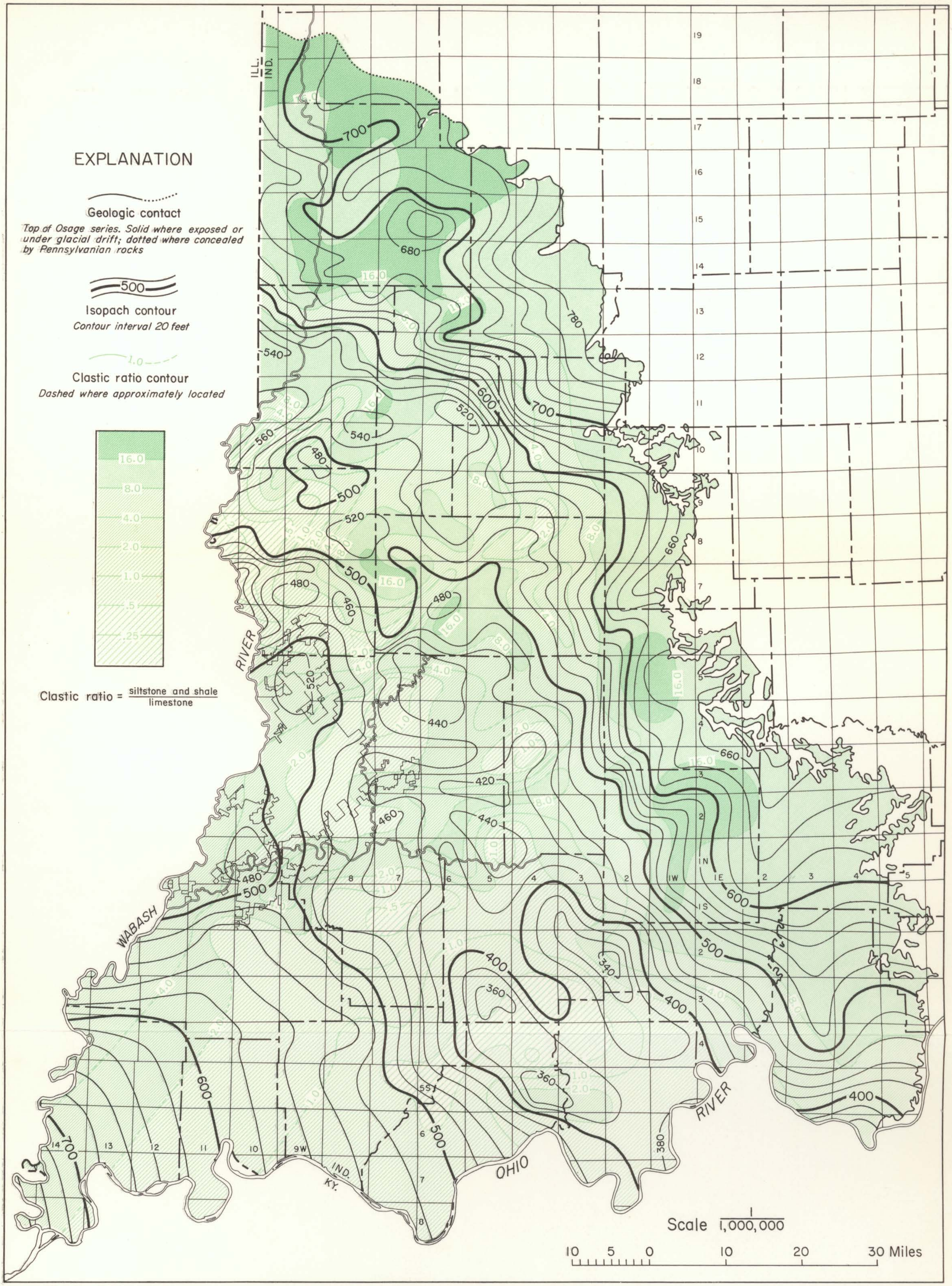
The New Providence formation, the basal formation of the group, is the one unit that can be recognized throughout its areal extent in the subsurface in Indiana (pl. 1). It ranges from 30 to 125 feet in thickness and averages about 100 feet thick between T. 4 N. and T. 12 N.; it thins to the north and south and reaches a minimum thickness of about 30 feet in eastern Spencer County, Perry and Crawford Counties, and western Harrison County.

LITHOLOGY

The Borden group comprises a variety of lithologic units and, with a few exceptions, no one lithologic unit is laterally persistent. The group is composed of innumerable discontinuous lenses and facies.

The New Providence formation consists of green to gray-green fissile shale and minor amounts of red shale; the latter is found most commonly in the northern half of the areal extent of the formation.

Borden strata above the New Providence formation between T. 18 N. and a line from northwestern Vigo County through central Owen County are composed almost entirely of medium-gray coarse-



Base modified from U.S. Geological Survey, Map of Indiana, 1950.

ISOPACH AND CLASTIC RATIO MAP OF OSAGE SERIES (BORDEN GROUP AND LOWER HARRODSBURG LIMESTONE) IN SOUTHWESTERN INDIANA

Geologic contact modified from Geological Map of Indiana (1932)

grained micaceous siltstone containing traces of glauconite. In the beds to the south and west the siltstone grades from coarse to fine and is irregularly interbedded with dark-gray shale and light-gray crystalline crinoidal limestone (pl. 1). The limestone fragments, embedded in a medium-gray somewhat argillaceous matrix, contain varying amounts of gray and white chert which commonly shows relict fossil structure.

In general, the basal unit of the Borden strata overlying the New Providence formation is coarse siltstone overlain by fine-grained siltstone or shale and coarse siltstone. At the top of the rock sequence is a very fine-grained calcareous siltstone, which commonly contains crinoidal limestone with varying amounts of chert. The unit probably is equivalent to the Edwardsville formation and typically constitutes about one-fourth of the Borden strata. The limestones occur rather irregularly and do not appear to be laterally persistent. A persistent limestone is present in the subsurface, however, at the base of this uppermost unit of the Borden group in the area between Greene and Harrison Counties (pl. 1). This limestone may be equivalent to the Floyds Knob formation (Stockdale, 1931, p. 76-77).

Some of the limestone in the Borden group is biohermal, the bioherms appearing to be restricted to two stratigraphic positions. They are found most commonly at the base of the upper calcareous siltstone unit but also are directly above the New Providence formation near the base of the Borden group. A few bioherms are indicated in plate 2 by the relatively low clastic ratios in T. 4 S., R. 4 W.; T. 1 N., R. 5 W.; and T. 3 N., R. 4 W. The limestone unit at the base of the Borden group (pl. 1, well no. 64) is a bioherm.

North of T. 18 N., the basal formation (New Providence formation) of the Borden group thickens slightly. A light gray-tan very fine-grained soft quartzose chert with traces of glauconite appears above this basal shale unit and thickens in a northerly direction. Interbedded gray vitreous chert and light-gray crinoidal limestone appear at the top of the unit as it thickens.

If the Borden group were defined to include only the siltstones and shales, great variations in thickness of the group would result. An area in which the siltstone thins markedly includes southwestern Crawford County, Perry County, southern Dubois County, Spencer County, southern Pike County, Warrick County, southeastern Gibson County, and Vanderburgh County. The siltstone-shale section thins to a minimum of about 100 feet and in cross section (pl. 1) assumes the shape of a basin which is filled with light-gray coarsely crystalline cherty crinoidal limestone interbedded with siltstone and shale. Another pronounced thinning of the siltstone-shale section lies between T. 5 N. and T. 11 N. in Sullivan and Vigo Counties. The New Providence formation is the only member of the Borden group that can be recognized in these two areas of carbonate deposition. The siltstone above the New Providence grades to very fine grain size in the direction of the well-developed carbonate phase and "lenses out" irregularly into the limestone. The two areas of carbonate deposition can be recognized easily in plate 2, and the intimate association of limestone and shale is indicated by the irregular outlines. A lobe of clastic sediments extending along the west edge of Indiana through Knox County, western Gibson County, and Posey County separates the two areas of carbonate deposition. This lobe grades from fine-grained siltstone and shale to dark gray-brown argillaceous bedded chert to the southwest.

The lower boundary of the Borden group is well defined. The Rockford limestone of Kinderhook age, a tan to greenish- or reddish-tan medium crystalline limestone averaging 4 to 10 feet thick, is almost universally present below the base of the Borden group. The limestone rests on the New Albany shale (Upper Devonian-lower Mississippian).

In most of the subsurface in Indiana the upper boundary of the Borden group is vague. The siltstones in most places grade imperceptibly into the Harrodsburg limestone. The limestones which are present in the Borden group are lithologically the same as those in the lower Harrodsburg limestone. In Putnam and Parke Counties, where the coarse siltstone extends directly to the base of the lower Harrodsburg, a contact can be accurately picked. But, as the contact is traced to the west and south, alternating beds of limestone and siltstone dominate the upper part of the Borden group and obscure the Borden-Harrodsburg contact. If the limestones were included in the Harrodsburg, the Borden would thin with complementary thickening of the Harrodsburg until, in the two areas of carbonate deposition which have been mentioned above, the Borden would be no more than 150 feet thick.

If the Borden group and the lower Harrodsburg are regarded as a single depositional unit, the relationships between the limestone and siltstone seem logical. The sediments deposited in Indiana during Osage time were transported from the northeast.

The Borden rocks of the Putnam County-southern Montgomery County area are closer to the original source of sediments than any other Borden rocks in the Indiana part of the Illinois Basin. Therefore, a consideration of the depositional history of Osage sediments must commence from this area. Here the Borden group is virtually a continuous coarse siltstone sequence with a well-defined thin crinoidal limestone unit on top of it. As the Borden is traced to the north, west, and south, the siltstone grades from coarse to fine grain size and is interbedded with shales; the limestone-siltstone contact at the top becomes vague, and discontinuous limestone lenses become more and more common within the fine-grained clastic section. At the edges of the two areas within which the carbonate phase predominates, the fine-grained clastic particles reached the limit of transportation, and most of the Borden group is composed of crinoidal limestone that was deposited contemporaneously with the siltstone and shale.

CORRELATION

The Borden group probably is equivalent to the Keokuk (in part), Burlington, Fern Glen, and Sedalia limestones of the western part of the Illinois Basin. The limestone facies of the Borden group are probably the lithologic equivalents of the Fort Payne chert of Tennessee, Alabama, Georgia, and Mississippi.

STRATIGRAPHY OF THE SALEM LIMESTONE

NOMENCLATURE

When the Salem limestone was first exploited as a building stone in the middle of the nineteenth century, various trade names, such as Bedford stone, White River stone, Salem stone, and Bloomington stone, were used by the local industries. The prevalent thought was that similar stone was quarried in the different districts but that the deposits were isolated.

The famous fossil bed near Salem, Ind., became known to collectors as the "Spergen Hill bed." James Hall first described the fauna from the Spergen Hill bed in 1864 and correlated it with the Warsaw limestone of western Illinois. In 1883 Hall (p. 319-375) published a complete faunal description with accompanying plates by R. P. Whitfield of the American Museum of Natural History. A. H. Worthen (1866, p. 83) placed the formation in the St. Louis group, and it was regarded as belonging to this group for a number of years. T. C. Hopkins and C. E. Siebenthal (1897, p. 289-427) published the first detailed account of the Indiana building stone. They showed that it was continuous between the various quarry districts and proposed that the formation be called Bedford oolitic limestone. This name, which was the first formally proposed for the formation, was used in a few subsequent reports. Inasmuch as the name Bedford had been used for a shale formation in Ohio since 1871, the Ohio usage of the name had precedence; therefore, E. R. Cumings (1901, p. 232-233) formally proposed the name Salem limestone, taken from the old quarry district at Salem, Ind., to replace the name Bedford oolitic limestone. Cumings had considered the name Spergen but discarded it because the Spergen Hill location was not a typical exposure of the formation. E. O. Ulrich (1904, p. 90) included the name Spergen Hill limestone on a prelimniary chart he had prepared. Ulrich (Ulrich and Smith, 1905, p. 30) again used "Spergen" stating that "Salem" was a trade name and that "Spergen fauna" and "Spergen Hill beds" had been widely used for many years in reference to the characteristic fauna and to the famous collecting locality. The U. S. Geological Survey (Wilmarth, 1938, p. 2039-2040) adopted "Spergen limestone," but the Indiana Geological Survey recognizes "Salem limestone" as the name of the formation.

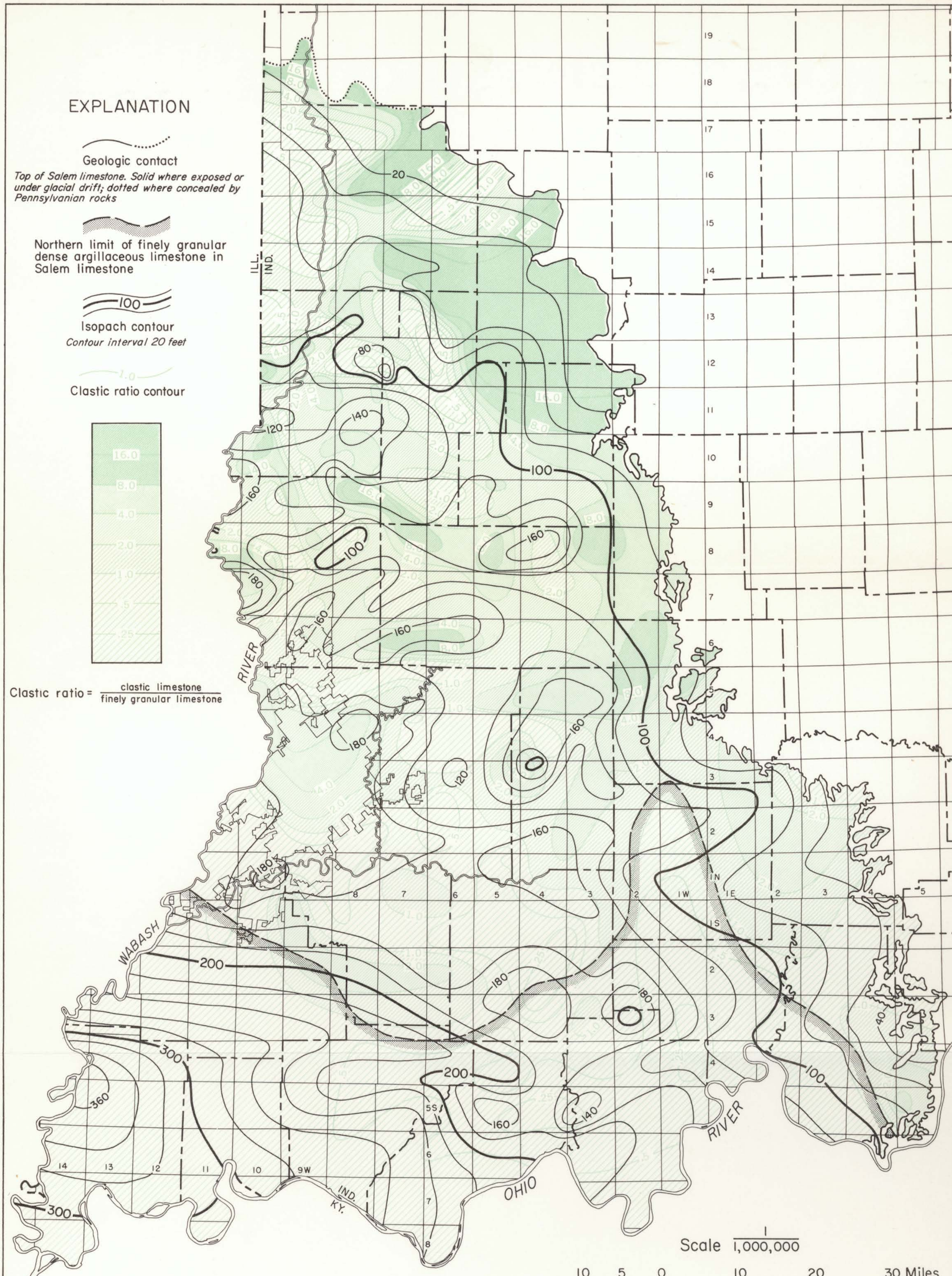
DISTRIBUTION

INDIANA

The Salem limestone is present in the subsurface throughout southwestern Indiana. The eastern boundary of Salem occurrence is an irregular, arcuate outcrop line extending southeastward from southwestern Montgomery County to the east edge of Harrison County (pl. 3).

The northward extent of the Salem limestone is limited largely by the Mississippian-Pennsylvanian erosional unconformity, but the limestone probably did not extend much farther north because of a depositional pinchout of the formation. The northernmost known outcrop of Salem limestone in Indiana is in sec. 5, T. 17 N., R. 6 W., at the Cumberland Quarries, Inc. The Salem is absent in parts of the quarry, and St. Louis limestone rests directly on Harrodsburg limestone. Where Salem limestone is present, it is conformable between St. Louis and Harrodsburg limestones and reaches a maximum thickness of 3 feet. The stratigraphic relationship at the Cumberland Quarries probably is good evidence for a depositional pinchout of the Salem limestone.

The northern boundary of the Salem limestone in the subsurface is very irregular. Erosion produced considerable relief on the



Base modified from U.S. Geological Survey, Map of Indiana, 1950.

ISOPACH AND LITHOFACIES MAP OF SALEM LIMESTONE IN SOUTHWESTERN INDIANA

Geologic contact modified from Geological Map of Indiana (1932)

pre-Pennsylvanian land surface; this topographic relief, coupled with a depositional pinchout of the Salem, results in an irregular boundary which is difficult to trace in detail in the subsurface.

ILLINOIS BASIN

The Salem limestone is present throughout most of the Illinois Basin, but it has not been separated from the Warsaw limestone in many areas. The typical lithology is best developed in Indiana south of a line through northern Owen County, northern Clay County, and northern Vigo County; this area includes the building stone district. North of Owen County the formation is somewhat gradational into and similar to the upper Harrodsburg limestone.

J. M. Weller and A. H. Sutton (1940, p. 811-813) listed occurrences of Salem limestone or its equivalents on outcrop around the edges of the Illinois Basin. Notes on occurrences outside Indiana have been taken largely from their observations. The characteristic Salem lithology persists only a few miles into Kentucky. In western Kentucky, Hardin and Union Counties, Ill., and Ste. Genevieve County, Mo., Salem limestone has not been separated in most places from Warsaw limestone, but it is a fairly pure calcarenite. Weller and Sutton state that "oolitic limestone" is recognized as far north as Alton, Ill., but north of there it becomes "earthy with minor shaly and sandy beds." However, farther north at Warsaw, Ill., 4 to 8 feet of crossbedded limestone have been referred to the Salem.

THICKNESS

Thickness of the Salem limestone is shown on the combined isopach-lithofacies map (pl. 3). The Salem thickens westward from its northernmost and easternmost extents toward the center of the Illinois Basin. It thickens rather uniformly from its northernmost extent to about 100 feet in northern Clay County and northern Vigo County. In the area lying between these two counties and an arcuate belt extending through Crawford County, northern Dubois County, and Pike and Gibson Counties (corresponding generally with the northern limit of the very fine-grained dense argillaceous limestone in the Salem), the Salem increases in thickness southward from about 100 to 160 feet with marked local fluctuations. In this area Silurian reefs are present and marked thinning occurs in the Salem above these reefs. The formation thickens rapidly in the extreme southwestern part of Indiana to a maximum of about 370 feet. The isopach pattern indicates a southerly thinning of the formation in western Kentucky in the direction of outcrop in that state.

LITHOLOGY

The Salem limestone is composed of many varied lithologic types, all of which can be recognized on outcrop. Much of the detail cannot be recognized in the subsurface, however, because this detail is masked in the cuttings which a driller collects only periodically. An attempt to identify each rock type would be virtually impossible, and the usefulness of the results would not outweigh the time factor. Most of the lithologic types grade into one another and differ only slightly. They appear to be gradational varieties of a relatively small number of types, which can be combined into the five major lithologies listed below.

1. *Medium- to coarse-grained calcarenite.*—The most characteristic and widely known rock type of the Salem formation is that which is popularly referred to in the Salem limestone quarry district of southern Indiana as the "building stone." It is tan to gray-tan medium- to coarse-grained porous fairly well-sorted clastic limestone deposited in the same manner as a sandstone. The individual grains are predominantly microfossils, macrofossil fragments, and whole diminutive forms of macrofossils. Oolites also are fairly common. The most common microfossil is *Endothyra baileyi,* a foraminifer which because of its great abundance is a guide fossil in the Salem limestone. Minor local variation can be noted in the ratio of microfossils to macrofossil fragments. The term "calcarenite" is used here in reference to clastic limestone which has the same texture as quartz sandstone but which differs in composition from quartz sandstone in that the individual grains are composed predominantly of the calcareous tests of small organisms.

2. *Medium- to coarse-grained fossil-fragmental limestone.*—A second prominent lithology is tan to gray-tan medium- to coarse-grained detrital limestone in which fragments of crinoid columnals are almost as common as microfossils. The composition and texture of this limestone vary more than those of any other lithologic type because the ratio of fragments to microfossils varies greatly. This limestone varies from a medium-grained calcarenite at one extreme to a Harrodsburg-like crinoidal limestone at the other. This type of lithology characterizes the lower half of the Salem formation.

3. *Finely granular argillaceous dolomitic limestone.*—Any stone in the building stone district in Indiana that cannot be used for building stone is colloquially referred to as "bastard stone." The typical "bastard stone" is yellow-tan to tan finely granular argillaceous dolomitic limestone containing closely spaced wavy black carbonaceous laminae. The concentration of laminae varies, and the laminae may be absent locally.

4. *Fine-grained detrital limestone.*—Another lithology in the Salem limestone is tan to medium gray-tan fine-grained detrital limestone. The detrital material is composed of finely disintegrated fossil and limestone fragments in a matrix which ranges from crystalline to granular, which is commonly dolomitic, and which may be dense or porous. Very fine-grained oolitic limestone is also included in this lithology. In most places this lithology is present as thin lenses and is most common near the top of the formation.

5. *Finely granular dense argillaceous limestone.*—Dark-gray to dark-brown somewhat carbonaceous limestone, although common in the Salem limestone, is restricted to the two southernmost tiers of counties in Indiana. Very thin, discontinuous lenses of fine-grained detrital limestone and medium- to coarse-grained fossil-fragmental limestone are interbedded with the dark finely granular argillaceous limestone and become very common westward toward the deep part of the Illinois Basin. The most persistent fossil-fragmental limestone is about two-thirds of the distance from the top of the dark argillaceous limestone.

Columnar sections of typical lithologies in the northern, central, and southern areas of occurrence of the Salem limestone in Indiana are shown in figure 2. These lithologies are typical of the three basic depositional environments of Salem sediments and are the most laterally persistent in the formation. The columnar sections necessarily are generalized; additional "bastard stone" may be present, or in the central area of occurrence only one of the lithologic types may be present locally. Distribution of the fine-grained detrital limestone is sporadic; typical occurrences of this lithologic type are shown at the top of the Greene County section and throughout the Warrick County section. The finely granular dense argillaceous limestone is shown in the Warrick County section; it is, at least in part, a southward-extending facies of the granular dolomitic limestone that appears in the middle of the Salem formation to the north. The lateral relationships of the five lithologic types within the Salem limestone are shown in figure 2.

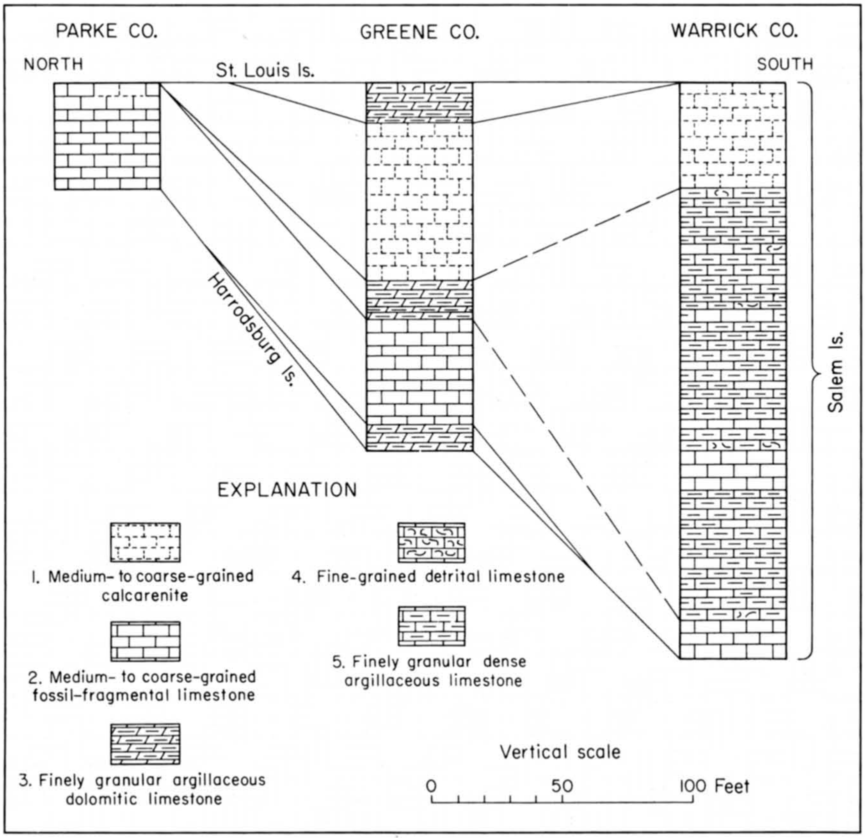


Figure 2.—Generalized columnar sections showing lithologic types and relationships of the Salem limestone in Indiana.

BOUNDARIES

UPPER BOUNDARY

Opinions concerning the position of the upper boundary of the Salem are varied. Many subsurface geologists place the boundary at the top of the medium- to coarse-grained calcarenite. The calcarenite (lithology 1) undoubtedly marks the first noticeable lithologic change between Salem and St. Louis, and it does have an electric log curve characteristic of the Salem. However, the calcarenite is found below the top of the Salem more commonly than at the top, and thus correlation on this unit rather than on the top of the formation may indicate a structural anomaly in an otherwise normal geologic section. The uppermost lithology of the Salem may be fine-grained detrital limestone (lithology 4) in a dense or granular matrix; granular dolomitic limestone with black carbonaceous laminae (lithology 3); very fine oolitic porous limestone; medium- to coarse-grained calcarenite (lithology 1); or a combination of any of these lithologies. Although the medium- to coarse-grained calcarenite is the most distinctive rock type, the others may be readily recognized. A prognosis concerning the exact lithologic unit that may be expected in any designated area is virtually impossible when one considers the irregular deposition and lateral discontinuity of individual units within the Salem limestone. An attempt has been made in plate 5 to outline the areas in which the calcarenite can be expected at the top or within 10 feet of the top of the Salem. Any one of the other lithologies may be expected at the top of the formation in the remainder of the area of Salem occurrence.

The lower part of the St. Louis limestone overlying the Salem limestone typically is an alternating series of gypsum and anhydrite and chemically deposited limestone. The ratio of anhydrite to gypsum in the lower St. Louis increases toward the center of the Illinois Basin. The most persistent evaporite zone in the St. Louis is the lowest, which lies 5 to 30 feet above the base of the formation generally as thin, closely associated stringers of gypsum or anhydrite. The typical strata between this lowest evaporite zone and the upper boundary of the Salem limestone is medium- to dark-gray fine-grained dense argillaceous limestone. This argillaceous limestone in combination with the evaporites (gypsum and anhydrite) is present in most places and constitutes a readily recognizable marker at the base of the St. Louis limestone. Where the basal evaporite zone of the St. Louis is not well developed, however, the rock unit at the base of the St. Louis is brown to dark-brown thin-bedded sublithographic limestone.

In an area extending across southern Indiana from Crawford and Perry Counties through Gibson and Posey Counties, the Salem-St. Louis contact is not as distinct as it is to the north. This is the area in which the Salem limestone is composed predominantly of finely granular dense argillaceous limestone. The basal evaporite zone of the St. Louis is developed only locally in this area, and thus the brown sublithographic limestone commonly marks the base of the St. Louis. Medium- to coarse-grained calcarenite is present at the top of the Salem limestone in most places in this area, and where finely granular dolomitic limestone is present at the top of the formation, it contains whole or partly disintegrated microfossils.

The chemical or precipitated limestones in the lower St. Louis commonly undergo a facies change to well-developed clastic limestones in southwestern Indiana. These clastic limestones appear to be best developed in an area that includes western Pike County, eastern Gibson County, and northern Warrick County. Lithologically these limestones resemble the Salem, but the predominance of clastic limestone fragments rather than fossil detritus, their association with the brown finely granular dense limestone and evaporite units of the lower St. Louis, and occurrence of *Millerella*, a foraminifer associated with the St. Louis, are distinctive.

LOWER BOUNDARY

The lower boundary of the Salem limestone is not as distinct at many places as the upper boundary, and thus some question exists concerning the location of the Harrodsburg-Salem contact.

The upper Harrodsburg is typically a relatively pure light tan-gray medium- to coarse-grained fragmental limestone. Fragments of large crinoid columnals and fenestellid bryozoan remains are abundant, and bryozoan coquinas are present locally at the top of the formation. An exceptionally good bryozoan coquina can be observed on outcrop at the quarry of the Lehigh Portland Cement Co. in the S½ sec. 30, T. 4 N., R. 1 E., about 2 miles northeast of Mitchell, Ind. White or dark-gray and white mottled secondary chert may be present at the top of the Harrodsburg limestone, but it is most common in the middle and lower parts of the formation. South of T. 1 N., medium-gray granular argillaceous limestone or calcareous siltstone is present near the top of the Harrodsburg, and the crinoidal limestone commonly is embedded in a medium-gray argillaceous matrix.

The Salem at its contact with the Harrodsburg varies in lithology. Either the gray-tan medium- to coarse-grained calcarenite or tan granular dolomitic limestone with carbonaceous laminae may rest on Harrodsburg limestone. These two lithologic types of the Salem appear irregularly. Plate 5 shows the Salem lithologic types present on top of the Harrodsburg throughout the areal extent of the Salem in Indiana. Where the granular dolomitic limestone lies at the base of the Salem, the contact can be picked with some certainty.

The Harrodsburg-Salem contact is somewhat vague in most places in areas where the fossil-fragmental limestone is at the base of the Salem. This lower foraminiferal limestone unit may be in part lithologically similar to both Salem and Harrodsburg limestones. The lithology may be explained as transitional. In these areas mentioned above, deposition was continuous from Harrodsburg into Salem time. The Salem type of clastic sediments was introduced during the late stages of Harrodsburg deposition or possibly in part during a postdepositional reworking of Harrodsburg sediments before diagenesis. The result was a mixture of the two types of sediments which resembles either or both of the clastic units in varying degree depending on the intensity of accumulation of either lithologic type. This transition unit is most pronounced in northern Owen County, Putnam County, and eastern Parke County. In this area, which probably was near the ancient shoreline, the total Salem formation appears to be composed of the transition sediments. *Endothyra* is rather uncommon in these transition sediments, but *Straparollus* is relatively more abundant in the Salem than in the Harrodsburg and thus may be used as a guide fossil.

The Harrodsburg-Salem contact also appears to be transitional in southern Indiana, where most of the Salem is finely granular dense argillaceous limestone. Just below the base of this argillaceous unit, however, local concentrations of medium- to coarse-grained fossil-fragmental Salem limestone, averaging only a few feet thick, grade downward into the Harrodsburg limestone. Because this unit is so thin and laterally discontinuous, and because the finely granular dense argillaceous limestone is a readily recognizable unit, the Harrodsburg-Salem contact may be conveniently placed at the contact of the fossil-fragmental limestone and the finely granular argillaceous limestone.

North of the two southern tiers of counties in southwestern Indiana, the transition sediments are included in the Salem on the assumption that introduction of a new sediment, coincidental with the introduction of a new fauna, indicates a change in environment of deposition.

RESULTS OF SPECTROGRAPHIC AND CHEMICAL ANALYSES

Spectrographic and chemical analyses of a few selected samples of the Salem and the upper Harrodsburg were made (see table 1) in an attempt to determine whether a difference in chemical composition might aid in identifying these formations. A variation in percentage of trace elements should be apparent in sediments from different environments.

The percentage of phosphorus was determined chemically, and the other constituents of the samples were determined spectro-

Table 1.—*Analyses of samples of Salem and upper Harrodsburg limestones*
[Determinations by Geochemistry Section, Indiana Geological Survey]

Name and location of well	Formation	Sample interval (feet)	$CaCO_3$ (pct.)	$MgCO_3$ (pct.)	SiO_2 (pct.)	Al_2O_3 (pct.)	Fe_2O_3 (pct.)	TiO_2 (pct.)	MnO (pct.)	P_2O_5 (pct.)
H. H. Kime No. 1 Mace, sec. 30, T. 16 N., R. 9 W.	Salem	570-575	78.1	6.48	11.9	1.55	0.86	0.086	0.919	0.051
	Salem	575-595	78.0	10.1	8.35	1.62	0.76	0.083	0.018	0.072
	Salem	595-605	82.6	2.89	11.3	1.01	1.05	0.071	0.016	0.082
	Harrodsburg	605-615	68.2	13.2	13.8	2.48	1.19	0.14	0.019	0.064
Lucht and Simpson No. 1 Fischer, sec. 23, T. 11 N., R. 6 W.	Salem	508-600	64.2	24.3	8.86	0.81	0.83	0.061	0.018	0.027
	Salem	600-620	94.3	2.89	1.67	0.19	0.43		0.0094	0.023
	Salem	620-630	78.3	16.6	3.52	0.45	0.56	0.041	0.015	0.037
	Harrodsburg	630-660	92.2	2.37	3.73	0.43	0.74	0.042	0.017	0.055
Morgan No. 1 Jeffers, sec. 16, T. 6 N., R. 6 W.	Salem	983-992	67.8	26.6	4.15	0.54	0.40	0.058	0.0095	0.008
	Salem	992-1,079	94.4	3.25	1.33	0.15	0.39		*	0.012
	Salem	1,079-1,119	94.7	2.06	2.11	0.15	0.45		0.0016	0.023
	Salem	1,119-1,132	91.5	5.35	2.23	0.15	0.24		*	0.023
	Salem	1,132-1,145	91.7	5.68	1.73	0.16	0.27		*	0.036
	Harrodsburg	1,145-1,215	90.5	4.68	3.48	0.34	0.47		0.013	0.040
Wires and Wires No. 1 McBride, sec 16, T. 4 N., R. 3 W.	Salem	440-465	88.4	6.28	4.08	0.44	0.30	0.042	*	0.005
	Salem	465 495	95.1	2.34	1.74	0.14	0.14		*	0.008
	Salem	495-515	68.6	21.7	7.27	0.89	0.47	0.069	0.0082	0.013
	Salem	515-575	85.6	8.73	4.88	0.20	0.16		*	0.013
	Harrodsburg	575-585	85.8	5.32	7.83	0.21	0.29		0.014	0.027
	Harrodsburg	585-670	92.8	3.10	3.07	0.28	0.22		0.011	0.038
Mulzer Bros. No. 1 Ash, sec. 20, T. 2 S., R. 2 W.	Salem	1,066-1,079	63.0	18.9	14.8	1.70	0.54	0.11	0.0094	0.030
	Salem	1,079-1,090	70.7	9.97	15.0	2.28	0.85	0.16	0.0081	0.036
	Salem	1,090-1,123	93.3	1.97	3.73	0.22	0.25	0.035	0.011	0.031
	Harrodsburg	1,123-1,140	67.8	13.4	15.1	1.25	1.39	0.098	0.013	0.072
Sargent No. 1 McCoy, sec. 10, T. 6 S., R. 4 W.	Salem	1,520-1,550	68.9	9.24	16.1	3.07	1.02	0.12	0.011	0.028
	Salem	1,550-1,560	90.3	2.12	5.96	0.39	0.68	0.045	0.0099	0.034
	Salem	1,560-1,575	93.3	2.03	3.23	0.41	0.48	0.038	0.0093	0.028
	Harrodsburg	1,575-1,595	88.7	2.85	6.79	0.62	0.46	0.051	0.0080	0.032
	Harrodsburg	1,595-1,605	88.9	1.85	8.35	0.19	0.22	0.026	0.0089	0.025

* Trace (less than 0.001 percent).

graphically. The analyses are quantitative and were calculated as percentage of oxide in the final tabulation.

The results of analyses of the major constituents tend to agree with observations obtained from microscopic examination of the samples. The medium- to coarse-grained calcarenites and crinoidal limestones contain a high percentage of calcium carbonate and minor amounts of the other constituents. The presence of chert is indicated by an increased percentage of silica. The dolomitic limestones contain a relatively high percentage of magnesium carbonate. One also should expect relatively high percentages of iron, silica, and alumina in these dolomitic limestones because the rock is argillaceous.

Some variation in the percentage of phosphate in the Salem and Harrodsburg limestones is evident. Many outcrop samples have been analyzed by the Geochemistry Section of the Indiana Geological Survey, and the results of these analyses indicate that the Harrodsburg limestone contains a greater percentage of phosphate than the Salem limestone does in most of the sample localities. Only a few samples from subsurface sections have been analyzed, but the phosphate content of the Harrodsburg from most of these samples is also higher. The increase in the phosphate content of the Harrodsburg is only relative in the subsurface, however, as the amount of phosphate varies from well to well. In areas where the Salem and Harrodsburg limestones are distinctly different in lithology, an increase in phosphate content in the Harrodsburg is indicated. In the vicinity of the northernmost extent of the formations and in the extreme southern part of Indiana, where the Salem and Harrodsburg limestones are similar in lithology, no significant difference in the phosphate content of the two formations is apparent.

The reason for the variation in phosphate content has not been determined. Some types of fossils such as mollusks and bryozoans are reported to contain more phosphorus than others (Vinogradov, 1953, p. 460), but the results of analyses of these fossils are vague and inconclusive; at the present time spectrographic analyses of fossils from the Salem and Harrodsburg limestones have not substantiated the reported variation in the amount of phosphorus. Phosphorus content is greater in deep water than in shallow water because of the dissolution of organic material. This fact does not explain the difference in the percentage of phosphate in the Salem and Harrodsburg limestones, however, because both must have been deposited in relatively shallow seas. Moreover, postdiagenetic leaching or concentration does not appear to explain the difference. Further work may provide a solution to the problem of the variation in phosphate content.

Chemical analyses of the rocks are helpful, but their principal use appears to be in identifying minor constituents and confirming observations made during microscopic examination of samples.

PALEOGEOGRAPHY

A useful tool in interpreting geologic phenomena that has been emphasized in recent years is the lithofacies map (Krumbein and Sloss, 1951, p. 403-407). In preparing this kind of map the components of a stratigraphic unit are determined and their ratios are plotted on a standard triangular phase diagram with three end members. A variation of the standard lithofacies map was prepared (pl. 3) to show the lithologic phases of the Salem limestone. As the clastic rocks in the Salem are carbonate rocks, and as an attempt was made to emphasize the calcarenite phase, only two end members were used. The map shows the ratio of the medium- to coarse-grained calcarenite and fossil-fragmental limestone to all other lithologic types in the formation. The contours are drawn on the basis of a geometric progression which minimizes marked differences in the higher clastic ratios that might occur by variations of only a few feet in thickness of the components.

Plate 3 shows that, in general, the clastic ratio of the Salem limestone decreases from north to south in Indiana. Instead of progressive regional variations, however, the clastic ratio generally is subject to very pronounced local fluctuation. Areas having local increases in thickness of the Salem almost invariably have an increase in the clastic ratio. Locations of known Silurian reefs coincide with many of these anomalous areas; precise relationships between the location of Silurian reefs and areas having local increases in the thickness of the Salem and accompanying increase in the clastic ratio are not shown on plate 3, however, because the limited well control in this regional study may mask the presence of a reef or cause adjacent reefs to appear on the map as one large reef.

South of the zone in southern Indiana marked by the dash-dot line (pl. 3) the clastic ratio is fairly constant. This fairly constant clastic ratio probably is due to the uniform lithology of the Salem formation over wide areas but may be due, in part at least, to lack of well control.

The clastic ratio is high near the northernmost extent of the Salem limestone. This can be expected if the northern boundary of the formation approximates the ancient shoreline. The sediments would have been sorted, and the almost constant movement of water in the epineritic zone would have tended to carry the fine sediments to deeper water.

An isopleth map (fig. 3) was prepared to show the distribution of *Endothyra* in the Salem in Indiana. The map is based on the average abundance of fossils per unit volume of sediment in the formation. Barren zones as well as fossiliferous zones were included in the calculation of volume. Including barren zones in the calculation reduces apparent abundance of *Endothyra* but directly relates control points to each other rather than to the thickness of a restricted zone. Contour values are based on a simple arithmetic progression, and the isopleth contours pass through points of equal density of *Endothyra*. The percentage of *Endothyra* was generalized in order to reduce the factor of error, inasmuch as the figures are visual estimates rather than actual counts. Methods of drilling and of collecting and processing samples may either reduce or increase the number of *Endothyra* per sample; therefore generalizations probably give a truer representation of the distribution than a detailed analysis would.

Endothyra is common to abundant in the area between an irregular line extending from T. 12 N. in Vigo County eastward to about T. 10 N. in Monroe County and an east-west line that passes through T. 2 S. *Endothyra* also is found locally north and south of these two limits; in fact, some *Endothyra* is present throughout the areal extent of the Salem.

The area between T. 2 S. and T. 10 N., the downdip equivalent of that area in which the building stone is present on outcrop, has the greatest concentration of *Endothyra*. Good Salem building stone may be directly related to the abundance of *Endothyra*. The building stone is essentially a well-sorted porous sandstone in which the grains consist to a large extent of *Endothyra* tests. Because of porosity, the rock absorbs heat and cold with no noticeable amount of expansion or contraction, thereby withstanding climatic changes for many years. North of T. 10 N. and south of T. 2 S., the characteristics which constitute desirable building stone have disappeared, and in these areas of Indiana, Salem lithology is similar to Harrodsburg lithology.

Some conditions of environment during Salem time are evident from a study of the Salem. Calcium salts must have been concen-

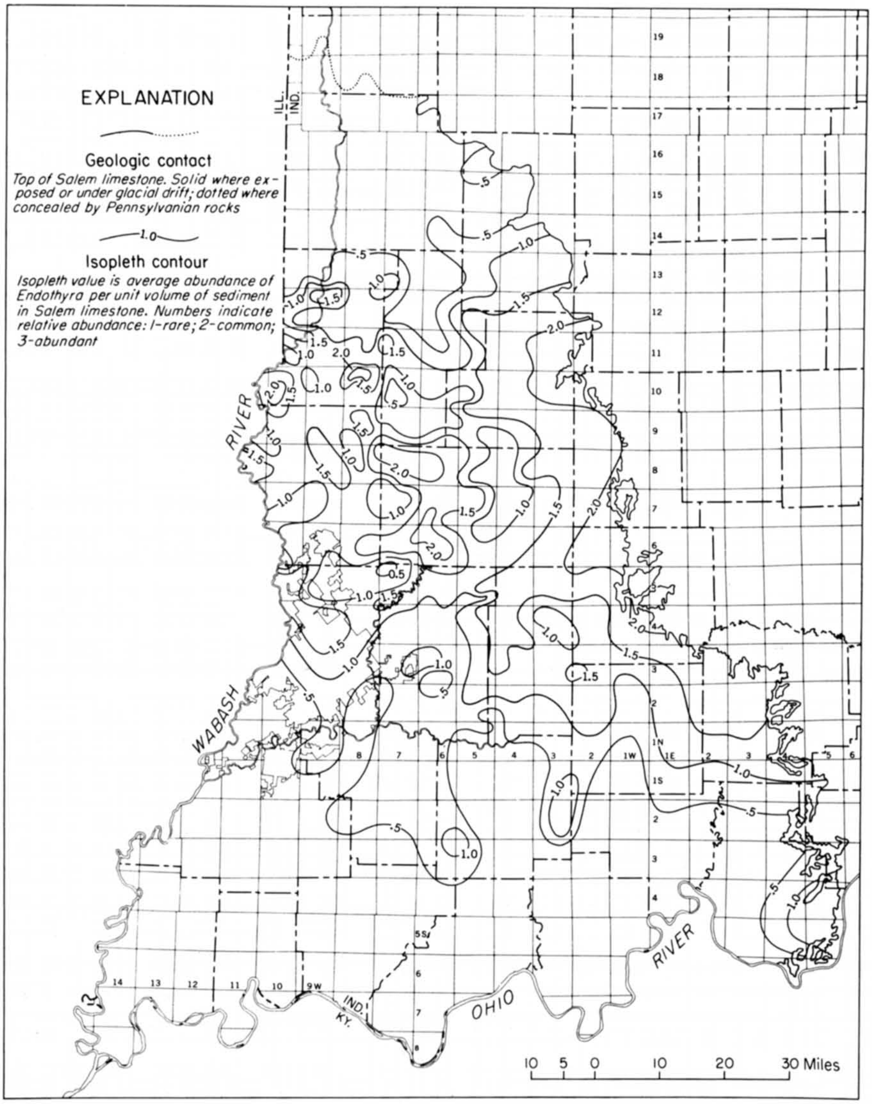


Figure 3.—Isopleth map showing relative abundance of *Endothyra baileyi* in the Salem limestone of southwestern Indiana.

trated to supply the calcium needed by the prolific fauna that thrived at the time. That forelands had to be predominantly calcareous to supply a source of the salts and were low is indicated by the sparsity of stable clastic minerals in the Salem limestone. Water had to be warm to keep a high concentration of calcium salts in solution and must have been deep enough so that the sea floor was essentially below wave base. A sea floor below wave base does not necessitate exceptionally deep water, because if the entire sea were relatively shallow, as would be expected in an epicontinental sea, maximum wave base would not be deep. Turbidity of the water during extended periods of time would disintegrate such fragile organisms as *Endothyra* and could not sustain the living fauna. The water was clear and shallow enough, however, for photosynthesis to take place.

A study of the maps illustrating various aspects of the Salem limestone does not suggest that typical Salem limestone was deposited as a large bank or purely as a series of bars. No regional trends or suggestions of that sort of deposition are apparent in any of the maps or map combinations. Perhaps, if it were possible to pick a rock unit within the Salem throughout the area of Salem occurrence which represented a very restricted time interval, an accumulation pattern might be evident.

In an area similar to Rich's "unda" environment (1951, p. 4), but in which seas were somewhat more quiescent, possibly because they were restricted, the fauna consisting predominantly of *Endothyra* thrived. Such was the area between T. 10 N. and T. 2 S., and it is roughly the one in which the Silurian reefs are found. Comparison between the area of calcarenite deposition and that of reef occurrence can be made, however, only because basin-shoreline relationships during Meramec and during Niagaran (Late Silurian) time were similar.

The physical environment affecting Salem deposition would be a relatively flat sea floor with scattered positive elements. The tests of the protozoans contained sealed air chambers which gave them some bouyancy. Mild currents and water movement shifted and transported the fragile tests with relative ease, and buffeting was reduced somewhat by the water layer surrounding each of them. Deposition would have taken place where the load, because of cessation of water movement or change in current direction, could no longer be supported or moved. The flank of any positive element would act as a barrier to water movement. Loads piled on the sea floor because of a local change in physical conditions would at some later time act as a barrier, however slight, to the shifting of clastic sediments. A phenomenon such as this would cause the irregularity and discontinuity in bedding.

Even though the tests were protected from one another to some extent, transportation over any great distance or shifting for an extended period of time would cause at least partial disintegration of the fragile tests. The fine-grained detrital limestones are composed in large part of disintegrated tests which have been transported a great distance or which have been subjected to pronounced turbidity of the water.

It is reasonable for the Salem limestone to exhibit characteristics such as crossbedding, lenticularity, change in sorting from bed to bed, and other irregularities peculiar to clastic deposits because it was deposited as a sandstone differing only in composition of individual grains from any similar quartz sandstone.

When a critical depth was reached above which the water was too shallow, wave action and longshore currents disintegrated fragile tests which had been transported into the area. Such is the area north of northern Vigo County, northern Clay County, and northern Owen County; it is the epineritic environment in which only faunas hardier than *Endothyra* could survive.

The physical environment was different toward the deeper part of the depositional basin. Water was quieter because of an increase in depth. Fine argillaceous sediments settled out of suspension and in combination with deeper water created an adverse environment in which the fauna comprising most of the Salem limestone could not exist. The clastic sediments in this environment, except for local accumulations, were transported into the area; they consist largely of medium- to coarse-grained calcarenite and fine-grained detrital limestone interbedded with argillaceous sediments. The area south of T. 2 S. could be classed broadly in Rich's "clino" environment (the part of a basin below wave base) (1951, p. 6-9).

OIL PRODUCTION FROM THE SALEM LIMESTONE

LOCATION

The Salem limestone is an oil reservoir in the subsurface of the Illinois Basin, but only a small number of fields produce oil from the formation. In Indiana, all or part of the reported production from 11 oil fields has come from the Salem limestone. The Carlisle field in sec. 17, T. 6 N., R. 9 W., Sullivan County, had an initial production of 4 barrels of oil per hour from a single Salem well. This field is not active at the present time.

Salem production has been reported from the Lysle field in sec. 1, T. 2 S., R. 12 W., and from the adjacent part of the Owensville North field in secs. 11 and 12, T. 2 S., R. 12 W., Gibson County. The oil reported as from the Salem in these two fields is actually produced from the lower St. Louis. The reservoir is the downdip equivalent of the stratigraphic unit in which gypsum and anhydrite are found. The St. Louis production is from 2 reservoirs in different stratigraphic positions; they are about 100 and 160 feet above the base of the lower St. Louis limestone. The reservoirs are well-developed somewhat restricted oolitic limestones in which individual oolites have been formed around dark-brown dense limestone nuclei. Porosity is high as the interstices are not filled. The porosity is restricted areally, however, because the same unit in adjacent areas is dense. The development of oolites helps substantiate the belief that the lower St. Louis is a shallow-water sediment deposited in an environment of fluctuating sea level.

Salem oil production has been reported from the Troy field along the Ohio River at the Perry County and Spencer County boundary, but the oil appears to be from the Harrodsburg limestone just below the Harrodsburg-Salem contact. The reservoir rock contains abundant fenestellid bryozoan remains and may be a bryozoan coquina. Oil is present in a similar geologic setting in T. 3 S., R. 3 W., Perry and Dubois Counties, and in survey 5, T. 1 N., R. 9 W., Pike County.

Table 2 lists the oil fields in Indiana in which at least part of the oil produced during 1955 was from the Salem limestone. Average daily production from the Salem is not as great as that from some other reservoirs. A well drilled in the Salem may have an initial production of as much as 100 barrels per day, but the average production decreases quickly to something less than 20 barrels per day. Reports of minor shows of oil from the Salem limestone are common, and shows probably are more common than reports indicate. The character of the reservoir rock apparently is not conducive to retention of traces of oil. Oil tends to be washed from the smooth, loosely cemented grains by drilling mud before the cuttings reach the surface.

All oil production from the Salem in Indiana is in an area that may be classified broadly as a shelf. Oil was not formed in the near-shore (epineritic) environment. In the southern two tiers of counties in Indiana, where the Salem was deposited in relatively deep water, the dominant type of lithology is finely granular dense argillaceous limestone (pl. 3). Salem oil has not been found in the area in which this lithology is present. The Siberia field produces from the Salem, but it is on the fringe where the dark-gray dense argillaceous limestone is not fully developed. Conditions apparently were not conducive to formation, or at least to the accumulation, of

Table 2.—*Oil fields in Indiana producing from the Salem limestone during 1955*

No. shown on plate 5	Field	County	Location			Depth to production (feet)	Producing thickness (feet)	Type of Accumulation
			Sec.	Tp.	R.			
1	Alfordsville South	Daviess	11	1 N	5 W	975	5	Porous lens of calcarenite
2	Siberia	Dubois	15	3 S	3 W	1,172	8	Porous lens of calcarenite
3	Carlisle (abandoned)	Sullivan	17	6 N	9 W	1,720	7	Porous lens of calcarenite
4	Dodds Bridge	Sullivan	3, 4, 8, 9, 10	8 N	10 W	1,433	22	Closure due to compaction associated with Silurian reef
5	Elnora	Daviess	33, 34, 35	5 N	6 W	1,095	7	Porous lens of calcarenite
			4	4 N	6 W			
6	Graysville	Sullivan	19, 30	8 N	10 W	1,754	6	Porous lens of calcarenite
7	Montgomery	Daviess	16	3 N	6 W	1,210	20	Closure due to compaction associated with Silurian reef
8	Oaktown (deep)	Knox and Sullivan	1, 2, 10, 11, 12, 13	5 N	10 W	1,870	3	Porous lens of calcarenite
			7, 18	5 N	9 W			
9	Odon East	Daviess	21, 22, 23, 26, 27	5 N	5 W	855	7	Porous lens of calcarenite
10	Prairie Creek	Vigo	9, 10, 15, 16	10 N	10 W	1,262	20	Closure due to compaction associated with Silurian reef
11	Washington	Daviess	12, 13	3 N	7 W	1,388	8	Closure due to compaction associated with Silurian reef

oil in that part of the basin which included the extreme southwestern part of Indiana. This area may not be completely devoid of Salem oil, for some of the rocks contain traces of hydrocarbons. From available data, however, the generalization can be made that conditions were not favorable in the extreme southwestern part of Indiana for the accumulation of oil in the Salem limestone; certainly reservoir conditions in the Salem are poor in this area.

GEOLOGIC SETTING OF THE OIL

An inspection of all fields that are producing oil from the Salem limestone discloses a marked similarity in their geologic setting. All known commercial accumulations of Salem oil are within the upper few feet of the medium- to coarse-grained calcarenite. Traces of oil are found in the finely granular dolomitic limestone in some places where it overlies the calcarenite, but these occurrences of oil are noncommercial.

The lithologic difference between the medium- to coarse-grained calcarenite in the upper half of the Salem formation and the fossil-fragmental limestone in the lower half has been described. (See p. 36.) Formation of petroleum in the calcarenite rather than in the lower fossil-fragmental limestone may be explained in part by the fact that the upper calcarenite appears to contain a diminutive fauna, whereas the fossil-fragmental limestone contains reworked fragments of larger organisms, which indicate more aerated and turbulent water and an oxidizing environment not conducive to the preservation of organic matter.

If the well-preserved tests in the upper calcarenite were deposited in essentially the same environment in which they lived, the organic material could have been concentrated and preserved if it was subjected to reducing conditions. Even though carbon dioxide, a major factor in creating oxidizing conditions, was generated by decaying organic material, the living organisms would use some carbon dioxide, and some of it would escape into the atmosphere because warm water with relatively low pressure is unable to retain large quantities of carbon dioxide in solution. Abundant carbon dioxide would form weak carbonic acid that would tend to cause dissolution of the deposited calcite tests as well as to help to create an oxidizing environment. Of course, conditions suitable for the formation of petroleum could not have been universal. Variations in depth, temperature, currents, proximity to shore, and sources of sediment would have caused at least minor changes in the composition of water and therefore in the environment of deposition. Nevertheless, the formation of petroleum was probably widespread rather than localized, and as a result, small quantities of oil were present originally over wide areas in the shelf (infraneritic) area.

STRUCTURAL INFLUENCE

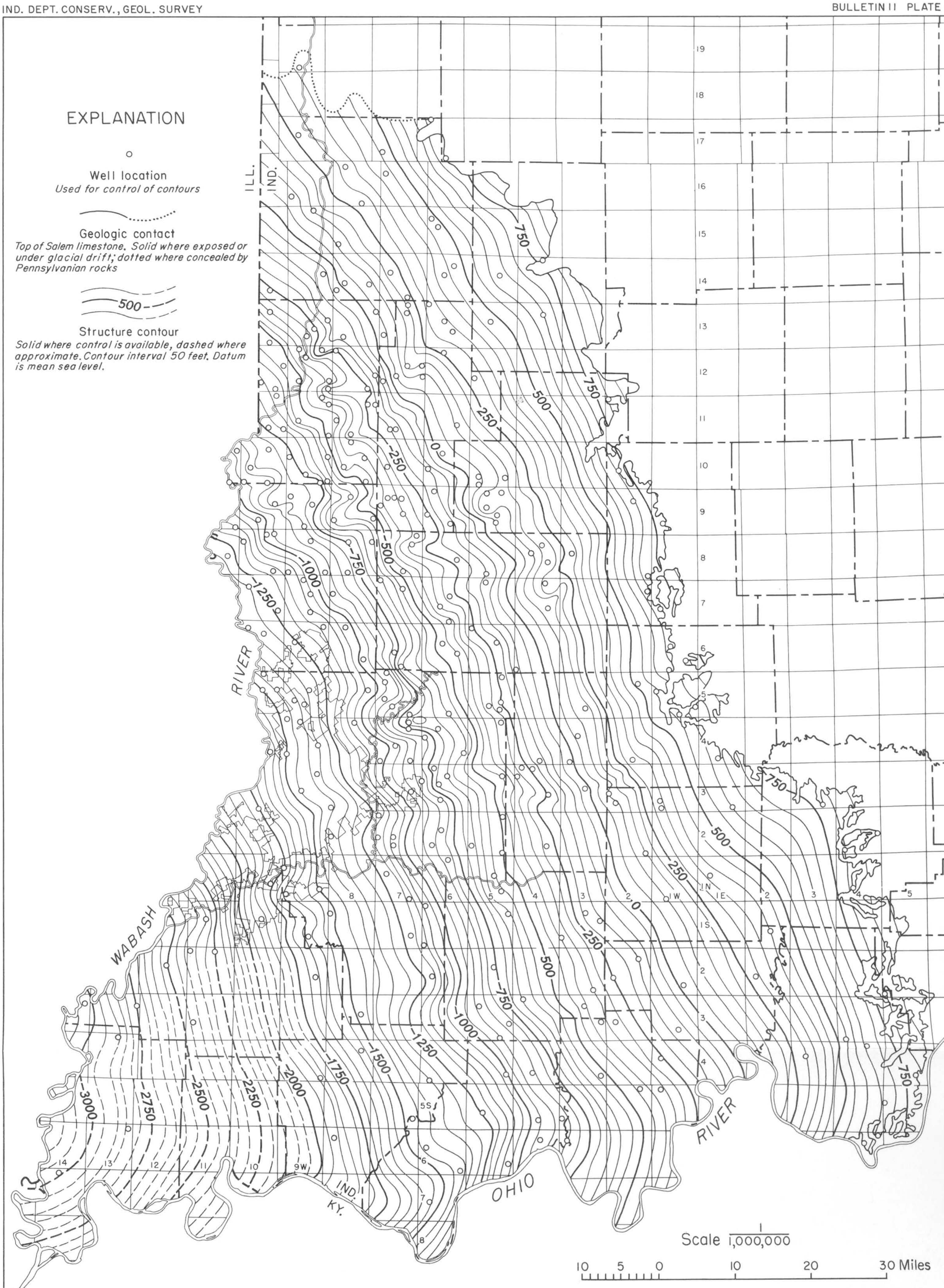
Observations indicate that the accumulation of oil in the Salem limestone is controlled by structural closure on the upper medium- to coarse-grained calcarenite. Structures at the top of the formation are reflections of Silurian reefs, a result of differential accumulation of sediments, and a result of tectonic changes that occurred after deposition of the formation. Differential accumulation of the sediments can be attributed to changes in the environment of deposition and also to topographic features that existed on the floor of the depositional basin.

Plate 4 is a structure map drawn on top of the Salem limestone. It exhibits no anomalous regional structures or trends. It is drawn on top of the formation rather than on the distinctive medium- to coarse-grained calcarenite near the top, as structure drawn on the calcarenite unit would not depict true structure on top of the formation. Because much of the area, especially the southwest corner of the State, lacks any sort of detailed control, structure has been generalized. The dip is rather uniform to the west-southwest. Regional strike is fairly uniform and is somewhat arcuate around the Illinois Basin. In most of southwestern Indiana the strike trends northwestward-southeastward, but at the south edge of Indiana it changes sharply to north-south. The change in direction of the strike was influenced by the Nashville dome, which lies on the south side of the Illinois Basin.

Faults are not indicated on the structure map, as well control is limited in the extreme southern part of Indiana, the area where faulting is known to occur. A change in strike is indicated in western Washington County where the Mt. Carmel fault is located, but subsurface control is not detailed enough to indicate the fault.

The area between T. 2 N. and T. 14 N. exhibits the most anomalous structure. The most pronounced local structural anomalies coincide with the Silurian reefs, the structure being induced primarily by differential compaction in the Silurian. Some of the minor highs may reflect bioherms in the Borden group.

Figures 4, 5, 6, 7, and 8 are structure maps of the Montgomery and Odon East oil fields, which are typical of Salem oil fields in Indiana. (See table 2 and plate 5 for the location of these fields.)



Base modified from U.S. Geological Survey, Map of Indiana, 1950.

MAP OF SOUTHWESTERN INDIANA SHOWING STRUCTURE ON TOP OF SALEM LIMESTONE

Geologic contact modified from Geological Map of Indiana (1932)

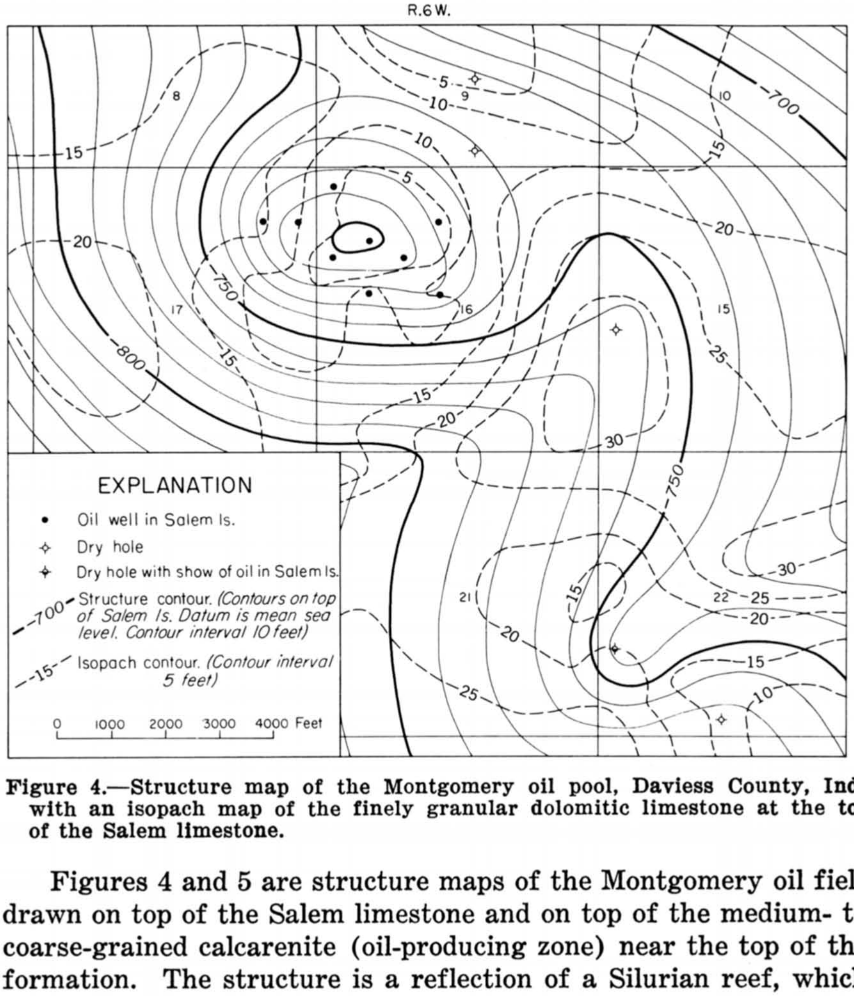


Figure 4.—Structure map of the Montgomery oil pool, Daviess County, Ind., with an isopach map of the finely granular dolomitic limestone at the top of the Salem limestone.

Figures 4 and 5 are structure maps of the Montgomery oil field drawn on top of the Salem limestone and on top of the medium- to coarse-grained calcarenite (oil-producing zone) near the top of the formation. The structure is a reflection of a Silurian reef, which is well defined by the concentric structure on the Salem limestone. The oil has accumulated at the crest of the structure, and the thickest producing intervals are at the apex. The closure is more pronounced in figure 5 than in figure 4 because the finely granular dolomitic limestone and fine-grained detrital limestone on top of the calcarenite thicken away from the apex of the positive structure.

Figures 6 and 7 are structure maps of the Odon East field drawn on top of the Salem limestone and on top of the oil-producing zone near the top of the formation. The structure in this field is due to a localized accumulation of medium- to coarse-grained calcarenite within the formation. The accumulation has the charac-

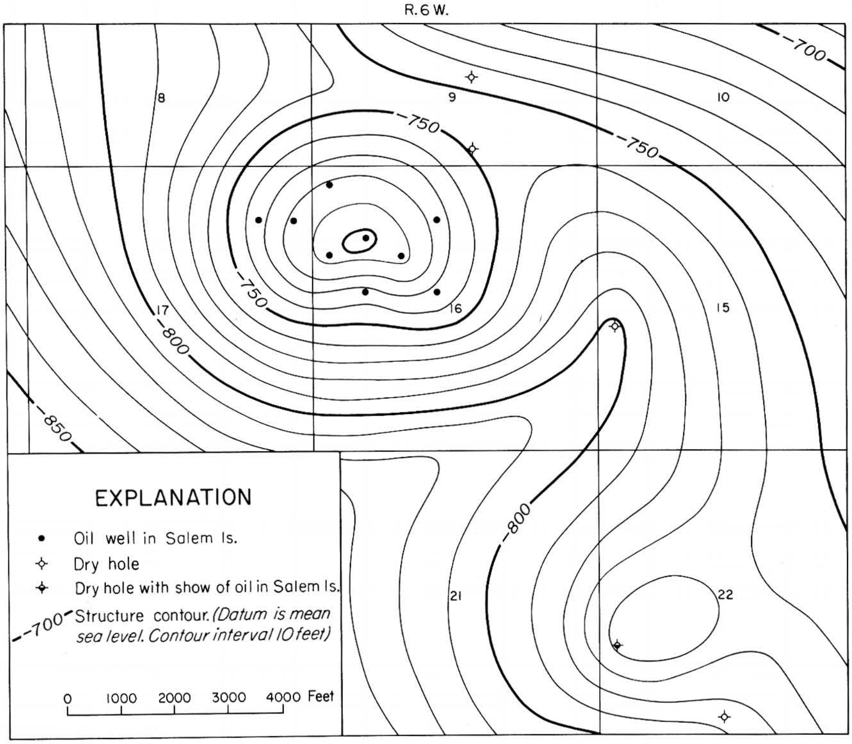


Figure 5.—Structure map on top of the calcarenite (oil-producing interval) in the Salem limestone, Montgomery oil pool.

teristics of two coalesced sand bars. In this pool, as in the Montgomery pool, closure is not as great on the top of the formation as on the oil-producing calcarenite because the finely granular dolomitic limestone at the top of the formation thickens away from the axis of the structure.

The oil reservoir in the Odon East pool is structurally higher on the east flank than on the west flank. This phenomenon can be reasonably explained by reconstructing the original conditions of sedimentation and accumulation, that is, by removing the present regional dip. (See figure 8.) The migrating oil was trapped in the high parts of this bar. If the water underlying the oil caused some solution and redeposition of calcite, or if calcite was precipitated out of solution in the pore spaces, the permeability of the rock below the oil would have been reduced. When the trap was tilted to the southwest to conform with the present structural pattern of the Illinois Basin, the secondary calcite which had filled pore space below the oil prevented further migration of

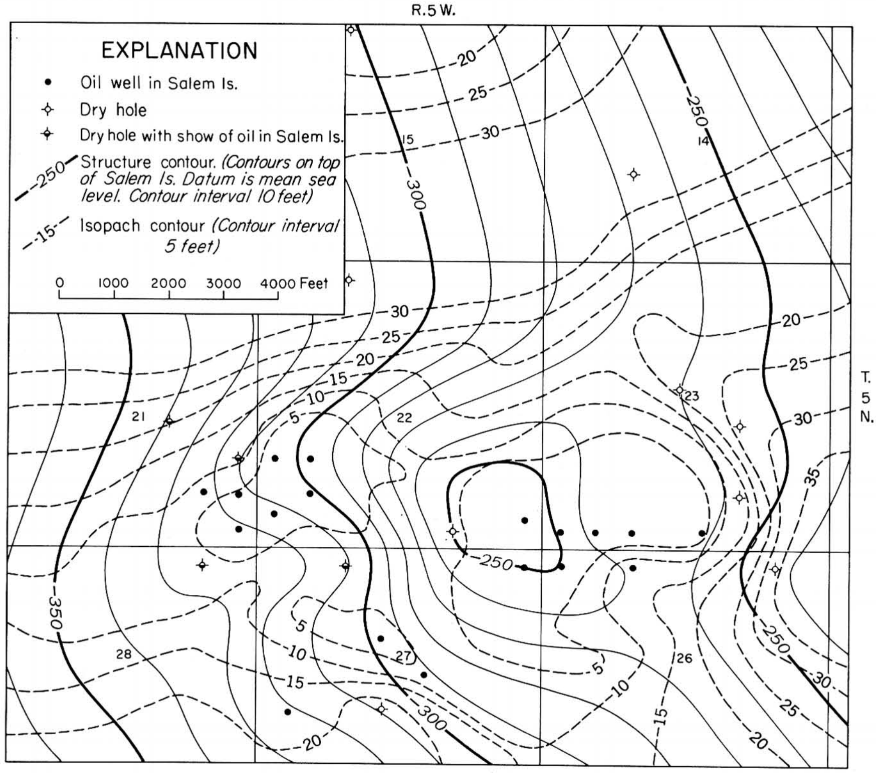


Figure 6.—Structure map of the Odon East oil pool, Daviess County, Ind., with an isopach map of the finely granular dolomitic limestone at the top of the Salem limestone.

the oil updip and formed a secondary stratigraphic trap. This reasoning leads to the conclusion that the oil accumulated before the present structure was imposed on the basin.

Some characteristics of the Salem limestone where it has been deposited over a buried structure, such as a reef, are similar to those where the structure is developed within the formation. The distribution of the finely granular dolomitic limestone at the top of the formation is the same in both types of structure. Other characteristics of the Salem differ markedly according to the mode of development, although the mode of oil accumulation is the same. The most obvious change in sedimentation where the Salem has been deposited over the topographic reflection of a reef occurs in the fossil-fragmental limestone near the base of the formation, whereas the greatest change in sedimentation where structure is developed within the formation occurs in the calcarenite

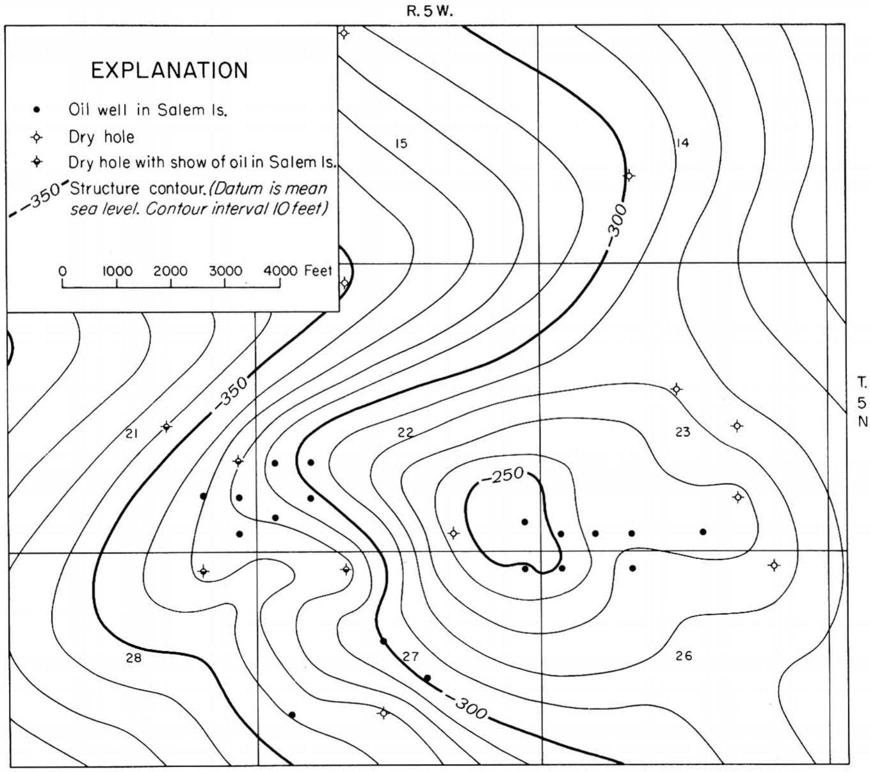
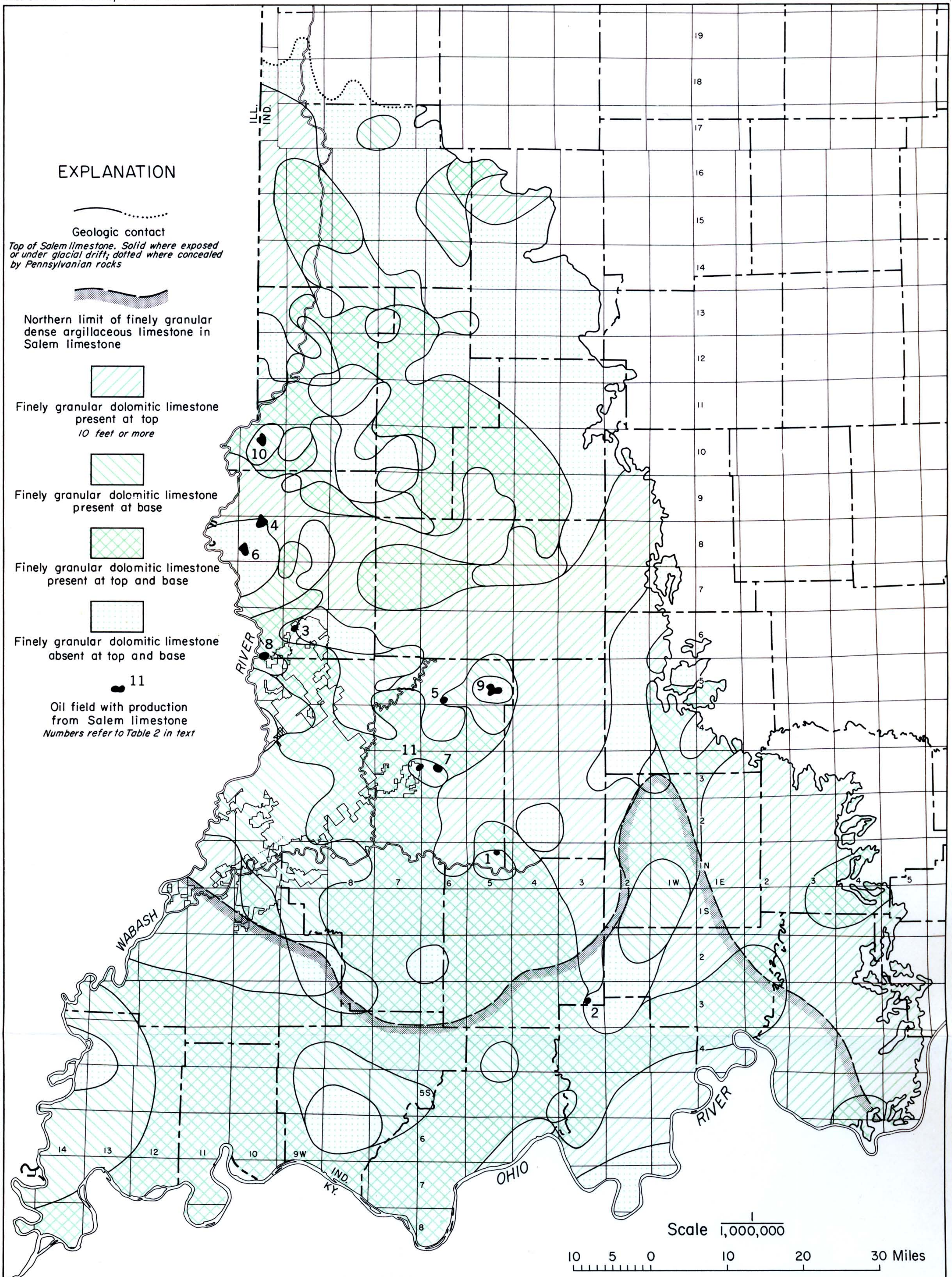


Figure 7.—Structure map on top of the calcarenite (oil-producing interval) in the Salem limestone, Odon East oil pool.

near the top of the formation. The fossil-fragmental limestone grades to fine-grained argillaceous sediment where it has been deposited over a reef reflection, but the upper calcarenite unit maintains essentially the same character, although it does thin over the apex. Where structure is developed within the formation, however, the fossil-fragmental limestone has a fairly constant thickness, but the calcarenite unit near the top of the formation increases very markedly in thickness.

Plate 5 shows the distribution of the upper and lower finely granular argillaceous dolomitic limestone units in Indiana. The units are divided into 2 groups on the basis of thickness: those greater than 10 feet and those 10 feet or less. The Salem lithology varies laterally over short distances. Plate 5 is generalized because of the lack of dense well control. Detailed control would give a more intricate pattern and undoubtedly would indicate more



Base modified from U.S. Geological Survey, Map of Indiana, 1950.

MAP OF SOUTHWESTERN INDIANA SHOWING AREAL DISTRIBUTION OF FINELY GRANULAR DOLOMITIC LIMESTONE AT TOP AND BASE OF SALEM LIMESTONE AND LOCATION OF OIL POOLS PRODUCING FROM SALEM

Geologic contact modified from Geological Map of Indiana (1932)

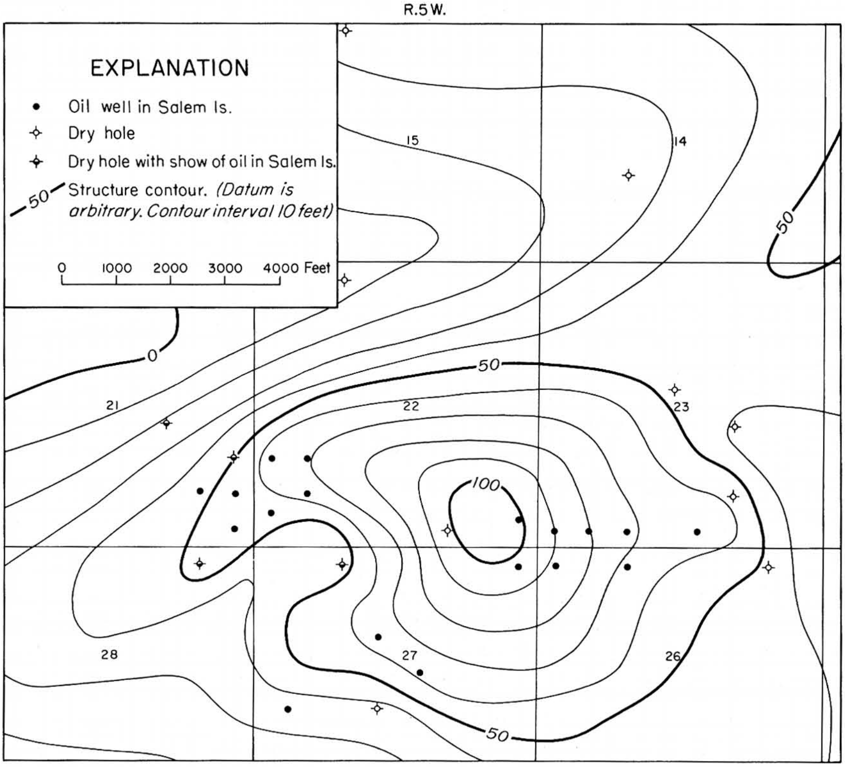


Figure 8.—Restored structure map on top of the calcarenite in the Salem limestone, Odon East oil pool.

areas in which the upper and lower dolomitic limestone units are less than 10 feet thick.

Most of the oil fields presently producing from the Salem limestone coincide with the areas on the map (pl. 5) in which the uppermost dolomitic limestone unit is absent or less than 10 feet thick. The exception is the now abandoned Carlisle pool. (See p. 48.) The uppermost dolomitic limestone unit in this pool, however, is only 11 to 15 feet thick.

The thinning of the uppermost dolomitic limestone unit is a result rather than a cause. Where the medium- to coarse-grained calcarenite is structurally high, the finely granular dolomitic limestone is relatively thin. The two units are complementary. A thin upper dolomitic limestone unit is thus a useful criterion in exploring for Salem oil because it generally indicates a structural high, whether structure is internal or imposed, in the upper calcarenite unit.

SUMMARY

The Meramec series in Indiana is composed of a sequence of intimately related limestones which may attain a thickness of nearly 1,000 feet. The series has been subdivided into formations, the boundaries of which have resulted in considerable disagreement among geologists from time to time. Formational boundaries have been redefined many times since they were first established. Contacts may be well defined in a specific area but are difficult to recognize when projected throughout the Illinois Basin.

The Borden group (Osage) underlies the Meramec series and is composed predominantly of laterally discontinuous lenses of siltstone and shale. These sediments appear to have been transported from the northeast. As the siltstones are traced southward from Putnam and Montgomery Counties, they become very fine-grained and apparently reach a limit of transport in Sullivan County and in the southwesternmost two tiers of counties in Indiana, where they grade into crinoidal limestone. The limestone facies in southwestern Indiana probably is equivalent to the Fort Payne chert. The lower Harrodsburg, a silty and cherty crinoidal limestone that is lithologically the same as the limestones in the Borden group, cannot be differentiated from the Borden group throughout much of its areal extent in Indiana. This very intimate association is excellent evidence for including the lower Harrodsburg in the Osage series.

A change in lithology is apparent between the lower and upper Harrodsburg limestones. The lower member is transitional into the top of the Borden group, whereas the upper member of the formation, a light-gray crinoidal limestone commonly containing fenestellid bryozoans, is transitional locally into the Salem limestone. Environment during upper Harrodsburg deposition was not very different from that during Salem deposition.

The lower St. Louis limestone is almost wholly a shallow-water cyclic deposit of gypsum and anhydrite and carbonaceous limestones; however, in Pike and Gibson Counties there is a locally developed oil-bearing oolitic limestone which is a facies equivalent of the evaporite units. Brown crystalline fragmental locally oolitic limestone is present at the top of the lower St. Louis; this distinctive and easily recognized unit probably was exposed locally to weathering after deposition. A change in depositional environment from the lower to the upper St. Louis is apparent. The upper St. Louis is composed principally of easily recognized cherty limestones and dolomites. Crystalline oolitic to pseudo-oolitic limestone is present at the top of the cherty limestone and is transitional into the overlying Ste. Genevieve limestone. A contact cannot always be picked accurately. In the subsurface the top of the St. Louis is usually placed at the top of the cherty limestone. This easily recognized unit lies in most places within 20 feet of the St. Louis-Ste. Genevieve contact.

The Ste. Genevieve limestone is composed predominantly of shallow-water clastic limestone. Quartz and limestone sand, shale, and fine-grained dense limestones are commonly present in the upper part of the formation.

Deposits in the Meramec series of the extreme southern part of Indiana, contrasted with the extensive shelf-type deposits to the north, exhibit a marked increase in thickness and a change from shelf- to basin-type lithology within a few miles of their outcrop. These are indications that the Meramec rocks have been eroded farther basinward in southern Indiana than they have to the north, or that shelf-type deposition was not as extensive in this area during early and middle Mississippian time as it was farther north.

The Salem limestone has become widely known because of its peculiar diminutive fauna and because of its extensive use as a building stone. It is easily recognized in the building stone district which extends from Washington County into Owen County, Ind., as this is the area in which the formation is typically developed. Except for local occurrences of the characteristic foraminiferal limestone, the formation is recognized with some difficulty in other areas around the fringe of the Illinois Basin.

Deposition of the Salem limestone in Indiana can be classified as belonging to three separate environments. In the northern area of occurrence the formation is a near-shore or epineritic deposit, in the central area it is a shelf or infraneritic deposit, and in the southwestern part of the State the sediments were deposited in deeper water seaward from the shelf. The latter may be considered a basin type of environment, but in so designating it one must bear in mind the meaning of basin in an epicontinental sea. In the area of shelf deposition, which is expressed at the surface in the building stone district, the Salem can be differentiated easily from overlying and underlying limestones. In the area of near-shore deposition, the Harrodsburg and Salem limestones are lithologically very similar and, except for local lenses of calcarenite composed predominantly of *Endothyra,* are virtually inseparable. The basin or seaward facies of the Salem in southwestern Indiana, although it does not resemble the near-shore facies, also loses typical Salem characteristics and is similar to the underlying Harrodsburg limestone. Thus in both the northern area of Salem occurrence and southwestern Indiana, the contact between the upper Harrodsburg and the Salem is vague and transitional. On the basis of regional associations, it is logical to consider the Salem a member of the Harrodsburg, but because of its economic importance, classifying the Salem as a separate formation is favored.

The Salem limestone in the shelf area was deposited in the same manner as a similar quartz sandstone and exhibits all characteristics, such as crossbedding, lenticularity, and bank and bar development, of a well-sorted subareal sandstone. Local structural highs on the formation may be due to deposition over topographic highs, to differential compaction of underlying sediments, or to localized bar development of clastic limestone within the formation.

The oil produced from the Salem limestone in Indiana is restricted to the region of shelf deposition. Environmental conditions north and south of the shelf region apparently were not favorable for oil accumulation. The oil is found in the calcarenite in the upper part of the formation and has accumulated where the calcarenite is both structurally high and encountered within a few feet of the top of the formation. Mode of occurrence of the oil indicates that the rocks were tilted to the southwest after the oil had accumulated.

It is hoped that this report will aid in a better regional understanding of the Salem limestone and that the information which has been presented may be used as a guide to detailed study of specific areas. A comparative study of the data and interpretations given in plates 3, 4, and 5 may help to isolate those areas which warrant a more detailed study of structure and sedimentation.

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GEOLOGICAL SURVEY
CHARLES F. DEISS, STATE GEOLOGIST

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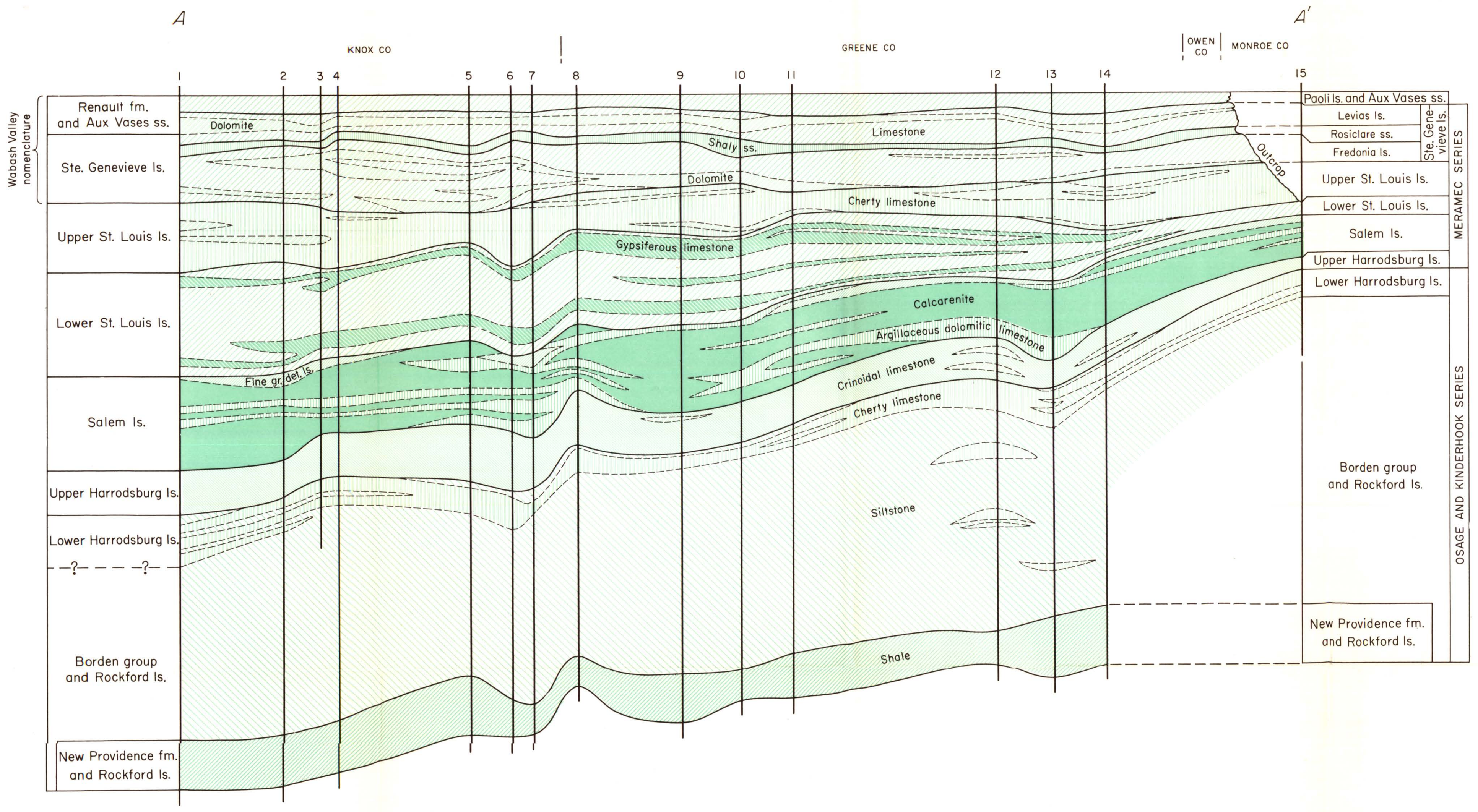
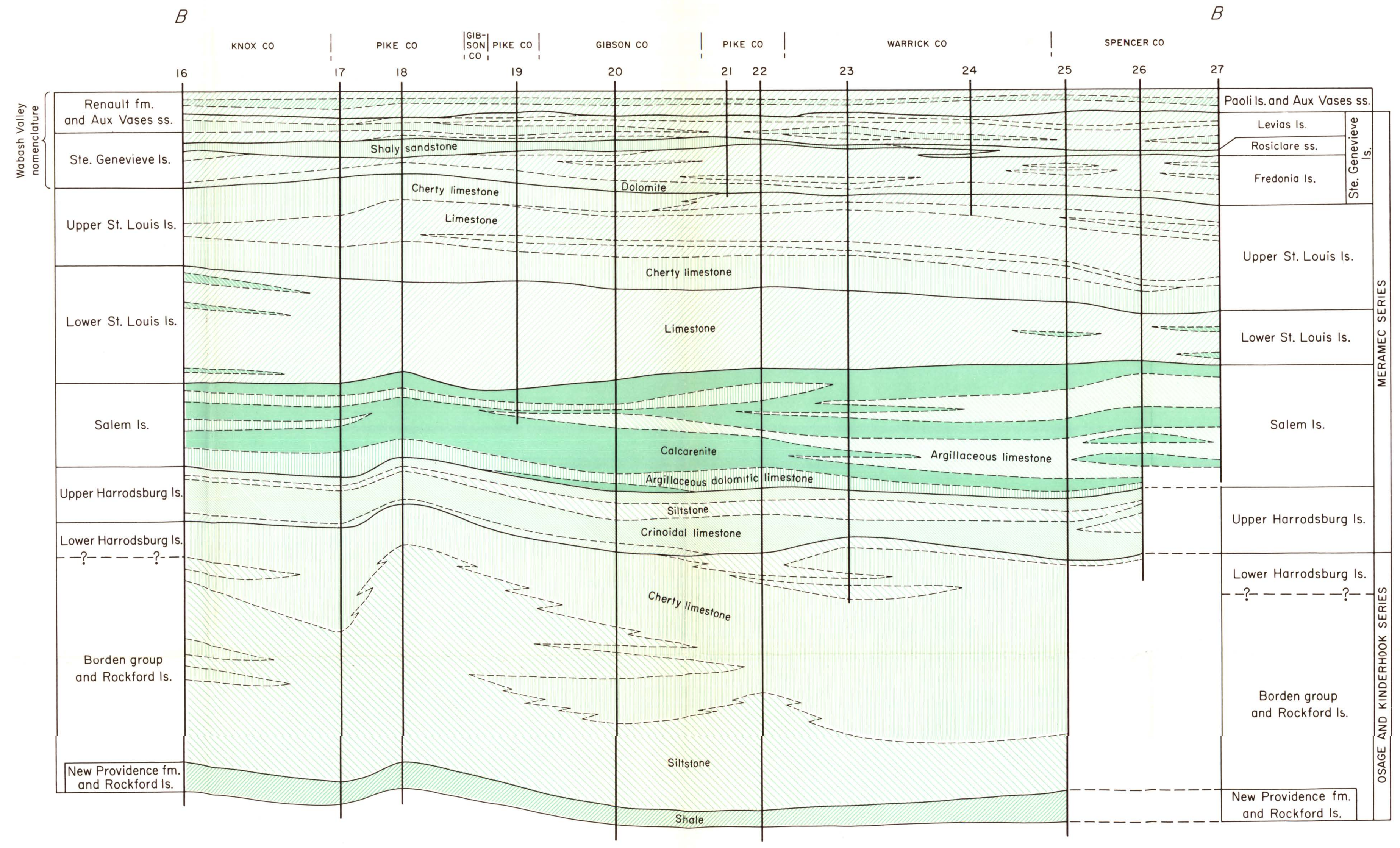
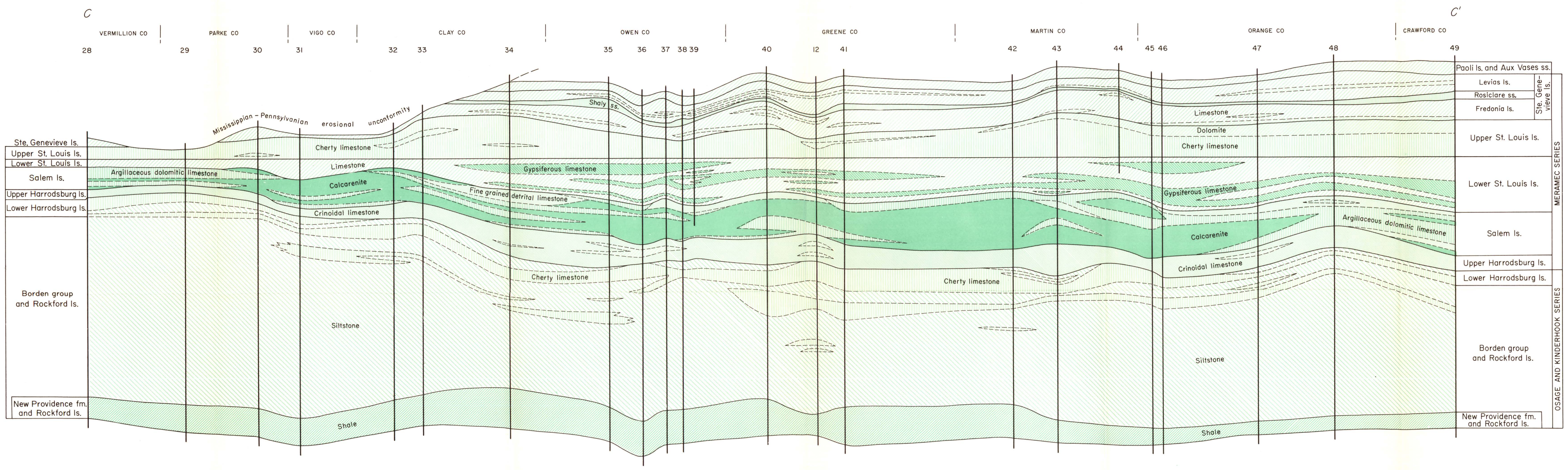
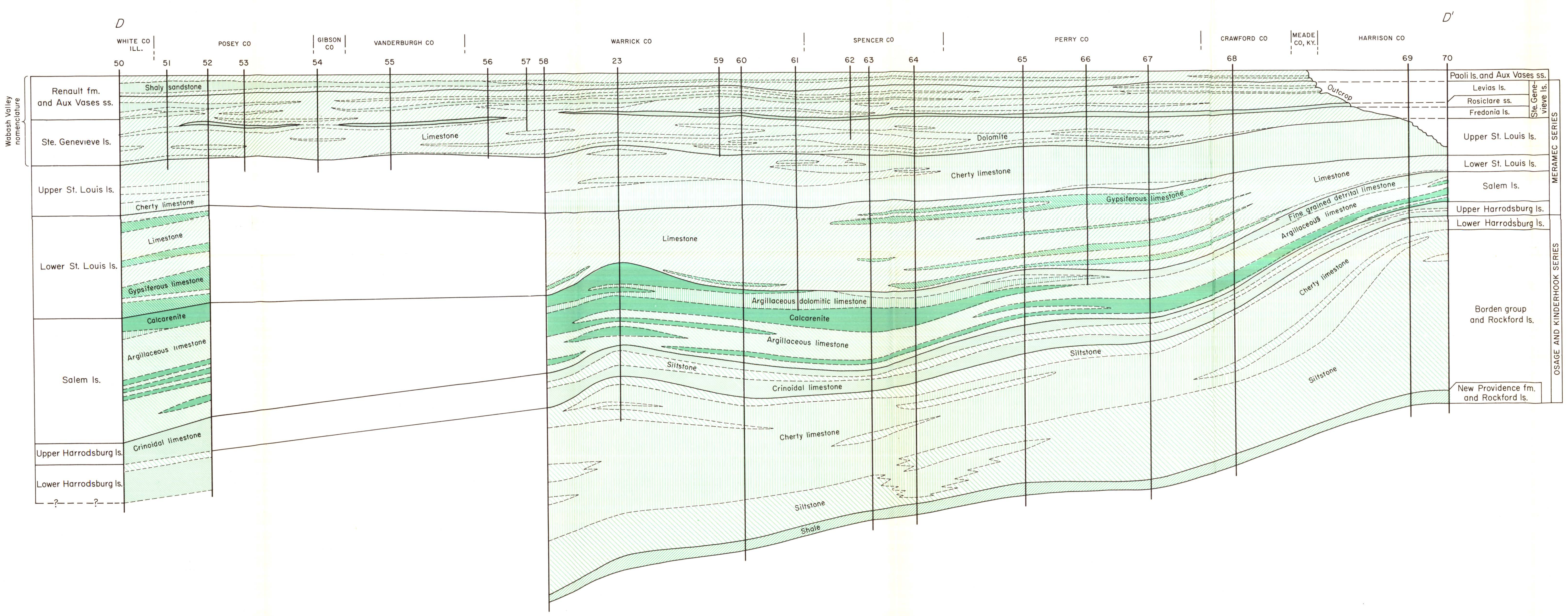
BULLETIN 11 PLATE 1



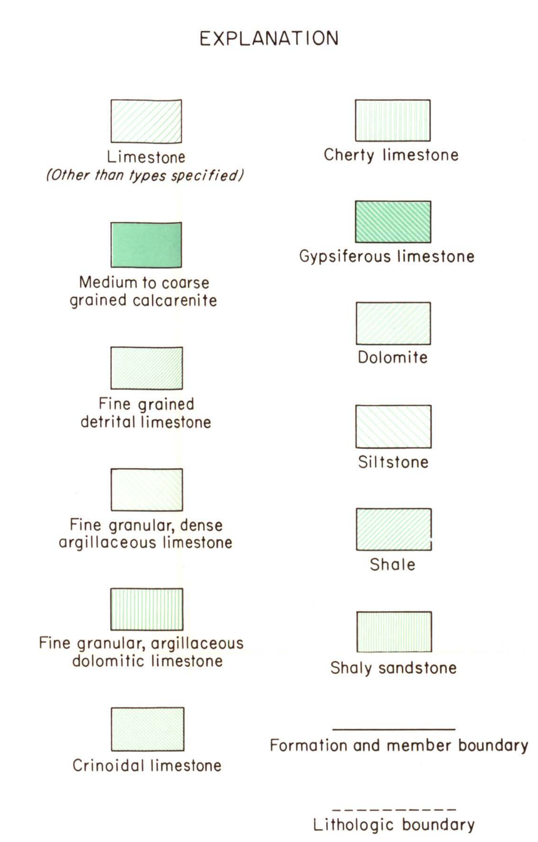


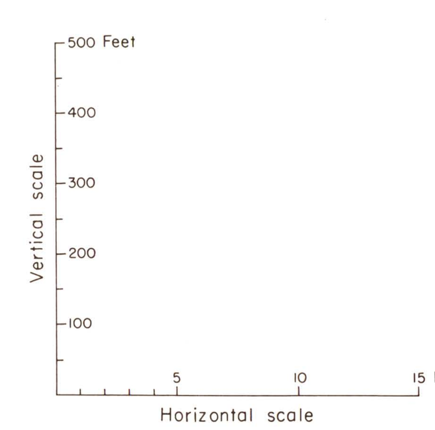


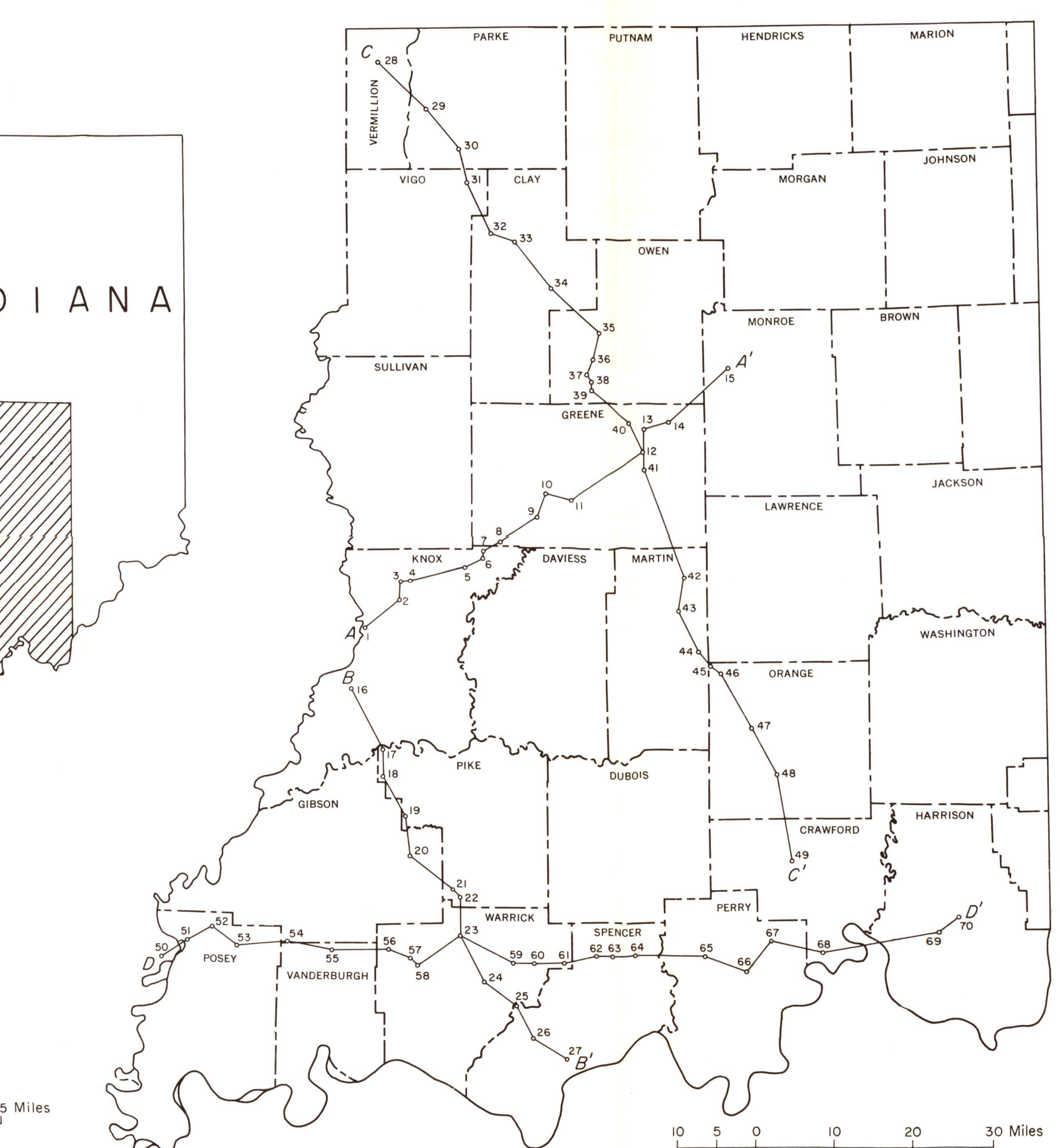


LIST OF WELL LOCATIONS

No.	Operator and Farm Name	County	Sec.	T.	R.
1	Smith No. 1 Haubeil & Fuller	Knox	26	4 N	10 W
2	MacDonnel & Thayer No. 1 Hill	Knox	Don. 199	4 N	9 W
3	MIT Syndicate No. 1 Keith	Knox	Don. 214	5 N	9 W
4	Coleman & Friestad No. 1 Trabant	Knox	26	5 N	9 W
5	Slagter No. 1 Stoelting	Knox	13	5 N	8 W
6	Sun Oil Co. Unit 1 Fry & Pohmeier	Knox	8	5 N	7 W
7	Sun Oil Co. No. 1 Weaver	Knox	5	5 N	7 W
8	Natl. Assoc. Petroleum Co. No. 1 Shake	Greene	34	6 N	7 W
9	Morgan No. 1 Jeffers	Greene	16	6 N	6 W
10	Hasler No. 1 Blanton	Greene	34	7 N	6 W
11	Young No. 1 Shepard, Jr.	Greene	6	6 N	5 W
12	Ky. Nat. Gas Corp. No. 1 Well	Greene	2	7 N	4 W
13	Smith & Lichlyter No. 1 Fuller	Greene	23	8 N	4 W
14	Ky. Nat. Gas Corp. No. 1 Dilley	Greene	17	8 N	3 W
15	Dri-Gas Corp. No. 1 Warren Petroleum Corp.	Monroe	10	9 N	2 W
16	Poe & Elliot No. 1 Guerrettaz	Knox	Loc. 97	3 N	10 W
17	Stanford Oil Co. No. 1 Davidson	Pike	7	1 N	9 W
18	R. D. Brown, Inc. No. 9 Peed	Pike	Sur. 5	1 N	9 W
19	Cochran No. 1 Belcher	Pike	27	1 S	9 W
20	Midwest Devel. Corp. No. 1-A Barthold	Gibson	23	2 S	9 W
21	Evans & Dobbs Drilling Co. No. 1 Yager	Pike	10	3 S	8 W
22	Miller No. 1 Nixon	Pike	14	3 S	8 W
23	Dearing No. 1 Gentry	Warrick	11	4 S	8 W
24	Cherry, Kidd & Ashland No. 1 Vernon Coal Co.	Warrick	8	5 S	7 W
25	Kingwood Oil Co. No. 1 McDaniel	Spencer	25	5 S	7 W
26	West & Tatum No. 1 Hinkle	Spencer	17	6 S	6 W
27	Walter No. 1 Wagoner	Spencer	36	6 S	6 W
28	Kime No. 1 Mace	Vermillion	30	16 N	9 W
29	Clouse No. 1 Clouse	Parke	30	15 N	8 W
30	Cunningham No. 1 Beatty et al.	Parke	23	14 N	8 W
31	Lauer & Keeler No. 1 North	Vigo	12	13 N	8 W
32	Carter Oil Co. No. 1 Keller, Ell & Ayrshire Collieries Corp.	Clay	15	12 N	7 W
33	Kumpf No. 1 Kumpf	Clay	24	12 N	7 W
34	Luncht & Simpson No. 1 Fischer	Clay	23	11 N	6 W
35	Sun Oil Co. No. 1 Chambers	Owen	23	10 N	5 W
36	Brake No. 1 Hauser	Owen	4	9 N	5 W
37	Gulf Refining Co. No. 1 Fiscus	Owen	16	9 N	5 W
38	Burrage No. 2 Collenbaugh	Owen	22	9 N	5 W
39	Reed No. 1 Stantz	Owen	27	9 N	5 W
40	Skiles Oil Corp. No. 1 Stephens	Greene	16	8 N	4 W
41	Shell Oil Co. No. 1 Jones	Greene	23	7 N	4 W
42	Harrison Devel. Corp. No. 1 Lewis	Martin	27	5 N	3 W
43	Wires No. 1 McBride	Martin	16	4 N	3 W
44	Ruble No. 1 Sutton	Martin	12	3 N	3 W
45	Bedford Devel. Corp. No. 1 Brothers	Orange	19	3 N	2 W
46	Hays No. 1-A Baker	Orange	29	3 N	2 W
47	Lightfoot & Siddons No. 1 Charles	Orange	36	2 N	2 W
48	United States Oil Co. No. 1 Willyard	Orange	33	1 N	1 W
49	Snyder & Vickers No. 1 Brown	Crawford	26	2 S	1 W
50	Superior Oil Co. No. C-17 Ford et al.	White, Ill.	27	4 S	14 W
51	Skiles No. 1 Kern	Posey	18	4 S	13 W
52	Sun Oil Co. No. 1 Reynolds	Posey	3	4 S	13 W
53	Superior Oil Co. No. 1 Mienerding	Posey	18	4 S	12 W
54	Ashland Oil & Refining No. 1 Blakenburger	Gibson	18	4 S	11 W
55	Jarvis No. 1 Tepe	Vanderburgh	19	4 S	10 W
56	Natl. Assoc. Petroleum Co. No. 1 Kampe	Warrick	20	4 S	9 W
57	Highlands Oil Co. No. 1 Grimwood	Warrick	26	4 S	9 W
58	Reynolds No. 1 Weyerbacher	Warrick	36	4 S	9 W
59	White Eagle Oil Co. No. 1 Scales	Warrick	36	4 S	7 W
60	Phillips No. 1 Phillips	Warrick	32	4 S	6 W
61	Wilson No. 1 Sergesketter	Warrick	36	4 S	6 W
62	Sargent No. 1 Kaetzel	Spencer	27	4 S	5 W
63	Texas Co. No. 1 Gogel	Spencer	25	4 S	5 W
64	Ohio Oil Co. No. 1 Holtzman	Spencer	28	4 S	4 W
65	Central Pipe Line Co. No. 1 Delaise	Perry	25	4 S	3 W
66	Basin Drilling Co. No. 1 Zuelly	Perry	2	5 S	2 W
67	Sun Oil Co. No. 1 Gibson	Perry	17	4 S	1 W
68	Pfeffer No. 2 Gaither	Crawford	28	4 S	1 E
69	Hayes No. 1 Grove et al.	Harrison	11	4 S	3 E
70	Ind. Utilities Corp. No. 2 Ernstine	Harrison	32	3 S	4 E







MAP OF SOUTHWESTERN INDIANA SHOWING LOCATION OF CROSS SECTIONS

STRATIGRAPHIC CROSS SECTIONS OF OSAGE AND MERAMEC (MISSISSIPPIAN) ROCKS IN SOUTHWESTERN INDIANA

By Arthur P. Pinsak

1957