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Stratigraphy sedimentation and petroleum possibilities of the Middle Ordovician (Kimmswick-Galena) rocks of Missouri, Illinois and Iowa

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STRATIGRAPHY SEDIMENTATION AND PETROLEUM POSSIBILITIES OF THE MIDDLE ORDOVICIAN (KIMMSWICK-GALENA) ROCKS OF MISSOURI ILLINOIS AND IOWA

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Dr. A. C. Spreng Dissertation Supervisor

Dedicated to . . . .

FREDERICK GEORGE PHELPS

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ABSTRACT

Detailed surface and subsurface studies of the Kimmswick Limestone and the Galena Formation of Middle Ordovician age in eastern Missouri, western Illinois, and southeastern Iowa were conducted in order to examine their stratigraphic relations, geological history, environment of deposition, and petroleum possibilities.

The main objective of this study was to seek a stratigraphic subdivision of the Kimmswick Limestone in Missouri, based on its gross lithology and thin section study, and its correlation with the Galena Formation in Illinois and Iowa. As a result of this study, based on the examination of twelve surface sections and 92 thin sections a three-fold subdivision of the Kimmswick Limestone is proposed for Missouri. These subdivisions are designated the Lower, Middle, and Upper members in ascending order.

The Lower Member can be identified in the outcrops by its coarsely crystalline texture and frequent occurrence of dark-gray to black organic matter. In thin sections it is coarse-grained and well sorted and contains about 35 to 40 percent of sparry calcite. The Middle Member is essentially characterized in the outcrops by medium crystalline limestone, with several chert zones and common occurrences of *Receptaculites oweni* throughout the unit. In thin sections it is an aggregate of fine-grained fossil debris with up to 10 percent sparry calcite. All the beds above the bentonitic shale bed which

occurs at the top of the Middle Member belong to the Upper Member of the Kimmswick Limestone. In thin sections the Upper Member appears coarse-grained and well-sorted, and contains 40 to 50 percent sparry calcite and 15 to 20 percent brachiopod fragments.

The Lower, Middle, and Upper members of the Kimmswick Limestone in Missouri have been correlated with the formations of the Kimmswick Subgroup in Illinois and the members of the Galena Dolomite in Iowa. The Cape Limestone, occurring on the top of the Kimmswick Limestone in the Cape Girardeau sections, is retained as the lowermost beds of the Cincinnatian Series.

Regionally the lower contact of the Kimmswick and Galena shows conformable relationships with the underlying Decorah Formation, but locally, the contact is unconformable in the vicinity of the Ozark Dome. Their upper boundary is marked by a pronounced unconformity throughout the area.

The structure contour map drawn at the base and the isopach map of the Kimmswick-Galena Formation, based on the subsurface data from 299 wells in the area, regionally show a northwesterly structural trend with several major and minor local structural features. A change from a limestone facies in the south to a dolomite facies in the north occurs in the area.

The Ozark Dome was a major land area in southeastern Missouri during Kimmswick-Galena time. Continuous deposition of the Kimmswick-Galena strata occurred in north and northeastern Missouri, Illinois, and Iowa from Early to Late Kimmswick-Galena time, but the maximum flooding occurred during Middle Kimmswick-Galena time, which was also associated with volcanic activity in the area. The end of the Kimmswick-Galena deposition was marked by a widespread uplift of the area.

The Kimmswick Limestone seems to have been deposited in shallow water, warm temperature, and high energy conditions on the submerged flanks of the Ozark Dome, in southeastern Missouri and southwestern Illinois. The Galena Formation was deposited in relatively deeper water, and low energy conditions, initially as an aggregate of very fine-grained organic debris washed from the shore areas, and dolomitized by the magnesium-rich waters penecontemporaneously within a few feet of the depositional interface.

Oil production from the Kimmswick Limestone is associated with small anticlinal structures which have thin limestone cover. Several such anticlinal structures, bearing promise for future petroleum production, are described, mainly in northeastern Missouri and southeastern Iowa.

CHAPTER I

INTRODUCTION

Along the Mississippi River from Minnesota, Wisconsin, Iowa, Illinois, Missouri to Arkansas, the Galena Formation of Middle Ordovician age and its equivalent, the Kimmswick Limestone, are exposed in the bluffs of the river and on the crests of eroded anticlinal structures in incomplete segments ranging from fifteen to 120 feet in thickness (Figure 1). Exposures of the complete sections are rare.

The Galena Formation, for the most part, consists uniformly of dolomite with nodular chert in the lower part; the Kimmswick, on the other hand, is fossiliferous fragmental limestone with chert nodules in the middle part. Vugs and anastomosing cavities, caused by weathering, are typical of both units and readily help to identify them. In nearly all cases, the upper and lower contacts of the Kimmswick Limestone and the Galena Formation are distinct, but other than that it is difficult to assign these strata, especially in the incomplete sections, to one or another part of the formations. The fragmental nature of the fossils precludes stratigraphic subdivision and correlation of the Kimmswick Limestone in Missouri. As a result no stratigraphic subdivision or zonation of this formation seem possible on the basis of the fauna.

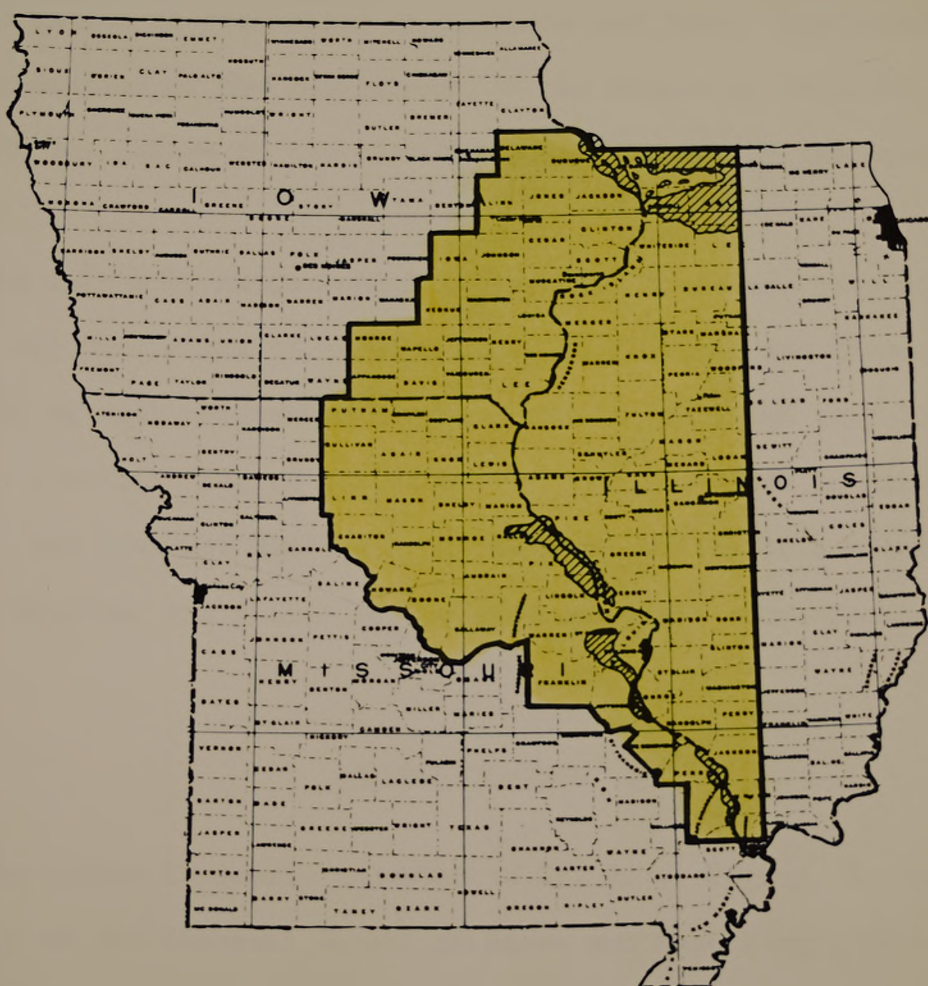

FIG. 1 INDEX MAP OF THE AREA OF STUDY SHOWING OUTCROPS OF KIMMSWICK AND GALENA FORMATIONS

A major part of this study was an attempt to subdivide the Kimmswick Limestone in Missouri based on lithologic and petrographic study. A three-fold subdivision of the Kimmswick Limestone in Missouri is proposed and these are correlated with the members of the Galena Formation as recognized in Illinois and Iowa. Furthermore, an interpretation of the environment of the Kimmswick deposition, along with the nature of the post-Kimmswick changes in the area, is discussed.

The Galena Formation and the Kimmswick Limestone have yielded sporadic oil production in various parts of Illinois and Missouri. The extent of such production has been and is small and very local. Petroleum possibilities of the Galena and the Kimmswick in Missouri, Illinois, and Iowa are discussed on the basis of the data obtained from the existing oil fields in the area and their subsurface characteristics.

ACKNOWLEDGMENTS

The author is deeply indebted to Dr. A. C. Spreng, Professor of Geology at the Missouri School of Mines and Metallurgy, Rolla, Missouri, under whose guidance this work was done, not only for his invaluable help in completing this work but also for his patience and generosity in resolving several difficulties encountered during the course of this study. Special thanks are due to other faculty members of the school for their generous help and guidance in this work. The V. H. McNutt Memorial Fund of the Missouri School of Mines, Rolla, Missouri provided the financial help for the preparation of the thin sections and a part of the expenses for the field work.

The author is grateful to the State Geological Surveys of Missouri, Illinois, and Iowa for allowing the unlimited use of their subsurface data files, without which this study would remain incomplete. A great sense of gratitude is expressed toward the Exploration Department of the Sunray DX Oil Company of Tulsa, Oklahoma, whose invaluable assistance in drafting the figures and plates and typing the manuscript made this work possible. A special note of thanks to Mr. H. O. Harder, Executive Vice President, Sunray DX Oil Company, is warranted for his very generous help in completion of this work. Finally, the writer expresses appreciation to Donna Collins and Fannie Carmen for patience and endurance in typing the manuscript.

LOCATION OF THE AREA

The area covered by this study lies on both sides of the Mississippi River in eastern Missouri, western Illinois, and southeastern Iowa (Figure 1). It is bounded on the north by Dubuque County, Iowa, and northern boundary of Illinois; the southern limit being marked by Cape Girardeau County, Missouri. The westernmost limit of the area is marked by Putnam, Sullivan, and Linn counties, Missouri, and the eastern boundary being the Third Principal Meridian in Illinois. The total area covered is approximately 80,000 square miles.

CHAPTER II

PREVIOUS WORK

Very little work has been done on the Kimmswick Limestone in Missouri since it was defined by Ulrich in 1904. The Galena Formation of Illinois and Iowa, on the other hand, has received much attention and a considerable amount of work has been done regarding its stratigraphy since Hall described it in 1851. Many authors have attempted to work out a correlation between these two formations in the past. A brief review of all the work done in this direction is given in the following paragraphs in a chronological order.

KIMMSWICK LIMESTONE

Although Ulrich (1904)* was the first to use the name Kimmswick Limestone for "more or less crystalline limestone quarried at Graysboro, Cape Girardeau, Glen Park, Kimmswick, and other localities in southeastern Missouri," Keyes (1898) had already proposed the name "McCune Limestone" for the "25 to 30 feet of fossiliferous, massive, buff, dolomitic limestone" that succeeded the "125 or 150 feet of light blue, gray, thinly bedded, compact, somewhat fossiliferous 'Bryant' (= ? Plattin) limestone in Pike and Lincoln counties, Missouri." In a later paper (1914), Keyes assigned a thickness of

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*All references included in bibliography at the end of the thesis.

50 feet to his McCune limestone in the same area. Rubey (1952) commented:

> Whether or not Keyes' name, McCune limestone, as thus proposed, was originally intended to include all the beds now referred to the Kimmswick is not certainly known but the term has since been used by some writers, in a restricted sense, to include only beds younger than or in the upper part of the Kimmswick.

Ulrich (1911) redefined the Kimmswick Limestone of eastern Missouri as "consisting wholly of beds of late Black River age," unconformably overlain by what he called "Upper Prosser," which in turn was unconformably overlain in places by the "McCune Limestone" of Keyes.

Foerste (1920) tentatively correlated the McCune Limestone with the upper part of the Kimmswick found along Sander's Branch in sections 28, 21, and 22, five miles northwest of New London in Pike County, Missouri, based on the occurrence of _Hormotoma major_ in the McCune Limestone. He stated, "when a better knowledge of the fauna of the McCune Limestone has been secured, it may be necessary to alter this correlation," (_ibid_. p. 184).

Bradley (1925), working in the type locality of the Kimmswick in Jefferson County, Missouri and in southeastern Missouri exposures, included the following beds in the Kimmswick Limestone in descending order:

1. McCune or _Fusispira_ Zone at the top;
2. _Camarocystites_ or _Echinosphaerites_ Zone (which forms the top beds of Kimmswick at Cape Girardeau, Missouri), 30 feet thick;

3. *Receptaculites oweni* Zone, 68 to 80 feet thick;

4. Basal beds, 50 feet thick.

In his study Bradley concluded that the Kimmswick Limestone in its type locality in southeastern Missouri does not contain beds younger than those occurring at the base of *Fusispira* or McCune Zone which was "only provisionally included in the Kimmswick" by him. Based on his faunal studies he strongly believed that "Kimmswick is at least as young as lower Trenton."

The Kimmswick Limestone of northwestern Missouri in the subsurface was divided by McQueen and Greene (1938) into three divisions based on lithology as following:

1. The uppermost division consisting of bluish-gray to brown crystalline dolomite with small amounts of white to dark brown chert;

2. The middle division of very cherty dolomite, the upper part of which is almost wholly chert;

3. The lowermost division consisting again of dolomite with small amount of gray to brown chert.

McQueen (1938) regarded the top of the very cherty middle division as the top beds of Black River age (Lower Mohawkian Stage of Middle Ordovician) and considered the uppermost division to be of probable Trenton age (Upper Mohawkian Stage of Middle Ordovician), lying unconformably upon the cherty Black River beds.

Templeton and Willman (1963) divided the Kimmswick in Illinois into two formations as follows:

1. The upper formation called Wise Lake, and
2. The lower, called Dunleith Formation.

These two together formed what they called the Kimmswick Subgroup of the Galena Group. The Dunleith Formation derived its name from the type locality in Dunleith Township, Jo Daviess County, Illinois. The exposure here consists of a sequence of alternating pure and argillaceous, partly cherty limestone and dolomite. The top of this formation is designated where the chert is absent. The Wise Lake Formation was named for a small lake in Mississippi River flood plain, south of the town of Galena, Jo Daviess County, Illinois. The strata consist of non-cherty, thick-bedded, pure dolomite or limestone.

These two formations of the Kimmswick Subgroup are not definitely recognized by Templeton and Willman (1963) in Missouri. Therefore they use the name Kimmswick (Subgroup) for the entire sequence of strata in Missouri.

The use of the term Kimmswick is practically non-existent in Iowa and the whole sequence of strata between the Maquoketa and Decorah formations is included in the "Galena Dolomite," which has been subdivided into three members as discussed on page 10.

The Missouri Geological Survey has not attempted to subdivide the Kimmswick Limestone into units less than the formation rank, either in the subsurface or on the surface. The term is used for the strata included between the Maquoketa and Decorah formations.

The United States Geological Survey has classified "The Kimmswick Limestone... as of Trenton age, but possibly including at base some beds of Black River age," (Wilmarth, 1938, p. 1095). This classification is not in accordance with the Code of Stratigraphic Nomenclature (1961), because this defines beds on the basis of time lines.

GALENA FORMATION

The beds called the "Upper Magnesian Limestone" or "Cliff Limestone" by Owen (1840, p. 19, 24) were designated "Galena" by Hall (1851, p. 146) from exposures in the vicinity of the town of Galena, Jo Daviess County, Illinois. The strata making up the "Galena" in its type locality were described by Hall as "gray, or drab-colored limestones." In 1862 he assigned these strata to Trenton Group. Although Winchell (1873) stated that lower beds of Hall's Galena are interbedded with underlying Trenton Limestone, he and others continued to treat the Galena as post-Trenton in age. In 1879 Winchell and Ulrich assigned the Galena to the Trenton and the underlying so called "Trenton shales and limestones" to the Black River.

C. W. Hall and Sardeson (1892) also definitely assigned the "Galena" to the Trenton and divided it and the underlying beds (also included in the Trenton previously) into several faunal zones. Bain (1905) named these underlying beds the "Platteville Limestone" in northwestern Illinois and southwestern Wisconsin. Calvin (1906) called the upper beds of Bain's "Platteville Limestone" the "Decorah Shale" and included them in his "Platteville Stage" along with his Platteville Limestone.

The Galena Formation along with the overlying Maquoketa and the underlying Decorah formations was considered to be equivalent to the Trenton Group of strata of New York until 1935, when Trowbridge used Galena to include only Dubuque, Stewartville, Prosser, and the Decorah in descending order, excluding the Maquoketa to be identified separately from the Galena Group. Kay (1935) also suggested a differentiation of a "Galena Group" as a provincial subdivision in the Mississippi River Valley, equivalent to the Trenton Group of New York. He included the Galena and the Decorah formations in the Galena Group and raised the members of the Galena (Dubuque, Stewartville, and Prosser) to formation rank.

Agnew (1955) divided the Galena Formation of Iowa in the subsurface as well as on the surface into the following two units:

1. The "Upper non-cherty" unit, consisting of fine to coarse-grained, crystalline to granular and vuggy dolomite, medium-bedded with interbeds of shales in its upper part but massive near the base;
2. The "Lower cherty" unit consisting of light brown to light gray, medium to coarse-grained, crystalline to granular and vuggy, medium-bedded to massive dolomite with bands of chert nodules common.

The "Upper non-cherty" unit includes the Dubuque, the Stewartville, and the upper part of the Prosser members, the "Lower cherty" unit containing the remainder of the Prosser. This scheme offered an easy and practical means of correlation between the surface and the subsurface formations.

In northern and western Illinois the name Galena has been used to designate the rocks included between the Maquoketa and the Decorah formations; there it is mainly dolomite. Its southern equivalent, the limestone facies, has been called the Kimmswick Limestone. This was emphasized by Dubois (1945) in the statement "the name Galena Formation has been used in Illinois to show the contemporaneity of the Galena and the Kimmswick formations." Templeton and Willman (1963) proposed to drop the name Kimmswick from this combination because "Galena has priority" and because "neither the top nor the bottom boundaries of the Galena and Kimmswick are the same," (p. 95). They retained the name Kimmswick as a subgroup of the Galena Group as mentioned before (p. 8), and lowered the base of the Galena Group to include the Spechts Ferry Formation which previously was Spechts Ferry Member of the Decorah Formation as discussed elsewhere in this study.

Thus according to Templeton and Willman (1963) the Galena Group in Illinois includes the Decorah and Kimmswick subgroups, whereas in Iowa the Galena is recognized as a formation separate from the underlying Decorah and is divided into Dubuque, Stewartville, and Prosser members. The Missouri Geological Survey does not employ the term Galena and prefers to call the whole sequence of strata occurring between the Maquoketa and the Decorah formations the Kimmswick Limestone.

CAPE LIMESTONE

A brief review of the nomenclature and age of the Cape Limestone, previously known as the Fernvale Formation, is included here because of the uncertainty of its stratigraphic relationship with the underlying Kimmswick Limestone in southeastern Missouri.

The Fernvale Formation was first named by Hayes and Ulrich (1903) for the type section in Fernvale, Williamson County, Tennessee and described as:

> soft green and chocolate colored shales, including one or more layers of coarsely crystalline, occasionally flesh-colored limestone, usually with greenish specks; the lower part not infrequently conglomeratic and highly phosphatic. In some areas the lower part of the formation is composed of 5 or 6 feet of strongly ferruginous, often vermillion red limestone.

They considered the Fernvale to be the uppermost strata of the Richmond Group. Marshall (1950) studied the Fernvale Formation around Cape Girardeau, Missouri, and assigned it to the Lower Cincinnatian Series.

Templeton and Willman (1963) proposed "Cape Limestone as a replacement for the name Fernvale" (p. 134). The type locality of their Cape Limestone is in Cape Girardeau on Main Street north of Broadway, and consists of "limestone which, except for scattered, thin argillaceous laminae, is pure, light gray, weathering brownish gray to reddish gray, coarse-grained, calcarenitic, very fossiliferous, and medium to thick-bedded" (p. 135). They state:

> The Fernvale Limestone of Illinois and Missouri is now believed to be an initial Cincinnatian deposit that may be equivalent to or older than basal Cincinnatian beds in the Cincinnatian type area (p. 131).

DECORAH FORMATION

A review of the nomenclature and age assignments of the Decorah Formation is included here because there is some doubt about the position of the lowermost beds of the Kimmswick Limestone which, in Illinois and Iowa, have been included in the Decorah from time to time. Also since the Decorah-Kimmswick contact seems unconformable, at least locally, it was considered important to review this and then tie it with the problem of stratigraphic position of the Kimmswick Limestone as discussed elsewhere (p. 72).

The name Decorah was given by Calvin (1906, p. 61) to the rocks exposed in the city of Decorah in northeastern Iowa which he described as "persistent body of shale between the two parts of what has generally been called the Trenton Limestone." He further stated (p. 85) that "the Decorah shale ranges from 25 to 35 feet in thickness and is everywhere very calcareous with numerous bands and nodules of limestone distributed through it."

Kay (1928) divided the Decorah of northeastern Iowa into three members which he named Ion, Guttenberg, and Spechts Ferry members in descending order. He applied the name Ion to the "sixteen feet of calcareous shale and argillaceous limestone that constitutes the top member of the Decorah," (p. 16). The type locality was "about a mile southeast of hamlet of Ion." The Guttenberg Member was described by him as "about fifteen and one-half feet of brownish, fine-textured limestone exposed in the bluff of the Mississippi River just northeast of the town of Guttenberg," (p. 16). His "Spechts Ferry Member" was:

> the eight and one-half feet of shale and interbedded limestone which formed a lithologic unit lying above the Platteville limestone in the sequence of the strata exposed in the ravine southeast of the C. M. & St. P. railroad station of Spechts Ferry, (p. 16).

He included the Ion and the Guttenberg members in the Trenton and the Spechts Ferry in the uppermost Black River strata.

Similarly Trowbridge (1935, p. 64) included all the Decorah in the Trenton with the exception of Kay's "Spechts Ferry" which he put in the Platteville Limestone. Agnew (1955) and Agnew et al (1956) accepted Kay's original classification of Decorah and included all three members in the Decorah.

Cooper (1956) proposed the name "Barnhart" to replace the name Decorah in Missouri for an exposure at Koch Valley School, Jefferson County, Missouri. He correlated the Barnhart with the Guttenberg Member of the Decorah in Iowa and Illinois.

In northern Illinois and Missouri the name Decorah has generally been applied to shaly beds occurring between the Plattin and the

Kimmswick formations. Herbert (1949) showed that in southern Illinois the Decorah contained both Spechts Ferry and Guttenberg beds with distinctive lithology and that the Ion was represented in the basal beds of the Kimmswick. He differentiated silty strata between the Guttenberg and Spechts Ferry as a new member which he called the Kings Lake Member. This member was not described by Kay in the type locality of the Decorah in Iowa.

Templeton and Willman (1963) made Decorah a subgroup of the Galena Group and divided it into Spechts Ferry, Kings Lake, and Guttenberg formations in ascending order. Their Kings Lake Formation is more or less the same as that of Herbert as described above. They included the Ion Member in their Dunleith Formation of the Kimmswick Subgroup and replaced it by two members which they called Buckhorn and the St. James in their new classification.

A chart of the stratigraphic nomenclature and age assignment of the Kimmswick Limestone in Missouri and the Galena Formation in Illinois and Iowa has been given in Plate I.

Page 16 can be found in the Supplemental Files

CHAPTER III

STRATIGRAPHY

The Kimmswick Limestone in Missouri occurs as discontinuous bands in the eastern part of the State along the Mississippi River (Figure 1). The best exposed section of the Kimmswick Limestone in Ulrich's type area is in an abandoned quarry near Glen Park, Jefferson County, Missouri (Locality 10, Plate VI). The outcrop can be traced southward along the Mississippi River in the form of a narrow belt, generally less than five miles wide, to Riverside about ten miles south of the type locality. Southeastward this outcrop continues in a sinuous belt across Ste. Genevieve, Perry, and Cape Girardeau counties, Missouri. The southernmost outcrop of the Kimmswick in Missouri occurs near the town of Ilmo, Scott County, on the bank of the Mississippi River.

Northward from the Glen Park section the Kimmswick Limestone occurs in isolated outcrops in Franklin, St. Louis, and St. Charles counties, Missouri. It is not exposed on the surface again until Lincoln County, Missouri and from here it follows northward across Pike County to Ralls County, Missouri where it occurs on the crest of the Lincoln Anticlinorium. No surface exposures of the Kimmswick in Missouri are known farther north of Ralls County, Missouri where it disappears beneath the cover of younger rocks in the subsurface.

The occurrences of the Kimmswick Limestone in Illinois are found directly across the Mississippi River from those of Missouri. The northernmost exposures of the Kimmswick are associated with the Lincoln Anticlinorium and occur along the Mississippi River in Pike and Calhoun counties, Illinois. Southward the Kimmswick is exposed in Monroe County in the bluffs of the Mississippi River across from the type locality of the Kimmswick in Missouri. Southeastward the Kimmswick Limestone outcrops in Jackson County, Illinois and the southernmost exposures are found near the town of Thebes, Alexander County, Illinois.

The Galena Formation in Illinois occurs in outcrops in the extreme northern part of the state (Figure 1). The type locality is near the town of Galena, Jo Daviess County, Illinois and the outcrop extends mainly eastward from here. A westward extension of these exposures, across the Mississippi River, occurs near the town of Dubuque, Dubuque County, Iowa. No other exposures of the Galena are known in Iowa away from this vicinity (Figure 1).

One of the major objectives of this study was the stratigraphic subdivision of the Kimmswick Limestone in Missouri and its correlation with the Galena Formation in Illinois and Iowa. Most of the work done by the author was confined to Missouri, however, a few sections of the Kimmswick Limestone and the Galena Formation in Illinois and Iowa were examined during the course of this study. The latest work of Templeton and Willman (1963) on Kimmswick and Galena formations in Illinois is discussed later in this chapter for the sake of comparison and correlation with the Missouri sections. The "Galena Dolomite" as used by Agnew (1955) in Iowa is also discussed in this chapter for the same reason. Finally a correlation of the subdivisions of the Kimmswick as proposed in this study with those of the Galena Formation in Illinois and Iowa is given. A correlation chart including the measured surface sections of the Kimmswick Limestone in Missouri and the subdivisions of the Galena in Illinois and Iowa, as proposed by Templeton and Willman (1963) and Agnew (1955) respectively, has been given in Plate VI (also Figure 6).

FIELD WORK

The field work was begun in the Fall of 1960 when representative outcrop sections of the Kimmswick Limestone in northeastern Missouri were examined and measured in detail. This was followed up by further checking and sample collection from this area in the Spring of 1961. During the Fall of the following year the sections near St. Louis area and the type locality of the Kimmswick Limestone near Glen Park, Jefferson County, Missouri were measured. At this time the field work had to be stopped for about five months due to the injuries suffered in an accident while measuring the Kimmswick section near Antire Road, St. Louis County, Missouri. During the Spring of 1962, the type locality of the Galena Formation near the town of Galena, Jo Daviess County, Illinois and the Dubuque section near Dubuque, Iowa were examined but not measured in detail or sampled. The main reason

LOCALITY INDEX

1. SE¼,NE¼,NW¼,Sec.36,T.56 N., R.5 W., Ralls Co., Mo.
2. SW¼,SW¼, SE¼,Sec.5,T.55 N., R.4 W., Ralls Co., Mo.
3. SE¼,NE¼,SE¼,Sec.21,T.55 N., R.4 W., Ralls Co., Mo.
4. SW¼,NE¼,SE¼,Sec.2,T.54 N., R.4 W., Pike Co., Mo.
5. NW¼,NW¼,SW¼,Sec.25, T.44 N., R.3 E., St. Louis Co., Mo.
6. NW¼,NW¼,SE¼,Sec.24,T.44 N., R.3 E., St. Louis Co., Mo.
7. SW¼,SW¼,SE¼,Sec.33,T.44 N., R.3 E., St. Louis Co., Mo.
8. SE¼,SE¼,NW¼,Sec.20, T.45 N., R.3 E., St. Louis Co., Mo.
9. NE¼,NE¼,SW¼,Sec. 3, T.43 N., R.4 E., St. Louis Co., Mo.
10. SE¼,SE¼,NW¼,Sec. 5, T.41 N., R.6 E., Jefferson Co., Mo.
11. SW¼,NW¼,Sec. 24, T.39 N., R.7 E., Ste. Genevieve Co., Mo.
12. Section on Main St. North of Broadway, Cape Girardeau, Mo.

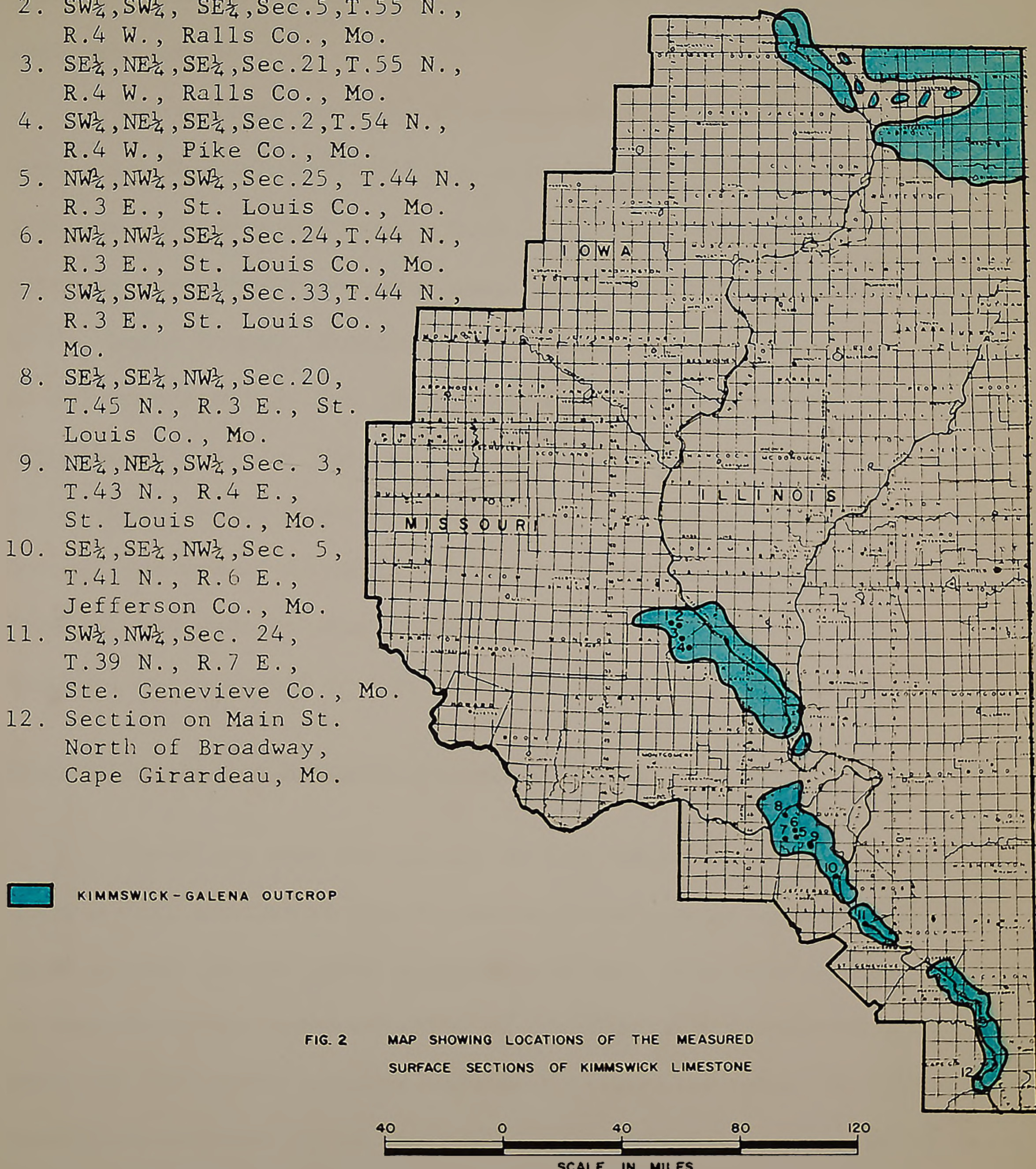


FIG. 2 MAP SHOWING LOCATIONS OF THE MEASURED SURFACE SECTIONS OF KIMMSWICK LIMESTONE

for not measuring these sections in detail was the limited maneuverability of the author in the field due to the result of the accident mentioned before.

The outcrop sections of southeastern Missouri were measured during the Fall of 1962 with the help of Dr. A. C. Spreng, under whose guidance this work was done. Some later field work, consisting of rechecking the already measured sections in northeastern Missouri and in St. Louis County, Missouri and detailed measurement of the section at Brickeys Landing, Ste. Genevieve County, Missouri was done, again with the help of Dr. Spreng. The measurement of the section near Antire Road in St. Louis County, Missouri was completed by Dr. A. C. Spreng, the use of which in this study is gratefully acknowledged. Finally, the section near Babler State Park in St. Louis County, Missouri was measured by the author in the Spring of 1963.

Description of the Measured Surface Sections

There are very few places in the entire State of Missouri where a full section of the Kimmswick Limestone is exposed with the upper as well as the lower contacts present. One such section, which is considered the representative of the Kimmswick Limestone with the upper and the lower contacts exposed is described here. All the localities referred to in the following paragraphs correspond to those shown in Plate VI and Figure 2.

Plate II Section at Locality 11, in Menefee Quarry, at Brickeys Landing, SW$\frac{1}{4}$, NW$\frac{1}{4}$, Sec. 24, T. 39 N., R. 7 E., Ste. Genevieve County, Missouri,(Decorah exposed to the left of this section, see Plate XI).

Locality 11 Menefee quarry at Brickeys Landing, SW¼, NW¼, Sec. 24, T. 39 N., R. 7 E., Ste. Genevieve County, Missouri.

Here a section of rocks commencing with the Decorah Formation and continuing into the Mississippian is exposed with about sixty feet of the Kimmswick Limestone present. The basal contact of the Kimmswick Limestone with the underlying Decorah Formation is distinctly exposed. Similarly the upper contact with the overlying Devonian rocks is distinct. The Kimmswick Limestone consists almost entirely of coarsely crystalline, gray to pinkish gray, richly fossiliferous fragmental limestone with several prominent chert nodules and lenses distributed throughout its middle part. The chert is light gray to light brown and sometimes pinkish gray.

Another section of the Kimmswick Limestone, with its upper and lower contacts exposed, occurs at the following locality. Since the Kimmswick here is only nineteen feet thick it is not considered a good representative section, however, it has been included in this study for completeness and is described below.

Plate III Section at Locality 7, in New roadcut on Interstate Highway 44, near Allenton, SW$\frac{1}{4}$, SW$\frac{1}{4}$, SE$\frac{1}{4}$, Sec. 33, T. 44 N., R. 3 E., St. Louis County, Missouri.

Locality 7 New roadcut on Interstate Highway 44, near Allenton, SW¼, SW¼, SE¼, Sec. 33, T. 44 N., R. 3 E., St. Louis County, Missouri.

This roadcut shows a section of rocks belonging to Plattin, Decorah, Kimmswick, and Mississippian in ascending order. The Decorah which overlies the Plattin is about fourteen feet thick and, in turn, is overlain by about nineteen feet of the Kimmswick Limestone. The Kimmswick Limestone consists of a one and one-half foot thick bed of yellowish-gray fine-grained dolomite at its base, and light brownish-gray, medium- to coarse-grained, medium- to thick-bedded, fossiliferous fragmental limestone above. A six-inch thick bentonitic shale bed occurs about five feet above the Decorah-Kimmswick contact, which is distinct and well exposed (Plate III). The upper contact of the Kimmswick Limestone with the Mississippian rocks appears unconformable and is distinctly exposed in this section.

The exposures of the Kimmswick Limestone in the following localities show only the basal contact of the Kimmswick with the underlying rocks. These are described in sequence from north to south.

Locality 3 Roadcut on Highway 61 north, near Pike and Ralls County boundary line, SE¼, NE¼, SE¼, Sec. 21, T. 55 N., R. 4 W., Ralls County, Missouri.

A section comprising Joachim, Plattin, Decorah, and Kimmswick formations is exposed here, in ascending order. The contacts of each of these formations are very distinct. Only eighteen feet of Kimmswick is exposed here, with its eroded top covered by soil. The limestone, which is medium- to coarse-grained, light brownish gray to light gray, abundant with fragmental fossils, contains a six-inch thick conglomeratic bed at its base. The uppermost beds are weathered and have anastomosing cavities on the surface.

Locality 4 Galloway quarry, Frankford, SW¼, NE¼, SE¼, Sec. 2, T. 54 N., R. 4 W., Pike County, Missouri.

A nearly complete section of the Kimmswick Limestone is exposed in the quarry, in contact with the underlying Decorah Formation. The thickness of the Kimmswick Limestone is about ninety feet. It shows cavernous-weathering in its middle part. The limestone contains a two-inch thick bentonitic shale bed about fourteen feet below the eroded top of the Kimmswick. Minor shale partings occur near the base. Residuum obscures the Kimmswick-Maquoketa contact. Numerous dark gray to black streaks and specks of organic matter are commonly found in the lower fifteen feet of the Kimmswick.

Locality 5 Roadcut on Highway 109, 3 miles north of Eureka, NW¼, NW¼, SW¼, Sec. 25, T. 44 N., R. 3 E., St. Louis County, Missouri.

Exposed here is a thick Plattin Limestone section directly overlain by about 25 to 30 feet of the Kimmswick Limestone. The Decorah Formation is absent here and the Kimmswick Limestone contains a two- to three-inches thick bentonitic shale bed at its base. The eroded top of the Kimmswick Limestone is covered by residuum and soil.

Locality 6 Roadcut on Highway 109, 2 miles north of Locality 5, NW¼, NW¼, SE¼, Sec. 24, T. 44 N., R. 3 E., St. Louis County, Missouri.

Here, as at Locality 5 above, the Kimmswick Limestone directly overlies the Plattin Limestone and the contact is very distinct. The exposed thickness of the Kimmswick Limestone is about thirteen feet, which contains a four- to six-inch thick bentonitic shale bed at its base; a six-inch thick conglomeratic bed occurs above the shale bed. The eroded top of the Kimmswick is covered by the chert residuum and soil.

At the following localities the basal contact of the Kimmswick with the underlying Decorah Formation is covered. In these cases part of the Decorah is exposed but the beds near the very top of the Decorah are covered by soil and vegetation.

Plate IV Section at Locality 4, in Galloway Quarry, Frankford, SW¼, NE¼, SE¼, Sec. 2, T. 54 N., R. 4 W., Pike County, Missouri (Decorah-Kimmswick contact as shown near the bottom of the quarry).

Locality 1 Inactive quarry, 2 miles north of New London, SE¼, NE¼, NW¼, Sec. 36, T. 56 N., R. 5 W., Ralls County, Missouri.

About 43 feet of Kimmswick Limestone is exposed in the quarry face. The basal contact with the underlying Decorah Formation is not exposed in the quarry but should be only a few feet below the quarry floor based on exposures of the Decorah in the road cut on Highway 61, a little less than a mile east of the quarry. The eroded top of the Kimmswick is covered by chert residuum and soil. The limestone is light brownish gray to light gray or buff colored, medium- to coarse-grained, massive-bedded and is abundant with fragmental fossils.

Locality 2 Bluff on Salt River on County Highway V, 3 miles east of New London, SW¼, SW¼, SE¼, Sec. 5, T. 55 N., R. 4 W., Ralls County, Missouri.

Here about six feet of Decorah Formation is exposed at the road level but the uppermost beds are covered by soil and vegetation. The Kimmswick Limestone commences above this covered interval, but the Decorah-Kimmswick contact lies within three to four feet below the lowermost exposed beds of the Kimmswick. The Kimmswick is very much similar to that of Locality 1. The eroded top of the Kimmswick is covered by soil and vegetation. Although the thickness of the Kimmswick exposed in this section is only about 34 feet, a much thicker section is exposed further eastward along Salt River.

The exposures of the Kimmswick Limestone in the following localities show a distinct contact with the overlying formations but the contact with the underlying Decorah Formation is covered. In certain places a part of the Decorah is exposed but the uppermost beds are covered by soil and vegetation.

Locality 8 Abandoned quarry near Babler State Park, SE¼, SE¼, NW¼, Sec. 20, T. 45 N., R. 3 E., St. Louis County, Missouri.

A thick Decorah section is overlain by about 65 feet of Kimmswick Limestone in this exposure. The Decorah-Kimmswick contact is covered by soil and vegetation; however, parts of the Decorah Formation are exposed in the creek and about half way between the creek bottom and the quarry floor. The Kimmswick consists almost entirely of medium- to coarse-grained, light gray to buff colored, medium to thick-bedded limestone with an eleven-foot thick chert zone near the quarry floor. An eight- to eleven-inch thick bentonitic shale bed occurs about 25 feet below the top of the Kimmswick Limestone. The uppermost beds of the Kimmswick are overlain by the Bushberg Sandstone of Devonian or Mississippian age. The Bushberg-Kimmswick contact is very distinctly exposed on the quarry face.

Locality 9 Inactive quarry near Antire Road and south of Tyson Valley Ordnance Plant, NE¼, NE¼, SW¼, Sec. 3, T. 43 N., R. 4 E., St. Louis County, Missouri.

Here the section consists of Plattin Limestone at the road level overlain by the Decorah Formation which in turn is overlain by about 110 feet of the Kimmswick Limestone. The basal contact of the Kimmswick with the Decorah is covered, although most of the Decorah beds are exposed. The upper contact of the Kimmswick with the overlying Bushberg Sandstone of Devonian or Mississippian age is distinctly exposed. The Kimmswick here consists entirely of coarse-grained, white to buff colored, thick-bedded, richly fossiliferous fragmental limestone with a seven-foot thick cherty zone in the middle. The chert is white to gray to brown and ranges from small pebble size to almost boulder size.

Locality 10 Abandoned quarry near Glen Park, SE¼, SE¼, NW¼, Sec. 5, T. 41 N., R. 6 E., Jefferson County, Missouri.

This is in the type area of the Kimmswick Limestone as mentioned by Ulrich (1904). The exposure here consists of about 70 feet of Kimmswick Limestone overlain by the Bushberg Sandstone of Devonian or Mississippian age. The limestone is uniformly coarse-grained, massive- to thin=bedded, richly fossiliferous, with several chert nodules and lenses distributed throughout the unit.

Plate V Section of the Kimmswick Limestone exposed at locality 10, in an abandoned quarry near Glen Park, SE¼, SE¼, NW¼, Sec. 5, T. 41 N., R. 6 E., Jefferson County, Missouri, (Bushberg Sandstone is exposed on the very top of the section, but is not seen in this picture).

The chert nodules are smaller in size than those at the Locality 9 above. The Decorah-Kimmswick contact is covered but is present in a pit nearby about four feet below the lowermost exposed beds of the Kimmswick on the quarry floor.

Locality 12 Section on Main Street north of Broadway, Cape Girardeau, Missouri.

The section here shows about eight feet of what has generally been recognized as Fernvale or Cape Limestone underlying the Maquoketa Formation with an apparent unconformity. This unit consists of dark gray to almost black, coarse-grained, medium- to thick-bedded limestone with abundant crinoidal fragments and other fossil fragments. The Kimmswick Limestone is very similar to the overlying Cape Limestone in lithology. A very thin bentonitic shale bed occurs between the two units. The Kimmswick here is only about sixteen feet thick but an additional 60 feet is exposed under the bridge on the road and the railroad cut, about one-half mile toward southeast. The basal contact of the Kimmswick with the underlying Decorah is not exposed in this section.

All these surface sections are diagrammatically illustrated in Plate VI on a vertical scale of one inch equal to two feet. These sections have been correlated with the bentonitic shale bed at the top of the Middle Member of the Kimmswick, which correlates with the Moredock, Beecher, and Eagle Point members of Templeton and Willman (1963) in Illinois. A complete description of each of these surface sections is given in Appendix A at the end of this thesis.

Sampling

Rock samples were taken from the exposed surfaces of the Kimmswick Limestone sections, starting from the base upward, from the localities shown in Figure 2. The samples were chipped off from such horizons in a section which, on visual examination in the field, showed lithologic variations. Such samples were collected from localities 1, 2, 3, 4, 5, 7, and 12. Also a core from the Galloway Quarry (Locality 4) was sampled on the same basis. The horizons sampled are designated by a letter shown on the left hand side of the graphic column in Plate VI. The core from the Galloway Quarry is included with the whole section at Locality 4 in Plate VI for completeness and similar letter designation is shown for the sampled horizons. A part of the core from Laclede Gas Company, Lange #3 well in Florissant Pool, St. Louis County, Missouri was also sampled. The only part available from this core was a portion in the producing horizon of the Kimmswick Limestone. As a result, this core was only used for determining the nature of its hydrocarbon contents and not as a guide for correlation with other sections observed and sampled in the field. No other cores were available for similar study.

LABORATORY STUDY

The laboratory study included a detailed petrographic study of the rocks in the surface exposures of the Kimmswick Limestone in Missouri, along with the insoluble residue study of these rocks in order to find some basis of correlation with the similar rocks occurring on the surface in other areas as well as in the subsurface. Also a test for the presence or absence of hydrocarbons in the samples of the Kimmswick Limestone, collected from the surface exposures as well as from the cores, was performed. These procedures are described in the following paragraphs.

Petrographic Study

Thin sections for the purpose of the petrographic studies were made partly by the author in the laboratory of the Missouri School of Mines, and the remainder were prepared commercially. The objectives of the petrographic study were to:

a. Determine the percentage composition of the rock constituents at the sampled horizon; the various components usually include fragments of echinoderms, brachiopods, bryozoans, crinoids, ostracods, and other unidentifiable fossil debris, calcite contents of various origins, chert and quartz particles, clay particles, pyrite grains and dolomite;

b. Determine the amount of pore space in the rock in order to demonstrate porosity variations in the sections;

c. Study any pattern of regularity exhibited by the particle size distribution and the nature of sorting of such particles constituting the limestone and thereby determine the degree of transport to which they might have been subjected;

d. Study evidence of:

   1. secondary alterations such as secondary growth around the original grains;

   2. introduction of chemically precipitated or otherwise deposited quartz or chert, dolomite, pyrite, or any other material present in the rock;

   3. fracturing and recementation of the grains and the rock;

   4. development of styolite and similar solution features;

   5. recrystallization or any other effects caused by the diagenesis of the original sediments or by introduction of chemical solutions into the sediments at later date;

e. Study the nature of the carbonaceous material and the presence of the hydrocarbon residue in the rock.

<u>Particle Count</u> - In most cases the constituent particles of the thin sections were visually estimated under the microscope. As a means of checking the accuracy of the visual estimation, the constituent

particles in a few thin sections were counted. The results of these counts were compared with the visual estimates; these two results for the same thin sections were in sufficiently close agreement to permit the use of the visual method. The counting included the number of broken fragments of distinct organisms along with the unidentifiable fossil debris, calcite content, quartz and chert grains, dolomite crystals, and pyrite and clay particles if any. The amount of pore spaces present in each thin section was determined similarly. All the data were recorded on a form especially designed by Dr. A. C. Spreng for tabulating the megascopic characteristics of the hand specimens and the microscopic features of thin sections of carbonate rocks used in previous theses at this school. The separate identification of echinoids and crinoids was not possible, therefore these have been included together under echinoderms. From the figures thus obtained, the estimated percentages of these constituents were calculated for each horizon sampled. The results of these calculations have been plotted in the form of a bar diagram for each horizon as shown in Plate VI. In these bar diagrams only major constituents, such as sparry calcite, brachiopod and echinoiderm fragments, have been plotted separately; others have been grouped together.

In an attempt to seek a relationship between the distribution pattern of these components of the limestone in various parts of the sections two ternary diagrams were plotted. These are shown in figures 3 and 4 on pp. 45 and 54. In these diagrams the apex C of the triangle represents 100 percent brachiopod fragments, point B represents 100 percent sparry calcite and the point A represents other constituents of the limestone including the echinoderm fragments. Since the echinoderm fragments are rather uniformly distributed throughout the limestone sequence, a diagram using these as separate component did not show any distinctive character of various horizons of the limestone. As a result, these were included with the other constituents of the limestone. The proportion of the sparry calcite and the brachiopod fragments clearly shows a distinctive change in the lower beds of the limestone as compared with the upper beds. The diagram in Figure 3 has been used to show the distribution of these components for the lower beds (Lower Member) of the Kimmswick Limestone. This clearly shows the concentration of brachiopod fragments in the 10 to 15 percent range and the sparry calcite in the 30 to 40 percent range; 90 percent of the samples fall in this range. The diagram in Figure 4 shows sparry calcite contents for the lower part of the higher horizons (Middle Member of the Kimmswick) of the limestone in the range of 5 to 15 percent with brachiopod fragments being mostly in 5 to 10 percent range; almost 95 percent of the samples fall in this range. The beds occurring higher in the sequence (upper part of the Middle Member of the Kimmswick) show average sparry calcite content of 45 percent, with the brachiopod fragments being the same as the lower beds of this sequence.

Measurement of the Particle Size - The particle size measurement was done on the microscope stage by the usual method by using a calibrated ocular grid. This measurement was not performed in all the cases because of the difficulty encountered in distinguishing primary particles from those in which secondary growth was the result of recrystallization. In several cases very fine fossil debris present in the thin section hindered such measurements greatly. As a result, these data have not been used quantitatively in arriving at the results pertaining to the interpretation of the environment of deposition. However, a relative degree of sorting has been established from these observations which have been used in such interpretation. Other characteristics resulting from diagenesis and recrystallization were noted wherever necessary and applicable and such observations have been used in the environmental studies.

Insoluble Residue Study

A portion of each rock collected in the field were digested with a dilute solution of hydrochloric acid and washed very carefully for the purpose of collecting insoluble residues after McQueen's method (1931). These residues were examined under a binocular microscope to study their nature and properties. These residues showed a trace of silicified fossil fragments and few quartz grains of very small size in a few samples. The results of such examinations were not plotted as the amount of the residue collected from each sample was insignificant and could not be used in the correlation of these horizons.

Tests for Hydrocarbons

Several thin sections show dark brown specks disseminated over the surface of the slide and in certain cases the same material is seen as filling the minute fractures and in intergranular spaces. An attempt to collect such material from the samples by dissolving the sample in dilute hydrochloric acid failed. The filter paper on which the residue was collected showed a little brown to dark brown staining, which was not enough for any kind of test.

In a further attempt to identify this brown material a thin section of a part of a saturated core from Lange #3 well of the Laclede Gas Company, St. Louis, Missouri, was made. A similar thin section was made from the dry part of the core of the same well just below the producing horizon. An examination of the thin section of the saturated core showed the dark brown material filling the fractures (Plate VII) and a trace of this was present around the grains near the fracture. The material under cross nicols showed isotropism. A part of this core cut from the area containing brown material, was dissolved in hydrochloric acid which yielded a dark brown, very sticky material as residue. This material was treated with carbon tetrachloride and was completely dissolved in it. A similar test with benzene showed the same result. A thin section examination of

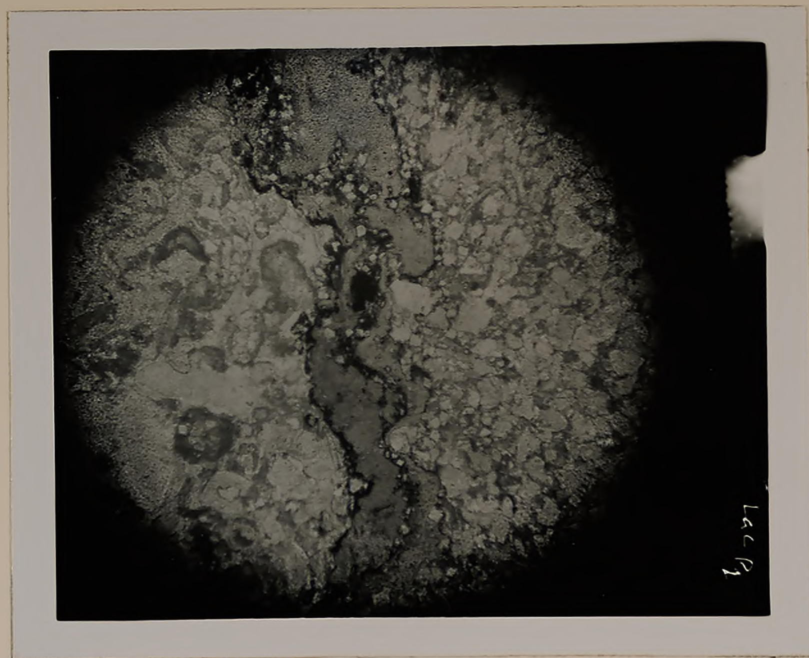


Figure 1

Figure 2

Plate VII Photomicrographs of the thin sections of the core from Laclede Gas Co., Lange #3 well Florissant Pool, St. Louis County, Mo. Figure 1 shows the oil producing horizon of the Kimmswick Limestone; the dark gray material is oil filled in the fracture in the limestone, notice the development of dolomite grains along the fracture (13.5x). Figure 2 shows the dry part of the core; notice the absence of fracturing, hydrocarbons, and dolomite grains, (12.5x).

the dry part of the core did not show such material. As a matter of fact, there was no evidence of such material present in this part of the core in the megascopic sample. A similar test to obtain some dark brown material was performed on this core without any success. Thus it is evident that the dark brown material present in the Kimmswick Limestone in the form of specks and streaks is a hydrocarbon residue. The contrasting pictures of the saturated core versus the dry part of the core are shown in Plate VII.

STRATIGRAPHIC SUBDIVISIONS
OF
THE KIMMSWICK AND GALENA FORMATIONS

The Subdivision of the Kimmswick Limestone in Missouri

A threefold subdivision of the Kimmswick Limestone is proposed in Missouri, on the basis of megascopic and microscopic characters of the rocks. These units are designated the Lower, Middle, and Upper members in ascending order and are described in the following paragraphs.

Lower Member - The Kimmswick Limestone in the area of this study, as seen in the surface exposures, commences with white, gray or buff colored, medium- to coarse-grained, massive-bedded limestone with abundant fossil fragments distributed throughout the unit. Fossils are generally finely broken fragments but larger pieces of bryozoans

Plate VIII Photomicrograph of a representative thin section (SA_2) of the Lower Member of the Kimmswick Limestone, (Horizontal section, 32x).

The following abbreviations are used to describe the constituents of the limestone in Plates X to XIV and XVI.

b = brachiopod fragments

br = bryozoan fragments

c = sparry calcite

d = dolomite rhombs

e = echinoderm fragments

p = pore spaces

Plate VIII (See facing page for description).

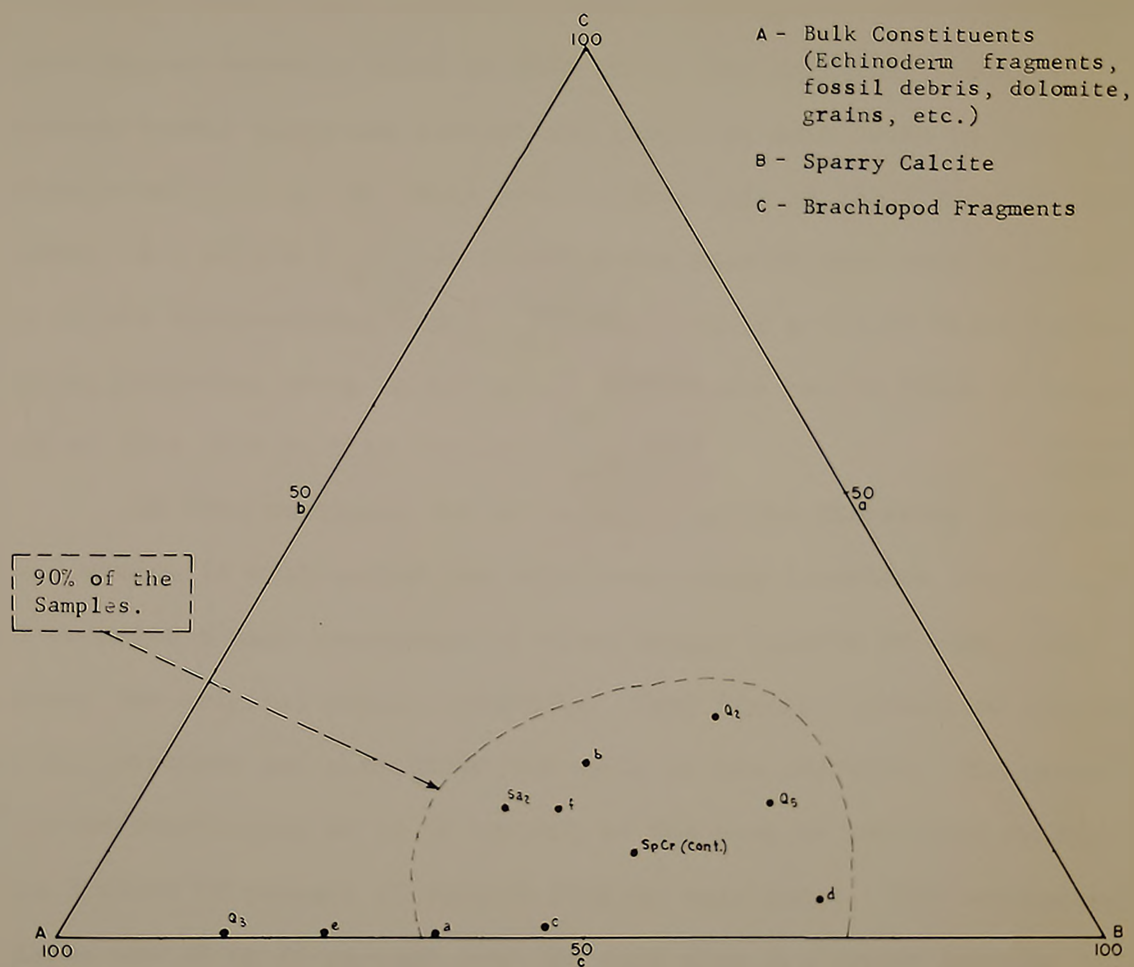


Fig. 3: Ternary diagram showing the composition of the Lower Member of the Kimmswick Limestone in Missouri. (The symbols inside the diagram refer to the samples in Plate II).

and brachiopods are occasionally recognizable. Few layers and laminae of fragmental fossils are seen in this unit, especially in the lower part. Numerous cavities, ranging from microscopic size to as much as two inches across and partially to fully filled with clear crystalline calcite, are commonly found in this unit. The unit also contains several widely scattered streaks and specks of dark brown to black organic matter which are only seen in this unit of the Kimmswick Limestone. A thin chert zone occurs near the base of this unit at Locality 11 (Plate VI), Ste. Genevieve County, Missouri; a six to eight inches thick, yellowish brown to gray bentonitic shale bed is found at the top of this unit at this locality.

In thin sections, the Lower Member of the Kimmswick Limestone, as a whole, is well-sorted and relatively clean limestone (Plate VIII). It contains a high percentage of clear sparry calcite as overgrowth around the original fossil fragments. Very finely crystalline calcite fills fractures and also lines the walls of the cavities. The sparry calcite constitutes 40 to 50 percent of the rock as indicated in Figure 3 where 90 percent of samples fall in this range. The echinoderm plates are 20 to 25 percent near the base with decreasing amounts toward the top of the unit. Brachiopods constitute from 10 to 15 percent of the rock (Figure 3). Locally a trace of dolomite is found in some of the thin sections, especially those from near the basal contact of the unit with the underlying Decorah Formation. Most of the dolomite seen in the sections is in the fractures and in the

KIMMSWICK LIMESTONE

MIDDLE MEMBER

LOWER MEMBER

Plate IX Photomicrograph of thin section (f), showing the proposed boundary between the Lower and the Middle members of the Kimmswick Limestone at Locality 3. The characteristic lithologic differences of the two members are evident in this thin section, (32x).

Figure 1 Q_6

Figure 2 Q_5

Plate X Photomicrographs of thin sections Q_5 and Q_6 collected from the horizons one foot apart at Locality 1. Figure 1 shows the lithology of the Middle Member of the Kimmswick above, and Figure 2 shows the lithology of the Lower Member below the proposed contact between the two members, (12.5x).

intergranular spaces (Plate VII). The insoluble residue is in insignificant amount and consists of a very small amount of crystalline quartz grains and a trace of silicified fossil fragments.

The best and thickest exposures of the Lower Member of the Kimmswick in Missouri are found in localities 1, 2, 3, and 4 in Ralls and Pike counties. It is about fifteen feet thick in localities 1, 2, and 3; but may be thinner in Locality 4 in Pike County, Missouri. It shows a general depositional thinning in southeasterly direction and is absent in localities 5, 6, and 7, in St. Louis County (Figure 5). A three-foot ten inch bed of this unit is found in Locality 11, Ste. Genevieve County, Missouri. Although the Lower Member has not been definitely identified at localities 8, 9, 10, and 12, there is a possibility that a few feet of this unit are present at these localities (Figure 5).

The basal contact of the Lower Member of the Kimmswick Limestone with the underlying Decorah Formation is distinctly exposed in localities 3, 4, and 11, (Plate VI). It is covered in localities 1 and 2. The upper boundary of this unit is drawn at the bentonitic shale bed in Locality 11 in Ste. Genevieve County (Plate XI) for the reasons that the bentonitic shale bed provides a good marker between the Lower and Middle members, and that the Kimmswick strata below this shale bed at this locality are lithologically very similar to those assigned to the Lower Member in localities 1, 2, 3, and 4, in northeastern Missouri. In localities 1, 2, 3, and 4, where no such

P Plate XI The upper and lower contacts of the Lower Member of the Kimmswick Limestone at Locality 11, Menefee Quarry, at Brickeys Landing, SW$\frac{1}{4}$, NW$\frac{1}{4}$, Section 24, T. 39 N., R. 7 E., Ste. Genevieve County, Missouri.

bentonitic shale bed is present, the boundary has been drawn on the top of the zone consisting of about 60 percent of sparry calcite, which indicates a change in the conditions of the deposition. This is clearly seen from the photographs of the thin sections of samples f (Locality 3, Plate IX), Q_5, and Q_6 (Locality 1, Plate X). These photographs show a sudden change in the grain size, sorting, and the constituents of the limestone at these horizons, and the contact between the Lower and Middle Members of the Kimmswick has been drawn at this horizon. Other factors justifying this top in the surface exposure were cessation of the dark brown to black streaks and specks of organic matter at this horizon, and a conspicuous absence of the calcite filled cavities in the higher beds. Also a change in the grain size and better sorting character of the grains at this horizon in thin sections, compared to the horizon lying above, was used to draw such a boundary (Plate VI).

Middle Member - The Middle Member of the Kimmswick Limestone, as defined here consists of buff to white-gray, medium- to fine-grained, medium- to massive-bedded, locally cavernous limestone with abundant fossil fragments distributed throughout the unit. A few layers and laminae of fragmental fossils are occasionally found in this unit. Calcite-filled cavities are found but are not as common as in the Lower Member of the Kimmswick. The most conspicuous character of the Middle Member is the presence of several zones of nodular chert distributed throughout this unit, especially in the outcrops in

St. Louis County and in Ste. Genevieve County, Missouri (localities 8, 9, 10, and 11, Plate VI). The chert is generally chalcedonic and is white, gray, pink, and occasionally smoke-colored. The nodules vary from very small to as much as six inches across. Receptaculites oweni Hall occurs throughout the unit, but is more common in the middle part. In the Cape Girardeau and vicinity this unit is cross-bedded and abundant with crinoidal debris. Styolites are commonly seen in the unit. The top of this unit is marked by a one and one-half to eight inch thick bentonite shale bed, which is persistently exposed throughout the area.

In thin sections this unit shows finer grain size than the underlying Lower Member and also has a relatively greater concentration of unidentifiable fossil debris, which constitutes from 50 to 70 percent of the rock (Plate XII). About 10 percent of sparry calcite is found in the rock (Figure 4), and the porosity is from a trace to 5 percent. The brachiopod fragments average 5 to 10 percent of the rock (Figure 4). The beds near the top of the Middle Member show higher concentrations (about 30 percent) of clean sparry calcite (Figure 4), and appear better sorted than the rest of the unit. Widely scattered dolomite grains occur in the thin sections, especially near the base and the top of the unit. The insoluble residue is noticeably higher than in the Lower Member and consists of chert grains, a few small grains of crystalline quartz, and a trace of silicified fossil fragments.

Plate XII Photomicrograph of a representative thin section (E_2) of the Middle Member of the Kimmswick Limestone; note the heavy concentration of very fine-grained organic debris (32x).

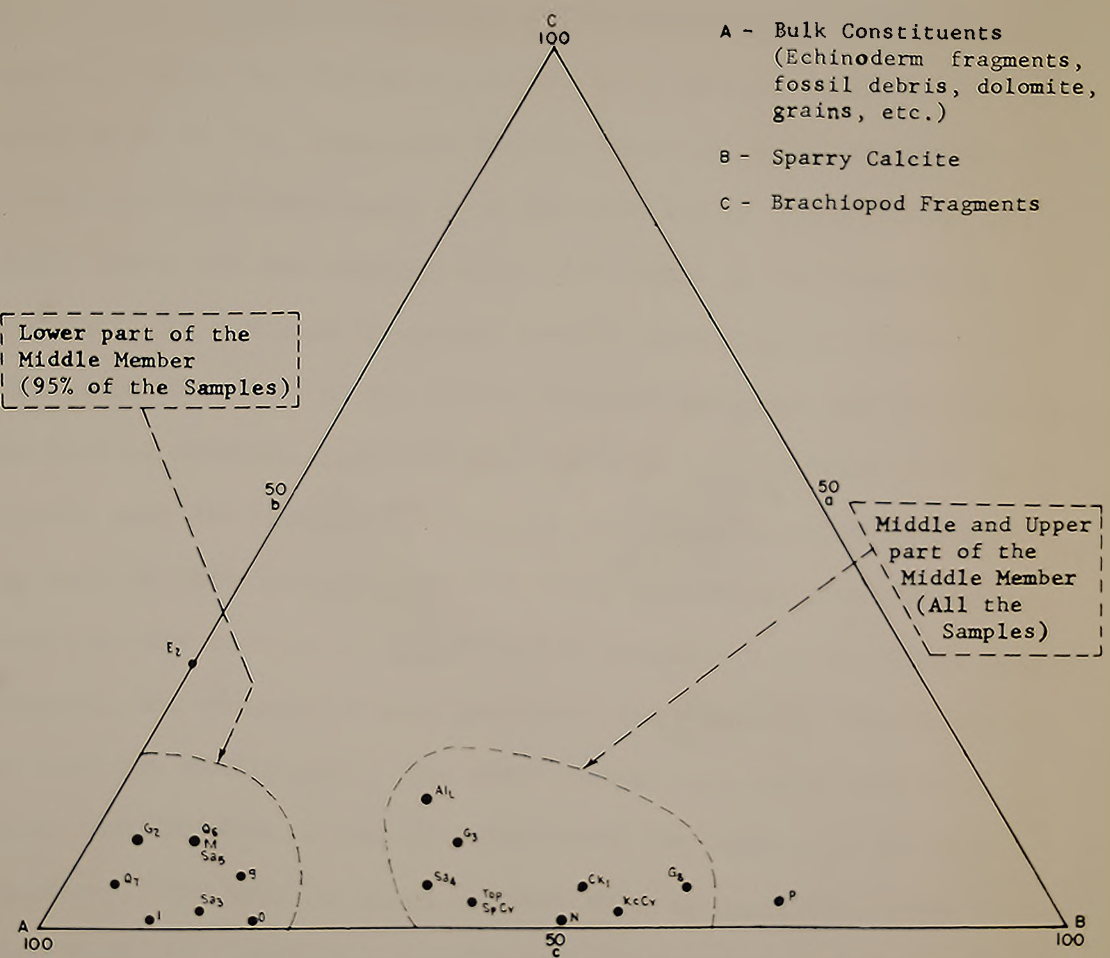
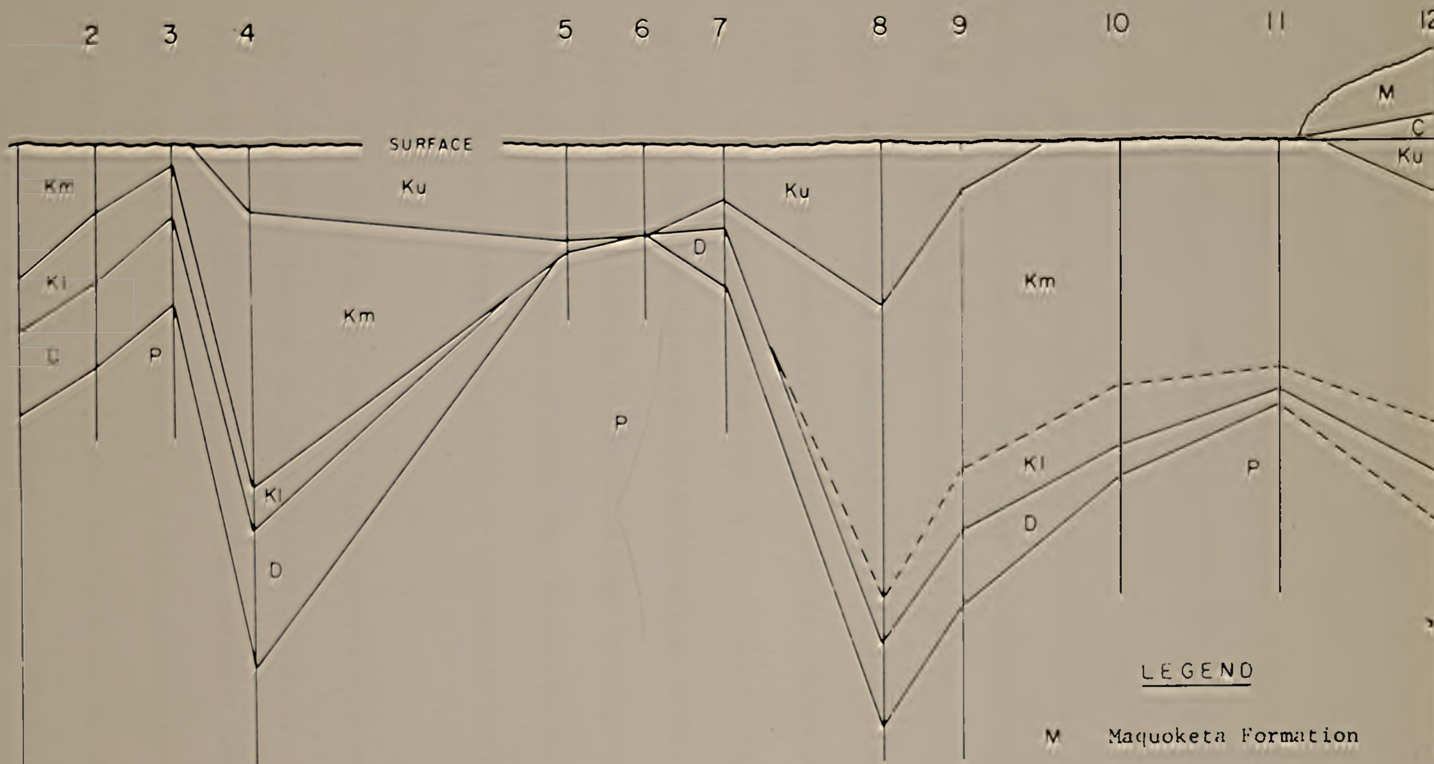


Fig. 4: Ternary diagram showing the composition of the Middle Member of the Kimmswick Limestone in Missouri. (The symbols inside the diagram refer to the samples in Plate II).

The Middle Member of the Kimmswick Limestone is best exposed at Locality 10 in Jefferson County, Missouri, which is in the type area of the Kimmswick. Here the unit is about 62 feet thick although its base is not exposed. The section contains at least four prominent nodular chert zones ranging from one to three feet in thickness as shown in Plate VI. The unit persists as a 56-foot thick limestone at Locality 11 in Ste. Genevieve County, Missouri, where it contains several nodular chert bands in a six-foot bed of limestone in the middle part, and two similar thin chert bands in the lower part. Southward, in the Cape Girardeau section (Locality 12, Plate VI), only about five feet of the Middle Member is exposed and the base of the unit is covered; however, an additional 60-foot thick unit is exposed near the bridge about one-half mile southeast of Locality 12. The unit at this locality is chert free. Northward from its type locality, the unit is 70 feet thick at Locality 9 in St. Louis Cpunty, Missouri, and contains a very prominent chert zone in the limestone bed near its middle part. The chert ranges from small pebble to almost boulder size, a few of which cross the bedding plane of the limestone. The unit is about 65 feet thick at Locality 8 near Babler State Park, St. Louis County, Missouri (Plate VI), and again contains an eleven-foot thick chert zone starting at the quarry floor upward. The character of the chert nodules and bands is similar to those at Locality 8 described above. Farther northward the unit is extremely thin, being only five feet thick at Locality 7, one foot eight inches



VERTICAL SCALE
1": 40 FEET

Fig. 5: Sketch Map Showing Thickness Distribution of the Kimmswick Limestone in Missouri Outcrops (Numbers Refer to the Localities in Plate VI).

LEGEND

M	Maquoketa Formation
C	Cape Limestone
Ku	Upper Member of the Kimmswick Limestone
Km	Middle Member of the Kimmswick Limestone
Kl	Lower Member of the Kimmswick Limestone
D	Decorah Formation
P	Plattin Limestone

at Locality 5, and is absent at Locality 6, in St. Louis County, Missouri (Plate VI). Northward from the above localities the Middle Member is about 66 feet thick at Locality 4 in Pike County, Missouri, but due to erosion it is only 32 feet thick at Locality 1, twenty feet at Locality 2, and twelve feet at Locality 3 in Ralls County, Missouri (Figure 5).

The bentonitic shale bed, which marks the top of the Middle Member of the Kimmswick Limestone in Missouri, is thickest at Locality 8 near Babler State Park, St. Louis County where it is eight to eleven inches thick. It thins to about six inches at Locality 7 and is only one and one-half to two inches thick at Locality 5. Southward in the Cape Girardeau section it is only one-half to one inch thick. Northward, in the Lincoln Anticlinorium area, this shale bed is exposed only at Locality 4 in Galloway Quarry, near Frankford, Pike County, Missouri, and is only two to three inches thick. It is absent in all other outcrop localities primarily because of removal by erosion.

The Middle Member of the Kimmswick Limestone in Missouri overlies the Lower Member at localities 1, 2, 3, in Ralls County, and Locality 4 in Pike County, but the contact between these two units is very difficult to determine in the outcrop sections. However, the lithologic differences between the two units as described above (p. 51) can be used to draw the boundary line between the two.

The ternary diagram (Figure 4) shows about 90 percent of the samples collected from near the base of the Middle Member fall in the lower sparry calcite range (about 10 percent). This suggests a definite change in the conditions of deposition from the Lower Member to the Middle Member (PlatesIX and X sample f, Q_5, and Q_6, pp. 47 and 48). The top of the Middle Member is very distinctly marked by the presence of the bentonitic shale bed described before. In thin sections, the beds near the top of the Middle Member show higher concentrations of sparry calcite and higher porosities than the rest of the unit. The top can be approximately placed near these beds in absence of the shale beds when used with the other lithologic characters described above. South and southeastward from Ralls County, Missouri, the Middle Member directly overlies the Decorah Formation in all the localities as shown in Plate VI, with the exception of the Locality 6 in St. Louis County, where it is absent.

Upper Member - All the beds of the Kimmswick Limestone in Missouri above the bentonitic shale bed at the top of the Middle Member, are here designated the Upper Member of the Kimmswick. This unit consists of light brownish, buff or gray colored, very coarse-grained, massive-bedded limestone, rich in fragmental fossils. These fragmental fossils occasionally occur as laminae. *Receptaculites oweni* is present in the unit but is not as common as in the Middle Member. The unit is generally chert-free, but two thin chert bands occur near the base and a one-foot six inch zone occurs near the top at Locality 9 in St. Louis

County, Missouri. The chert is similar to those in the Middle Member but is very much smaller in size. In the Cape Girardeau section (Locality 12, Plate VI) the unit shows cross-bedding and contains abundant crinoidal fragments.

In thin sections this unit shows a higher concentration of clear sparry calcite, mostly as overgrowth around the original fossil fragments, and is coarser grained than the underlying Middle Member (Plate XIII). It also shows better sorting of the grains than the underlying unit. The sparry calcite constitutes from 40 to 50 percent of the rock with brachiopod fragments making up to 15 to 20 percent. Echinoderm plates average about 30 percent of the total constituents. Although unidentifiable fossil debris is minor, being only up to 10 percent, locally as much as 70 percent have been found (Locality 5 Plate VI). The porosity varies from a trace to 2 percent. No chert or dolomite grains occur in this unit. The insoluble residue is very insignificant in amount and consists of a few grains of fine crystalline quartz and rare silicified fossil fragments.

The Upper Member of the Kimmswick Limestone has been eroded in most of the area and is seen only as remnants in Localities 5, 6, 7, and 8 in St. Louis County, and at Locality 4 in Pike County, Missouri (Plate VI and Figure 5). Southeastward at Cape Girardeau section, it is present as a thin unit. The maximum exposed thickness of this member is at Locality 8, where it is about 40 feet thick. It thins to about 25 feet at Locality 9, 23 feet at Locality 5, 22 feet

Plate XIII Photomicrograph of a representative thin section (Al_L) of the Upper Member of the Kimmswick Limestone (32x).

at Locality 6, and fourteen feet at Locality 7 (Plate VI). Northward in Pike County, at Locality 4, it is only about fourteen feet. In the Cape Girardeau section the Middle Member is only about twelve feet (Plate VI, Locality 12). It is absent in Localities 1, 2, 3, 10, and 11 because of its removal by erosion (Plate VI and Figure 5).

The Upper Member of the Kimmswick Limestone overlies the Middle Member at Localities 4, 5, 7, 8, 9, and 12 (Plate VI). At Locality 6, where the Middle and Lower members of the Kimmswick and the Decorah Formation are absent, the Upper Member directly overlies the Plattin Limestone. In the Cape Girardeau section, the Upper Member is conformably overlain by the Cape Limestone. A very thin (one and one-half inch) bentonitic shale bed occurs between the two. The Bushberg Sandstone of Devonian or Mississippian age unconformably overlies the Upper Member of the Kimmswick Limestone at Localities 8 and 9 in St. Louis County. The Glen Park Limestone of Mississippian age overlies the Upper Member of the Kimmswick at Locality 7. At Locality 6 this unit is overlain by Mississippian chert residuum. The Upper Member of the Kimmswick Limestone at Locality 4 in Pike County, Missouri is overlain by chert residuum of probable Mississippian age with possible Maquoketa Formation in between, but the Maquoketa is not exposed. At Locality 10 the Bushberg Sandstone of Devonian or Mississippian age overlies the Middle Member of the Kimmswick Limestone. At Locality 11 in Ste. Genevieve County, thin beds of Devonian shale overlie the Middle Member of the Kimmswick, since the Upper Member is also absent here. In other localities the Kimmswick Limestone is exposed at the surface with a soil cover only.

In summary, the following features characterize the three members of the Kimmswick Limestone in Missouri:

1. The Lower Member is characterized by its:
   a. coarse-grained texture, rare chert content, common occurrence of black streaks and specks of organic matter, and fully to partially filled vugs with clear calcite crystals up to two-inches in size,
   b. coarse-grained texture, and well sorted nature in thin sections, and 20 to 25 percent echinoderm fragments, 10 to 15 percent brachiopod fragments, and 40 to 50 percent sparry calcite content,
   c. porosity range from 5 to 10 percent,
   d. very insignificant amount of insoluble residue contents consisting of a few small grains of crystalline quartz and a trace of silicified fossil fragments.
2. The Middle Member is characterized by its:
   a. medium- to coarse-grained texture, considerably higher chert content, and common occurrence of _Receptaculites oweni_ Hall throughout the unit,
   b. rather fine-grained texture, poorly sorted nature in thin sections, and 50 to 70 percent fossil debris, 5 to 10 percent brachiopod fragments, and up to 10 percent sparry calcite content,

c. porosity range from a trace to 5 percent.

d. considerably higher insoluble residue content than in the Lower Member, consisting of chert fragments, a few small grains of crystalline quartz, and a trace of silicified fossil fragments.

3. The Upper Member is characterized by its:

a. coarse-grained texture, rare chert content, prominent cross-bedding, and considerable amount of crinoidal debris, especially in southeastern Missouri outcrops,

b. coarse-grained texture, well sorted nature in thin sections, and up to 30 percent echinoderm fragments, 15 to 20 percent brachiopod fragments, and 40 to 50 percent sparry calcite content,

c. porosity range from a trace to 2 percent,

d. very insignificant insoluble residue content consisting of a few small grains of crystalline quartz, and a trace of silicified fossil fragments.

While it is evident that a three-fold division of the Kimmswick Limestone in Missouri, based on lithologic and petrographic characteristics in the surface exposures is possible, it may not be possible in the subsurface. Successful identification of beds of the Kimmswick in the subsurface in Missouri has been done by the Missouri Geological Survey by means of insoluble residue study. An insoluble residue study, conducted during the course of this study on 92 samples collected from the surface exposures of the Kimmswick, did not yield positive results. The amounts of the residues obtained were so insignificant that they could not be used in such correlation. The residue consisted of very minor amounts of small silicified fossil fragments and few quartz grains. While the formation may be identified by insoluble residue studies, it is concluded that a subdivision of the Kimmswick Limestone in the subsurface of Missouri is not possible either from these residues or lithology.

Cape Limestone

A brief mention of the Cape Limestone is warranted here because of its close lithologic similarity and uncertain stratigraphic relationship with the underlying Kimmswick Limestone. The type locality is the section on Main Street north of Broadway in Cape Girardeau, Missouri (Locality 12, Plate VI). The strata consist of dark to light gray, weathering to light brownish gray, coarse-grained, thin- to thick-bedded limestone abundant with crinoidal debris and other fossil fragments. The unit is typically chert free, with a one and one-half inch thick bed of bentonitic shale at its base.

In thin section the sparry calcite constitutes about 20 percent of the rock; the echinoderm plates being about 60 percent, with about 5 percent of brachiopod fragments, (Plate XIV). The porosity is from a trace to about one percent. Considerable amount of limonite grains are seen distributed throughout the slide. The remainder of the rock

Plate XIV Photomicrograph of a representative thin section (CK_2) of the Cape Limestone from Cape Girardeau, Missouri (32x). l = limonite grains. e = echinoderm fragments.

consists of the unidentifiable fossil debris. No quartz or dolomite grains were noted in the rock. The rock on the whole appears well sorted.

The unit at this locality is only about eight feet thick and this is the thickest exposure found in the area (Figure 5). It is absent northward in all other localities covered in this study. It conformably overlies the Upper Member of the Kimmswick Limestone at this locality with a very thin (one and one-half inch) bentonitic shale bed between the two units, and in turn is unconformably overlain by the Maquoketa Formation (Plate VI).

Subdivisions of the Kimmswick Limestone in Illinois

The Kimmswick Limestone is the term used to designate the limestone facies of the Galena Formation in the southern one-third of the State of Illinois, in conjunction with the exposures of the Kimmswick Limestone in Missouri (Figure 1). Templeton and Willman (1963) designated the term Kimmswick as a Subgroup of the Galena Group in Illinois as mentioned before (p. 8). Their Kimmswick Subgroup consists of the Dunleith Formation below and the Wise Lake above. The usage of these two terms was extended by these authors to include "Equivalent, relatively pure dolomitic strata in northern Illinois instead of restricting it to the limestone facies" (p. 114). They further subdivided the Dunleith and the Wise Lake formations in several members to be applied to Illinois and Missouri sections as shown in the chart below.

<table>
<tr><td rowspan="12">GALENA GROUP</td><td colspan="4">Dubuque Formation</td></tr>
<tr><td rowspan="8">Kimmswick Subgroup</td><td rowspan="2" colspan="2">Wise Lake Formation</td><td>Stewartville Member</td></tr>
<tr><td>Sisinawa Member</td></tr>
<tr><td rowspan="6" colspan="2">DUNLEITH FORMATION</td><td>New London Member</td></tr>
<tr><td>Moredock Member</td></tr>
<tr><td>Eagle Point Member</td></tr>
<tr><td>Beecher Member</td></tr>
<tr><td>St. James Member</td></tr>
<tr><td>Buckhorn Member</td></tr>
<tr><td rowspan="3">Decorah Subgroup</td><td colspan="3">Guttenberg Formation</td></tr>
<tr><td colspan="3">Kings Lake Formation</td></tr>
<tr><td colspan="3">Spechts Ferry Formation</td></tr>
</table>

An examination of the exposures of the Kimmswick Limestone at the mouth of Dixon Hollow, about one and one-half miles northwest of Batchtown, Calhoun County, Illinois, revealed that the limestone here is very similar to those in the Missouri outcrops. It is richly abundant with fragmental fossils, *Receptaculites oweni* commonly occurring in the upper part. The thickness of the Kimmswick Limestone is about 40 feet and it overlies the Decorah Formation. The contact of the Kimmswick with the underlying Decorah Formation is very distinct and appears conformable. According to Templeton and Willman (1963), about twelve feet of Moredock Member is present and constitutes the uppermost beds of the Kimmswick, with about nine feet of Eagle Point, one and one-half feet of Beecher, and seven feet ten inches of the St. James members below it. From the correlation chart given on page 79 it is apparent that the Kimmswick here is represented by the Middle and the Lower Members of the Missouri outcrops.

Subdivisions of the Galena Formation in Illinois

The Galena Formation in its type locality near the town of Galena, Jo Daviess County, Illinois, consists of fine- to medium-grained dolomite, the lower half of which is cherty. A few thin shaly partings are present near the top and the base. The thickest section of the Galena Formation is exposed in the Mississippi River bluffs, about three miles south of Galena, where about 98 feet of dolomite rock is exposed. The next thickest exposures occur in the north bluff of East Fork, about three miles northeast of Galena, where the section is about 80 feet thick.

Templeton and Willman (1963) divided the "Galena Group" of Illinois into "Kimmswick Subgroup" and the underlying "Decorah Subgroup" based on lithologies. The uppermost beds of the Galena, which contain shaly beds, were designated Dubuque Formation, the Dubuque Member of the earlier classification. They also lowered the base of the Decorah Subgroup to include the "Spechts Ferry Formation" which was only a member of the Decorah Formation of the previous classification as noted on p. 14 of this thesis. The Prosser Member of the Galena Formation of the previous classification was replaced by the Wise Lake and the underlying Dunleith formations, which have been further subdivided into several members (Templeton and Willman, 1963). They recommended that the use of the term Kimmswick Limestone in Illinois be discontinued in favor of their Wise Lake and Dunleith formations.

The Galena Formation in Illinois overlies the Decorah Formation in the above localities and appears to be conformable. The upper contact of the Galena with the overlying Maquoketa Formation is sharp and unconformable, and traced southward, it truncates the older beds of the Galena Formation as the beds younger than the Dunleith Formation of Templeton and Willman are absent in the southern part of Illinois.

Subdivisions of the Galena Formation in Iowa

The Galena lithology in Iowa is very similar to that in Illinois. The strata consist uniformly of fine- to coarse-grained, buff colored dolomite. The lower part of these strata is cherty, consisting of light brown to light gray, medium- to coarse-grained, vuggy dolomite. Bands of chert nodules and large lenses of chert commonly occur in the lower part of the sequence. Locally a bentonite bed has been noted at the horizon normally represented by a shale parting near the base of this unit. The upper part of the Galena consists of fine- to coarse-grained, non-cherty dolomite, which is medium-bedded with few interbeds of shale above and massive near the base. The beds normally show a vuggy and anastomosing cavities as a result of weathering. A thin bentonite bed is found locally in the lower part of this unit; the upper part containing thin interbeds of platy dolomitic shale.

These two units were designated lower "Cherty Unit" and upper "Non-cherty Unit" by Agnew (1955) primarily to be used in the subsurface. However, a three-fold classification of the Galena, as shown in the chart below has generally been accepted for the surface exposures.

<table>
<tr><td rowspan="4">GALENA DOLOMITE</td><td rowspan="3">Non-Cherty Unit</td><td>Dubuque Member</td></tr>
<tr><td>Stewartville Member</td></tr>
<tr><td rowspan="2">Prosser Member</td></tr>
<tr><td>Cherty Unit</td></tr>
<tr><td rowspan="3">DECORAH FORMATION</td><td colspan="2">Ion Member</td></tr>
<tr><td colspan="2">Guttenberg Member</td></tr>
<tr><td colspan="2">Spechts Ferry Member</td></tr>
</table>

According to this classification the Galena Formation consists of the Prosser, Stewartville, and the Dubuque members in ascending order. The Prosser includes all the beds of the "Cherty Unit" and the lower beds of the "Non-cherty Unit." The top boundary of the Prosser is drawn near the base of the Upper Receptaculites zone, which marks the initial beds of the overlying Stewartville Member. Bentonite beds are found locally in the Stewartville beds. The top of the Stewartville Member is marked by the first strong shaly partings, which characterizes the overlying Dubuque Member. A change from very thick-bedded Stewartville to much thinner-bedded Dubuque strata is also diagnostic. Thin interbeds of platy dolomitic shale characterize the beds of the Dubuque Member, also the brachiopod Pseudolingula iowensis is commonly found in this member. The contact with the overlying Maquoketa Formation is regionally disconformable.

The identification of the Cherty and Non-cherty units of the Galena Formation in Iowa in the subsurface was readily recognized in the well cuttings examined during the course of this study. The three-fold subdivision applied to the surface sections cannot be used in the subsurface primarily because of the loss of details in the well cuttings.

STRATIGRAPHIC RELATIONSHIPS OF THE KIMMSWICK LIMESTONE IN MISSOURI

The Kimmswick Limestone, as designated in this study, includes all the strata that overlie the Decorah Formation and are in turn overlain by the Maquoketa Formation or Cape Limestone regionally. The Decorah Formation, as observed in the surface exposures, is represented by its uppermost beds, the Guttenberg Member (p. 14). In the surface exposures the upper contact of the Guttenberg Member with the overlying Kimmswick Limestone is regionally sharp and unconformable. This is seen in the exposures found at Localities 3 in Ralls County, (Plate XV), 4 in Pike County, (Plate XVI), 7 in St. Louis County, and 11 in Ste. Genevieve County, Missouri (Plate XI). Locally, the Kimmswick shows a six inches thick conglomeratic bed (Plate XV) at its base indicating an erosional contact. This is best observed at Locality 6 in St. Louis County, where a six inches thick conglomeratic bed occurs at the base of the Kimmswick Limestone. Here the Kimmswick directly overlies the Plattin Limestone and the Decorah is absent. The thickness of the Decorah, just a few miles east at Locality 7, is about four feet. Further east, at Locality 9, it is about seventeen feet. This variance in thickness of the Decorah and the occurrence of the conglomeratic bed suggests an erosional unconformity between the Kimmswick Limestone and the Decorah Formation, in Missouri. This is also indicated by a local thinning of the Decorah Formation in the subsurface in Illinois well numbers 47, 48, 50, and 60 (Plate XXI). However, in the subsurface the Kimmswick-Decorah contact appears disconformable throughout Missouri, Illinois, and Iowa, without much variation in the thickness of the Decorah (Plates XX and XXI). The data show a general thinning of the Decorah toward the northwest from the area of the Lincoln Anticlinorium into Iowa (Plate XX), and indicate slight unconformity at the base of the Kimmswick Limestone.

Kimmswick Limestone

Decorah Formation

Plate XV Decorah-Kimmswick contact at Locality 3, SE¼, NE¼, SE¼, Section 21, T. 55 N., R. 4 W., Ralls County, Missouri. (cgl = Conglomerate)

Plate XVI Decorah-Kimmswick contact at Locality 4, Galloway Quarry, Frankford SW¼, NE¼, SE¼, Section 2, T. 54 N., R. 4 W., Pike County, Missouri.

Thus it is evident that the Decorah-Kimmswick contact is disconformable regionally with local unconformities as noted above.

The Maquoketa Formation, which overlies the Kimmswick Limestone regionally, is poorly exposed in almost all of the surface exposures studied. In many areas it has been eroded off due to post-Maquoketa disturbances in the region. The Maquoketa is present, however, in the Cape Girardeau section where it unconformably overlies the Cape Limestone. The relationship of the Kimmswick and Cape limestones at this locality appears conformable since there is no major break between the two; also they both are similar lithologically. The Cape Limestone is absent in other localities and the Maquoketa unconformably overlies the uppermost beds of the Kimmswick Limestone. The unconformity at the top of the Kimmswick is very profound as suggested by the occurrences of shales and sandstones (Sulphur Springs Group) of Devonian or Mississippian age directly above the Kimmswick in most of the St. Louis County exposures, and also in the exposures of Jefferson and Ste. Genevieve counties, Missouri, (Plate VI).

In the subsurface the Maquoketa Formation generally unconformably overlies the Kimmswick Limestone with the exception of the area near the Ozark Dome where the Maquoketa is absent. of

Thus it is evident that the upper boundary of the Kimmswick is marked by a profound unconformity which persists throughout the area.

STRATIGRAPHIC CORRELATION

The Kimmswick Limestone of Missouri has been correlated with the Dunleith Formation of the Kimmswick Subgroup of Templeton and Willman (1963). The Lower Member of the Kimmswick correlates with the St. James Member based on the lithologic similarity and the presence of a bentonitic shale bed on its top at Locality 11 in Ste. Genevieve County, Missouri. This Member is also equivalent to the Ion Member of the Decorah Formation of Iowa, thus making the Decorah-Kimmswick contact correlative with the base of the Ion Member in Iowa. The Middle Member of the Kimmswick Limestone in Missouri is equivalent to the Moredock, Eagle Point, and Beecher members of the Dunleith Formation in Illinois by virtue of its high chert content and the occurrence of a persistent bentonitic shale bed on its top. These beds are the same as the "Cherty Unit" of the Prosser Member of the Galena Formation in Iowa. The Upper Member of the Kimmswick Limestone in Missouri, which includes all the beds above the bentonitic shale bed occurring at the top of the Middle Member, has been correlated with the New London Member of the Dunleith Formation for their lithologic similarity and stratigraphic position. The uppermost beds of the Dunleith Formation, and all the beds belonging to the Wise Lake and Dubuque formations of Illinois and Iowa sections, are absent in Missouri due to their removal by subsequent erosion. The profound unconformity at the top of the Kimmswick Limestone in Missouri coincides with the

Figure 1 CK_2 Cape Limestone, (Plate XVI is an enlargement).

Figure 2 CK_1 Upper Member of the Kimmswick Limestone, (R= Bryozoan Rhynidictya sp.).

Plate XVII Photomicrographs of thin sections (CK_2 and CK_1) from Cape Girardeau, Missouri showing their lithologic and textural similarities, (12.5x).

unconformity at the top of the Galena Formation in Illinois and Iowa. Thus the Kimmswick Limestone in Missouri correlates with the lower beds of the Galena Formation in Illinois and Iowa (Figure 6, p. 79).

The Cape Limestone, which overlies the Upper Member of the Kimmswick Limestone in the Cape Girardeau section (Locality 12, Plate VI), appears conformable and lithologically is very similar to it. It looks very similar to the Kimmswick Limestone not only in the surface exposure, but also in thin section; there is hardly any distinction between the two (Plate XVII) with the exception of occurrence of limonite grains in the former. Thus it seems quite logical to presume that, based on its lithologic similarity and the stratigraphic relationship with the Kimmswick, the Cape Limestone belongs to the uppermost Kimmswick Limestone, and is not the initial beds of the Cincinnatian Series as suggested by previous authors. However, the abundant occurrence of Lepidocyclus capax (Conrad) in the Cape Limestone at this locality contradicts the above presumption, since this fossil has been found to be restricted only to the middle beds of the Cincinnatian Series, (Twenhofel, et al, 1954) in the midcontinent region of the United States. As a result, the Cape Limestone has been included in the Cincinnatian Series in this study (Figure 6), however this correlation is still open to question.

The Correlation Chart in Figure 6 shows the relationships of the Cape and Kimmswick limestones of Missouri with the Maquoketa and Galena formation of Illinois and Iowa, respectively.

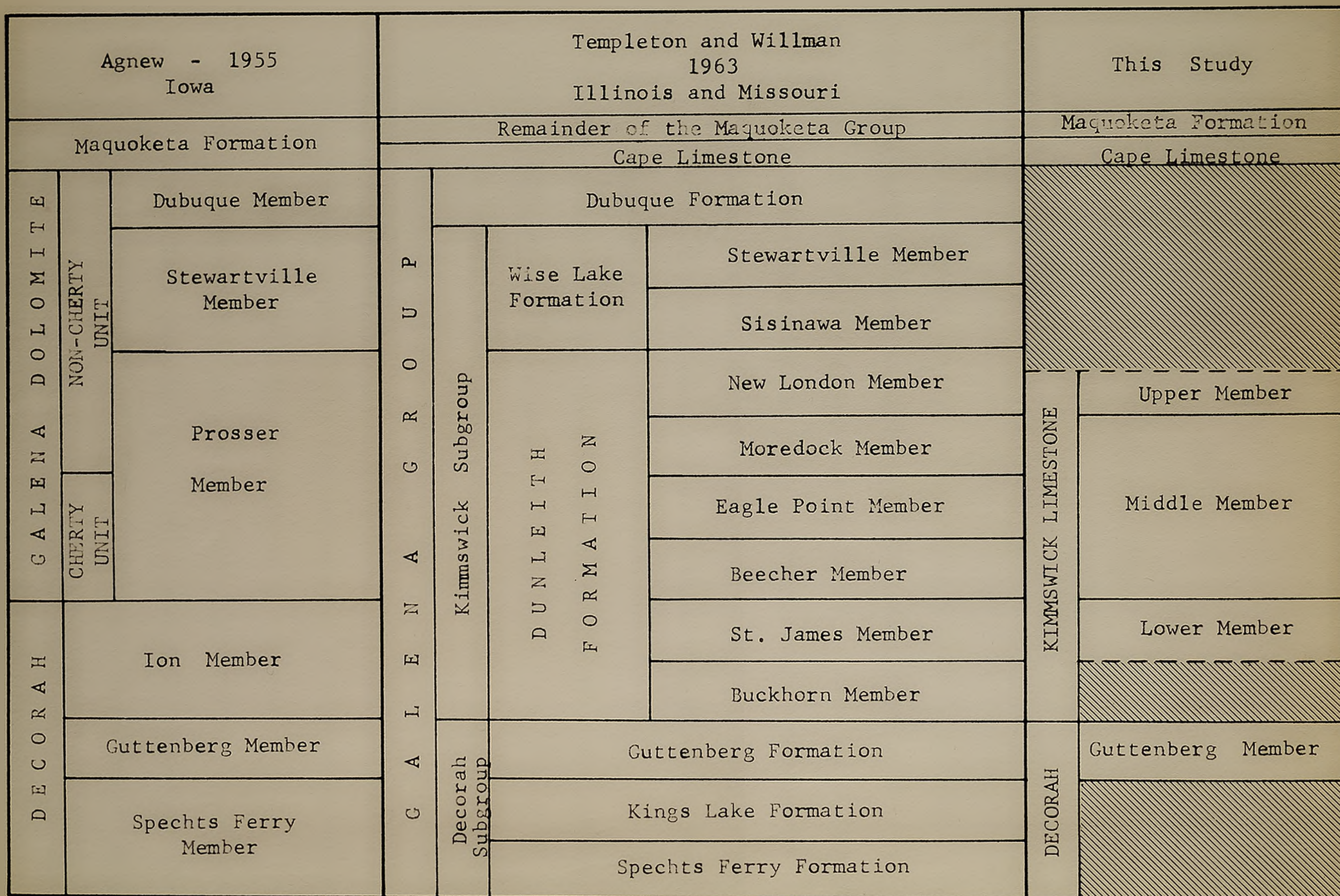


Fig. 6: Correlation chart of the Galena and Kimmswick formations in Missouri, Illinois, and Iowa.

CHAPTER IV

SUBSURFACE GEOLOGY

The subsurface study was based on data gathered from lithologic sample logs, well cuttings, and cores of the wells, kept in the files of the State Geological Surveys of Missouri, Illinois, and Iowa. All these data were utilized to achieve the following objectives:

1. To construct a subsurface structure contour map at the base of the Kimmswick and Galena formations in southeastern Iowa, western Illinois, and eastern Missouri in order to study the structural trends of these formations in the subsurface.
2. To construct an isopach map of the Kimmswick and Galena formations in the area.
3. To determine the nature of the lithologic variations of the Kimmswick and Galena formations and their relationship to the subsurface structural features, if any.
4. An interpretation of the environment of deposition of the Kimmswick and Galena formations in the area.
5. An appraisal of possible oil-bearing structures based on subsurface characteristics of existing oil fields producing from the Kimmswick and Galena formations in the area.

A brief review of the previous subsurface work done in the area is presented here. This is followed by a description of the methods used in gathering the data for this study and a discussion of the structures occurring at the base of the Kimmswick and/or Galena formations in the area under study. The last part of the chapter deals with a discussion of lithologic variations of the Kimmswick and/or Galena in the subsurface. The environment of deposition and the petroleum possibilities are discussed in Chapters VI and VII.

PREVIOUS WORK

One of the earliest works on the subsurface study in the Mississippi Valley area of Missouri and Illinois was that of Krey (1924). He used the base of the Burlington Limestone to draw a structure contour map and described the Lincoln fold as the major feature. He called it the Lincoln Anticline "because it reaches its greatest development in Lincoln County, Missouri," (p. 45). Another feature described by him was the Cap au Gres Fault, which "parallels the Lincoln fold and breaks it just south of the crest" (p. 46). The Pittsfield--Hadley Anticline in Illinois was so named by him because, "This fold attains its greatest prominence near Pittsfield in Pike County, Illinois" (p. 46). He also described the "Western Adams County Terrace near the center of T. 3 S., R. 7 W., Adams County, Illinois," as being "caused by the convergence of three distinct anticlinal areas." The general trend of this terrace "...is about north and south" (p. 46).

McQueen, et al (1941) and Rubey (1952) described the Lincoln fold in their studies as a broad asymmetrical anticline.

The Cap au Gres Fault derived its name from Cap au Gres Landing, Calhoun County, Illinois, on the Mississippi River (Keyes, 1894). Rubey (1952) described the east-west trending Cap au Gres Fault as a narrow band of steeply dipping rocks and discontinuous faults.

Grohskopf (1933 and 1941) determined from magnetic survey and subsurface studies in Missouri that the upthrown side of the Cap au Gres Fault is to the north and that the throw is approximately 1,100 feet.

Mateker (1956) working in the same area determined a throw of about 1,000 feet based on gravity work.

Cole (1962, p. 88), concluded "It seems possible... to conclude that the Cap au Gres is a left-lateral fault that has experienced movement of approximately 30 miles, offsetting the Lincoln fold and Dupo-Waterloo Anticline...."

Weller (1911) described the occurrence of Dupo-Waterloo Anticline in St. Clair and Monroe counties, Illinois. He mapped this feature as an asymmetrical anticline having a steeper west flank and striking N. 10° W.

SOURCE OF DATA

All the subsurface data were acquired from the records of the deep wells kept in the files of the Iowa, Illinois, and Missouri State Geological Surveys. The upper and lower contacts of the Kimmswick and/or Galena formations have been used as picked by these surveys, based on the lithologic character of these formations. The subsurface correlations of these formations in Iowa and Illinois are based solely on the lithology, whereas those of Missouri are partially substantiated by the insoluble residue studies. The top and the base of the Kimmswick and/or Galena formations for the purpose of this study have been accepted without question.

The surface elevations of the wells and the tops and bases of the Kimmswick and/or Galena formations were taken from the lithologic logs kept in the state surveys. A close examination of the well cuttings was made to ascertain the subsurface lithologies of these formations. Questionable surface elevations of the wells in Missouri were corrected by means of a Paulin altimeter.

A structure contour map was drawn at the base of the Kimmswick-Galena Formation (Plate XVIII). The base was used as a datum for the reasons that the top of this unit has been eroded and obscures the depositional history and its environment. An isopach map (Plate XIX) of the Kimmswick-Galena Formation was drawn in order to seek the relationship between the thickness of the strata and the structural pattern. This isopach map consists of the thicknesses of the strata occurring between the base of the Maquoketa Formation and the top of the Decorah Formation.

A list of the wells used in this study is given in Appendix B (Table 1) at the end of this thesis. The elevations of the base of the Kimmswick Formation, where exposed in the sections studied, were determined by use of a Paulin altimeter and these are shown on the map (Plate XVIII) with a letter "S" affixed to the number of such exposures as shown in Appendix B (Table 2).

Almost all the names of the structures described by previous authors have been retained. A few of these, however, have been used with slight modifications in this study. Several new structures, previously not described in print, have been named here and are so designated in the text.

STRUCTURAL FEATURES

Regionally the area under study is a part of the Central Stable Region (Eardley, 1962, p. 12; King, 1951, p. 3) of the North American continent. The Central Stable Region, which occupies the Midcontinent Region of the United States merges northward into the Canadian Shield and is bounded on the east and south by the orogenic belts of the Appalachian Mountains and the Ouachita Mountains, respectively. On the west side, this region is bounded by the Rocky Mountains and the Cordilleran orogenic belts.

The regional structural trend of the area is essentially northwesterly (Figure 7). This trend is almost parallel to the northeastern flank of the Ozark Dome. The regional dip in the northern area is toward the south and southeast and the dip in the southern area is toward the east and northeast. This regional dip is mainly controlled by two major structural elements occurring in the area, the Ozark Dome and Illinois Basin, which are briefly reviewed below.

Ozark Dome

The Ozark Dome is a broad, nearly circular, dome-shaped feature located in the southern part of Missouri and extending into the northern part of Arkansas. Its main core is located in the St. Francis Mountain area of southeastern Missouri, but several knobs of Precambrian crystalline rocks project through the Cambrian and Ordovician strata to the surface, peripheral to the St. Francis Mountain area. The Precambrian surface slopes rather steeply, but locally as much as 30 degrees of initial dip has been measured in the overlying Cambrian strata (Bridge and Dake, 1929).

Only the northeast portion of the Ozark Dome lies in the extreme southwestern corner of the thesis area in Howard, Boone, Callaway, Montgomery, Warren, Franklin, Jefferson, and possibly in Audrain counties in Missouri. Here the Kimmswick is absent and post-Ordovician rocks directly overlie the St. Peter Sandstone or older rocks. The northward and northwestward dips of the Kimmswick rocks, away from the portion of the Ozark Dome, are very gentle, but the eastward and southeastward dips are relatively steeper. The Kimmswick rocks, in Jefferson County, Missouri, dip off the flank of the Ozark Dome, 700 to 800 feet within a distance of eight to ten miles. The dome, in southeastern Missouri is flanked by the Devonian and

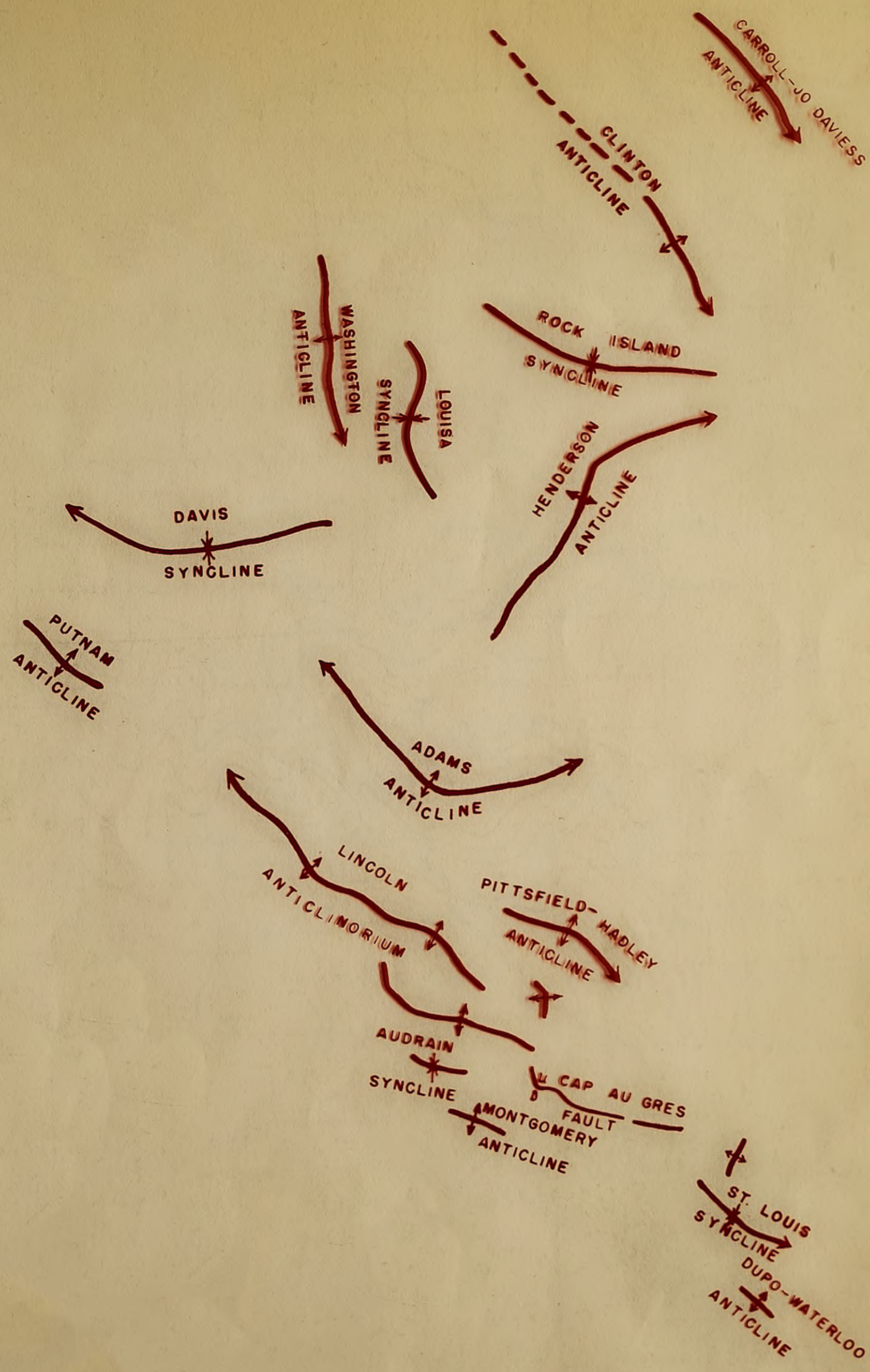
Mississippian limestones, which truncate the strata occurring between the St. Peter and Maquoketa formations. The Silurian System is thin to absent in the area except in southeastern Iowa and parts of western Illinois. The sediments are involved in complicated post-Mississippian folding and faulting in Ste. Genevieve and nearby counties in Missouri, (Weller and St. Clair, 1928).

Illinois Basin

Most of the state of Illinois lies within the Illinois Basin, a great structural feature that occurs between the Cincinnati Arch on the east, the Wisconsin Arch on the north, and the Ozark Dome on the west. Well data indicate that practically all the systems of rocks thicken considerably southward or southeastward toward the center of this basin. The estimated thickness of the strata in this basin is about 15,000 feet near the center of the basin, which lies roughly near the line between Wayne and Edwards counties, Illinois.

St. Louis Syncline (New Name)

The St. Louis Syncline is a northwest trending structure located in the northeastern part of St. Louis County, Missouri. It covers an area about 30 miles long along its axis and is about fifteen miles wide. The syncline plunges toward the southeast and contains about 100 feet of Kimmswick sediments underlain by the Decorah Formation and overlain by the Maquoketa Formation. The syncline, which



STRUCTURAL TRENDS AT THE BASE OF THE KIMSWICK-GALENA FORMATION

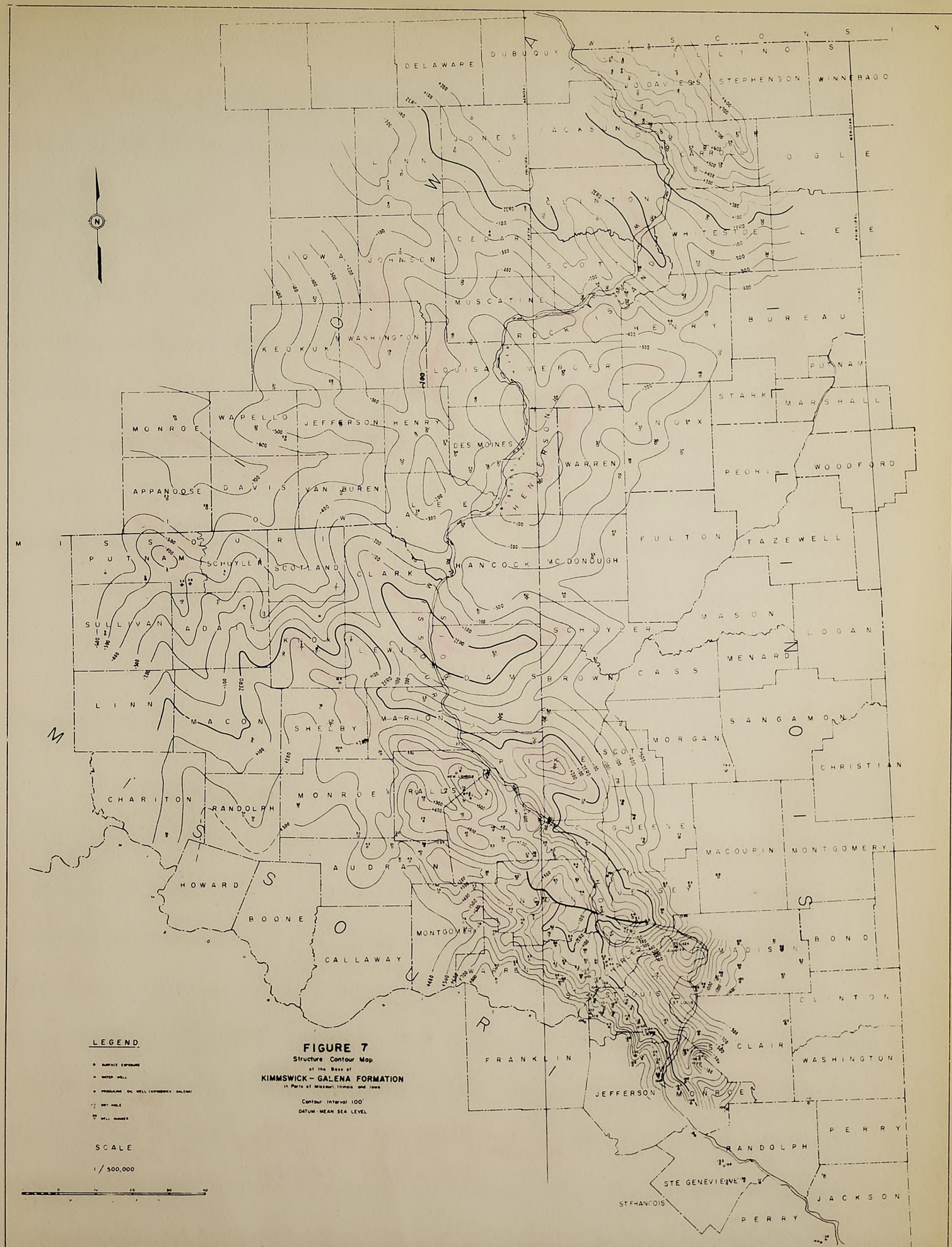


FIGURE 7
Structure Contour Map
of the Base of
KIMMSWICK – GALENA FORMATION
in Parts of Missouri, Illinois and Iowa

Contour Interval 100'
DATUM - MEAN SEA LEVEL

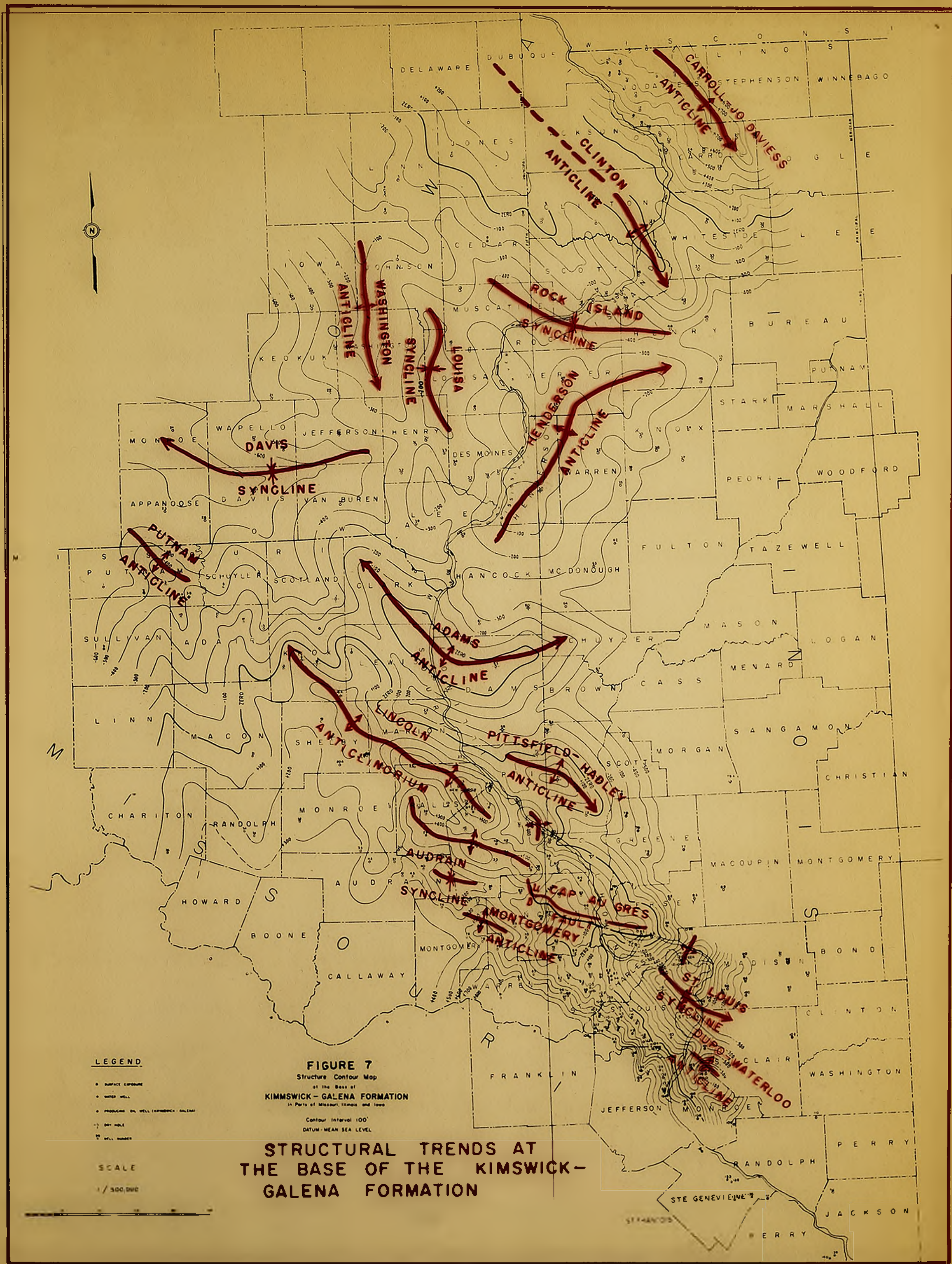


FIGURE 7
Structure Contour Map
of the Base of
KIMMSWICK - GALENA FORMATION
in Parts of Missouri, Illinois and Iowa
Contour Interval 100'
DATUM - MEAN SEA LEVEL

STRUCTURAL TRENDS AT THE BASE OF THE KIMSWICK-GALENA FORMATION is here named the St. Louis Syncline, seems to be a structural embayment of the Illinois Basin which lies to the east and southeast.

Florissant Dome

On the extreme northeastern edge of the St. Louis Syncline, is the Florissant Dome located about ten miles north of the city of St. Louis. It covers an area of only a few acres and has a closure on the Kimmswick of 25 to 75 feet. It is such a small structure that it could not be shown on Plate XVIII. It is an almost dome-shaped structure and according to McCracken (1956) is on the downthrown side of the Cap au Gres Fault, which runs in almost west-east direction, as described below.

Cap au Gres Fault

The Cap au Gres Fault is an almost east-southeast trending fracture, which is present on the surface in Pike, Lincoln, and Ralls counties of Missouri. It continues into Calhoun County, Illinois, where it appears only as a flexure and does not show the distinctive characteristics of a fault as in Missouri. The Cap au Gres Fault, with about 500 feet of throw on the Kimmswick Limestone (Plate XVIII), is almost vertical and probably reaches the basement rocks (Douthit, 1959). The upthrown block of the fault is toward the north and the downthrown block toward the south (Overlay, Figure 7). While it seems to be closely associated with the Lincoln Anticlinorium it does not seem to have affected the Dupo-Waterloo Anticline, as suggested by Cole (1962), for the reasons that the Florissant Dome and the St. Louis Syncline intervene between the fault and the Dupo-Waterloo Anticline (Overlay, Figure 7). The Dupo-Waterloo Anticline does not seem to extend to the fault and thus Cole's idea of its being a left-lateral fault does not seem to be well founded.

Dupo-Waterloo Anticline

Another north-northwest trending anticlinal structure appears on the extreme southeastern edge of the St. Louis Syncline in Monroe County, Illinois, and extends into Missouri across the Mississippi River up to the city of St. Louis (Fenneman, 1911). It occupies an area of about nine square miles and has a closure of about 150 feet. The thickness of the Kimmswick Limestone is of the order of 100 feet. The Kimmswick is overlain by the Maquoketa and younger formations.

Lincoln Anticlinorium

This structure has previously been referred to in literature as the Lincoln Fold, Lincoln High, and Lincoln Anticline. But the complexity and extent of this structure justify the usage of the term Lincoln Anticlinorium. It is a complex of several almost parallel to en echelon type of anticlinal folds occupying an area about 120 miles long and 50 miles wide, in northeastern Missouri, and extreme west-central Illinois along the Mississippi River (Overlay, Figure 7). It trends roughly in a northwest direction and plunges beneath the surface near the Missouri-Iowa state line. It is an almost symmetrical anticline with its crest lying near the Ralls and Pike County boundary line in Missouri. On the crest there is an indicated closure of 300 feet in an area of about 1,800 square miles. The Kimmswick shows a thickness of about 100 feet on the top of the structure and is thicker along its axis (Plate XIX). The northeastern flank is bounded by a structural low in Adams County, Illinois, and Clark and Lewis counties, Missouri, whereas the southwestern flank is separated from the Ozark Dome by the Audrain Syncline (discussed on p. 91) with the Cap au Gres Fault bounding a part of it.

The main structure is broken into two ridges parallel to each other, separated by a low sag. One of these is the crest described above and the other is a narrow ridge running slightly west of northwest in southwest Ralls and central Pike counties, Missouri with a closure of about 100 feet with 125 feet of Kimmswick on the crest (Overlay, Figure 7). A southeastward extension of this lies in northeastern Lincoln County, Missouri and a small extension is found in Calhoun County, Illinois. These extensions are bounded on the southwestern side by the similarly trending Cap au Gres Fault described before, with a throw of about 500 feet and the downthrown side on the southwest. The structure immediately against the fault shows a closure of 250 feet, and the Kimmswick is exposed on the surface. As the Kimmswick is traced toward the crest of the Lincoln Anticlinorium, it is found to be overlain by Maquoketa, Devonian, and Mississippian rocks in an ascending order.

Shelby Anticline (New Name)

A northwestward extension of the Lincoln Anticlinorium is found in Shelby County, Missouri, where it occupies an area about twenty miles long and five miles wide with a closure of about 100 feet. Here the Kimmswick is 125 to 150 feet thick in its crestal part and thins away from it in the subsurface (Plate XIX) under the cover of Pennsylvanian, Mississippian, and Maquoketa rocks, the Silurian rocks being absent.

Audrain Syncline (New Name)

A synclinal area, here called the Audrain Syncline and running parallel to the major fold of the Lincoln Anticlinorium, is found in the eastern part of Audrain County, Missouri and extends into the northwestern part of Lincoln County, Missouri. It occupies an area about 30 miles long and ten miles wide and appears as a closed syncline. The thickness of the Kimmswick Limestone is about 100 feet which decreases toward the southwest on the flanks of the Ozark Dome, (Plate XIX).

Montgomery Anticline (New Name)

A small anticline, here called the Montgomery Anticline, is found in eastern Montgomery County and extends into southwestern Lincoln County, Missouri, with its crest on the boundary line of these two counties. It occupies an area of about fifteen miles in length along its axis and about five miles in width with a possible closure of about 100 feet. It trends parallel to the Lincoln Anticlinorium and is closely related with it. The thickness of the Kimmswick Limestone is about 75 feet on its crest thinning to about 35 feet eastward.

<u>Putnam Anticline</u> (New Name)

A northwest trending anticlinal structure is found in the east-central part of Putnam County, Missouri. It occupies an area about twenty miles long along its axis and about ten miles wide and shows a closure of 100 feet. This may be a northwestward extension of the Lincoln Anticlinorium. The Kimmswick is 175 feet thick on its crest and thins outward from here (Plate XIX).

<u>Pittsfield-Hadley Anticline</u>

An anticlinal structure, very closely related to and running parallel to the Lincoln Anticlinorium, occurs in Pike County, Illinois and has previously been called the Pittsfield-Hadley Anticline (Krey, 1924, p. 46). It occupies an area of approximately 200 square miles and shows a closure of 200 feet on the Kimmswick. The Kimmswick is about 125 feet thick on its crest and thickens on its flanks (Plate XIX) under the cover of Mississippian, Devonian, and upper Ordovician (Maquoketa) rocks, Silurian rocks being absent.

Adams Anticline (New Name)

Another major anticlinal structure, in all probability related to the Lincoln Anticlinorium and running parallel to it, occupies an area about 70 miles long and twenty miles wide in south-central part of Clark and the northeastern part of Lewis counties, Missouri, and the central part of Adams County, Illinois (Overlay, Figure 7). From the south-central part of Clark County, Missouri through Lewis County, Missouri to the central part of Adams County, Illinois, it trends parallel to the Lincoln Anticlinorium, but from this point it swings toward the northeast and adopts a northeasterly trend up to the northeastern corner of Adams County, where it dies out. It is a symmetrical anticline doubly plunging northwestward and eastward. It shows a closure of about 50 feet; the Kimmswick is 100 feet thick on the structure. The slopes on both flanks of this anticline are very gentle as compared with that on the flanks of the main fold of the Lincoln Anticlinorium.

Henderson Anticline (New Name)

The Henderson Anticline is the name assigned to a major structural feature, most of which occupies Henderson County, Illinois and a minor part of which is found in Warren County, Illinois. It occupies an area approximately 80 miles long and 50 miles wide, trending in a north-northeasterly direction. The crest of this anticline lies in the northeastern part of Henderson County, Illinois and shows a closure of 200 feet. The eastern and southern flanks are much gentler than the western and northern flanks. It is separated from the Adams Anticline on the south side by a structural low and on the north side from the northwest trending high structure of eastern Iowa by a similar, structurally low area (Overlay, Figure 7). The Galena Formation is in the subsurface under the cover of the Maquoketa Formation and younger rocks and is thickest (235 feet) on the crest of the structure (Figure 8 and Plate XIX). The structure plunges in a northeasterly direction in Henry County, Illinois where it disappears under the sedimentary cover.

A northerly branch of the Henderson Anticline occurs in Des Moines County, and the southeastern part of Louisa County, Iowa. Another branch, toward the southwest in Lee County, Iowa, shows a closure of 100 feet. The Galena Formation is 200 feet thick on the top of the structure and thins on its flanks. A third branch occurs northeastward in extreme southeastern Mercer, extreme southwestern Henry, and extreme northwestern Knox counties, Illinois with a closure of 100 feet. The Galena is 150 feet thick on the structure and thins on its flanks (Plate XIX).

On each of the structures described above under the Henderson Anticline, the Galena Formation is dolomite and occurs beneath the cover of Pennsylvanian, Mississippian, Devonian, Silurian, and Ordovician (Maquoketa) rocks.

Louisa Syncline (New Name)

A north-south structure, here called the Louisa Syncline, occupies an area approximately 30 miles long and ten miles wide in western Louisa, extreme southeastern Johnson, and northeastern Henry counties, Iowa (Overlay, Figure 7). It is a closed and rather symmetrical syncline. The Galena Formation consists of 200 feet of dolomite in the central part of the structure and thins on its limbs.

Washington Anticline (New Name)

A south trending anticlinal nose occurs in western Johnson, northeastern Iowa, and central Washington counties, Iowa. The Galena Formation, which consists of dolomite, is 200 feet thick on the top of the structure but is slightly thinner southward (Plate XIX).

A branch of this structure, which trends southeastward, lies in northern and northeastern Johnson County, Iowa. The Galena Formation is 275 feet thick dolomite on the structure with a thinning on its southwestern flank and thickening on its northeastern flank (Plate XIX).

Clinton Anticline (New Name)

A northwest trending anticline, here called the Clinton Anticline (Figure 7), occurs in southeastern Clinton County, Iowa. It shows a probable southeast plunge and possible closure of 25 to 50 feet. The Galena Formation is 200 feet thick dolomite on the structure.

Carroll-Jo Daviess Anticline (New Name)

The name is given to the southeastward plunging, anticlinal structure which occupies Jo Daviess and Carroll counties, Illinois. The fold is very closely related to the Wisconsin Arch which lies farther north and probably represents an extreme southeastward extension of the Arch. The latter is a major tectonic feature in the Upper Mississippi River Valley area. It strikes N. 20° W. across central Wisconsin and extends into northwestern Illinois (Pirtle, 1932).

The Carroll-Jo Daviess Anticline of the map area is a symmetrical anticlinal nose which trends southeastward and disappears beneath the sedimentary cover just south of Carroll County, Illinois (Overlay, Figure 7). The Galena Formation is exposed at the surface on its crest. Here it is dolomite and has an exposed thickness of 75 to 200 feet (Plate XIX).

Rock Island Syncline (New Name)

A synclinal structure, here called the Rock Island Syncline because its center lies in Rock Island County, Illinois trends west to west-northwest in an area about 60 miles long and about 20 miles wide from Muscatine County, Iowa to Henry County, Illinois (Figure 7). It is a closed asymmetrical syncline with the northeast flank slightly steeper than the southwest flank. The thickness of the Galena Dolomite is about 225 feet in the central part of the syncline and thins toward the northeast and thickens toward the northwest, (Plate XIX).

Davis Syncline (New Name)

A major syncline, here called the Davis Syncline, occurs in Monroe, Davis, Appanoose, and Wapello counties in Iowa and extends eastward into Van Buren and Jefferson counties (Overlay, Figure 7). The name is given to this structure mainly because its center lies approximately in Davis County, Iowa. It occupies an area about 70 miles long and about 35 miles wide. It trends almost in a westerly direction and plunges toward the northwest. The Galena Dolomite is thinnest in the central part of the syncline (125 feet) and thickens all around it to about 200 feet (Plate XIX).

SUBSURFACE LITHOLOGIC RELATIONS OF KIMMSWICK-GALENA TO THE STRUCTURES

A close examination of the lithologic well logs and well cuttings of the Kimmswick and Galena formations indicates that the lithologic variations are independent of the structures in the subsurface. As shown in Plate XVIII all of the area north of the line C-C' is predominantly dolomite and the area to the south is limestone, with the exception of the area in Iowa (enclosed by solid line, Plate XVIII), where calcareous dolomite is found in the subsurface. The line C-C' roughly marks the zone along which the limestone of the south changes to dolomite in the north. This change takes place within a distance of four to five miles as ascertained from the available well-log data.

Dolomitic limestones belonging to the Kimmswick are also present in the subsurface in southeastern Missouri. Exceptions occur notably in Ste. Genevieve County where the dolomite seems to be associated locally with faults present in the area. However, no such relationship between the faults and the dolomite exists in the area on a regional scale. There is no evidence of large scale dolomitization near the Cap au Gres Fault where it should be most expected if the faulting and dolomitization were related on a regional scale. Similarly the largest structural feature, the Lincoln Anticlinorium, contains a limestone facies whereas the Henderson Anticline, a similar structure in Illinois, mainly contains a dolomite facies (Figure 8). All the anticlinal, as well as the synclinal areas, in Iowa primarily show dolomite facies without any regard to the nature of the structural trends in the area. Similarly in Missouri, the limestone facies of the Kimmswick occurs from the area of the Ozark Dome to the Lincoln Anticlinorium toward the north, and Illinois Basin toward the east, irrespective of the presence of anticlines or synclines in the area. In northern Illinois, the dolomite facies predominates throughout the area. This further suggests that the dolomitization has taken place without any control being exerted by local structures in the area.

A few limestone beds are partially dolomitized in the subsurface as well as in the surface exposures (localities 1 and 7, Plate VI) near the base of the Kimmswick. Here such horizons have been altered along the zone of the local unconformity near the base of the Kimmswick. Apparently such erosional surfaces offered easy access to magnesium-bearing solutions which locally altered the limestone to dolomite.

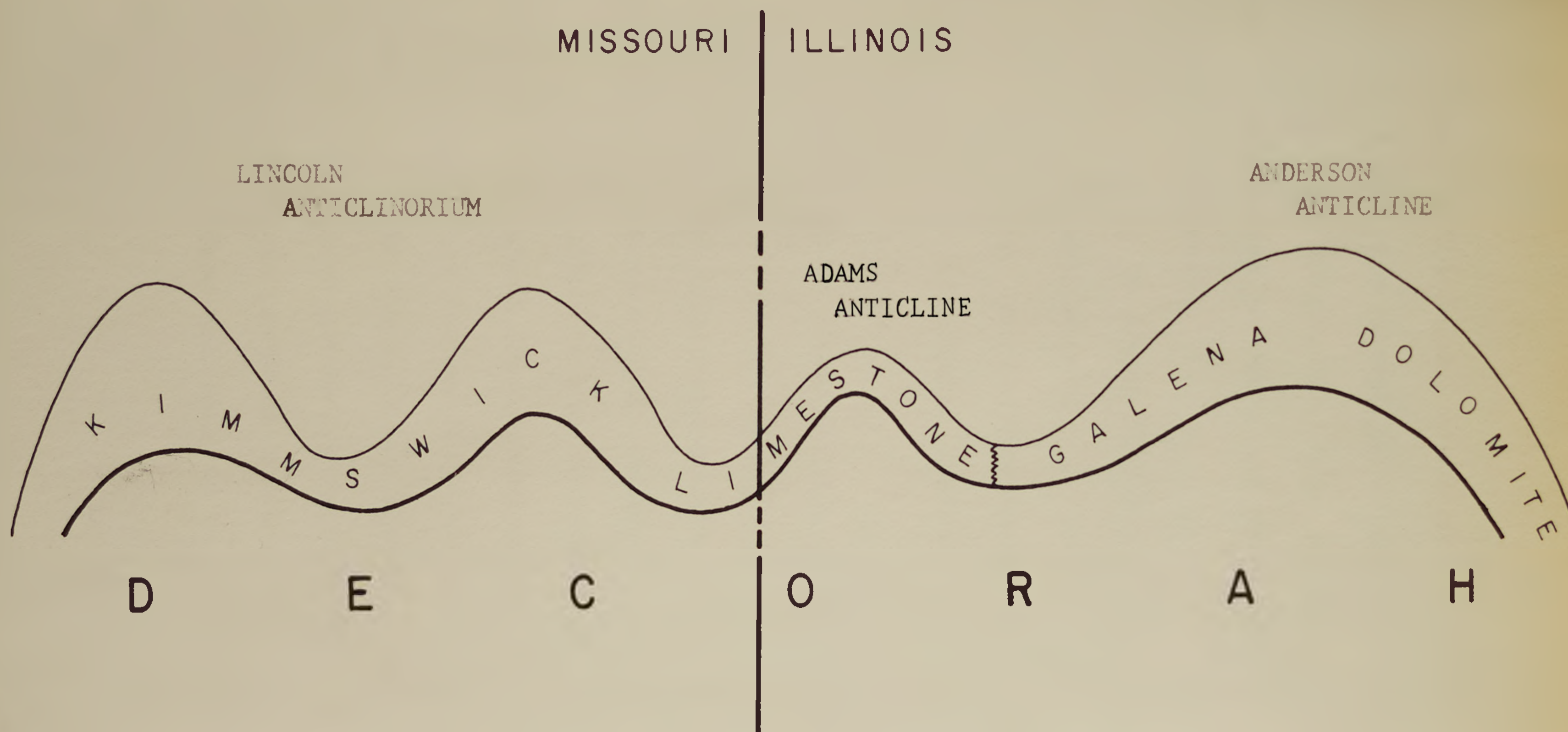


Fig. 8· Sketch map showing subsurface relations between thicknesses of the Kimmswick-Galena Formation and the structures from Lincoln Anticlinorium to the Henderson Anticline. A thickening of the strata is generally found on the crests of the anticlines, with the exception of the Adams Anticline. Thinning of the strata is common in the synclinal areas.

In Iowa the Galena rocks are predominantly dolomite in the subsurface with the exception of the area mentioned before (p. 98). Here again this slight change in facies from pure dolomite to calcareous dolomite does not show any relationship to the subsurface structures in the area.

According to Agnew (1955) a facies change in the Galena from dolomite to limestone occurs in Iowa from the eastern to the central part of the state, and farther westward it changes to limestone again. No major structural control seems to have affected the facies change in Iowa.

According to Rubey (1952), in northwestern Illinois the facies change from limestone to dolomite in the Galena Formation has been controlled by the Wisconsin uplift. No such similar relationship appears in the area of this study.

In conclusion it can be said that the limestone facies of the Kimmswick and Galena formations seem to lie on the flank of the Ozark Dome and extend as far north as the area of the Lincoln Anticlinorium and eastward into the Illinois Basin. Further north from this area, the dolomite facies predominates with the exception of the calcareous dolomite facies in parts of southeastern Iowa. The distribution of the two facies does not seem to be related to structures in the area.

CHAPTER V

GEOLOGIC HISTORY

This chapter deals mainly with the geologic history of the area under study during Kimmswick-Galena time. An account of the geologic conditions during pre-Kimmswick-Galena time and the changes that took place after Kimmswick-Galena time, has also been included. Most of the pre-Kimmswick-Galena history discussed here is based on the observations of other authors. The history of the area during and after Kimmswick-Galena time is largely based on the inferences drawn from this study.

Since post-Kimmswick-Galena tectonic movements have obscured the paleogeographic conditions of the land and the sea which originally prevailed in the area, the use of the structure contour map drawn at the base of these formations is, by itself, not sufficient for recapitulating the history of the area during Kimmswick-Galena time. The isopach map of the Kimmswick-Galena (Figure 9), on the other hand, definitely demonstrates the relief conditions in the depositional basin during Kimmswick-Galena time. The interpretation of the geologic history of the area during this time is based on these observations.

Since the Ozark Dome, Wisconsin Arch, Canadian Shield, and the area of subsidence (Craton), covering Illinois, Iowa, and northern and eastern Missouri, were the most prominent tectonic elements which influenced the sedimentation and structural history of the area throughout Paleozoic time, a brief account of their geologic history is given in this chapter first. This is followed by an account of the geologic history of the area during pre-Kimmswick-Galena time. The last part of this chapter deals with the geologic history of the area during Kimmswick-Galena time and changes that occurred afterward.

REGIONAL TECTONIC ELEMENTS

Positive Elements

Ozark Dome - As indicated from the geologic record, the Ozark Dome started to rise slowly in the area of the St. Francis Mountains in southeastern Missouri sometime early in Cambrian or possibly in Precambrian time. However, it did not become a land area until the beginning of St. Peter time, since this is the first regionally unconformable break in the entire sequence of the carbonate strata belonging to Paleozoic Era. The widespread distribution, rather uniform thickness, and well sorted and well rounded character of the St. Peter Sandstone indicates that the uplift of the Ozark Dome was very gradual during this time. The Ozark Dome since then has remained rather stable throughout geologic time except for local encroachments of the sea on its flanks during Ordovician, Silurian, Devonian, and most of Mississippian times.

Wisconsin Arch - The Wisconsin Arch mainly occupies the area of central Wisconsin and extends southeastward into northwestern Illinois. The isopach maps of the existing thicknesses of the various formations or groups for the area of the Wisconsin Arch, (Ninth Annual Field Conference, Kansas Geological Society, 1935) suggest two pre-Devonian uplifts; the first preceded the deposition of the St. Peter Sandstone in early Ordovician time, and the second followed the deposition of the Silurian beds. Thus it seems that a major part of the Arch was submerged under the middle and late Ordovician seas and possibly under the Silurian seas. At the end of Silurian Period, and the beginning of the second uplift, which followed the deposition of the Silurian rocks, an arch was formed in central Wisconsin and extended southeastward to northwestern Illinois, (Figure 20, Ninth Annual Field Conference, Kansas Geological Society, 1935).

A pronounced dome appeared toward the end of Mississippian time and a broad arch appears to have extended southeastward from the area of the Wisconsin Arch to northwestern Illinois, which is now reflected in the Carroll-Jo Daviess Anticline of this study, (Figure 9).

Canadian Shield - That part of the Canadian Shield, which occupies northern Minnesota and extends southward into Wisconsin, consists of exposed Precambrian rocks, (Eardley, 1962, p. 22). These Precambrian rocks are overlapped successively by the Cambrian, Ordovician, Silurian, and Devonian rocks indicating that this part of the shield area was submerged under the seas of Paleozoic Era from time to time.

The thick sequences of carbonate rocks of Ordovician age near the southern margin of the Canadian Shield in Minnesota and Wisconsin suggest that the relief of the shield in this area was very gentle during Ordovician time. As a result, these chemical carbonate rocks were deposited in the Cratonic area of the shield.

Except for these minor fluctuations during the Paleozoic Era, the Canadian Shield has remained rather stable throughout geologic time.

Negative Element

The negative tectonic element present in the area was a broad area of subsidence (Craton) which covered Illinois, Iowa, and north and eastern Missouri throughout Paleozoic time. This is clearly indicated by the occurrence of several thousand feet of strata belonging to the Cambrian through the Mississippian systems in the area. Several unconformities of regional nature are present in the Paleozoic section in the area, which indicate occasional fluctuations of the sea which covered this area. Tectonic movements of a major nature occurred toward the close of the Mississippian Period when this negative element was broken up and the Illinois Basin was formed as a separate basin (Weller, 1937). Deepening of the Illinois Basin and accentuation of the smaller structures continued in varying degrees throughout Pennsylvanian Period. The last important structural movement in the Illinois Basin occurred at the close of Paleozoic Era or possibly early in the Mesozoic (Weller, 1937). Minor encroachments of the seas occurred on the southern tip of the Illinois Basin during the Cretaceous, but the main basinal area itself was not affected by such movements of the seas.

PRE-KIMMSWICK-GALENA TIME

The geological history of the area during pre-Kimmswick-Galena time can be divided into two phases of tectonic movements, the first phase is the period of sedimentation between Precambrian and St. Peter time, the other phase dealing with the history from St. Peter to Kimmswick-Galena time.

Little is known about the history of the area previous to St. Peter time since few wells have been drilled through the Cambrian strata or to the Precambrian surface. However, a thickness map of the strata between the Precambrian surface and the St. Peter Sandstone drawn for northern Missouri and southern Iowa (Lee, 1954, Figure 9, p. 77) indicates that a deep "syncline" of northerly trend developed in the area extending from the Ozark Dome northward into Iowa between the time of deposition of the Cambrian strata and the St. Peter Sandstone. The thickness map drawn for the strata between the Precambrian and the top of the Roubidoux Sandstone for southern Missouri, in the same figure by Lee (*ibid*, p. 77) reveals the same structural pattern as in northern Missouri. This northerly trend seems to have been reversed sometime between St. Peter time and the beginning of Devonian as shown by the thickness map of the strata between the base of the

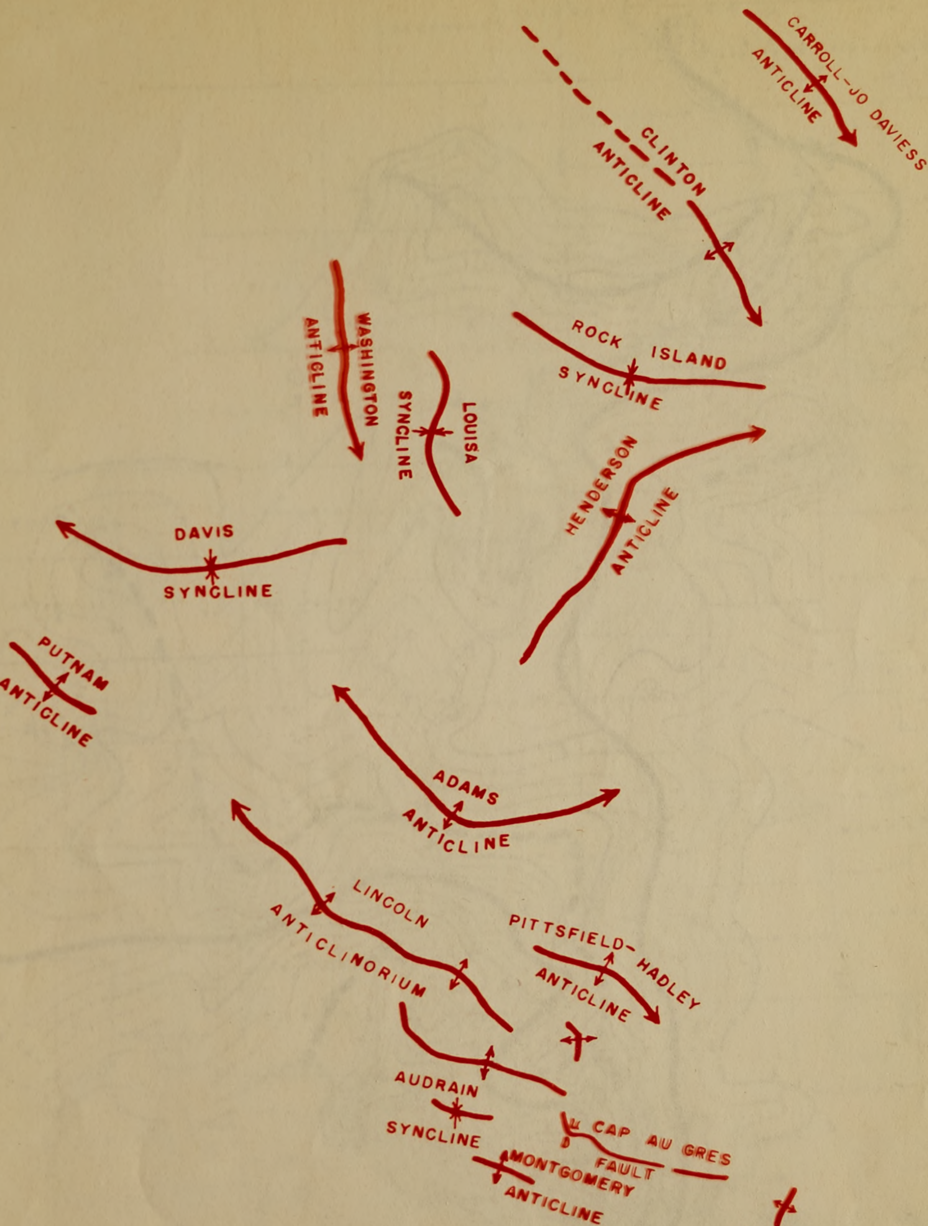
St. Peter Sandstone and the base of the Devonian limestones and dolomites (Lee, 1954, Figure 10, p. 79).

Two geologic cross-sections were drawn in this study; one along the strike of the Kimmswick-Galena Formation and the other at right angles to it in order to examine the subsurface structural and stratigraphic relations of the strata above the St. Peter Sandstone. Cross-section A-A' (Plate XX), parallel to the strike, and B-B' (Plate XXI) at right angles to it, reveal that sedimentation after St. Peter time continued over much of the area, with the exception of the Ozark Dome, without any major break until the end of Decorah time and possibly through Maquoketa time. The thicknesses of the strata between the St. Peter Sandstone and the Decorah Formation appear to be rather uniform over the area except in southeastern Missouri. Here the strata are very thick and suggest that a "syncline" (Lee, 1954) that developed before St. Peter time in that area persisted throughout post-St. Peter-pre-Decorah time. All these strata are thinner toward the north in northern Missouri, western Illinois, and southeastern Iowa. This suggests that this area had assumed a platform-like configuration since the end of St. Peter time and maintained it until the beginning of Decorah time, when thin but continuous sequences of strata belonging to the Joachim and Plattin were deposited.

The beginning of Decorah time was marked by a slow regional uplift of the area north and east of the Ozark Dome as indicated by highly clastic nature (shale) of the Decorah strata throughout the area. Decorah time was perhaps one of frequent fluctuation of sea level as indicated by the alternate beds of shale in the limestone sequence of the Decorah. Regionally the end of Decorah time seems to have been marked by a slight tilting of the Decorah surface northward from the area of the Ozark Dome. The Decorah beds tend to thin from north to south due to subsequent erosion. The absence of the Decorah strata at localities 5 and 6, St. Louis County, Missouri, (Plate VI) suggests that locally the Decorah strata were exposed to the surface, and were removed from the area by erosion. This land mass, in all probability, was connected with the main land mass of the Ozark Dome (Figure 10). Similar indications are implied from the subsurface data where the Decorah suddenly thins as seen in the wells numbered 47, 48, 50, and 60 in Illinois (Plate XXI). Thus the paleogeographic conditions of the area at the end of Decorah time were roughly as shown in Figure 10.

KIMMSWICK-GALENA TIME

The paleogeographic conditions existing in the area at the end of Decorah time (Figure 10) persisted in early Kimmswick-Galena time. This is especially indicated by the absence of the Lower Member of the Kimmswick in the same localities where the Decorah is absent or is very thin. The Lower Member of the Kimmswick Limestone is thickest in the area of the Lincoln Anticlinorium but thins south and southeastward. Also the beds equivalent to the Lower Member of the Kimmswick Limestone in Iowa and Illinois are not very well developed. Thus it appears that the main encroachment of the sea after Decorah time occurred at the



STRUCTURAL TRENDS AT
THE BASE OF THE KIMSWICK-
GALENA FORMATION

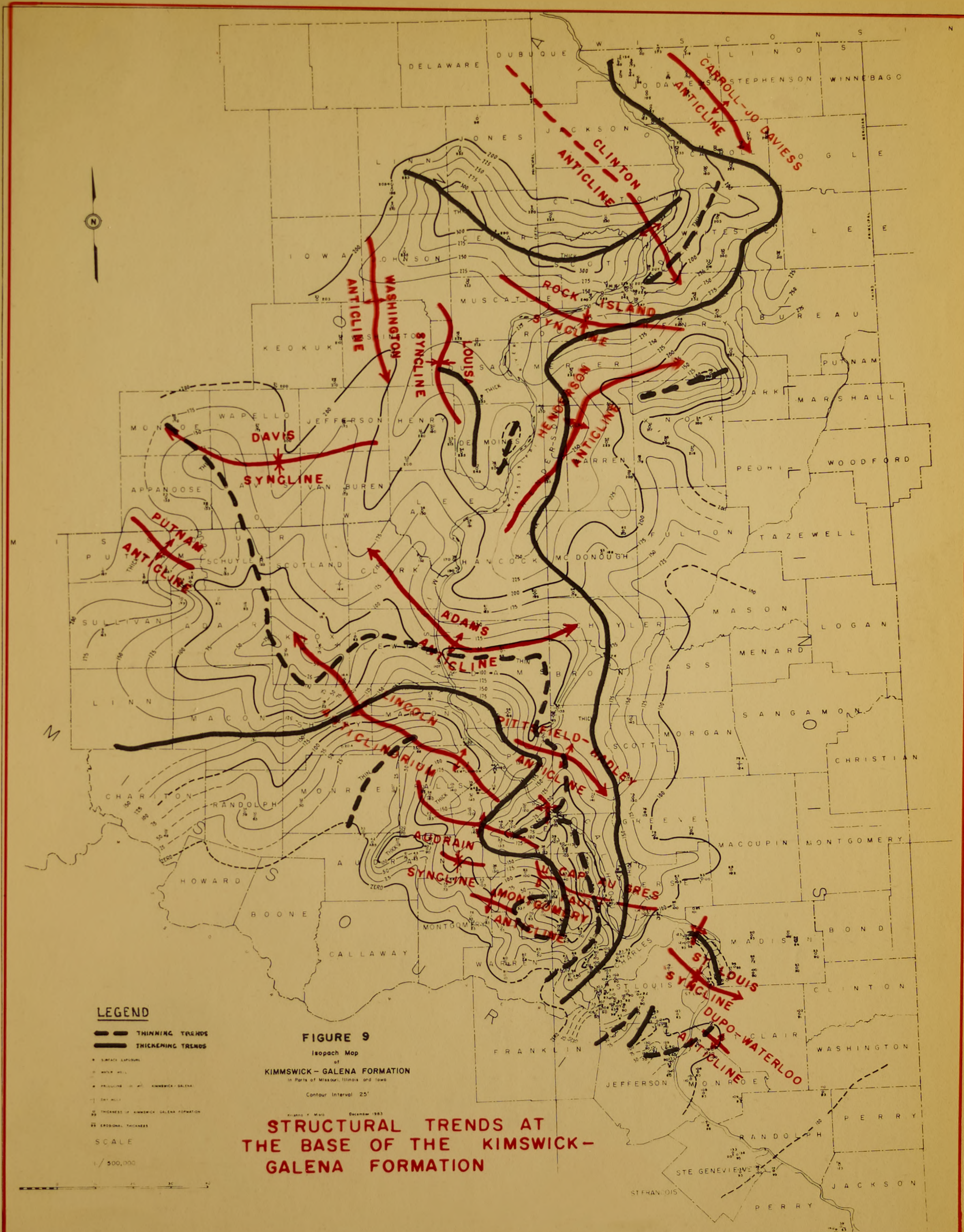


FIGURE 9
Isopach Map
of
KIMMSWICK – GALENA FORMATION
In Parts of Missouri, Illinois and Iowa
Contour Interval 25'
December 1963

STRUCTURAL TRENDS AT THE BASE OF THE KIMSWICK-GALENA FORMATION

FIG: 10

PALEOGEOGRAPHIC MAP OF THE AREA DURING KIMMSWICK-GALENA TIME beginning of deposition of the Middle Member of the Kimmswick in Missouri, of the equivalent lower Prosser in Iowa, and the Moredock, Beecher, and Eagle Point members of the Dunleith Formation in Illinois. These beds are the most widespread geographically throughout the area of the study and are rather uniformly distributed and possess very similar lithologies.

As is apparent from the isopach map of the Kimmswick-Galena Formation (Figure 9) two major trough-like, linear, depositional basins developed in this area during Kimmswick-Galena time. The larger one of these two, began in western St. Charles County, Missouri and continued north to Pike County, Illinois from where it took a northerly course continued through Henderson County, Illinois. At this point it took a turn in an easterly direction but again turned back to a northwesterly direction in northeastern Whiteside County, Illinois, and continued through Carroll and Jo Daviess counties, Illinois.

The other, smaller trough originated near the flank of the Ozark Dome in southern part of Lincoln County, Missouri, and paralleled the periphery of the Ozark Dome in the area of this study. An area of upwarping existed between the two troughs as indicated by a thinning trend of the Kimmswick-Galena Formation (Figure 9). This feature ran parallel to the Ozark Dome along its periphery up to southern Knox County, Missouri from where it took a northerly course and continued into Davis and Monroe counties Iowa, and beyond (Figure 9). Several other similar features of local nature are indicated by this isopach map which may have influenced the deposition of the Kimmswick-Galena strata locally but certainly did not affect the regional picture.

A comparison of the present subsurface structural trends (Overlay, Figure 9) with the isopach trends clearly shows that the original depositional trough-like structures described above lie either very close to or directly on the crests of present anticlinal structures, indicating that if these features that developed during Kimmswick-Galena time, were the result of the tectonic movements, then they were completely reversed in post-Ordovician time. The upwarping trend indicated by the thin trends of the Kimmswick-Galena Formation on the isopach map (Figure 9) also does not follow the present anticlinal trends (Overlay Figure 9), but it seems to lie close to or in several cases crosses them. It appears that these trough-like structures were the representatives of the major depositional basin present in the area during Cambrian and early Ordovician times as mentioned by Lee and discussed before. Although this major depositional basin had started filling up rather rapidly after St. Peter time and a reversal of its nature had started (p. 105), it still persisted in the Kimmswick-Galena time as a minor feature. It appears that a little doming had already started in the area along the axes of the Pittsfield-Hadley and Adams anticlines (Figure 9) as indicated by the occurrence of thin Kimmswick-Galena beds on their crests. This structural feature probably was the forerunner of the Lincoln Anticlinorium; and although it was not a land mass above sea level during Kimmswick-Galena time, it was present as a structural high beneath the waters of the Kimmswick-Galena sea. This feature occupied a position between the two trough-like structures described before which served as the main depositional basin for the Kimmswick-Galena rocks.

The above features continued to persist through the time of deposition of the beds belonging to the Upper Member of the Kimmswick in Missouri, the New London Member of the Dunleith Formation and part of the Wise Lake Formation in Illinois. The deposition of the succeeding beds belonging to the Stewartville and Dubuque members of the Galena in Illinois and Iowa continued but in shallower seas than the underlying beds as indicated by the occurrence of frequent beds of clastic nature in these strata. Apparently the retreat of the sea started toward the close of Kimmswick-Galena time because of renewed but slow activity in the area, which continued through the succeeding Maquoketa time. It is possible that the beds equivalent to the Stewartville and the Dubuque members of the Galena of Illinois and Iowa were deposited in Missouri but were eroded in this area due to subsequent uplift.

POST-KIMMSWICK-GALENA TIME

After the deposition of the Kimmswick-Galena Formation, the sea began to retreat mainly from the Lincoln Anticlinorium area as indicated by the beginning of clastic concentration in the overlying Maquoketa Formation in the area. The absence of the Maquoketa, along the axis of the Lincoln Anticlinorium in northern Missouri and southern Iowa, (Cross-section A-A', Plate XX), suggests that this area was uplifted before the deposition of the Maquoketa Formation. This was associated with a down-warping of the area toward the east and southeast of the Lincoln Anticlinorium at the beginning of Maquoketa time, as thick deposits of this formation are preserved in the subsurface in this area (Cross-section B-B', Plate XXI). The Maquoketa is thin in southeastern Missouri, indicating that the uplift of the Lincoln Anticlinorium also affected the area during this time. These tectonic movements continued through Silurian period and the movement seems to have been accelerated in the area during this time, as very thin beds of Silurian age are found only locally in structurally low areas in eastern Missouri but are completely absent in southeastern Iowa (Cross-section A-A', Plate XX). Occurrence of thick Silurian beds in parts of western and east-central Illinois (Cross-section B-B', Plate XXI) indicates that the tectonic conditions in this area did not change very much from Maquoketa to Silurian time.

Devonian rocks are present in northern Missouri and southeastern Iowa suggesting that this part of the Lincoln Anticlinorium was submerged again in Devonian time, along with the adjacent area in western Illinois, where thick sequences of the Devonian strata are found in the subsurface. Devonian rocks are entirely missing in the area southeastward from the Lincoln Anticlinorium in eastern and southern Missouri, and western Illinois, indicating that this area was not flooded by the sea during Devonian time. However, the presence of Devonian rocks in southwestern Illinois, and parts of southeastern Missouri (Ste. Genevieve County and vicinity), south of the thesis area, suggests that the area was submerged under the sea during Devonian time.

The next widespread submergence of the sea occurred during Mississippian period when the whole area of eastern Missouri, western Illinois, and southeastern Iowa was flooded by the sea as indicated by the presence of thick sequences of the Mississippian carbonate rocks throughout the area. A thin cover of the Mississippian rocks occurs in the area of the Lincoln Anticlinorium, which is an erosional remnant of the original sequences. The most significant tectonic movements occurred at the end of the Mississippian period which gave the area its present configuration. The Lincoln Anticlinorium along with all the associated structures in the area achieved its greatest development at this time and the Cape au Gres Fault originated in the eastern Missouri along with the development of the major faults now present in the Ste. Genevieve County, Missouri and the adjacent area. The the area has since been subjected to erosion and the Pennsylvanian rocks have been deposited on the peneplaned surface of the Mississippian strata, mainly in the northern and western part of the area of this study.

The movements after Pennsylvanian time modified the area only moderately and developed the present configuration of the land in this area.

CHAPTER VI

ENVIRONMENT OF DEPOSITION

The subject of the environment of carbonate rock deposition has attracted much attention in the last two decades. A great deal of research has been conducted in order to study the physico-chemical conditions of the inorganic as well as organic processes controlling the precipitation of calcium and magnesium carbonates from sea water. As a result, it is generally agreed that carbonate rocks are deposited as aragonite mud or organic shell debris in the shallow platform areas of the modern seas where sufficient calcium carbonate is dissolved in the sea water and the temperatures are moderately warm. Various organisms seem to play a very important role in carbonate rock deposition. In fact, it has generally been found that "...the organic processes are by far the most important cause of marine $CaCO_3$ precipitation," (Revelle and Fairbridge, 1957, p. 256). Calcium- and magnesium-secreting organisms contribute to such deposition. Dolomitization and other alteration processes are mostly recognized as secondary, although the problem is controversial and open to question.

Various factors, essential to the deposition of carbonate rocks, are discussed in this chapter in order to recapitulate the conditions of deposition of the Kimmswick Limestone and Galena Formation in the area of this study. The first part of the chapter deals with the environment of deposition and the post-depositional changes of the Kimmswick Limestone; the second part concerns the depositional environment of the Galena Formation and its dolomitic aspects.

ENVIRONMENT OF KIMMSWICK DEPOSITION

Insofar as the depositional environment of the Kimmswick Limestone is concerned, the following factors are considered important.

Regional Tectonics

As discussed in Chapter V on geologic history, mainly the Ozark Dome and the marginal shelf areas of the cratonic area of Iowa and Illinois appear to have influenced the sedimentation of the Kimmswick Limestone in this area. Other topographical or structural features, present in the area during Kimmswick time, may have influenced the distribution of the sediments but only locally.

Presumably, since the Ozark Dome was the main landmass present in the area since St. Peter time (Lee, 1954, p. 78), the Kimmswick Limestone evidently was deposited on its submerged flanks which formed the shelf area of the Kimmswick sea. As evident from the isopach map of the Kimmswick-Galena Formation (Figure 9), the zero isopach marks the approximate limit of the Kimmswick deposition and thus indicates the presence of the shoreline of the Kimmswick sea (Figure 10). The shelf area, occupying the margins of the cratonic area toward the east, southeast, and north (Figure 10), along with other local, low-lying areas, served as a depositional basin for the Kimmswick Limestone. As the Kimmswick Limestone increases in thickness slowly basinward, it appears that the slope of the surface of deposition was very gentle, and sharp changes in the slope or steep dips seem not to have existed at that time. The upwarping along the Pittsfield-Hadley and Adams anticlines (Figure 9) was perhaps the only exception to this gentle slope, but it did not seem to have influenced the sedimentation greatly, as these were minor features and still submerged under the sea.

Depth Conditions

As the zero isopach line (Figure 9) marks the limit of Kimmswick deposition and the presence of the shore line in the immediate vicinity, and also as the slope of the surface of deposition was gentle, the depth of the sea seems to have been very moderate during Kimmswick time. The well-sorted nature of the Kimmswick Limestone and its extremely fragmental nature also suggests very shallow water conditions of depositions, well above the "wave-base," where the effect of the wave action was strong enough to break the hard parts of the organisms into small fragments. High concentration of brachiopods, echinoderms, and bryozoans in the limestone throughout the area further indicates a shallow water environment, since these are known to thrive in such environments (Schrock and Twenhofel, 1953). The pronounced, cross-bedded nature of the Kimmswick Limestone in the outcrops near Cape Girardeau, Missouri suggest an almost shore-line condition of deposition in this area (Figure 10).

Temperature Conditions

In recent studies on carbonate deposition on the Bahama Banks and off the coast of Florida it was found that calcium carbonate precipitation from the sea water occurs under shallow water, warm temperature conditions (Smith, 1940). Revelle (1934, p. 1) states that:

> Although the experimental results obtained by various authors for the solubility product [of calcium carbonate] are not in agreement, it is at least certain that the surface water at a temperature of 30°C. is saturated with calcium carbonate.

Thus it is evident that the sea water can become saturated with calcium carbonate at a temperature of at least 30°C. Higher temperatures will cause the precipitation of calcium carbonate from the sea water, other conditions being favorable. A high concentration of sparry calcite in the Kimmswick Limestone suggests that it was deposited in warm temperature conditions from the waters of the Kimmswick sea, which was saturated with calcium carbonate, for the reasons given elsewhere in this thesis (p. 122).

The presence of echinoderms, brachiopods, bryozoans, and other organisms in the Kimmswick Limestone does not indicate the temperature conditions of deposition of Kimmswick, since these are not reliable temperature indicators.

Energy Conditions

The highly fragmental nature of the Kimmswick Limestone clearly indicates a highly agitated shallow water environment of deposition. Extremely small fossil fragments indicate a very agitated wave condition evidencing high energy environment of deposition. This was possible during Kimmswick time because of the very gentle slope of the bottom of open Kimmswick sea. The presence of the shoreline, as indicated by the zero isopach line (Figure 9), suggests a shallow bottom on which these high energy waves and currents worked continuously to break the shell material into small fragments. The finer material from the shell fragments was probably washed away to the deeper part of the sea and coarser well-sorted calcitic debris was preserved in the shallow areas. The absence of clay and quartz particles in the Kimmswick Limestone along with its other features classify it as type V limestone of strongly agitated environment as proposed by Plumley *et al* (1962).

Under the conditions described above more resistant shell material accumulated near the shore on the gently sloping platform, later being sorted by wave action and then cemented by sparry calcite. This is clearly indicated by the well-sorted nature of the limestone constituting the Lower Member of the Kimmswick Limestone. These conditions were prevalent in the immediate vicinity of the Ozark Dome in eastern and southeastern Missouri, throughout early Kimmswick time. As the sea deepened slightly during Middle Kimmswick time, finer shell fragments accumulated in areas where previously the coarser material had accumulated in shallower water. Higher concentration of fine-grained organic debris in the strata, belonging to the Middle Member of the Kimmswick Limestone, strongly suggests that the energy condition at the sea bottom was of moderately low nature which resulted in the deposition of this fine-grained material well below the "wave-base." The low energy condition of the sea bottom is further suggested by poor sorting of the beds constituting the Middle Member of the Kimmswick Limestone. The deposition of the Upper Member of the Kimmswick was associated with the shallowing of the sea and return of the conditions prevalent during Early Kimmswick time in the area. This is evidenced by the better sorting and high sparry calcite content of the beds constituting the Upper Member. ıg and

The change in the energy conditions from the Early to Middle and Middle to Late Kimmswick was very relative, but still noticeable in changes in the character of the rocks in the Lower, Middle, and Upper members of the Kimmswick Limestone as discussed in the chapter on stratigraphy.

<u>Chemical Factors</u>

The chemical factors deal with the consideration of availability of calcium, magnesium, carbon dioxide, and silica; the solubilities of these in the sea water and the chemical reactions involved in the precipitation of calcium and magnesium carbonates in a given medium; the chlorinity and p^H conditions of the medium in which the deposition of the carbonate rocks takes place.

The main source of calcium and magnesium is sea water. The amounts of these elements in the modern sea water, for a normal chlorinity of 19 parts per thousand, are 400 parts per million for calcium and 1,272 parts per million for magnesium (Sverdrup, *et al*, 1942, p. 176). The amount of dissolved carbon dioxide in sea water, for normal chlorinity and 0°C. temperature, is 34 to 56 ml per liter (Mason, 1952, p. 168). The uniformitarian view maintains that the composition of the sea water has remained unchanged since the Archean 'Era', (Mason, 1952, p. 176). Thus it will seem apparent that sea water has maintained its chemical balance and the deposition of huge amounts of limestone throughout the geologic time has not altered this balance.

Biological activity is of great importance in controlling the concentration of calcium, magnesium, and silica in sea water. These elements may be removed from the surface waters by organisms through abstraction, which may or may not be returned to the water after the death of the organism by dissolution depending on the degree of saturation of the sea water in these elements in a particular environment.

Perhaps the most important source of silica in the ocean water are volcanoes. This supply mostly comes in the form of volcanic dust which may cover several hundred square miles area around the erupting volcano. Minor parts of silica are added locally in the forms of lava erupting from such volcanoes. Chemical weathering of siliceous sediments in nearby land area may also supply silica to the sea water.

Carbon dioxide plays a major role in precipitation of calcium carbonate from sea water since it provides the carbonate ion through chemical reaction which combines with the calcium ion to yield $CaCO_3$. The following chemical equations control the precipitation of calcite:

+ H

1. $H_2O + CO_2 \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + H\,CO_3^-$
2. $H^+ + CO_3^= \rightleftharpoons H\,CO_3^-$
3. $Ca\,CO_3 \rightleftharpoons Ca^{++} + CO_3^=$

In the above equations, with an increase in the amount of CO_2 in sea water, the equation 1 goes to right giving more H^+ ions. These H^+ ions react with $CO_3^=$ as shown in equation 2 giving more $H\,CO_3^-$. The reaction shown in equation 3 goes to right to replace $CO_3^=$ ions, resulting in dissolution of calcite.

With the loss of CO_2 from sea water, the reaction in equation 1 goes to left reducing the concentration of H^+ ions. The reaction in equation 2 goes to left giving more $CO_3^{=}$. This, according to the equation 3 going to left, precipitates calcite.

An increase in the concentration of carbon dioxide in the sea water may be caused by the increased metabolic activity of organisms. Also in the deeper part of the sea, where less oxygen is available for aeration of the water, carbon dioxide content is generally increased because of organic respiration. A loss of CO_2 in sea water may be caused by a rise in temperature or sudden agitation of the sea water.

The p^H of the sea water in contact with the air will vary between about 8.1 and 8.3, depending upon the temperature and salinity of the water and the partial pressure of carbon dioxide in the atmosphere (Sverdrup, et al, 1942, p. 209). However, below the water level where exchange of carbon dioxide with the atmosphere is impossible, the p^H will vary with the extent to which the carbon dioxide content of water is modified by biological activity. The total content of carbon dioxide in sea water is chiefly dependent upon the salinity and to some extent upon the temperature. Thus in warm temperature conditions, where the salinity will tend to be high, the p^H will be high. Such, perhaps, was the condition in the Kimmswick sea, at least in near shore areas, where the precipitation of calcium carbonate took place under warm temperature conditions.

It is apparent from the above discussion that precipitation of calcium carbonate is most likely to occur where the concentration of the calcium or carbonate ion or both are high and the solubility of the calcium carbonate in the sea water is low. This could be brought about by several processes as listed by Revelle and Fairbridge (1957, p. 256)

1. increase of temperature, which lowers the solubility product of calcium carbonate and also the solubility of carbon dioxide, thus increasing the carbonate ion concentration;

2. evaporation, which increases the calcium concentration and carbonate alkalinity;

3. movement of supersaturated water into a region where nuclei or catalyzers of precipitation are present;

4. photosynthesis, which lowers the carbon dioxide content and hence increases the carbonate concentration;

5. bacterial production of ammonia or other weak bases, tending to raise the p^H and hence to increase the carbonate concentration;

6. various, largely unknown, processes taking place in the body fluids or tissues of organisms, tending to increase the calcium or carbonate concentrations, to reduce the ionic strength, to produce nuclei, or otherwise to catalyze carbonate precipitation;

7. upwelling of deep water, in which the alkalinity has been increased by solution of calcium carbonate under pressure, might result in precipitation, because of the reduction in solubility as the pressure is reduced;

8. mixing of high-carbonate low-calcium waters with sea water....

All the factors listed above apply to the near-shore carbonate deposition with the exception of 7, which may not be true for shallow water environments, as the process of deposition in such an environment presumably is a dynamic one, in which continuous deposition takes place and the sea water passes through this environment continuously. Also continuous agitation of the water keeps the waters well mixed in the bottom as well as the surface part.

The above-mentioned basic chemical factors provide a sound basis for the interpretation of the environment of deposition of the Kimmswick Limestone. As discussed on previous pages, it is apparent that the Kimmswick Limestone was deposited on the shallow shelf area of the Kimmswick sea which submerged the flanks of the Ozark Dome. Thus the shallow nature of the Kimmswick sea along with the warm temperature conditions had perhaps made the sea water already saturated with calcium and carbonate ions. Additional amounts were acquired from the exposed limestones in the adjacent land area of the Ozark Dome, where these rocks were undergoing continuous chemical weathering. The life in the Kimmswick sea, as evidenced from the richness of the Kimmswick Limestone in fossils, was plentiful and these organisms, which acquired calcium to build their shells from the sea, partly returned it to the sea water under favorable chemical conditions, thus keeping the chemical balance of the water rather steady. All these factors together resulted in rapid precipitation of calcium carbonate on the bottom of the Kimmswick sea. The continuous supply of calcium and also carbonate ions maintained the dynamic process of precipitation of the limestone throughout Kimmswick time, with the exception of some changes in the rate of precipitation during Middle Kimmswick time. This is concluded from a low concentration of sparry calcite in the Middle Member of the Kimmswick Limestone as compared to the Lower and Upper members. As mentioned before under the depth and energy conditions of the Kimmswick sea, a relative deepening of the sea during Middle Kimmswick time, perhaps caused lower than average temperature in the bottom part of the sea; also this depth increase reduced the effect of the wave action in the bottom part, thus hindering the mixing of the surface waters with the deeper waters. This created an upper water $CaCO_3$-saturated zone and the deeper water undersaturated zone, causing the dissolution of calcite in the deeper part, which may be the explanation for the low calcite content of the Middle Member of the Kimmswick Limestone. During the deposition of the Upper Member of the Kimmswick, the conditions were more like those during Early Kimmswick time, which again accounts for the high percentage of calcite in these beds.

The source of silica in the Kimmswick sea was primarily a land area where volcanic activity was going on from time to time. The evidence of volcanic activity lies in the occurrence of a prominent bed of bentonite at the base of the Decorah Formation (Allen, 1932). This perhaps was the most intensive volcanic activity in the area which started at the beginning of Decorah time and perhaps continued through Kimmswick time, but with less vigor. The occurrence of a bentonite bed at the top of the Middle Member of the Kimmswick Limestone, and also a thin bed at the top of the Lower Member of the Kimmswick in Ste. Genevieve County, Missouri, indicates that the volcanic activity occurred during these times and these beds are the records of activity which reached this far to affect the sedimentation of this otherwise uniform deposition of the limestone. The source area of the volcanic activity may have been far from this area, most probably toward the southeast, since the beds of the bentonite are more prominent in the outcrops toward southeast and are present only as thin bands in the outcrops in north and northeast Missouri. This is further suggested by the fact that the outcrops of the Kimmswick Limestone, in the southern part of the area of this study, contain thick beds of chert in the Middle Member which are absent or present only as a trace in northern outcrop areas in Missouri. Since these chert beds are most prominent in the Middle Kimmswick Member, it is evident that most intensive volcanic activity in Kimmswick time occurred during Middle Kimmswick time, and relative deepening of the Kimmswick sea, as suggested before, may have resulted from the tectonic activity associated with this volcanism in some other area toward the south or southeast.

Practically all the chert nodules in the Kimmswick Limestone occur far below the bentonite bed, suggesting that the silica was not derived from this bentonite bed. The silica may have been obtained from the volcanic eruptions active in other areas, and carried to this area dissolved in sea water. It also may have been acquired partly from the chemical weathering of the siliceous rocks exposed on the nearby land areas.

The secondary origin of the chert in the Kimmswick is ruled out because of the low permeability of the Kimmswick Limestone, which will hinder the permeation of solutions after consolidation; also since the bentonite is found in impervious shale bed, it is quite unlikely that the silica-bearing solutions, which might have derived their silica from the bentonite bed, could have permeated through the shale and replaced the limestone.

Spar Development

The sparry calcite in thin sections is present as growth around the original fossil fragments, and has the same optical orientation as the original fragments. This very strongly suggests that the fossil fragments served as nuclei of initial precipitation for calcium carbonate while suspended in the sea water because of the wave action. Most of the spar is associated with the echinoderm fragments, which, being very light, were easily accessible to such wave action and provided very suitable nuclei of crystallization. Most secondary growth would appear to have taken place after these particles sank to the bottom. On the whole, it seems that perhaps more than 90 per cent of the spar present in the Kimmswick Limestone was the result of direct precipitation from sea water with the fossil fragments serving as the nuclei for such precipitation.

Microcrystalline calcite, which is seen as lining on the walls of the pores in thin sections, most probably precipitated during the diagenetic process, and partly after the consolidation of the sediments through the agency of ground water or other such solutions. It is quite possible that this microcrystalline calcite in the pores of the limestone precipitated from the calcium carbonate in solution which may have been trapped in these pores at the time of deposition and burial of the sediments. The large calcite crystals, up to two-inches in size, in the Kimmswick Limestone, might have been the results of secondary crystallization, as suggested by their large size and near perfect scalenohedral and rhombohedral shapes.

Organisms

The most common organism found in the Kimmswick Limestone are the fragments of echinoderms which constitute about 35 to 40 percent of the limestone. According to Cook (1957, p. 1191), echinoids generally favor shallow waters, and they dislike mud; they are most abundant in clear water with either sandy or limy bottom. Thus the shallow sea of Kimmswick time with their clear limy bottom probably favored the growth of this organism. Because they were not the forms with large plates at this time, the larger forms are not found in the Ordovician rocks in North America.

The next most abundant organism in the Kimmswick Limestone are brachiopods, whose fragments make up to 15 percent of the limestone. Schuchert (1911) studied 158 brachiopod species, and 33 genera of recent seas, and concluded that about 80 percent of the brachiopods inhabit waters shallower than 1,000 feet and over 70 percent live in water shallower than 600 feet in depth. He further stated that brachiopods generally indicate shallow waters of continental or epicontinental seas. Thus the common occurrence of brachiopod fragments in the Kimmswick Limestone suggests that the Kimmswick sea was a shallow epicontinental sea which supported brachiopod fauna.

The bryozoans make up the third most common organic group in the Kimmswick Limestone. Osburn (1957, p. 1109), was of the opinion that while the bryozoans range from the shore to a depth of more than 3,000 fathoms, the great majority of the species are limited to the comparatively shallow water of the coastal shelves, from low tidemark to 100 or 200 fathoms. He also suggested that the normal salinity of the sea, which is 35 parts per thousand, is most favorable to bryozoan growth and the number of genera and species are rapidly reduced below the salinity of 20 parts per thousand. Thus, relatively less common occurrence of bryozoan in the Kimmswick Limestone suggests that perhaps the salinity of the sea water was somewhere between 35 and 20 parts per thousand. A higher than normal salinity ought to have been present for the Kimmswick sea due to the warmer temperatures as already noted under the discussion of chemical factors.

In the vicinity of Cape Girardeau, Missouri, crinoidal fragments constitute a major part of the Middle Member of the Kimmswick Limestone. Clark (1957, p. 1183) states:

> The crinoids more than any other echinoderms need well-aerated water of relatively high minimum salinity and an abundance of suspended food matter. Although various species inhabit various depth conditions, it appears that most favor deeper water environment.

This suggests that the Middle Kimmswick sea may have been deeper and of high salinity favorable to the growth of crinoids in this part along with low carbonate precipitation as noted before.

Receptaculites oweni commonly occurs in the Middle Member of the Kimmswick Limestone throughout the area. This species along with a morphologically similar form, has generally been considered to be a sponge in the past. However, doubt exists as to their affinity to this organic group and Kesling and Graham (1962) report that *Ischadites* is dasycladacean alga. Because of the similarity of the characters of *Receptaculites* and *Ischadites*, *Receptaculites* could also be an algae. It is difficult to use these as definite depth or temperature indicators because of their uncertain biologic affinity. However, the perfect preservation of the broken parts (up to 16 inches in length) of *Receptaculites oweni* and *Ischadites* sp. in molds found in the Kimmswick Limestone suggests that in spite of their being large-bodied organisms, they were rather delicate and not rugged as has been generally believed. Such preservation could only have been possible in a rather calm and deep water environment where these broken parts might have escaped further disintegration due to lack of high energy waves in such environment. Perhaps that is why they are not found in the Lower Member of the Kimmswick Limestone which was deposited in shallow water and high energy environment.

In summary, all the factors discussed on the previous pages indicate that the deposition of the Kimmswick Limestone took place in shallow seas and warmer temperature conditions where the organic life was rich and the wave action strong. However, there was a relative change in conditions during the Middle Kimmswick time, as mentioned before, which was marked by relative deepening of the sea and volcanic activity in the area.

Dolomitization of the Kimmswick Limestone

Dolomite in the Kimmswick Limestone generally occurs in association with fracturing or local unconformable zones at the base or top of the formation. Exceptions occur in northern Missouri (Plate XVIII) where the Kimmswick is mainly represented by dolomite in the subsurface. Since these latter dolomite beds are lithologically closely related to the Galena Formation of Illinois and Iowa, their dolomitic aspect is discussed under the Galena Formation later in this chapter.

The dolomitization of the Kimmswick, as discussed in Chapter IV, is not related to the subsurface structural trends. Locally, as in Ste. Genevieve County, Missouri, it is associated with the faults in the area; also in the subsurface, it seems to be associated with minor fracturing of the limestone (Plate VII, p. 41). These occurrences of dolomite in the Kimmswick certainly indicate that the dolomitization is of secondary nature. The magnesium-bearing solutions found access to the limestone, along these faults, fractures, and similar other zones of weakness in the rock and altered it locally to dolomite.

In the case of dolomite near the top and base of the Kimmswick Limestone, where erosion has cut the rocks deeply, a similar process of secondary dolomitization seems to have occurred. In the subsurface occurrences of this nature, it is definite that the magnesium-bearing solutions permeated along the bedding planes or the local unconformable zones, or any other such zones present in the rock, and locally altered the limestone to dolomite. A good example of this is found in the occurrence of a sixteen-inch bed of pure dolomite at the base of the Kimmswick Limestone at Locality 7 (Plate VI), St. Louis County, Missouri. In thin section this dolomite shows a microcrystalline character uniformly throughout the rock (Plate XXII). As noted (p. 72), the base of the Kimmswick Limestone in this local area lies on an erosional unconformity, and it is very likely that the occurrence of this dolomite bed is a direct result of the solutions permeating along this unconformity and replacing the limestone under favorable chemical conditions. Similar occurrences of local dolomite beds have been noted in the subsurface in southern Illinois. These are mostly associated with the oil-producing horizons of the Kimmswick Limestone, as mentioned in the chapter on petroleum possibilities.

It is concluded, from the above discussion, that the dolomite found in the Kimmswick Limestone, although minor in amounts, is the result of secondary alteration which took place much after the consolidation of the limestone.

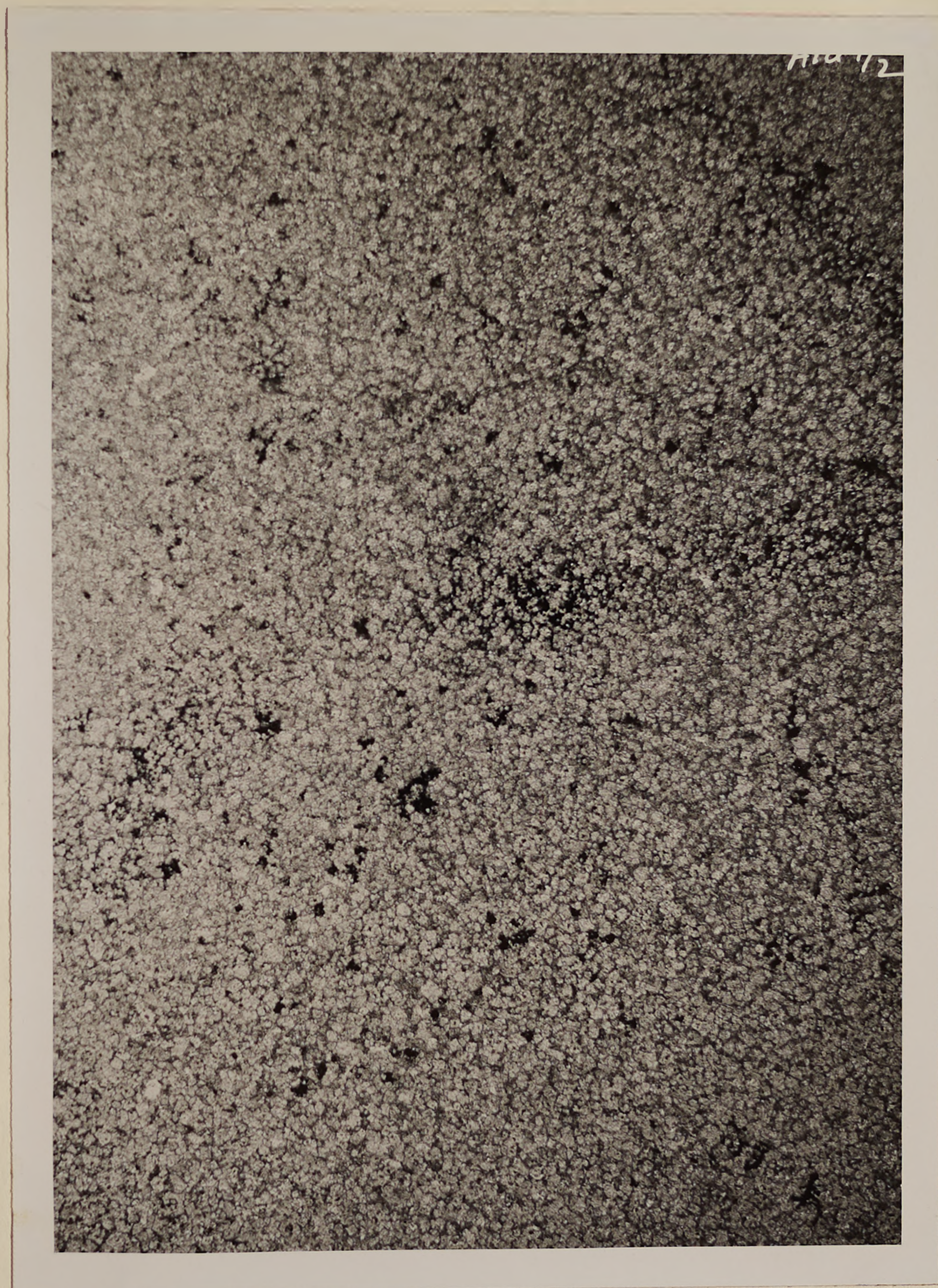


Plate XXII Photomicrograph of thin section (Al_D) from the 16-inch dolomite bed at the base of the Kimmswick Limestone at Locality 7, St. Louis County, Missouri (32x).

Pyritization

Pyrite crystals occur in the Kimmswick Limestone near the Decorah-Kimmswick contact at Locality 3, and a few feet above the base at Locality 9 (Plate VI). A thin section examination of this pyrite zone at Locality 3, (Plate XXIII) revealed that the pyrite was the result of secondary replacement of the limestone along the Decorah-Kimmswick contact zone. The pyrite is disseminated throughout the slide and occurs in association with the very fine-grained matrix in the limestone. Whatever the source of this pyrite, it has locally replaced the limestone under favorable physico-chemical conditions. In Plate XXIII some isolated very small calcite crystals are seen in the middle of the large pyrite crystal, and suggest that the replacement of the limestone was not complete. The pyrite also replaces the dolomite grains. The latter are secondary to the limestone. Thus the pyrite was the last in sequences of replacement.

The source of pyrite might have been ground water or connate water, which sometime or another after the consolidation of the Kimmswick Limestone found access to this zone along the unconformity at the base of the Kimmswick Limestone, and precipitated pyrite locally under favorable chemical conditions.

Recrystallization

Recrystallization in the Kimmswick Limestone is rare and of very local nature. This occurs in the surface rocks, and may have been caused

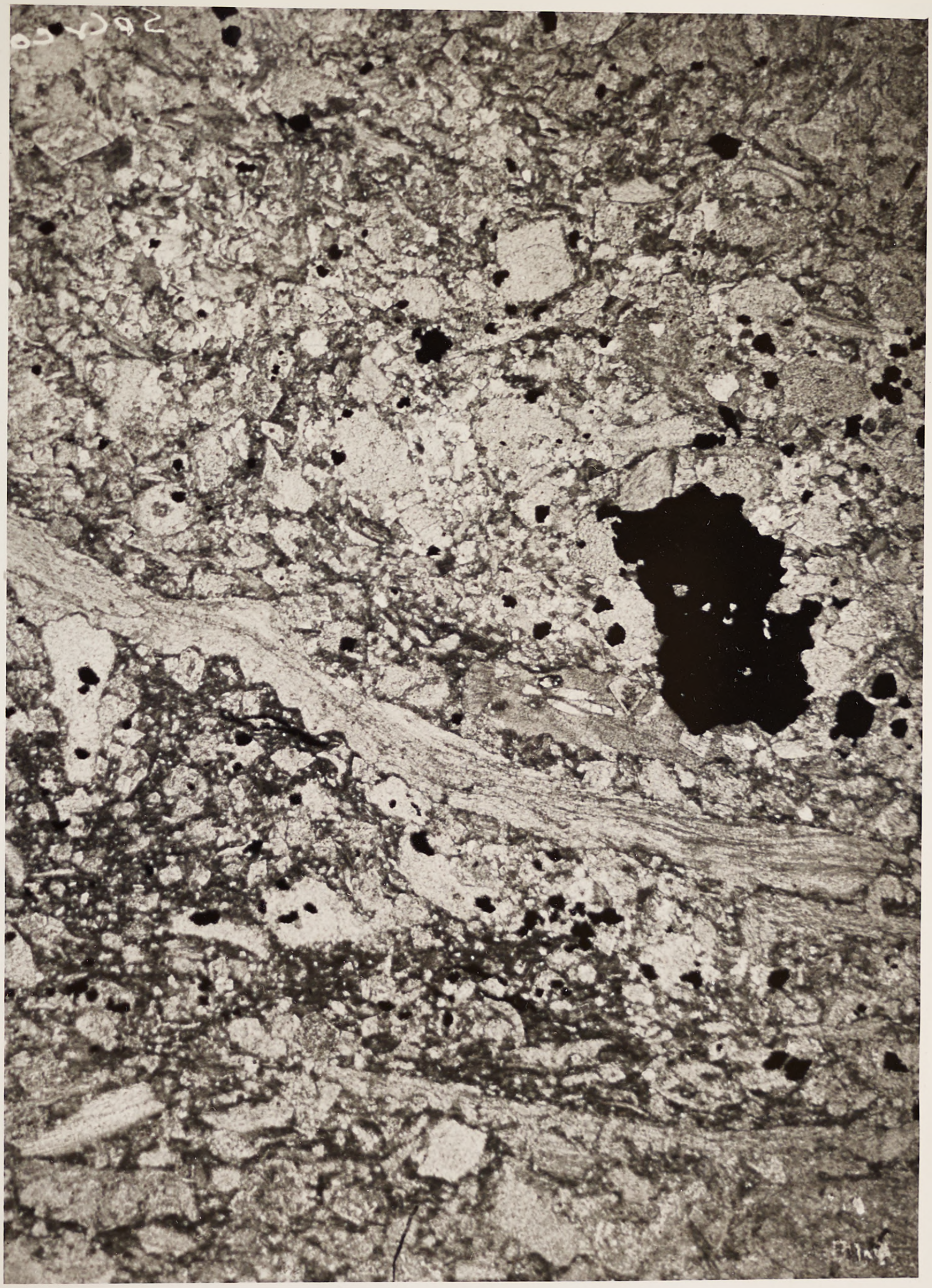


Plate XXIII Photomicrograph of thin section (Spcr) from the contact zone of the Decorah and Kimmswick at Locality 3, Ralls County, Missouri. The black areas are pyrite crystals. Notice the replacement relationships of pyrite with dolomite and limestone along the edges of the largest pyrite crystal. Evidently the sequence of replacement is limestone - dolomite - pyrite (32x).

by local and recent agents of weathering and/or underground waters or even surface waters.

ENVIRONMENT OF DEPOSITION OF THE GALENA FORMATION AND ITS DOLOMITIC ASPECT

Although the Kimmswick Limestone and the Galena Formation were deposited in similar environmental conditions, the following distinction in the environment of Galena deposition seems to have prevailed throughout the area of its occurrence.

Depth Conditions

As the Galena Formation shows a basinward thickening (Figure 9), presumably it was deposited in relatively deeper water conditions than the nearshore facies of the Kimmswick. The deeper water conditions and calm environment of the Galena sea are further evidenced by very frequent occurrence and delicate preservation (p. 131) of *Receptaculites oweni* in the Galena strata, which otherwise would have been destroyed, under high energy conditions and agitative wave action.

Energy Conditions

Because of the greater depth of the sea, the energy conditions at the bottom of the Galena sea were very low and the deposition of the Galena strata must have taken place well below the "wave base." This condition perhaps was comparable with the deepening of the sea in Middle Kimmswick time in Missouri. Under these conditions of deeper water and calm environment, the Galena strata were probably deposited in the form of very fine-grained organic debris washed from the shore and deposited in the limy mud environment at the bottom of the sea.

Temperature Conditions

Since the depth of the Galena sea was greater, and the energy conditions low, the temperature at the bottom of the sea must have been much cooler than that of the water at the surface or near the shore. As a result, the precipitation of calcium carbonate from the sea water must have been slower, even though the surface waters might have been saturated in calcium carbonate and precipitation might have been occurring in this zone. The lower temperature and low energy conditions at the bottom prevented the mixing of the surface waters with the bottom waters thus creating a calcium carbonate-depleted zone at the bottom. This dissolved the calcium carbonate precipitating in the surface zone. Thus the precipitation of the calcium carbonate at the bottom of the Galena sea was entirely dependent on the degree of saturation of the bottom waters, and deposition of calcium carbonate must have been very slow. Furthermore, the calcium carbonate content of the sea water in this part of the sea must have been lower than those near the shore, where a continuous deposition of limestone was going on.

Source of Magnesium in the Galena Formation

The observations made during the course of this study suggest the following sources of magnesium present in the Galena Formation:

1. A part of magnesium perhaps was carried into the sea water from the land area due to chemical leaching of the carbonate rocks.

2. The water in the deeper part of the sea was richer in magnesium than calcium because of higher solubility of magnesium in sea water and relative depletion of calcium due to rapid precipitation of calcium carbonate near the shore (Figure 11). The evidence of relative enrichment of magnesium with regard to calcium in deeper waters is found in the modern seas. Fairbridge (1957, pp. 150-151) commenting on Hogbom's (1894) analyses of samples from the Atlantic coasts, concluded:

    > There is no doubt that Hogbom's determination of mean figures [of $MgCO_3$] is useful in demonstrating the differential removal of $CaCO_3$ with depth and stability of the $MgCO_3$.

    He further concluded (p. 151), "There thus appears to be a progressive tendency with depth toward inorganic enrichment of magnesium...."

3. Additional amounts of magnesium perhaps were added from the dissolution of the magnesium-bearing shells of the organisms after their death. Chave (1954) analyzed the shells and shell fragments of 52 species of modern echinoids collected

from the coastal regions of various parts of the world and reported up to 16.7 percent $MgCO_3$ in their shells. A similar analysis of 22 species of modern crinoids by him gave up to 15.9 percent $MgCO_3$ in their shells. The most abundant organisms in the limestone facies of the Galena Formation are echinoids and crinoids and it is certain that these were originally as abundant in the rocks which are now represented by the dolomite facies. Assuming that the chemical composition of their shell material was similar to that of the modern species, it is quite possible that a part of magnesium required for the dolomitization of the Galena Formation was supplied by these organisms by dissolution of their shell material after their death.

Dolomitization of the Galena Formation

The foregoing observations and discussions suggest that the dolomite constituting the Galena Formation is a "stratigraphic type," a term used by Dunbar and Rodgers (1957, p. 239). Such types have been explained to have originated from the penecontemporaneous dolomitization of the original limestones (Van Tuyl, 1916).

As a result of this study, the following sequence of events are suggested in the dolomitization of the Galena strata in this area.

1. The availability of magnesium to sea water from land areas and the magnesium-secreting organisms after their death as noted before.

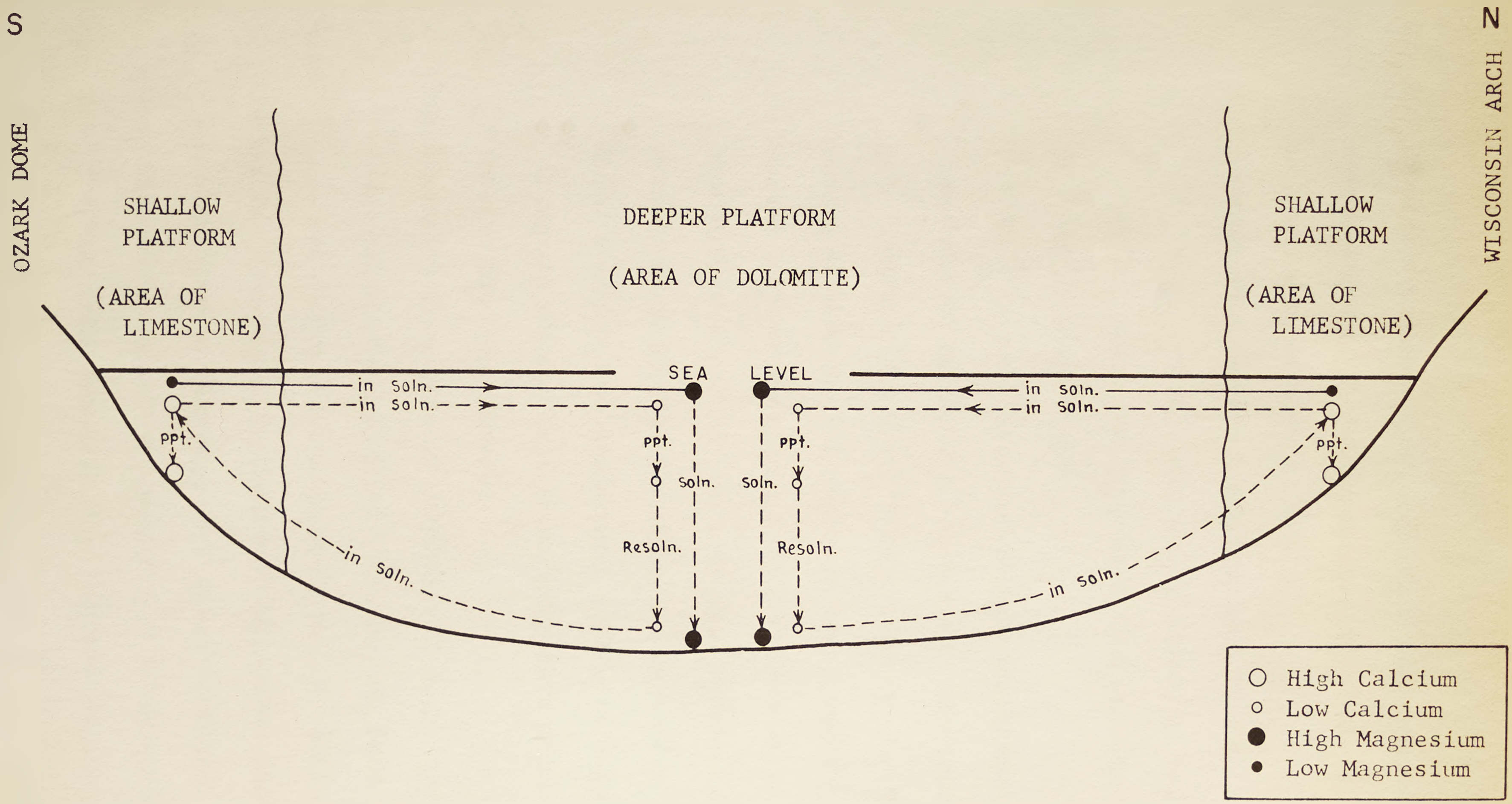


Fig. 11: Sketch showing a possible mean of enrichment of magnesium with respect to calcite in the deeper part of the Kimmswick-Galena seas and the resulting penecontemporaneous dolomitization of the Galena strata. Limestone facies occurs in the vicinity of the Ozark Dome toward the south and Wisconsin Arch toward the north.

2. Possible enrichment of magnesium with regard to calcium in deeper waters of the Galena sea as shown in Figure 11 and as discussed before (p. 140).
3. Penecontemporaneous dolomitization of the limy mud and very fine-grained debris originally deposited on the sea bottom, through a continuous replacement of calcium by magnesium at the depositional interface.
4. Perhaps the most important factor in alteration of the limestone to dolomite was its very fine-grained nature, which provided easy and uniform access for the magnesium-rich sea water to all parts of the limestone.
5. As the penecontemporaneous dolomitization progressed, the impoverishment of the interstitial waters (in the pore spaces and intergranular film) in magnesium content provided a mean of an additional influx of magnesium from bottom waters due to the concentration gradient created between the two waters.

The Kimmswick Limestone of northern Missouri is very similar in lithology to the Galena Formation of Illinois and Iowa and it is assumed that it was deposited and dolomitized by similar processes.

The Galena Formation, northward in Minnesota and Wisconsin, is mainly a limestone facies (Spreng, oral communication). The shallow seas, which flooded the platform area of the Wisconsin Arch during Galena time in this area, were similar to those in the platform area of the Ozark Dome in Missouri where the deposition of the Kimmswick Limestone took place, (Figure 11). This provides an explanation for the predominant limestone facies in this area.

CHAPTER VII

PETROLEUM POSSIBILITIES

The stratigraphic and structural studies of the Kimmswick Limestone and Galena Formation in Missouri, Illinois, and Iowa, have lead to some definite conclusions regarding their petroleum possibilities in the area. The subsurface characteristics of the existing oil fields, concerning the structures, lithologies, and nature of the oil production associated with these formations, have been critically examined in order to find guides to future petroleum exploration applicable to these formations in the area.

A brief description of the location, size, area, structure, and the nature of the production of the oil fields, producing from the Kimmswick Limestone and Galena Formation in the area, is given in this chapter. This is followed by a discussion of the possible factors controlling such production as suggested by this study. Finally, the areas favorable for oil production from the Kimmswick Limestone and Galena Formation are described.

The locations of the existing oil fields in the area are shown in Figure 12; all the numbers assigned to the fields in this figure correspond with those in the text. The data regarding these fields were mostly obtained from Illinois Petroleum 76, (1963, Table 10, pp. 23-59).

Illinois

1. Centralia Field
2. Craig Pool
3. Dupo Field
4. Fairman Pool
5. Irvington Pool
6. Patoka Field
7. Posen Pool
8. North Posen Pool
9. St. Jacobs Field
10. Salem Pool
11. Shattuck Pool
12. Turkey Bend Pool
13. Waterloo Field
14. Woburn Pool

Missouri

1. Florissant Pool

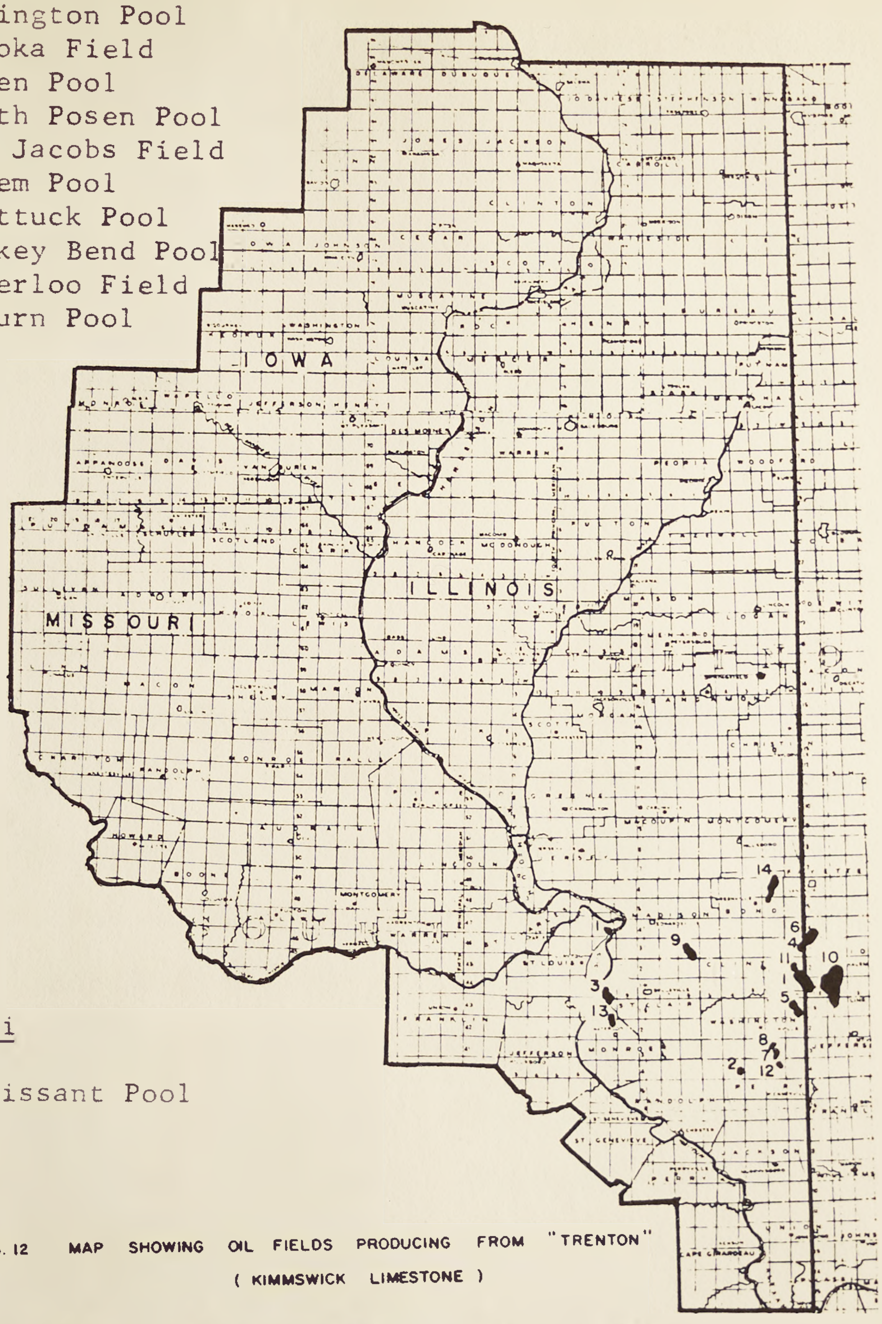


FIG. 12 MAP SHOWING OIL FIELDS PRODUCING FROM "TRENTON" (KIMMSWICK LIMESTONE)

40 0 40 80 120
SCALE IN MILES

"TRENTON" PRODUCTION IN ILLINOIS

The name "Trenton" as used in Illinois includes all the strata below the Maquoketa Formation to the top of the St. Peter Sandstone, (Cohee, 1941). Production to date has been found only in the Kimmswick Limestone, therefore all the production listed under "Trenton" in effect refers to the Kimmswick Limestone. In the following paragraphs the name "Trenton" is used for the Kimmswick Limestone from the petroleum production point of view.

Although the first "Trenton" discovery in Illinois was achieved in section 32, T. 30 N., R. 10 E., Kankakee County in 1900, commercial production was not established until 1910. The first well was a producer which led to the discovery of the Westfield pool in Clark County. This well had an initial production of 65 barrels of oil for the first 24 hours, declining to only 20 barrels for the next. The well, which was abandoned ten years later, produced an estimated total of 10,000 barrels of oil during that time, (Cohee, 1941).

Several "Trenton" fields were developed later, the locations of which are shown in Figure 12. These are described in the following paragraphs in alphabetical order. The numbers preceding the field names in the following paragraphs correspond to those shown in Figure 12.

1. Centralia Field

This field is in Townships 1 and 2 North, Ranges 1 East and 1 West, Clinton and Marion counties. The field was discovered in 1937 and produces from several formations of Pennsylvanian, Mississippian, Devonian, and Ordovician age. Only two wells have been drilled to the "Trenton" and one was abandoned in 1961. The "Trenton" producing area covers 1,400 acres and the production comes from a horizon at an average depth of 3,930 feet. The pay zone is light gray to buff crystalline limestone, slightly dolomitic and stylolitic in the lower part with only slight original porosity; it occupies an anticlinal structure and is 22 feet thick. It is now producing under water-flooding operations. No separate cumulative production data is available for the "Trenton" limestone.

2. Craig Pool

Located in Township 4 South, and Range 4 West in Perry County, the Craig Pool was discovered in 1948 with only one well completed in the "Trenton." This was abandoned in 1951 after producing 2,000 barrels of 35° API gravity oil from a depth of 3,650 feet. The producing area was 20 acres and the thickness of the pay zone is 20 feet in the Kimmswick Limestone. The production was from a very small anticlinal structure.

3. Dupo Field

The Dupo Field is located in Townships 1 North and 2 South, Range 10 West, in St. Clair County. The field was discovered in 1928 and has produced from "Trenton" only. The production area is 1,020 acres with 321 wells completed to date. Only 29 wells are producing now. The field has produced a cumulative total of 2,865,000 barrels of 33° API gravity oil from an average depth of 700 feet. Thickness of the pay zone is 50 feet and the oil is now recovered by a special pumping technique.

The structure of the Dupo field is an anticline known as Dupo Anticline with at least 100 feet of closure. The producing horizon is five feet below the top of the Kimmswick which consists of light brown to buff limestone, coarsely granular, compact, fossiliferous, and the drill cuttings show much clear calcite. Solution cavities and crevices have been encountered in the upper part of the producing zone in a few wells near the top of the structure. The study of the cores show that the porosity of the limestone varies from 2.6 to 19.0 percent with an average of 14 percent; permeability ranges from zero to 61 millidarcys with an average of 7.7 millidarcys; the average total fluid saturation of the pore space is 54.3 percent, (Cohee, 1941, p. 7).

4. Fairman Pool

This pool, located in Township 3 North, Ranges 1 East and 1 West, Marion and Clinton counties, was discovered in 1957 and a total of 14 wells have been completed in "Trenton" limestone. The production is from an average depth of 3,950 feet over an area of 300 acres. The field has produced a cumulative total of 159,000 barrels of oil from a 20-foot thick pay zone of the Kimmswick Limestone. The oil is found in a small anticlinal structure.

5. Irvington Pool

Located in Township 1 South, Range 1 West, Washington County, the Irvington Pool was discovered in 1956, and produces oil from several formations of Mississippian, Devonian, and Ordovician age. Six wells have been completed in the "Trenton" to date. The production comes from a 90-foot thick zone at an average depth of 4,275 feet over an area of 120 acres. The 39° API gravity oil comes from an anticlinal structure. No separate "Trenton" production data are available.

6. Patoka Field

The Patoka field, located in Townships 3 and 4 North, Ranges 1 East and 1 West in Clinton and Marion counties, was discovered in 1956, and produces oil from several formations of Mississippian, Devonian, and Ordovician age. Thirty-four wells have been completed in the "Trenton," six of which were abandoned through 1961. The production comes from a 25-foot thick pay zone in the Kimmswick Limestone, at an average depth of 3,950 feet. The Kimmswick pay area, lying on top of an anticlinal structure, is 740 acres and the gravity of the oil is 39° API; cumulative production figures are not available. No separate data for "Trenton" production is available.

7. Posen Pool

The Posen Pool is located in Township 3 South, Range 2 West, in Washington County, and was discovered in 1952. Since then the field has produced 69,000 barrels of oil from four wells covering an area of

80 acres. Presently only one well is producing. The production comes from a 25-foot thick pay zone of Kimmswick at an average depth of 3,900 feet. The reservoir occurs on an anticlinal structure on top of the Kimmswick.

8. North Posen Pool

This pool is located in Township 3 South, Range 2 West in Washington County. Discovered in 1953, it produced a total of 4,000 barrels of oil from one well up to 1959 when it was abandoned. The production was from 15-foot thick pay zone in Kimmswick Limestone at a depth of 4,015 feet. The factors responsible for the accumulation of oil are an anticlinal structure and a change in the character of rocks in the structure.

9. St. Jacobs Field

The biggest producer from the "Trenton," St. Jacobs Field, is located in Township 3 North, Range 6 West, in Madison County. With its discovery in 1942 it has produced a cumulative total of 3,104,000 barrels of 40° API gravity oil from 53 wells, 39 of which are still producing. The area covered by the producing zone is 1,120 acres and the thickness of the pay zone is 17 feet in the Kimmswick which occurs at an average depth of 2,260 feet. The accumulation of oil is in an anticlinal structure on the top of the Kimmswick Limestone.

10. Salem Pool

The first well in the Salem Pool was drilled to the "Trenton" in 1941 which is located in Townships 1 and 2 North, and 1 South, Ranges 1 and 2 East in Jefferson County. The pool produces from several formations of Mississippian, Devonian, and Ordovician age. To date 97 wells have been completed in the "Trenton" which produce from a 50-foot thick pay zone of the Kimmswick at an average depth of 4,500 feet. The area of the "Trenton" production is 2,200 acres which is occupied by an anticlinal structure. The pay zone consists of buff slightly dolomitic limestone which is fine- to coarse-grained and partly crystalline and is stylolitic in the lower part. The cores taken near the base of the producing zone, which is also the base of the Kimmswick, showed a variation in permeability of from zero to 195 millidarcys and an average porosity of 7 percent. The total water content varied from 8.8 to 34.5 percent of the pore space, and residual oil averaged 7 percent of the pore space (Cohee, 1941, p. 9). No separate "Trenton" production data are available.

11. <u>Shattuck Pool</u>

Located in Township 2 North, Range 1 West, Clinton County, the Shattuck pool was discovered in 1945, and produces from Mississippian and Ordovician rocks. Since then 15 wells have been completed in the "Trenton" which produce 40° API gravity oil from an average depth of 4,020 feet. The production area is 240 acres occupied by an anticlinal structure. The thickness of the pay zone in the Kimmswick is 13 feet. No separate "Trenton" production data are available.

12. Turkey Bend Pool

This pool is located in Township 4 South, Range 2 West in Perry County. Discovered in 1957, it has produced a cumulative total of 24,000 barrels of oil from only one well. The average depth to the producing horizon is 3,940 feet and the production area is 20 acres. No further data are available regarding the structural conditions.

13. Waterloo Field

One of the earliest "Trenton" fields, the Waterloo field, is located in Townships 1 and 2 South, Range 10 West, Monroe County. Since its discovery in 1920 it has produced 238,000 barrels of 30° API gravity oil from a 50-foot thick pay zone in the Kimmswick, at an average depth of 410 feet. The area of production covered by four wells is 230 acres.

The Kimmswick Limestone consists of light gray to buff fine- to medium-grained fossiliferous limestone. The structure shows an anticlinal closure of more than 100 feet on the top of the Kimmswick. Production is limited to the uppermost part of the structure.

14. Woburn Pool

Located in Townships 6 and 7 North, Range 2 West, Bond County, the Woburn pool produces from several horizons of Mississippian, Devonian, and Ordovician age, the oldest being the "Trenton." It has 18 wells that have been completed in "Trenton" with a production area of 380 acres. The production comes from a 12-foot thick pay zone in the Kimmswick at an average depth of 3,170 feet. The oil accumulation is in an anticlinal structure which shows a slight facies change of the Kimmswick, from limestone to dolomite. No separate "Trenton" production figures are available.

KIMMSWICK PRODUCTION IN MISSOURI

The only producing field in Missouri is located near the city of Florissant about 10 miles north of St. Louis. Since its discovery in 1953 until the middle of 1954, 50 tests were drilled; 45 were producers and five were dry (McCracken, 1956). About 400 acres on the structure is productive.

The production comes from the uppermost beds of the Kimmswick Limestone at an average depth of 1,100 feet. The anticlinal structure on the top of the Kimmswick shows a closure of 25 to 75 feet.

FACTORS INVOLVED IN KIMMSWICK PRODUCTION

The foregoing review of the "Trenton" fields in Illinois and Missouri points out certain generalities regarding the geological factors contributing to the production in the area. These are important in connection with the future exploration for petroleum in the area and emphasized in the following paragraphs.

There has been no indication of oil in this area below the Galena or Kimmswick except for some local odor and staining in the deeper-lying St. Peter Sandstone. The next higher producing horizon in this part of Illinois is in the Silurian reef rocks, although no production has been achieved in Missouri from formations other than the Kimmswick.

All these fields are located on the shelf area of the Illinois basin in the vicinity of the Ozark Dome. The production is, without any exception, found in the crestal parts of small local anticlinal structures with closures of 25 to 100 feet. All these anticlinal structures are so small that they are not apparent on a regional structure map and do not seem to bear any close relationship with the regional structural trends of the area. The production comes from the upper 50 feet of the limestone, especially where the Maquoketa unconformity on the top of the Kimmswick is well-developed. The production is confined to the limestone facies only. Any dolomitization of the pay zone is associated with the unconformity at the top of the Kimmswick and the fractures in the rocks.

Although the Kimmswick is fairly porous throughout, higher porosities occur in the uppermost beds near the unconformity. As a general rule, however, the permeability of the Kimmswick is very low. Although porosities up to 25 percent have been measured in the cores, the measured permeability in the same core has been found to be very low. This suggests that there is no primary permeability connecting the pore spaces in these rocks. As a result commercial production has been in the consistent "breaks" in the same bed which are locally usually at the same depth below the top of the formation. The only permeability found in the rock is of secondary nature created by fracturing, solution channels, and local dolomitization. This is evident from the thin section study of the core from Lange #3 well in the Florissant field in Missouri, which clearly shows the confinement of the oil in the fractures in the rock (Plate VII). There is no trace of oil in the dry part of the same core immediately below the producing horizon (Plate VII). The permeability associated with the dolomitization is generally found near the unconformity at the top of the Kimmswick.

SOURCE OF OIL IN KIMMSWICK

The oil found in the Kimmswick fields in Illinois and Missouri is evidently not indigenous to the limestone. The following evidences point out this inference:

1. The Kimmswick Limestone, although very rich in fossils and other organic remains, does not show any indication of heavy oil residue in the rock except for some partially decayed organic material which is seen in the lower part of the section as dark brown streaks and specks. A thin section of the nonproducing horizon, immediately below the producing horizon in the Lange #3 well in the Florissant Field in St. Louis (Plate VII), does not show any trace of oil residue or dead oil or any stain, indicating that the oil in the Kimmswick has migrated from some other horizon along the fractures and similar other accessible zones of weakness. This is also indicated by the presence of hydrocarbon residue in fractures in the samples from surface exposures of the Kimmswick Limestone (Plate XXIV).

Plate XXIV Photomicrograph of thin section (Sa_3) of the Kimmswick Limestone showing hydrocarbon residue in the fracture (dark black material across the slide). The absence of hydrocarbon outside the fractures indicates its migration along the secondary permeability features (32x).

2. The underlying Decorah Formation contains several dark black carbonaceous shale horizons in addition to being richly fossiliferous, which might have served as potential source bed for the oil in the overlying Kimmswick. A thin section of the shaly part of the Decorah showed heavy oil-like residue under the microscope, which indicates the source of oil being in the Decorah. The limestone part of this thin section of the Decorah also showed this residue disseminated through the entire body of the rock.
3. The fact that most of the production in the Kimmswick comes from the uppermost beds, especially where the Maquoketa unconformity on the top of the Kimmswick is well developed, indicates that migration of the oil took place along this unconformity zone which apparently provided easy access to the oil along the leached and permeable zones. Furthermore, the leaching along this unconformity zone caused the higher porosities in the uppermost beds of the limestone which served as reservoir beds.
4. Favorable source beds of oil existed in the nearby Illinois Basin. This oil migrated updip along the flanks of the Ozark Dome through the fractures and along the unconformities in the Kimmswick and was trapped in the upper parts of the Kimmswick structures under the impervious cover of the Maquoketa shale.

5. The actual migration of oil took place after the deposition of the overlying Maquoketa shale and the subsequent uplift which originated the structures. The hydrostatic disturbance caused by post-Maquoketa movements started the updip migration of the fluids from the Illinois basin toward the Ozark Dome. Most of this movement took place along the Maquoketa-Kimmswick unconformity and local fractures. The low permeability of the limestone hindered the movement of oil in any greater amounts and that is why none of these fields have proved to be big producers.

PROSPECTIVE AREAS

The above factors clearly indicate that most favorable areas for future petroleum exploration will be found in local anticlinal structures on the top of the Kimmswick Limestone and the Galena Formation where an impervious cover of the Maquoketa shale exists. A thin limestone section on these structures will be more favorable than the thick sequences, especially where the Maquoketa unconformity at the top of the Kimmswick and the Galena is well-developed, because a thin sequence near the unconformity is likely to be more porous and permeable than the thick sequences due to the leaching of the limestone along these zones. The limestone facies of the Kimmswick seems to be more favorable than the dolomite facies, since no production has yet been found in the dolomite facies in the area. However, local dolomitization, associated with the unconformity or the fractures in the limestone, may have caused porosities and permeabilities and the use of such dolomitized zones may help in exploration for oil in these strata.

Although geologically the Kimmswick Limestone provides an ideal condition for oil accumulation because of porosity and presence of anticlinal structures between two impervious shale beds (namely Decorah below and Maquoketa above), yet its very low permeability makes it a poor risk from the petroleum exploration point of view. Local accumulations of oil are more likely to be found in the Kimmswick and Galena, yet these may or may not be of economical value for the reasons cited. With these conditions in mind, the following areas are considered favorable for future petroleum exploration:

Putnam County, Missouri

From the structure map drawn at the base of the Kimmswick and the Galena formations (Plate XVIII) it is evident that a dome-like structure, with up to 100 feet of closure, occurs in the central part of the county. The thickness of the Kimmswick, which is predominently dolomite, is 150 to 175 feet. Two dry holes, drilled by the Cities Service in 1960, were to the south and away from the top of the structures, but had oil shows in the Kimmswick Limestone. A good Maquoketa shale cover provides favorable caprock. The above factors make this area a good prospect for oil and a test should be drilled on the top of this structure to evaluate the economics of the area.

Shelby and Knox Counties, Missouri

The Shelby Anticline, (p. 91) with its 100 feet of closure and about 100 feet of Kimmswick Limestone cover, appears to be a potential oil-bearing structure. The Kimmswick Limestone is thinnest (25 feet) on the Shelby-Knox county line and thickens to about 150 feet on the structure southward. This variation in the Kimmswick thickness, in all probability, is due to erosion which indicates the presence of the unconformity on top of the Kimmswick Limestone in the area.

At least four wells have been drilled around this structure, which had shows of oil in the Kimmswick Limestone. These wells appear to lie on the flanks of the structure. Further drilling on top of the structure is recommended for the evaluation of the area.

Chariton County, Missouri

A prominent northwest trending anticlinal nose occurs in northeastern Chariton County, Missouri and shows a possibility of about 100 feet of closure in the extreme northeastern part of the county (Figure 7, p. 87). The thickness of the Kimmswick Limestone on the structure is about 150 feet and thins southeastward. No test wells have been drilled in the area.

Clark and Lewis Counties, Missouri

A small anticlinal structure with about 100 feet of closure is located in extreme southeastern part of Clark County, and extreme northeastern part of Lewis County, Missouri. The Kimmswick on the structure is 100 to 150 feet thick, but thins northwestward; it is primarily dolomite, and has a good Maquoketa shale cover with well developed Maquoketa unconformity on its top. This area bears promise for petroleum and should be tested thoroughly.

Appanoose County, Iowa

The presence of a local anticlinal structure in extreme northeastern part of Appanoose County, Iowa is indicated from the isopach map of the Galena (Plate XIX). Although the structure contour map of the Galena (Plate XVIII) shows a structural low in this area, there may be a local anticlinal structure which is not apparent primarily because of poor control in the area. The area looks ideal and very much similar to the Florissant Dome in St. Louis County, Missouri. The presence of well developed unconformity on the top of the Galena dolomite along with other factors discussed above, makes this a very promising area.

Des Moines County, Iowa

A similar anticlinal structure is indicated from the isopach map of the Galena, which occupies the eastern part of the Des Moines County, Iowa. The structure contour map at the base of the Galena dolomite (Plate XVIII) shows a possible structure on the Galena, and a good Maquoketa unconformity and shale cover, giving this area future promise of oil production.

Illinois

Several exploratory wells have been drilled in northern and northwestern Illinois on apparently major structures without success. On almost all these major structures the thickness of Galena Formation exceeds 150 to 200 feet. Since the tectonic movements in the area have been slow, no major fracturing has occurred in these thick sequences to allow for secondary permeability. The thin sequences of the Galena, which owe their thinning primarily to the post-Galena erosion, on the other hand, possess secondary porosity and permeability mainly due to the erosion and fracturing. Therefore, it is recommended that future exploration in northern and northwestern Illinois for oil production in the Galena Formation be concentrated in such areas where small local structures contain thin sequences of the Galena Formation.

No specific areas in Illinois have been discussed here because in order to locate favorable local structures a more detailed map with closer well control will be needed.

RECOMMENDATIONS

All the prospective areas discussed above are of shallow nature and the Kimmswick and Galena occur within the depths of 2,000 feet. As a result the areas can be quickly and economically tested for their potential. A detailed seismic survey is recommended in these areas for testing the presence of such small structures as Florissant Dome, St. Louis County, Missouri, which are otherwise rather difficult to locate.

The seismic work should be followed by a well organized drilling program of wildcat wells, the locations of which should be very carefully chosen in the area. The cores and well-cuttings should be very carefully tested for the minor shows, odors, and stains, because it is very easy to miss these in these formations. Because of the low permeability of the Kimmswick and Galena, a good perforation program will be needed in order to establish any commercial production from these horizons. Further development will entirely depend on the result of the above tests.

CHAPTER VIII

CONCLUSIONS

The following conclusions are drawn from the foregoing study.

1. Lithologically, the Kimmswick Limestone is an aggregate of small fragments of echinoderms, brachiopods, bryozoans, and fine-grained fossil debris, which are cemented together by clear sparry calcite. A three-fold subdivision of the Kimmswick Limestone in Missouri has been proposed on the basis of their gross lithologies and thin section study. These subdivisions are designated the Lower, Middle, and Upper members in ascending order. The Lower Member has been correlated with the St. James Member of the Dunleith Formation in Illinois and the Ion Member of the Decorah Formation in Iowa. The Middle Member is equivalent to the Beecher, Eagle Point, and Moredock members of the Dunleith Formation in Illinois and the Lower Prosser Member of the Galena Dolomite in Iowa. The Upper Member is correlative with the New London Member of the Wise Lake Formation in Illinois and the Upper Prosser Member of the Galena Dolomite in Iowa. The beds younger than the Upper Member of the Kimmswick Limestone are

absent in Missouri. The Cape Limestone, occurring in Cape Girardeau sections, has been included in the lowermost beds of the Cincinnatian Series.

2. Although the base of the Kimmswick Limestone in Missouri is regionally conformable with the underlying Decorah Formation, it is marked by a local unconformity in the vicinity of the Ozark Dome. The top of the Kimmswick Limestone is marked by a pronounced unconformity throughout the area of this study.

3. The area of this study shows a northwesterly structural trend at the base of the Kimmswick-Galena Formation, with Lincoln Anticlinorium and the Henderson Anticline being two major structural features.

4. The Kimmswick-Galena Formation shows much thicker trend northward from the Lincoln Anticlinorium. These formations also tend to be thick on the top of the present anticlinal structures in the subsurface with the exception of the Pittsfield-Hadley and Adams anticlines in Illinois. Similarly they tend to be thin in the synclinal areas, indicating that the present structural features were not present at the time of the deposition of the Kimmswick-Galena Formation.

5. Regionally the Kimmswick-Galena Formation is represented mainly by a dolomite facies north of the Lincoln Anticlinorium while a limestone facies predominates toward the south. The dolomitization does not seem to be associated with the present subsurface structural features, with the exception of some local dolomitization which seems to be related to the local faulting and similar other secondary features.

6. A brief discussion of the geologic history of the area during the Paleozoic Era has been given, with special emphasis during Kimmswick-Galena time. It is inferred that the maximum flooding occurred in the area during Middle Kimmswick time, which was followed by an uplift at the end of Late Kimmswick time, as indicated by the presence of a pronounced unconformity at the top of the Kimmswick Limestone in the area. Volcanic activity in Kimmswick time was at its peak during Middle Kimmswick time, which seems to have subsided toward the end of Middle Kimmswick time.

7. The Kimmswick Limestone seems to have been deposited in the shallow water, warm temperature, and high energy conditions on the platform formed by the submerged flanks of the Ozark Dome. The Galena Formation was deposited initially in deeper water and low energy conditions

toward north, formed perhaps by accumulations of very fine-grained fossil debris washed away from the shallow shore areas and limy mud as chemical precipitate. This was dolomitized penecontemporaneously by the magnesium-rich sea water within a few feet of the surface of deposition after burial. Local dolomitization of the Kimmswick Limestone is purely a secondary feature.

8. A brief discussion of petroleum possibilities of the Kimmswick-Galena Formation in the area has been given and several potential areas in northeastern Missouri and southeastern Iowa have been described for future petroleum exploration.

BIBLIOGRAPHY

Agnew, A. F., 1955, Facies of Middle and Upper Ordovician rocks of Iowa: Amer. Assoc. Petroleum Geologist, Bull., v. 39, p. 1703-1752.

__________, Heyl, A. V., Jr., Behre, C. H., Jr., and Lyons, E. J., 1956, Stratigraphy of Middle Ordovician rocks in the zinc-lead district of Wisconsin, Illinois, and Iowa: U. S. Geol. Survey, Prof. Paper, 274-K, p. 251-312.

Allen, V. T., 1932, Ordovician altered volcanic material in Iowa, Wisconsin, and Missouri: Jour. Geol., v. 40, p. 259-269.

Bain, H. F., 1905, Zinc and lead deposits of northwestern Illinois: U. S. Geol. Survey, Bull. 246.

Bell, A. H., Oros, M. O., and Van Den Berg, J., 1963, Petroleum Industry in Illinois: Illinois State Geol. Survey, Illinois Petroleum 77, Pt. I, p. 1-59.

Bradley, J. H., Jr., 1925, Stratigraphy of the Kimmswick Limestone of Missouri and Illinois: Jour. Geol., v. 33, p. 49-74.

Bridge, J., and Dake, C. L., 1929, Initial dips peripheral to resurrected hills: in Appendix to Biennial Rept. of State Geologist to 55th. General Assembly, pp. 93-99.

Calvin, S., 1906, Geology of Winneshiek County, Iowa: Iowa Geol. Survey, v. 16, p. 37-146.

Chave, K. E., 1954, Aspects of biogeochemistry of magnesium: Jour. Geol., v. 62, Pt. 1, p. 266-283.

Clark, A. M., 1957, Crinoids: in Treatise on Marine Ecology and Paleoecology, v. 1., Ecology, Geol. Soc. America, Memoir 67, p. 1183-1185.

Cohee, G. V., 1941, "Trenton" production in Illinois: Illinois State Geol. Survey, Illinois Petroleum, no. 39, 15 p.

Cole, V. B., 1962, The Cap au Gres Fault: Kansas Geol. Soc., 26th Annual Field Conference, Guide Book, p. 86-88.

Cook, C. W., 1957, Echinoids: in Treatise on Marine Ecology and Paleoecology, v. 1, Ecology, Geol. Soc. America, Memoir 67, p. 1191-1192.

Cooper, G. A., 1956, Chazyan and related brachiopods: Smithsonian Misc. Collection, v. 127, Pt. 1.

Douthit, T. D. N., 1959, Magnetic surveys of the Cap au Gres faulted flexure: Unpublished Master's Thesis, St. Louis University.

Dubois, E. P., 1945, Subsurface relations of the Maquoketa and "Trenton" formations in Illinois: Illinois State Geol. Survey, Rept. Inv., Pt. I, p. 7-33.

Dunbar, C. O., and Rodgers, J., 1957, Principals of Stratigraphy: John Wiley & Sons, New York, N. Y., 356 p.

Duncan, H., 1957, Bryozoans: in Treatise on Marine Ecology and Paleoecology, v. 2, Paleoecology, Geol. Soc. America, Memoir 67, p. 783-790.

Eardley, A. J., 1962, Structural Geology of North America: Harpers Brothers Inc., New York, N. Y., 624 p.

Fairbridge, R. W., 1957, The Dolomite Question: in Regional Aspects of Carbonate Deposition: A Symposium, Society of Econ. Paleontologists and Mineralogists, Special Publication no. 5, p. 125-178.

Fenneman, N. M., 1911, Geology and Mineral Resources of the St. Louis Quadrangle, Missouri-Illinois: U. S. Geol. Survey, Bull. 438, 69p.

Foerste, A. F. 1920 The Kimmswick and Plattin limestones of northeastern Missouri: Denison Univ., Sci. Lab., Bull., v. 19, p. 182-183.

Grohskopf, J. G., 1933, Magnetic Surveys: Missouri Bur. Geol. and Mines, 57th. Biennial Report, App. 4, 20 p.

__________, 1941, Cross Section, Hannibal, Missouri to Dupo, Illinois: Kansas Geol. Soc. 15th Annual Field Conference, Guide Book, opposite p. 480.

Hall, C. W. and Sardeson, F. W., 1892, Paleozoic formations of southeastern Minnesota: Geol. Soc. America, Bull., v. 3, p. 331-365.

Hall, J., 1851, Lower Silurian System: Upper Silurian and Devonian Series: in Foster, J. W. and Whitney, J. D., Report on the geology of the Lake Superior land district, Pt. 2, U. S. 32nd. Cong., Spec. Sess., Senate Exec. Doc. 4, p. 140-166; also Amer. Jour. Sci., 2nd. Series, v. 17, p. 181-194.

Hayes, C. W. and Ulrich, E. O., 1903, U. S. Geol. Survey, Geol. Atlas, Columbia Folio, No. 95, p. 2.

Herbert, P., Jr., 1949, Stratigraphy of the Decorah Formation in western Illinois: Unpublished Ph. D. Thesis, Univ. Chicago, PH-1.

Hogbom, A. G., 1894, Ueber Dolomitbildung und dolomitische Kalkaorganismen: Neues Jahrt. f. Min. Geol. Pal., v. 1, p. 262-274.

Kay, G. M., 1928, Stratigraphy of the Decorah Formation: Science, New Series, v. 67, 16 p.

____________, 1935, Ordovician System in the Upper Mississippi Valley: Kansas Geol. Soc., 9th Annual Field Conference, Guide Book, p. 281-295.

Kesling, R. A. and Graham, A., 1963, Ischadites is dasycladacean alga: Jour. Paleontology, v. 36, p. 943-952.

Keyes, C. R., 1894, Crustal adjustments in the Upper Mississippi Valley: Geol. Soc. America, Bull., v. 4, p. 231-242.

____________, 1898, Some geological formations of the Cap au Gres Uplift: Iowa Acad. Sci. Proc., v. 5, p. 58-63.

____________, 1914, Scheme of Stratigraphic Succession in Missouri: R. Henderson, State Printer, Des Moines, Iowa, 4 p.

King, P. B., 1951, The Tectonics of Middle North America: Princeton Univ. Press, Princeton, New Jersey, 203 p.

Krey, F., 1924, Structural reconnaissance of the Mississippi Valley area from Old Monroe Missouri to Nauvoo, Illinois: Illinois State Geol. Survey, Bull., v. 45, 86 p.

Lee, W., 1954, Thickness maps as criteria of regional structural movements: Kansas Geol. Survey, Bull. 109, Pt. 5, p. 65-80.

Marshall, J. H., Jr., 1950, Geology in and adjacent to Cape Girardeau, Cape Girardeau, County, Missouri: Unpublished Master's Thesis, University of Missouri.

Martin, J. A., *et al*, 1961, Ordovician System: in Howe, W. B., *Coordinator*, and Koenig, T. W., *Editor*, Stratigraphic Succession in Missouri, Missouri Geol. Survey and Water Resources, 2nd. Series, v. 40, p. 20-32.

Mason, B., 1952, Principles of Geochemistry: John Wiley & Sons, New York, N. Y., 276 p.

Mateker, F. J., Jr., 1956, Gravity surveys of the Cap au Gres structure in the Hardin-Brussels quadrangles, Illinois: Unpublished Master's Thesis, St. Louis Univ.

McCracken, E., 1956, Northeast Missouri's oil possibilities improve: Missouri Geol. Survey and Water Resources, Rept. Inv. no. 21, 2 p.

McQueen, H. S., 1931, Insoluble residue as a guide to stratigraphic Studies: Missouri Bur. Geol., 56th. Biennial Report, p. 104-107.

McQueen, H. S. and Greene, F. C., 1938, The geology of northwestern Missouri: Missouri Geol. Survey and Water Resources 2nd. Series, v. 25, 215 p.

McQueen, H. S., Hinchey, N. S., and Aid, K., 1941, The Lincoln Fold in Lincoln, Pike, and Ralls counties, northeastern Missouri: Kansas Geol. Soc., 15th. Annual Field Conference, Guide Book, p. 99-110.

Osburn, R. C., 1957, Marine bryozoa: in Treatise on Marine Ecology and Paleoecology, v. 1., Ecology, Geol. Soc. America, Memoir 67, p. 1109-1111.

Owen, D. D., 1840, Report on geological exploration of part of Iowa, Wisconsin, and Illinois in 1839: U. S. 28th. Cong. 1st. Sess. Senate Exec. Doc. 239.

Pirtle, G. W., 1932, Michigan Structural Basin and its relationship to surrounding areas: Amer. Assoc. Petroleum Geologist, Bull., v. 16, p. 148-149.

Plumley, W. J., Risley, G. A., Graves, R. W., Jr., and Kaley, M. E., 1962, Energy index for limestone interpretation and classification: in Classification of Carbonate Rocks, a Symposium, Amer. Assoc. Petroleum Geologist, Memoir 1, p. 85-107.

Revelle, R., 1934, Physico-Chemical factors affecting the solubility of calcium carbonate in sea water: Jour. Sed. Petrology, v. 4, p. 103-110.

Revelle, R. and Fairbridge, R., 1957, Carbonates and carbon dioxide: in Treatise on Marine Ecology, and Paleoecology, v. 1, Ecology, Geol. Soc. America, Memoir 67, p. 239-296.

Rubey, W. W., 1952, Geology and mineral resources of Hardin and Brussels quadrangles (in Illinois): U. S. Geol. Survey, Prof. Paper 218, 179 p.

Schuchert, C., 1911, Paleogeographic and geologic significance of Recent brachiopods: Geol. Soc. America, Bull., v. 22, p. 258-275.

Shrock, R. R. and Twenhofel, W. H., 1953, Principles of Invertebrate Paleontology: McGraw-Hill Book Co., New York, N. Y. 2nd. Edition, 816 p.

Smith, C. L., 1940, The Great Bahama Bank: Jour. Marine Research, v. 3, p. 147-189.

Spreng, A. C., 1964, Oral communication.

Sverdrup, H. V., Johnson, M. W., and Fleming, R. H., 1942, The Oceans; their physics, chemistry, and general biology: Prentice-Hall Inc., New York, N. Y., 1807 p.

Templeton, J. S. and Willman, H. B., 1963, Champlainian Series (Middle Ordovician) in Illinois: Illinois State Geol. Survey, Bull. 49, 260 p.

Trowbridge, A. C., 1935, Dubuque, Iowa to La Crosse, Wisconsin: Kansas Geological Soc., 9th. Annual Field Conference, Guide Book, p. 61-73.

Twenhofel, W. H., et al, 1954, Correlation Chart of the Ordovician formations of North America: Geol. Soc. America, Bull., v. 65, p. 247-298.

Ulrich, E. O., 1904, in Buckley, E. R., and Buehler, H. A., The quarrying industry of Missouri: Missouri Bur. Geol. and Mines, 2nd. Series, v. 2, 111 p.

Ulrich, E. O., 1911, Revision of the Paleozoic System: Geol. Soc. America, Bull., v. 22, p. 281-680.

Van Tuyl, F. M., 1916, The Origin of Dolomite: Iowa Geol. Survey, Bull., v. 25, pp. 251-421.

Weller, J. M., 1937, Illinois Basin, Pt. I: Amer. Assoc. Petroleum Geologist, Bull., v. 21, p. 771-788.

Weller, S. and St. Clair, S., 1928, Geology of Ste. Genevieve County, Missouri: Missouri Bur. Geol. and Mines, 2nd. Series, v. 22, 124 p.

Wilmarth, G., 1938, Lexicon of Stratigraphic Names in the United States: U. S. Geol. Survey, Bull. 896, Pt. I, 1244 p.

Winchell, N. H., 1873, Sketch of geology of Minnesota: Minn. Geol. & Natural History Survey, 1st. Annual Report, p. 64-118.

__________, N. H. and Ulrich, E. O., 1879, Paleontology; in geology of Minnesota: Minn. Geol. & Natural History Survey, v. 3, Pt. 1.

APPENDIX A

DESCRIPTION OF THE MEASURED SURFACE SECTIONS

LOCALITY 1

Inactive quarry, 2 miles north of New London, SE¼, NE¼, NW¼, Sec. 36, T. 56N., R. 5 W., Ralls County, Missouri.

KIMMSWICK LIMESTONE

Middle Member

Limestone;	gray to buff fresh, weathers to light brownish gray; coarse-grained; massive- to thin-bedded, abundant fragmental fossils; vugs and anastomosing cavities on the surface ----------------------------	29'	
Limestone;	made up entirely of layers of fine fossil fragments ------------	1'	
Limestone;	coarse-grained, made up of layers of fossil fragments --------------	1'	4"
Limestone;	coarse-grained, made up of layers of fossil fragments ---------------	1'	

Lower Member

Limestone;	light gray to buff, coarse- to medium-grained, with up to 2-inch calcite-filled cavities in places, fossil fragments -----------------	3'	2"
Limestone;	light gray to buff, medium-grained, crystalline; fragments of brachiopods abundant, (Rafinesquina); calcite-filled vugs	5'	1"
Limestone;	brownish-gray, coarsely crystalline, massive, abundant fossil fragments	0'	6"

Limestone; light grayish white, fine- to medium-grained, fragmental fossils (corals), rare calcite fillings with dark brown streaks and specks of organic matter --------------------------	2'	9"
Quarry Floor		
Total Kimmswick	43'	10"

LOCALITY 2

Bluff on Salt River on County Highway V. 3 miles east of New London, SW¼, SW¼, SE¼, Sec. 5, T. 55N., R. 4 W., Ralls County, Missouri.

KIMMSWICK LIMESTONE

Middle Member

Limestone; gray to buff, light brownish gray on weathered surface; coarse-grained; massive to thin-bedded; abundant fragmental fossils and shell material; vugs and anastomosing cavities on the surface -------------------------	14'	6"
Limestone; gray-brown, medium- to fine-grained, massive, hard, made up almost entirely of fragmental fossil material, with rare calcite-filled cavities -----	3'	2"

Lower Member

Limestone; medium- to fine-grained, thin layers of fragmental fossils; vugs and cavities, up to 2 inches in size, filled with calcite --------------	1'	
Limestone; brownish to buff colored, thinly bedded, rather slabby, medium- to coarse-grained, with fragmental fossils, calcite-filled cavities up to 1 inch --------------------	3'	6"

Limestone; brownish gray to buff colored, massive- to thick-bedded, coarsely crystalline with abundant fragments of fossils, calcite-filled cavities dark brown specks and streaks of organic matter -------------------	11'	6"
Total Kimmswick	33'	8"

DECORAH FORMATION

Guttenberg Member

Limestone; chocolate-brown, very fine-grained to lithographic, thin interbeds of green to greenish gray shale, abundant whole fossils, Rafinesquina, Sowerbyella; contact with the Kimmswick is partly covered ------	5'	6"

LOCALITY 3

Road cut on Highway 61 north, near Pike and Ralls County boundary line, SE¼, NE¼, SE¼, Sec. 21, T. 55N., R. 4 W., Ralls County, Missouri.

KIMMSWICK LIMESTONE

Middle Member

Limestone; gray and buff, light brownish gray on weathered surface; coarsely crystalline with abundant fossil fragments; vugs and anastomosing cavities on the surface ----------	4'	6"

Lower Member

Limestone; brownish buff, thick-bedded, fossiliferous with several layers of fossil fragments; calcite-filled vugs up to 2 inches in size, dark-brown specks of organic matter common; pyrite common near the base	12'	

Limestone;	white, very fine-grained, with pebbles of subrounded Decorah limestone; fossiliferous; wavy surface at base and top ----------	0' 6"
	Total Kimmswick	17'

---------------------------- Elevation +604 ----------------------

DECORAH FORMATION

Guttenberg Member

Limestone;	very fine-grained to lighographic, near the top, coarse-grained with cross-beddings near the base; numerous green to greenish-gray shale partings, and few bentonite beds; fossils abundant, mainly brachiopods, Rafinesquina, Sowerbyella, Pionodema -----------	6' 6"

LOCALITY 4

Galloway quarry, Frankford, SW¼, NE¼, SE¼, Sec. 2, T. 54N., R. 4 W., Pike County, Missouri.

KIMMSWICK LIMESTONE

Upper Member

	Residual chert and soil cover ----	5'
Limestone;	gray to buff, brownish-gray on weathered surface, coarsely crystalline, massive to thin-bedded, several layers of fossil fragments and shell material, Receptaculites oweni common, vugs and anastomosing cavities on the surface --------------------------	14'
Shale;	thin shale zone, yellowish brown, making a slight reentrant in the quarry face ---------------------	4" to 6"

Middle Member

Limestone;	brownish-gray on weathered surface light gray when fresh, medium to coarse-grained, abundant fossil fragments, with numerous layers of fossils, Receptaculites rare; vugs and anastomosing cavities on the surface ----------------------	25'	
Limestone;	light gray to white, medium-grained, crystalline, massive, abundant fossil fragments, large calcite-filled cavities, cavernous in part Brachiopods ----------------------	18'	6"
Limestone;	light gray, massive rather finely crystalline, abundant fossil fragments ------------------------	7'	6"
Limestone;	light gray to gray, medium- to coarse crystalline, fragmental fossils, with anastomosing cavities and vugs on the surface ------------------	7'	7"

Lower Member

Limestone;	light gray to brownish gray medium to coarsely crystalline, abundant fossil fragments, with a few calcite-filled cavities, and dark brown streaks and specks of organic matter, trace of chert near the base	12'	9"
	Total Kimmswick	90'	10'

DECORAH FORMATION

Guttenberg Member

Limestone;	chocolate brown, very fine-grained to lithographic, with thin green to greenish gray shale partings, exposed	10'	

LOG OF THE 50-FOOT CORE AT LOCALITY 4

KIMMSWICK LIMESTONE

Middle Member

		Top	Bottom
Limestone;	light brownish gray, medium crystalline, fossil fragments visible bryozoan fragments, small calcite-filled cavities, porous	0'	1'
Limestone;	light gray, fine to medium crystalline, fossil fragments, large and small cavities partially filled with calcite, porous	1'	8' 3"
Limestone;	light brownish gray, coarse to medium crystalline, fossil fragments, brownish streaks and specks, partly weathered to vuggy texture with brownish lining around the rim of the streaks and specks of organic matter	8' 3"	10' 6"
Limestone;	light gray, coarsely crystalline, fossils common, thin black to brown streaks of organic matter present, porous	10' 6"	12'
Limestone;	gray, light gray, medium- to coarse-grained, almost entirely made up of fossil fragments, porous	12'	12' 6"

Lower Member

		Top	Bottom
Limestone;	light gray, rather fine-grained, few fossil fragments, calcite fillings common, very porous	12' 6"	13' 6"
Limestone;	light gray, coarse- to medium-grained, almost entirely made up of fossil fragments, few larger fragments of brachiopods seen on the surface	13' 6"	14'
Limestone;	light gray, fine-grained, fossil fragments, porous; Receptaculites oweni occurs with other larger fragments of fossils	14'	15' 1"

Limestone; medium- to coarsely crystalline, fossil fragments with dark brown specks and streaks of organic matter, trace of clear calcite crystals -------------------------	15' 1"	15' 4"
Limestone; rather finely crystalline, fine fossil fragments, occasional clear calcite fillings, porous ---------	15' 4"	17' 8"
Limestone; medium crystalline, almost entirely made up of fossil fragments, porous ---------------------------	17' 8"	18' 2"
Limestone; finely crystalline, abundant fossil fragments, with few larger fragments of brachiopods and bryozoans, calcite fillings with black to dark brown streaks and specks of organic matter, slightly porous ----------	18' 2"	24'

DECORAH FORMATION

Guttenberg Member

Limestone; chocolate brown, very fine-grained to lighographic, with thin green to greenish gray shale partings -----		26'

LOCALITY 5

Road cut on Highway 109, 3 miles north of Eureka, NW¼, NW¼, SW¼, Sec. 25, T. 44 N., R. 3 E. St. Louis County, Missouri.

KIMMSWICK LIMESTONE

Upper Member

Limestone; light brownish gray on weathered surface but gray to buff when fresh; coarsely crystalline, abundant fossil fragments, several layers of fossil fragments, vugs and anastomosing cavities on the surface -------------------------	14'

Limestone; light gray to gray, massive, crystalline, abundant fossil fragments, hard, Receptaculites and brachiopods common; lower 2 feet consisting of layered fossil fragments ---------------- 9'

Shale; yellow to yellowish brown platy shale, with paper-thin layers of calcareous shale, few fossils present, bentonitic -------------- 2" to 3"

Middle Member

Limestone; dark gray to light gray, massive, coarsely crystalline, abundant fossil fragment ----------------- 1' 9"

Total Kimmswick 25'

------------------------- Elevation +713 ---------------------------

Kimmswick-Plattin contact with possible very thin Decorah intervening.

LOCALITY 6

Road cut on Highway 109, 2 miles north of Locality 5, NW¼, NW¼, SE¼, Sec. 24, T. 44 N., R. 3 E., St. Louis County, Missouri.

MISSISSIPPIAN

Chert residuum ----------------------------- Not Measured

ORDOVICIAN

KIMMSWICK LIMESTONE

Upper Member

Covered ------------------------------------ 30' to 40'

Limestone;	light-brownish gray on weathered surface, light gray to buff when fresh, medium- to coarsely crystalline, fragmental fossil layers throughout, vugs and anastomosing cavities on the surface -----------	13'	10"
Limestone;	light gray, white to buff, massive coarsely crystalline, several layers of fossil fragments, rare calcite filled vugs up to 1 1/2" across, Receptaculites -----------	7'	
Conglomerate;	limestone pebbles embedded in limestone matrix, fossiliferous (brachiopods) ---------------------	0'	6"
Shale;	light brown to yellow shale bed, bentonitic -----------------	0'	2"
	Total Kimmswick	21'	6"

DECORAH FORMATION

Absent

PLATTIN LIMESTONE

Limestone; massive to thick-bedded, light-gray, fucoidal, richly fossiliferous

LOCALITY 7

New road cut on Interstate Highway 44, near Allenton, SW¼, SW¼, SE¼, Sec. 33, T. 44 N., R. 3 E., St. Louis County, Missouri.

MISSISSIPPIAN

GLEN PARK LIMESTONE

Limestone;	coarse-grained, phosphatic nodules weathered, shale cover	1' to 2'

Shale;	gray, maroon, with embedded nodules of Kimmswick Limestone -----------	0'	6"

ORDOVICIAN

KIMMSWICK LIMESTONE

Upper Member

Limestone;	buff to light gray, coarsely crystalline, massive, fragmental fossils, vugs and anostomosing cavities on the surface and near the top ----------	13'	11"
Shale;	yellow to yellowish brown, weathers brown; bentonitic	0'	6"

Middle Member

Limestone;	very light gray when fresh; coarse-grained, weathers to light brown, vugs and anastomosing cavities on the surface; Fossils: orthocerid cephalapod, Receptaculites, brachiopod fragments -------------	3'	6"
Dolomite;	brownish, fine crystalline, with large calcite crystals in the cavities. Laterally becomes dolomitic limestone. Forms a recessive unit	1'	4"
	Total Kimmswick	19'	5"

DECORAH FORMATION

Guttenberg Member

Limestone;	with interbedded shale -----------	14'	

LOCALITY 8

Abandoned quarry near Babler State Park,
SE¼, SE¼, NW¼, Sec. 20, T. 45 N., R. 3 E.,
St. Louis County, Missouri.

MISSISSIPPIAN

BUSHBERG SANDSTONE

Sandstone;	light-gray to white coarse- to medium-grained, massive -----------	Not Measured

ORDOVICIAN

KIMMSWICK LIMESTONE

Upper Member

Limestone;	light gray to buff, massive, coarsely crystalline, with several layers of fossil fragments -----------------------	25'	
Chert;	pinkish to grayish, nodules in limestone beds; nodules varying from 2 inches to 6 inches in their largest dimension ----------	0'	2"
Limestone;	light gray, medium to coarsely crystalline, abundant fossil fragments, several layered fossil fragments -----------------------	15'	
Shale;	yellow to yellowish brown, bentonitic ----------------------		6" to 8"

Middle Member

Limestone;	light gray to brownish gray, coarsely crystalline, abundant fossil fragments with layered fossils --------	21'	8"

Chert;	yellowish, brownish, pinkish, gray nodules, from 2" to 6" in their longest dimension, in the limestone bed ------------------------	1'	2"
Limestone;	light gray, coarsely crystalline, fossils in layers ----------------	2'	
Chert;	pink, white, smoky, gray, nodules from ½" to as much as 8" across, in beds of limestone, which looks thin-bedded, and is coarsely crystalline and richly fossiliferous	11'	
Covered Interval	---------------------------	39'	
	Total Kimmswick	115'	8"

DECORAH FORMATION

Guttenberg Member

Interbedded limestone and shale. Exposed ----	7'	9"

LOCALITY 9

Inactive quarry near Antire Road and south of Tyson Valley Ordnance Plant. NE¼, NE¼, SW¼, Sec. 3, T. 43 N., R. 4 E., St. Louis County, Missouri.

MISSISSIPPIAN

BUSHBERG SANDSTONE

Sandstone;	light gray to white, coarse- to medium-grained, massive ---------	Not Measured

ORDOVICIAN

KIMMSWICK LIMESTONE

Upper Member

Limestone;	light gray, fossiliferous-fragmental, 2 nodular chert layers; massive-bedded; weathers to a hackly surface ------------------	11'	
Shale;	3 layers of chert nodules in fossiliferous limestone matrix; weathers to a recessive unit -----	1'	6"
Limestone;	light gray to cream-colored, coarsely crystalline, bedding inconspicuous, cross-bedded; fossil debris throughout unit; two layers of chert nodules (2-6" in diam.) in upper part of unit, the upper layer forming a marker across the quarry face ----------	12'	

Middle Member

Shale;	fresh material inaccessible ------	0'	4"
Limestone;	cream-colored; massive and fossiliferous-fragmental as above; locally there are fine-grained masses (4-8" in diam.) surrounded by stylolites and enclosed in the coarse-grained matrix ------------------	29'	
Limestone and Chert;	limestone as above, light brown in color; chert in two layers of nodules, 1-1½' thick, gray with white rim (except orange-colored in NW part of quarry); chert grades into limestone; chert is fossiliferous; fragments, brachiopods, and straight cephalopod remains. Stylolites common in the limestone. Isotelus ------------	2'	8"
Covered;	Recessive weathering brown limestone, poorly exposed ------------------	2'	6"
Limestone;	nearly white at top, light gray toward		

	base, coarse-grained, (fossiliferous-fragmental) massive-bedded and cross-bedded; stylolitic; recognizable fossils (Receptaculites, brachiopods, and gastropods) occur in layers ---	8'	
Limestone;	transitional to underlying unit ---	1'	6"
Limestone;	light brown, weathers brown with caverns up to 3' high, clay-filled, developed in upper part; chert layers at top and base of cavernous zone and at base of unit ------------------	7'	6"
Limestone;	brown, finely crystalline ---------	1'	
Limestone;	buff-colored, coarse-grained (fossiliferous-fragmental); stylolites mark the base and top; much of the fossil material is bryozoal debris ------------------	0'	6"
Limestone;	white but gray at base, coarse-grained, (fossiliferous-fragmental); massive; upper 4' has large, scattered pyrite crystals; gray portion has shale streaks ----	15'	6"

Lower Member

Limestone;	incompletely exposed on the quarry floor; mostly medium-gray, coarse-grained, less "pure" than the overlying unit; vugs and anastomosing cavities on the surface ----------	11'	
	Total Kimmswick	104'	3"

------------------------------ Elevation +574 ----------------------

DECORAH FORMATION

Guttenberg Member

Limestone; with interbedded shale

LOCALITY 10

Abandoned quarry near Glen Park, SE¼, SE¼, NW¼, Sec. 5, T. 41 N., R. 6 E., Jefferson County, Missouri.

MISSISSIPPIAN

BUSHBERG SANDSTONE

Sandstone;	light gray to white, coarse to medium-grained, massive -----------	15' to 20'	

ORDOVICIAN

KIMMSWICK LIMESTONE

Middle Member

Limestone;	light gray, coarsely crystalline, massive, richly fossiliferous, with several layers of fossil fragments -----------------------	30'	
Chert;	pinkish, gray, in nodular form in limestone similar to above; 3" zone at the top and 6" at the base with few nodules scattered in between --	3'	1"
Limestone;	light gray to buff, coarsely crystalline, abundant fossil fragments, massive, with several fossiliferous layers -------------	20'	3"
Chert;	gray to pink nodules, 2-6" in size, in limestone matrix --------------	1'	
Limestone;	light gray, thick-bedded, fossiliferous-fragmental ----------------------	6'	6"

Lower Member

Limestone;	light to dark gray, finely crystalline slightly fossiliferous, thin-bedded, with numerous calcite-filled geodes and cavities --------------------	1'	

Limestone;	gray to white, coarsely crystalline, massive, thick-bedded, abundant fossil fragments, hard ----------	7'	3"
Limestone;	As above with 2-6" pinkish-gray chert nodules embedded in the limestone, exposed on the quarry floor ----------------------------	3'	
Limestone;	covered but measured in a pit reaching Decorah at this depth ----	3'	6"
	Total Kimmswick	72'	7"

LOCALITY 11

Menefee quarry at Brickeys Landing, SW¼, NW¼ Sec. 24, T. 39N., R. 7 E., Ste. Genevieve County, Missouri.

MISSISSIPPIAN

GLEN PARK LIMESTONE

Limestone;	light gray, massive, fossiliferous, with few interbeds of shale ------	Not Measured

DEVONIAN

Shale;	dark gray to greenish-gray fossiliferous (fish teeth and scales) ---	Not Measured

ORDOVICIAN

KIMMSWICK LIMESTONE

Middle Member

Limestone;	brownish pink on the face of the quarry otherwise, light gray to buff, coarsely crystalline, abundant fossil fragments, hard; several layers fossil fragments, estimated	28' to 30'

Limestone and Chert;	light gray to buff, coarsely crystalline limestone with layered fossils and <u>Receptaculites</u>, with gray to pink chert nodules occurring commonly throughout the unit, 2-6" in their longest dimensions ---------------	5'	8"
Limestone;	light gray, coarsely crystalline with several layers of fossil fragments; larger fragments of brachiopods, bryozoans, and crinoids	3'	3"
Chert;	white to gray broken nodules in limestone -----------------------		2" to 4"
Limestone;	same as 3' 3" unit ----------------	2'	1"
Chert;	nodules as above		2" to 4"
Limestone;	light gray, coarsely crystalline, abundant fossil fragments, with several fossil fragment layers ---	16'	6"
Shale;	dark gray and yellow, thin platy, with possible 2 beds of bentonite--	1' to	6"

Lower Member

Limestone;	light gray to buff, massive coarsely crystalline, with small fragments of fossils, a thin chert zone at the base, up to 2" across calcite fillings and dark brown to black streaks and specks --------------------------	3'	10"
	Total Kimmswick	63'	

----------------------- Elevation +391 ----------------------------

DECORAH FORMATION

Guttenberg Member

Limestone with interbedded shale ------------	2'	9"

LOCALITY 12

Section on Main Street north of Broadway, Cape Girardeau, Missouri.

ORDOVICIAN

MAQUOKETA SHALE --		40'	
CAPE LIMESTONE			
Limestone;	dark gray, coarsely crystalline, massive, bedded, abundant crinoidal debris with other fragments of fossil and shell material. *Rhynchotrema* ---------------------	7'	7"
KIMMSWICK LIMESTONE			
Upper Member			
Shale;	yellow, bentonitic ---------------	0'	½"
Limestone;	light gray to dark gray, coarsely crystalline, medium-bedded abundant crinoidal debris, other shell material common ------------	8'	
Limestone;	light gray to buff, coarsely crystalline, massive, cross-bedded, abundant crinoidal debris, with other fossil fragments common -----	3'	2"
Middle Member			
Limestone;	same as above, cross-bedded, with crinoidal debris and *Receptaculites*	4'	9"
Remainder of the section concealed.			
	Total Kimmswick	16'	

APPENDIX B

TABLE 1

SUBSURFACE DATA

MISSOURI

*Base of Kimmswick not reached.

Well No.	County	Well Location Sec.	T.	R.	Surface Elevation	Depth to Kimmswick or Galena Top	Base	Thickness of Kimmswick or Galena	Elevation Base of Kimmswick or Galena	Gross Lithology
1	Putnam	13	65N	21W	971	1458	1655	197	-684	Dolomite
2	"	26	65N	19W	1043	1360	1578	218	-535	"
3	"	14	65N	18W	1000	1165	1320	155	-320	"
3A	"	1	64N	17W	863	1083	1185	102	-362	"
3B	"	3	64N	17W	807	1115	1220	105	-413	"
4	"	25	65N	17W	860	725	915	190	- 55	Limestone
5	Schuyler	6	65N	13W	872	1155	1280	125	-408	Dolomite
6	"	21	65N	15W	983	1255	1390	135	-407	"
7	Scottland	10	64N	10W	673	878	1022	144	-349	Limestone
8	Clark	5	65N	6W	565	675	807	132	-242	Dolomite
9	Sullivan	12	62N	21W	994	1354	1517	163	-523	"

Missouri Continued

Well No.	County	Well Location Sec.	T.	R.	Surface Elevation	Depth to Kimmswick or Galena Top	Base	Thickness of Kimmswick or Galena	Elevation Base of Kimmswick or Galena	Gross Lithology
10	Adair	33	64N	17W	966	1193	1370	177	-404	Dolomite
11	"	31	64N	15W	794	955	1035	80	-292	"
12	"	18	63N	14W	962	1022	1115	93	-153	"
13	"	20	63N	13W	908	1154	1217	63	-309	"
14	Knox	1	64N	12W	807	577	637	60	-170	"
15	"	18	61N	12W	859	755	790	35	- 69	"
16	"	10	61N	11W	713	585	660	75	- 53	"
16A	"	24	63N	11W	754	855	965	110	-211	"
17	Lewis	29	62N	9W	714	790	875	85	-161	"
18	"	31	61N	5W	486	375	485	110	+ 1	Limestone
19	Shelby	35	59N	11W	800	598	650	52	+150	Dolomite
20	"	20	58N	10W	765	535	575	40	+190	Limestone
20A	"	34	57N	10W	767	543	590	47	-177	Dol.-Lst.
21	Macon	22	57N	14W	830	764	895	131	- 65	Limestone
22	Marion	28	57N	4W	475	225	345	120	+130	"

Missouri Continued

Well No.	County	Well Location Sec.	T.	R.	Surface Elevation	Depth to Kimmswick or Galena Top	Base	Thickness of Kimmswick or Galena	Elevation Base of Kimmswick or Galena	Gross Lithology
23	Marion	22	59N	6W	492	468	635	167	-143	Limestone
24	"	3	56N	8W	673	515	540	25	+133	"
25	Ralls	6	56N	6W	715	180	248	68	+467	"
26	"	34	55N	5W	725	300	440	140	+285	"
27	"	32	55N	6W	750	240	333	93	+417	"
28	"	3	54N	6W	713	285	385	100	+328	"
29	"	3	53N	6W	743	180	305	125	+438	"
30	"	29	53N	7W	733	365	435	70	+298	"
31	Monroe	36	55N	8W	718	535	545	10	+173	"
32	"	14	54N	12W	797	515	565	50	+232	"
33	"	27	53N	7W	727	375	380	5	+347	"
34	Randolph	32	54N	14W	832	571	630	59	+202	"
35	"	2	53N	14W	830	580	645	65	+185	"
36	Chariton	35	53N	18W	771	645	693	48	+ 78	"
37	Audrain	7	52N	7W	766	420	535	115	+231	Dol.-Lst.

Missouri Continued

Well No.	County	Well Location Sec.	T.	R.	Surface Elevation	Depth to Kimmswick or Galena Top	Base	Thicknesss of Kimmswick or Galena	Elevation Base of Kimmswick or Galena	Gross Lithology
38	Audrain	14	52N	6W	772	430	475	45	+297	Dolomite.
39	"	5	52N	5W	764	415	525	110	+239	Limestone
40	"	21	52N	6W	757	400	490	90	+267	"
41	"	33	52N	7W	776	390	465	75	+311	"
42	"	12	52N	9W	-	Absent		Absent	-	-
43	"	36	52N	7W	733	310	375	65	+358	Limestone
44	Pike	3	55N	3W	546	35	165	130	+381	"
45	"	4	54N	4W	701	155	290	135	+411	"
46	"	33	54N	4W	797	295	415	120	+382	"
47	"	27	53N	4W	829	115	255	140	+574	"
48	"	23	53N	3W	866	310	440	130	+426	"
49	"	20	53N	2W	721	200	320	120	+401	"
50	"	25	54N	2W	547	160	280	120	+267	"
51	"	28	54N	1W	608	437	550	113	+ 58	"
52	"	12	53N	1W	626	100	145	45	+401	"

Missouri Continued

Well No.	County	Well Location Sec.	T.	R.	Surface Elevation	Depth to Kimmswick or Galena Top	Base	Thickness of Kimmswick or Galena	Elevation Base of Kimmswick or Galena	Gross Lithology
53	Pike	17	53N	1E	637	440	555	115	+ 82	Limestone
54	"	5	52N	2W	884	365	440	75	+444	"
55	"	14	52N	3W	825	230	365	135	+460	Dol.-Lst.
56	"	22	51N	3W	608	265	395	130	+213	Limestone
57	"	28	52N	1W	832	95	250	155	+582	"
58	"	26	52N	1W	769	155	280	125	+489	"
59	"	8	52N	1E	609	175	300	125	+309	"
60	"	22	52N	1E	581	135	250	115	+331	"
61	"	34	52N	1E	487	15	120	105	+367	"
62	Lincoln	36	51N	2W	670	265	365	100	+305	"
63	"	3	50N	1E	818	45	185	140	+633	"
64	Lincoln	21	51N	2E	452	70	80	10	+372	"
65	"	3	50N	2E	509	0	50	50	+459	Dol.-Lst.
66	"	26	50N	2E	648	0	25	25	+523	"
67	"	31	50N	1E	639	297	435	138	+204	"

Missouri Continued

Well No.	County	Well Location Sec.	T.	R.	Surface Elevation	Depth to Kimmswick or Galena Top	Base	Thickness of Kimmswick or Galena	Elevation Base of Kimmswick or Galena	Gross Lithology
68	Lincoln	2	49N	1W	682	215	255	40	+427	Dol.-Lst.
69	"	15	49N	2W	579	180	215*	-	-	"
70	"	31	49N	1W	695	265	330	65	+365	Limestone
71	"	27	49N	1W	642	420	530	110	+112	"
72	"	20	48N	1E	583	425	500	75	+ 83	Dol.-Lst.
73	Montgomery	5	50N	5W	764	412	500	88	+264	Limestone
74	"	17	50N	5W	796	285	360	75	+436	"
75	"	12	50N	4W	733	270	375	105	+358	"
76	"	28	49N	4W	765	275	310	35	+455	"
77	"	9	48N	4W	813	205	230	25	+583	"
78	"	6	48N	3W	728	170	205	35	+523	"
79	Warren	14	48N	3W	783	210	265	55	+518	"
80	"	36	47N	3W	910	165	220	55	+745	"
81	"	24	46N	3W	898	55	65	10	+833	"
82	"	26	47N	2W	862	122	150	28	+712	"

Missouri Continued

Well No.	County	Well Location Sec.	T.	R.	Surface Elevation	Depth to Kimmswick or Galena Top	Base	Thickness of Kimmswick or Galena	Elevation Base of Kimmswick or Galena	Gross Lithology
83	Warren	21	47N	1W	695	310	360	50	+335	Limestone
84	Lincoln	29	48N	2E	508	340	450*	-	-	Dol.-Lst.
85	"	9	48N	1E	471	350	470	120	+ 1	Limestone
86	St. Charles	34	48N	1E	557	335	425	90	+132	"
87	"	34	47N	1E	665	370	410	40	+255	Dol.-Lst.
88	"	25	47N	1E	593	377	440	63	+153	"
89	"	13	47N	2E	581	368	415	47	+166	Limestone
90	"	25	47N	2E	626	470	575	105	+ 51	"
91	"	28	47N	3E	571	355	450	95	+122	"
92	"	23	47N	3E	478	385	485	100	- 7	"
93	"	25	47N	3E	489	410	505	95	- 16	"
94	"	36	47N	3E	476	395	490	95	- 14	"
95	"	3	46N	2E	613	340	445	105	+168	"
96	"	15	46N	1E	754	-	-	Absent	-	-
97	"	26	46N	1E	784	115	195	80	+589	Limestone

Missouri Continued

Well No.	County	Well Location Sec.	T.	R.	Surface Elevation	Depth to Kimmswick or Galena Top	Base	Thickness of Kimmswick or Galena	Elevation Base of Kimmswick or Galena	Gross Lithology
98	St. Charles	24	46N	1E	671	80	160	80	+511	Limestone
99	"	14	46N	2E	500	255	325	70	+175	"
100	"	12	46N	2E	605	312	410	98	+195	"
101	"	13	46N	2E	549	300	410	110	+139	"
102	"	28	46N	3E	633	340	425	75	+198	"
103	"	35	46N	3E	501	235	325	90	+176	"
104	"	4	45N	3E	646	305	400	95	+246	"
105	St. Louis	18	45N	3E	543	0	75	75	+468	"
106	Franklin	13	44N	2E	816	0	90	90	+726	"
107	St. Louis	6	44N	3E	748	140	195	55	+553	"
108	"	7	44N	3E	763	0	90	90	+673	"
109	"	3	44N	3E	783	115	180	65	+603	"
110	"	27	45N	3E	700	192	275	83	+427	"
111	"	35	45N	3E	767	200	285	85	+482	"
112	"	30	45N	4E	635	183	275	92	+360	"

Missouri Continued

Well No.	County	Well Location Sec.	T.	R.	Surface Elevation	Depth to Kimmswick or Galena Top	Base	Thickness of Kimmswick or Galena	Elevation Base of Kimmswick or Galena	Gross Lithology
113	St. Louis	20	45N	4E	635	255	345	90	+290	Limestone
114	"	23	45N	4E	625	448	540	92	+ 85	"
115	"	36c	45N	4E	672	410	500	90	+172	"
116	"	7	44N	4E	735	185	275	90	+470	"
117	"	14	44N	4E	606	210	285	75	+321	"
118	"	20	44N	5E	474	265	360	95	+114	"
119	"	18	46N	6E	455	1040	1135	95	-680	"
120	"	1	47N	6E	485	1030	1155	125	-670	"
121	"	12	47N	6E	532	1040	1135	95	-603	"
122	"	7	47N	7E	585	1030	1128	98	-543	"
122A	"	6	47N	7E	558	980	1085	105	-427	"
123	"	22	44N	6E	458	655	740	85	- 82	"
124	"	34	44N	5E	412	285	380	95	+ 32	"
125	"	29	44N	5E	520	360	455	95	+135	"
126	Jefferson	14	43N	4E	950	120	205	85	+745	"

Missouri Continued

Well No.	County	Well Location Sec.	T.	R.	Surface Elevation	Depth to Kimmswick or Galena Top	Base	Thickness of Kimmswick or Galena	Elevation Base of Kimmswick or Galena	Gross Lithology
127	Jefferson	1	43N	5E	711	180	290	110	+421	Limestone
128	"	18	42N	5E	883	150	200	50	+683	"
129	"	1	42N	5E	753	195	285	90	+468	"
130	"	12	42N	5E	713	170	265	95	+448	"
131	"	9	42N	5E	696	0	40	40	+656	"
132	"	28	42N	6E	561	0	40	40	+521	"
133	"	29	42N	6E	548	70	150	80	+398	"
134	"	8	41N	6E	432	0	60	60	+372	"
135	Ste. Genevieve	36	38N	8E	521	195	285	90	+236	"
136	"	6	37N	9E	697	205	300	95	+397	"
137	"	28	37N	9E	520	235	330	95	+190	"
138	"	29	37N	10E	491	1195	1295	100	-804	"
139	Perry	22	34N	13E	472	0	65	65	+407	Dol.-Lst.
140	"	28	34N	13E	534	0	60	60	+474	"

ILLINOIS

Well No.	County	Well Location Sec.	T.	R.	Surface Elevation	Depth to Kimmswick or Galena Top	Base	Thickness of Kimmswick or Galena	Elevation Base of Kimmswick or Galena	Gross Lithology
1	Jo Daviess	34	29N	1W	865	25	249	224	+616	Dolomite
2	"	36	29N	1W	813	10	164	154	+649	"
3	"	25	29N	1E	925	19	129	110	+795	"
4	"	13	29N	2E	1132	167	390	223	+742	"
5	"	19	29N	4E	995	10	228	218	+767	"
6	"	4	28N	1E	867	55	230	175	+637	"
7	"	1	28N	1W	758	0	165	165	+593	"
8	"	24	28N	1W	605	60	72	12	+533	"
9	"	22	28N	1E	799	60	204	144	+595	"
10	"	36	28N	1E	760	25	221	196	+549	"
11	"	29	28N	3E	746.4	0	89	89	+657.4	"
12	"	30	28N	4E	940	10	180	170	+700	"
13	"	31	28N	5E	920	135	245	110	+675	"
14	"	11	27N	4E	1045	126	340	214	+705	"

Illinois Continued

Well No.	County	Well Location Sec.	T.	R.	Surface Elevation	Depth to Kimmswick or Galena Top	Base	Thickness of Kimmswick or Galena	Elevation Base of Kimmswick or Galena	Gross Lithology
15	Jo Daviess	20	27N	2E	730	60	162	102	+568	Dolomite
16	"	19	27N	4E	830	160	235	75	+595	"
17	"	9	26N	2E	630	60	157	97	+473	"
18	"	19	26N	2E	610	190	315	125	+295	"
19	"	33	26N	2E	622	220	300	140	+262	"
20	Carroll	2	25N	2E	599	155	350	195	+249	"
21	"	17	25N	3E	625	133	382	249	+243	"
22	"	27	25N	3E	760	235	455	220	+165	"
23	"	9	24N	3E	600	180	635	255	+165	"
24	"	9	24N	4E	860	157	360	203	+500	"
25	"	7	24N	5E	840	100	260	160	+580	"
26	"	5	24N	6E	880	90	170	80	+599	"
27	"	27	25N	6E	880	15	108	93	+772	"
28	"	19	25N	7E	940	252	470	218	+470	"
29	"	2	23N	5E	800	77	300	223	+500	"

Illinois Continued

Well No.	County	Well Location Sec.	T.	R.	Surface Elevation	Depth to Kimmswick or Galena Top	Base	Thickness of Kimmswick or Galena	Elevation Base of Kimmswick or Galena	Gross Lithology
30	Carroll	10	23N	4E	640	95	275	180	+365	Dolomite
31	Whiteside	18	21N	5E	640	505	710	205	- 50	"
32	"	27	21N	7E	625	315	540	225	- 85	"
33	"	5	19N	5E	622	560	800	240	-178	"
34	"	11	19N	7E	647	723	935	212	-288	"
35	"	22	19N	4E	607	636	855	219	-248	"
36	Rock Island	25	19N	1E	600	528	735	207	-135	"
37	"	19	18N	1E	668	703	910	207	-242	"
38	"	32	18N	1E	590	662	890	228	-300	"
39	"	8	17N	1E	620	653	900	247	-280	"
40	"	25	18N	1W	573	641	870	229	-297	"
41	"	35	18N	2W	565	620	865	245	-300	"
42	Henry	27	14N	4E	845	703	955	252	-110	"
43	"	36	17N	4E	637	786	1066	280	-420	"
44	"	8	16N	3E	734	855	1090	235	-356	"

Illinois Continued

Well No.	County	Well Location Sec.	T.	R.	Surface Elevation	Depth to Kimmswick or Galena Top	Base	Thickness of Kimmswick or Galena	Elevation Base of Kimmswick or Galena	Gross Lithology
45	Henry	28	15N	5E	820	998	1225	227	-405	Dolomite
46	"	27	14N	4E	845	1025	1220	95	-375	"
47	"	17	14N	3W	736	763	995	232	-259	"
48	Mercer	24	13N	4W	632	582	834	252	-202	"
49	Henderson	1	12N	5W	590	610	840	230	-250	"
50	"	18	9N	4W	597	445	670	235	- 75	"
51	Warren	1	12N	2W	700	720	934	214	-234	"
52	"	26	11N	2W	745	805	1028	223	-283	"
53	"	11	9N	1W	610	735	940	205	-330	"
54	Knox	36	12N	3E	742	1005	1265	260	-523	"
55	"	2	11N	1E	785	820	1037	217	-252	"
56	"	28	11N	2E	780	885	1090	205	-310	"
57	"	10	10N	3E	696	967	1185	218	-499	"
58	"	20	10N	1E	730	887	1065	178	-335	"
59	Hancock	15	7N	8W	700	744	935	191	-235	"

Illinois Continued

Well No.	County	Well Location Sec.	T.	R.	Surface Elevation	Depth to Kimmswick or Galena Top	Base	Thickness of Kimmswick or Galena	Elevation Base of Kimmswick or Galena	Gross Lithology
60	Hancock	28	4N	5W	614	690	883	193	-269	Dolomite
61	"	17	3N	7W	640	730	915	185	-275	Calc.-Dol.
62	McDonaugh	33	7N	1W	651	905	1118	213	-467	Dolomite
63	"	33	6N	2W	695	883	1051	168	-356	"
64	"	30	4N	3W	520	660	839	179	-319	Calc.-Dol.
65	Adams	13	1N	7W	739	570	655	85	+84	Limestone
66	"	7	3S	6W	690	699	895	196	-205	"
67	Schuyler	28	1N	2W	455	691	865	174	-410	"
68	Pike	5	3S	4W	600	637	790	153	-190	"
69	"	18	3S	4W	650	687	770	83	-120	"
70	"	15	4S	5W	716	578	730	152	- 14	"
71	"	21	5S	4W	811	361	500	139	+311	"
72	"	11	7S	3W	530	394	535	141	- 5	"
73	Scott	2	15N	13W	561	900	1045	145	-484	"
74	"	27	13N	13W	429	515	685	170	-256	"

Illinois Continued

Well No.	County	Well Location Sec.	T.	R.	Surface Elevation	Depth to Kimmswick or Galena Top	Base	Thickness of Kimmswick or Galena	Elevation Base of Kimmswick or Galena	Gross Lithology
75	Scott	26	12N	13W	636	720	850	130	-214	Limestone
76	"	17	11N	12W	564	782	895	113	-331	"
77	"	17	10N	10W	560	1165	1264	99	-704	"
78	"	22	10N	12W	606	900	998	98	-392	"
79	"	1	8N	14W	430	185	354	169	+ 76	"
79A	Morgan	15	13N	8W	630	1436	1560	124	-930	Dolomite
80	Calhoun	6	8S	4W	448	130	217	87	+231	Limestone
81	"	9	12S	2W	580	80	231	151	+349	"
82	Jersey	28	8N	11W	646	975	1080	105	-434	"
83	"	27	8N	10W	593	1300	1400	100	-807	"
84	"	1	6N	13W	560	64	170	106	+390	"
85	"	8	6N	12W	480	90	205	115	+275	"
86	"	32	7N	11W	655	805	905	100	-250	"
87	"	14	6N	12W	483	300	375	75	+108	"
88	Macoupin	13	8N	9W	634	1663	1765	102	-1131	"

Illinois Continued

Well No.	County	Well Location Sec.	T.	R.	Surface Elevation	Depth to Kimmswick or Galena Top	Base	Thickness of Kimmswick or Galena	Elevation Base of Kimmswick or Galena	Gross Lithology
89	Madison	5	6N	10W	517	942	1043	101	-526	Limestone
90	"	23	5N	8W	507	1910	2005	95	-1498	"
91	"	21	5N	6W	546	2451	2550	199	-2004	"
92	"	35	5N	6W	526	2507	2593	84	-2067	"
93	"	22	4N	5W	527	2702	2792	90	-2264	"
94	"	26	4N	8W	503	1942	2014	72	-1511	"
95	"	1	3N	6W	534	2518	2548	30	-2014	"
96	"	1	3N	9W	422	1630	1723	93	-1301	"
97	"	11	3N	9W	406	1495	1585	90	-1177	"
98	"	24	3N	10W	423	1183	1265	82	-842	"
99	"	19	3N	9W	418	1175	1305	130	-887	"
100	"	14	3N	8W	557.5	2012	2102	90	-1544.5	"
101	St. Clair	26	1N	10W	590	1015	1113	98	-523	"
102	"	14	1N	6W	464	2674	2765	91	-2301	"
103	Monroe	19	1S	10W	420	790	875	85	-455	"

Illinois Continued

Well No.	County	Well Location Sec.	T.	R.	Surface Elevation	Depth to Kimmswick or Galena Top	Base	Thickness of Kimmswick or Galena	Elevation Base of Kimmswick or Galena	Gross Lithology
104	Monroe	35	1S	10W	630	347	447	100	+183	Limestone
105	"	2	2S	9W	700	435	535	100	+165	"
106	"	31	2S	10W	645	650	730	80	- 85	"
107	"	11	3S	11W	790	380	490	110	+300	"
108	"	32	3S	10W	604	410	503	93	+101	"
109	Randolph	12	5S	9W	600	1240	1335	95	+135	"
110	"	3	4S	5W	548	3140	3235	95	-2687	"
111	"	29	7S	7W	370	1491	1590	99	-1220	"
112	Jackson	20	7S	4W	626	3290	3415	125	-2789	"

IOWA

Well No.	County	Well Location Sec.	T.	R.	Surface Elevation	Depth to Kimmswick or Galena Top	Base	Thickness of Kimmswick or Galena	Elevation Base of Kimmswick or Galena	Gross Lithology
1	Jones	21	86N	3W	875	505	603	98	+202	Dolomite
2	"	3	84N	4W	816	535	770	235	+ 46	Calc.-Dol.
3	Linn	6	83N	6W	860	750	975	225	-115	Dolomite
4	"	21	83N	7W	733	675	880	205	-147	"
5	"	28	83N	7W	729	705	900	195	-171	Calc.-Dol.
6	"	21	82N	7W	847	640	850	210	- 3	"
7	Johnson	25	80N	7W	808	755	1010	255	-202	"
8	Cedar	6	80N	2W	810	700	990	290	-180	"
9	"	35	82N	1W	783	585	805	220	- 22	Dolomite
10	Clinton	?	81N	1E	736	475	710	235	+ 26	Calc.-Dol.
11	"	18	81N	4E	696	475	705	230	-109	"
12A	"	22	81N	6E	588	385	620	235	- 32	Dolomite
12	Scott	28	78N	4E	585	608	860	252	-275	"
13	"	36	78N	3E	578	640	885	245	-307	Calc.-Dol.

Iowa Continued

Well No.	County	Well Location Sec.	T.	R.	Surface Elevation	Depth to Kimmswick or Galena Top	Base	Thickness of Kimmswick or Galena	Elevation Base of Kimmswick or Galena	Gross Lithology
14	Scott	5	77N	3E	660	680	920	240	-260	Calc.-Dol.
15	Muscatine	13	78N	4W	668	715	930	215	-262	"
16	"	29	76N	4W	606	750	972	222	-366	"
17	Louisa	6	75N	3W	698	810	1025	215	-327	"
18	"	29	73N	3W	685	720	955	235	-270	Dolomite
19	Washington	17	75N	7W	762	805	1005	200	-243	Calc.-Dol.
20	Keokuk	25	76N	10W	780	840	1050	210	-270	"
21	"	36	74N	13W	828	1170	1370	200	-542	"
22	"	27	74N	10W	775	1040	1250	210	-475	"
23	Iowa	36	78N	11W	806	1035	1240	205	-434	"
24	Monroe	9	72N	17W	928	1495	1665	170	-737	Dolomite
25	Appanoose	36	69N	18W	1015	1540	1695	155	-680	"
26	"	36	69N	18W	990	1495	1650	155	-660	"
27	Ottumwa	30	72N	13W	644	990	1165	175	-521	"
28	Wapello	9	71N	12W	792	1125	1325	200	-533	"

Iowa Continued

Well No.	County	Well Location Sec.	T.	R.	Surface Elevation	Depth to Kimmswick or Galena Top	Base	Thickness of Kimmswick or Galena	Elevation Base of Kimmswick or Galena	Gross Lithology
29	Jefferson	26	72N	10W	775	1025	1200	175	-425	Dolomite
30	Henry	1	71N	6W	720	850	1030	180	-310	"
31	"	9	71N	6W	732	825	1045	220	-313	"
32	"	23	70N	6W	720	880	1080	200	-360	"
33	"	26	71N	5W	765	865	1080	215	-315	"
34	Des Moines	16	70N	4W	717	835	1070	235	-352	"
35	"	1	69N	4W	721	800	1045	245	-324	"
36	"	35	70N	3W	704	695	904	209	-200	"
37	"	32	70N	2W	551	515	730	215	-179	"
38	Lee	33	68N	6W	705	850	1000	150	-295	"
39	"	13	65N	5W	547	610	780	170	-233	"
40	"	25	65N	5W	553	615	805	190	-252	"
41	Van Buren	20	69N	10W	635	905	1080	175	-445	"

TABLE 2

ELEVATIONS OF THE
BASE OF THE KIMMSWICK
LIMESTONE MEASURED
IN OUTCROPS

NO.	STATE	COUNTY	LOCATION Sec.	T.	R.	*ELEVATION
1S	Illinois	Calhoun	6	12S	3E	+403
2W	"	"	20	49N	3E	+489
1S	Missouri	Ralls	5	55N	4W	+508
2S	"	Pike	10	55N	3W	+381
3S	"	Ralls	21	55N	4W	+604
4S	"	Pike	33	55N	4W	+580
5S	"	"	28	55N	3W	+544
6S	"	"	35	55N	4W	+584
7S	"	St. Louis	20	45N	3E	+480
8S	"	"	25	44N	3E	+713
9S	"	Jefferson	6	41N	6E	+419
10S	"	St. Louis	11	44N	3E	+595
11S	"	Ste. Genevieve	24	39N	7E	+391

* Datum mean sea level

VITA

The author was born on July 21, 1932, at Gopi Ganj, Varanasi, India. The early education was achieved in various schools and he received his High School diploma from B. L. J. Intermediate College, Mirzapur, U. P., India, in 1948. He became interested in geological sciences during his second year in college, and worked toward a degree in geology. He was awarded a Bachelor of Science degree in physics, mathematics, and geology from Banaras Hindu University, Varanasi, India, in 1952, and a Master of Science degree in geology from the University of Lucknow, Lucknow, India, in 1954. He was a recipient of the Government of India Research Scholarship at Banaras Hindu University and pursued research work in Stratigraphy during 1954-55. Later he joined the Atomic Energy Commission of India as a Geologist and worked for the Commission until late 1956. He was awarded Howe Research Fellowship at Yale University, New Haven, Connecticut during 1957-58, where he pursued research work on the genesis of manganese ores of India. He later enrolled at the Missouri School of Mines and Metallurgy, Rolla, Missouri, to work for a Ph. D. degree in geology in the Fall of 1958.

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