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# The geology of the interstate highway 244 and 44 exchange, Kirkwood, Missouri

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# THE GEOLOGY OF THE INTERSTATE HIGHWAY 244 AND 44 INTERCHANGE, KIRKWOOD MISSOURI

BY

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A

THESIS

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## ABSTRACT

During the summer of 1964, construction was completed on the intersection of Interstate Highways 244, 44 and U.S. Highway 66, one mile southwest of Kirkwood, Missouri. During the construction of the interchange, numerous artificial exposures of rocks of the middle Mississippian Meramecian Series were exposed. This provided an excellent opportunity for examining fresh exposures near the type Meramecian Series. The formations of the area were studied, and startigraphic sections were prepared from three of the more complete sections that were measured and described. The highway cuts expose complete sections of the Warsaw and Salem formations, and the lower part of the St. Louis Formation. The exposed sections within the thesis area were correlated both locally and regionally. Correlations of the local sections indicate considerable lateral variability of the limestone and shale units within the Warsaw and Salem formations. A geologic map of the interchange area was prepared while the bedrock was still exposed along the roadway, prior to filling and grading.

Thirty-three thin sections were prepared from the limestones in the sections. The carbonate rock types varied from a biosparite in the Warsaw and lower Salem formations, to a micrite in the upper Salem and St. Louis formations. The implications of the observable features in the thin sections indicate that the Meramecian Series was laid down during moderately shallow water conditions. During Warsaw times the

seas were muddy as indicated by the prominence of shales in the formation, although there is the possibility of current action which either brought in no clays, or removed the finer muds during carbonate deposition. This lack of clays in the carbonate sections could also be the result of a lowering of the source area, thus eliminating the influx of muds and clays, allowing carbonate deposition to occur in the absence of the clay material.

The presence of ripple marks and cross-bedding in much of the Salem Formation indicates shallow water deposition.

The presence of intraformational breccia in rocks deposited during St. Louis time indicates that general quiescent conditions of sedimentation were periodically interrupted by possible tectonic activity. In general, the carbonates of the St. Louis Formation are very fine-grained. The presence of algal growths indicates that a very small part of the formation is of organic origin.

# ACKNOWLEDGMENTS

The author wishes to thank and express his appreciation to Professor A. C. Spreng who acted as advisor on the thesis and also supervised the field and laboratory work. The Missouri Highway Department furnished the necessary maps of the interchange and donated a core taken from the area. The author is indebted to his mother, Mrs. Dorothy O. Thomas, and Mrs. V. H. McNutt for financial aid during the period of his field work.

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# CHAPTER I

# INTRODUCTION

## A. Purpose and Scope

During the summer of 1963, the Weber Construction Company contracted to build the interchange of Interstate Highways 44 and 244, located in the southwestern corner of St. Louis County, Missouri. In their construction, they made numerous artificial exposures of the Meramecian Series of Mississippian age, which provided an excellent opportunity for examining fresh exposures of the type series.

It is the purpose of this paper to ascertain the geology of the interchange area and redescribe the lithologies of the type Meramecian Series. In addition to detailed mapping, attention was given in the investigation to the paleontology, petrology, and depositional conditions of the Warsaw, Salem and St. Louis formations.

The base map used in the study was surveyed by the Missouri Highway Department.

## B. Procedure of Study

During the summer of 1964, in the final phase of construction of the interchange, the writer was granted permission to begin a geological field investigation of the exposures. A general survey of the thesis area was made after which three of the more complete exposures were selected to be studied in detail. The thicknesses were measured with a steel tape and hand level. The lithologic units in these exposures were described in detail and sampled. The carbonate samples were later examined on the campus for their mineral constituents, fossil content, and sedimentary features. Thin sections were prepared from the carbonates and examined petrographically, while the shales were examined only for carbonate material.

C. Previous Work in the Area

The first geologic report which included a discussion of the Kirkwood area was prepared by B. F. Shumard (1855, pp. 169-184); this was published by the Missouri Bureau of Geology and Mines. The geology of the Kirkwood area was described in a very general way, and there was little information pertinent to the area under discussion in this thesis.

In 1904, E. O. Ulrich first proposed the name Meramec Group (Series). At that time he stated, "The Warsaw limestones (and shales) occur at the base of the group at Meramec Highlands and extend northward from that point. This together with the overlying Spergen Hill and St. Louis limestones are embraced in a group for which I propose the name Meramec group." (E. O. Ulrich, 1904, p. 110). His report also included a very brief and general description of the area.

The United States Geological Survey in 1911, published a bulletin by N. M. Fenneman dealing with the geology and mineral resources of the St. Louis Quadrangle (15 x 30 minutes). At this time Fenneman gave a brief description of the structure and environments of deposition of the formations included in the present interchange area being studied in this thesis.

Since publication of Fenneman's report, a few workers have made detailed studies of some of the formations in the area. R. G. Maxwell in 1929 made a study of the lithology of the Warsaw Formation. Stuart Weller in 1908 studied and described several exposures of the Salem Formation in Illinois and described the fauna of the formation. In 1923, W. D. Shipton described a Mississippian exposure which had been produced by railroad excavations in the vicinity of Osage Hills, Missouri (formerly Meramec Highlands). D. C. Barton (1918) described some Mississippian cherts which occur within the area. O. R. Grawe discussed the occurrence of breccias in the St. Louis Formation in a paper published in 1925. In 1947, the Missouri Geological Survey published a report by N. S. Hinchey et al., which furnished information on some limestones and dolomites in the area of the Kirkwood, Missouri, Quadrangle. In 1953, W. F. Baldwin mapped the Kirkwood Quadrangle which aided in locating and correlating additional areas where the formations of the Meramecian Series are exposed.

# CHAPTER II

# GEOGRAPHY AND PHYSIOGRAPHY

## A. Location

The area under investigation is located within the Kirkwood, Missouri, Quadrangle in sec. 14, Range 5 E., Township 44 N. The area is divided into quadrants by the intersection of Interstate Highways 44 and 244 located in the extreme southwestern corner of St. Louis County, Missouri. The area is one-quarter mile east of the Meramec River on U.S. Highway 66. The area is bounded on the west by the Meramec River, on the east by Geyer Road, north by Cragwold overpass, and is approximately three quarters of a mile square. See Plate 1 for an aerial view of the area.

## B. Culture

The culture within the immediate area consists of the intersection of Interstate Highways 44 and 244. Also, running through the area and coinciding with I-44, is U.S. Highway 66, which is the main artery from and to southwestern Missouri. Included in the surrounding area are several small towns. One and one-quarter mile northwest is the town of Fenton, located on the Meramec River. Three miles west on Highway 66 is the town of Valley Park located one-quarter mile north of the Meramec River on Highway 141. Going east on U.S. Highway 66, one enters the city limits of Kirkwood, Missouri, one mile from the center of the thesis area. Twelve miles northeast of the area on Highway 66 is the city of St.

Plate I

An aerial view of the interchange area, looking south-southwest.

Louis, Missouri. The remaining culture in the surrounding area consists of private homes, two country clubs, a golf course, and a private swimming club just to the northwest of the area. Also, along Highway 66, there are numerous service stations, restaurants, and motels. One-half mile to the west is a private airport and one mile north is the main track of the Missouri Pacific Railroad.

C. Regional Setting

The regional dip of the strata is to the northeast toward the Illinois Basin and away from the Ozark Dome. The dips of the Mississippian formations within the area are gentle, with most ranging from one-half to two degrees northeast.

According to Will Owens (1960), the outstanding structural feature in the St. Louis County area is a northeast-dipping monocline. This structure is modified by a syncline trending northwest.

D. Topography and Drainage

Topographically, the area is limited to the ridges and bluffs adjacent to the Meramec River and its tributaries. These features are the result of the dissection of the upland area by the Meramec River and its immediately adjacent tributaries.

According to N. M. Fenneman, 1931, this area is located on the extreme northeastern edge of the Ozark Plateau Province of the Interior Highlands division.

The maximum relief of the area is about 160 feet, with the highest point being about 560 feet above sea level.

The point of lowest elevation is where the Meramec River flows under U.S. Highway 66 on the western side of the exchange area. Here the elevation is approximately 395 feet.

The entire area is drained by the Meramec River and its tributaries.

# CHAPTER III

# STRATIGRAPHY

## A. History of Series and Formation Names

E. O. Ulrich, in 1904, proposed the name "Meramec group" to include, in descending order, the St. Louis limestone, Spergen Hill limestone, and Warsaw limestone. This proposal was to replace the broad usage of "St. Louis limestone" and "St. Louis group". The Meramec Group is overlain by the Ste. Genevieve limestone which at this time was considered the basal formation of the Chester group. The Ste. Genevieve limestone was excluded from the Chester group in 1907 by S. Weller. He subsequently continued to exclude it, but did not definitely place it in the Meramec group until 1920, when he drew the top of the Meramec group at the base of his Shetlerville Formation, or in the midst of the O'Hara limestone member of the Ste. Genevieve limestone of Ulrich. Weller stated that the original Ste. Genevieve limestone of Shumard did not include the Shetlerville Formation of Weller and that it does not belong to the Chester group, as contended by Ulrich, but to the Meramec group. The United States Geological Survey did not definitely assign the Ste. Genevieve limestone to either the Meramec group or the Chester group, due to the divergence of opinions of the geologists who had made a special study of the problem. However, in May of 1937, it was decided by the federal survey to include this formation in the Meramec group. Also, at this time it was decided to recognize the "Upper O'Hara" as a part of the Renault Formation, instead of the upper division of the Ste. Genevieve limestone.

James Hall named the Warsaw Formation in 1857, for exposures at Warsaw, Illinois. Although there has been some controversy as to its position in the series of the Mississippian System, it is considered by most to belong in the Meramecian series (Weller, 1960, p. 443). Ulrich (1904, p. 110) designated the Warsaw as the lowermost member of his Meramec Group when he defined the series at Meramec Highlands (now Osage Hills) in section 10, T. 44 N., R. 5 E. in the Kirkwood, Missouri, Quadrangle.

Originally the stratigraphic unit now known as the Salem Formation (Spergen) was included in Shumard's (1855, pp. 170-184) "Archimedes Limestone" in his description of the unit in the Kirkwood area. The Salem Formation has been included in the Warsaw and the St. Louis Group until it was recognized as a separate formation. In 1897, Hopkins and Siebenthal (1897, pp. 289-298) referred it to the Bedford Oolitic limestone in Indiana. As this name had already been assigned to another formation in Ohio, Cumings (1901, pp. 232-233) proposed the name Salem (for Salem, Indiana). Three years later Ulrich (1904, p. 110) called the formation the Spergen Hill limestone. This name was taken from a famous fossil locality in Indiana. The name was later shortened to Spergen limestone (Ulrich, 1905, p. 28). However, as stated in the Missouri Geological Survey Bulletin, vol. 40, p. 67, "The name "Spergen" has long been synonomous with the term Salem and has been extensively used in publications of the Missouri Geological Survey in place of the term Salem. However, in view of the fact that the latter term has recently been officially adopted by the U.S. Geological Survey and has been customarily used for years by the Illinois and Indiana Geological Surveys, the term Salem is herein used in preference to the term "Spergen"."

The St. Louis Formation was named by Engleman (1847, pp. 119-120) for exposures found in the city of St. Louis, Missouri. Shumard (1860, p. 406) restricted the formation to include only those rocks below his newly defined Ste. Genevieve limestone and above the third Archimedes limestone (now the Warsaw Formation). Later, Ulrich (1904, p. 120) raised the lower limit of the St. Louis Formation when he defined the underlying Spergen Formation. The formation is included in the Meramecian Series.

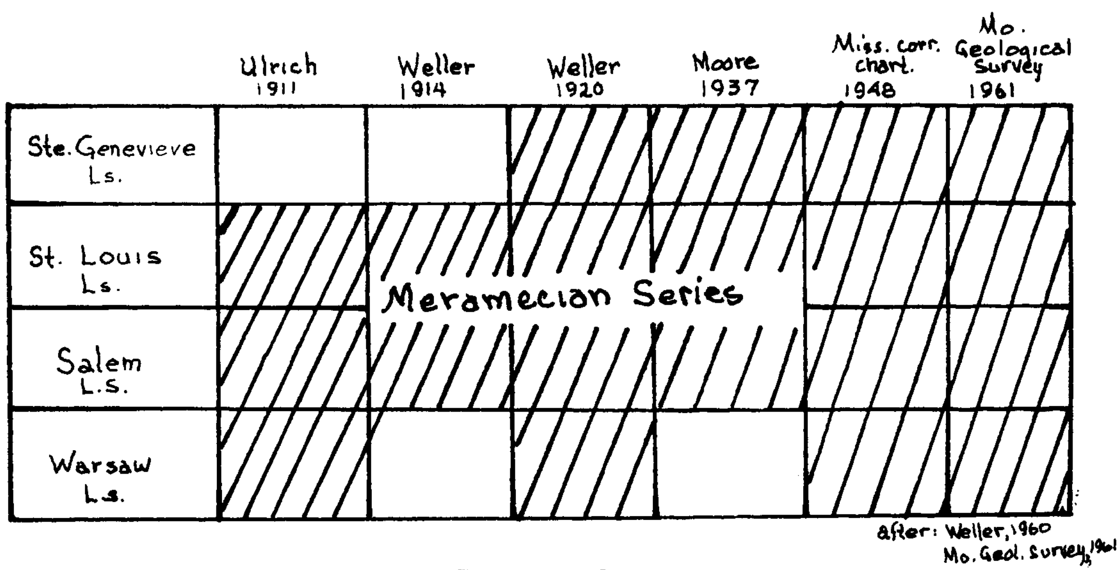



Figure 1

Evolution of Formations in the Meramecian Series

B. Sections

The following stratigraphic sections were measured within the Interstate 44, 244 interchange area. The first section is the Sylvan Beach section. The total thickness is 126 feet, and includes the Keokuk Formation of Osagean age, Warsaw and Salem formations of Meramecian age. (Plate II, XIII, and figures 2 to 6).

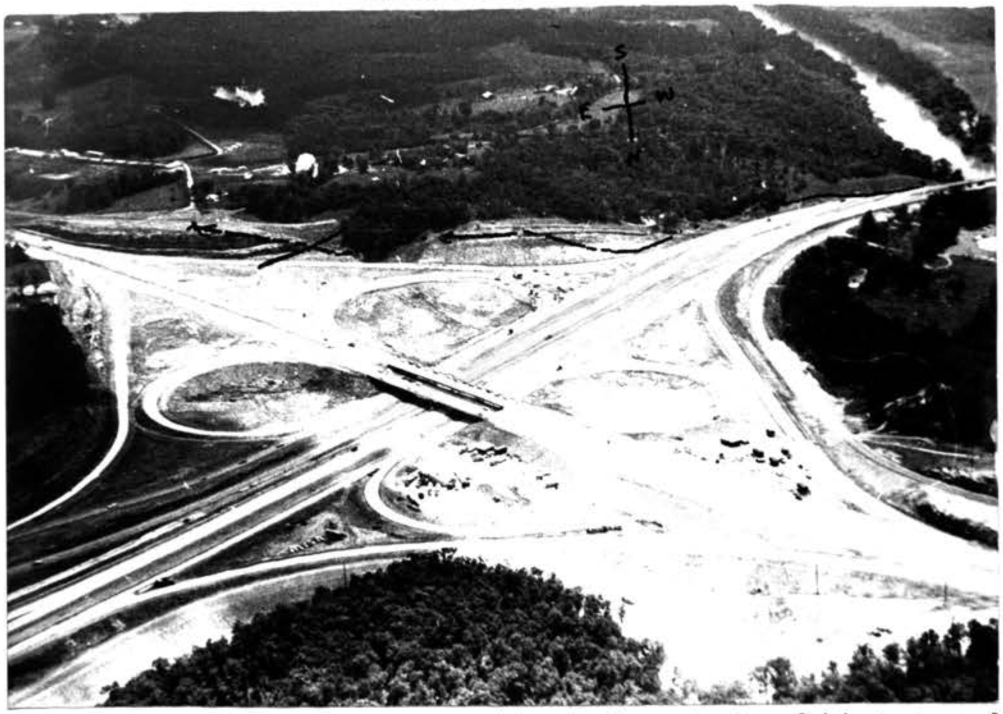
The Northeast section is composed of 62 feet of Warsaw shale and limestone and 34 feet of Salem (Plates II, XIII and figures 7 to 11).

The third section was measured east from the 244 overpass on U.S. Highway 66, and incorporates the upper portion of the Salem Formation and the lower units of the St. Louis Formation (Plates III, XIII and figures 12 to 14).

The only location in the thesis area where the Osagean and Meramecian contact is exposed, is in the Sylvan Beach section. This contact is at the approximate level of the bridge crossing the Meramec River in the extreme western part of the thesis area, on the south side of U.S. Highway 66 (Interstate 44) and the east side of the Meramec River.

The best exposure of the Warsaw-Salem contact is also located in the Sylvan Beach section, and is in the southwest quadrant of the interchange (Plate X). The contact is also located in the northeast section approximately seven feet above the level of Cragwold Bridge, which crosses Interstate 244 (Plate IIB).

PLATE II




A. Aerial view of Interstate 44, Interstate 244 interchange showing location of Sylvan Beach stratigraphic section.


B. An aerial view of Interstate 44, Interstate 244 interchange showing location of the northeast stratigraphic section.

PLATE III

An aerial view of the Interstate 44, 244 interchange, showing the location of the East stratigraphic section.

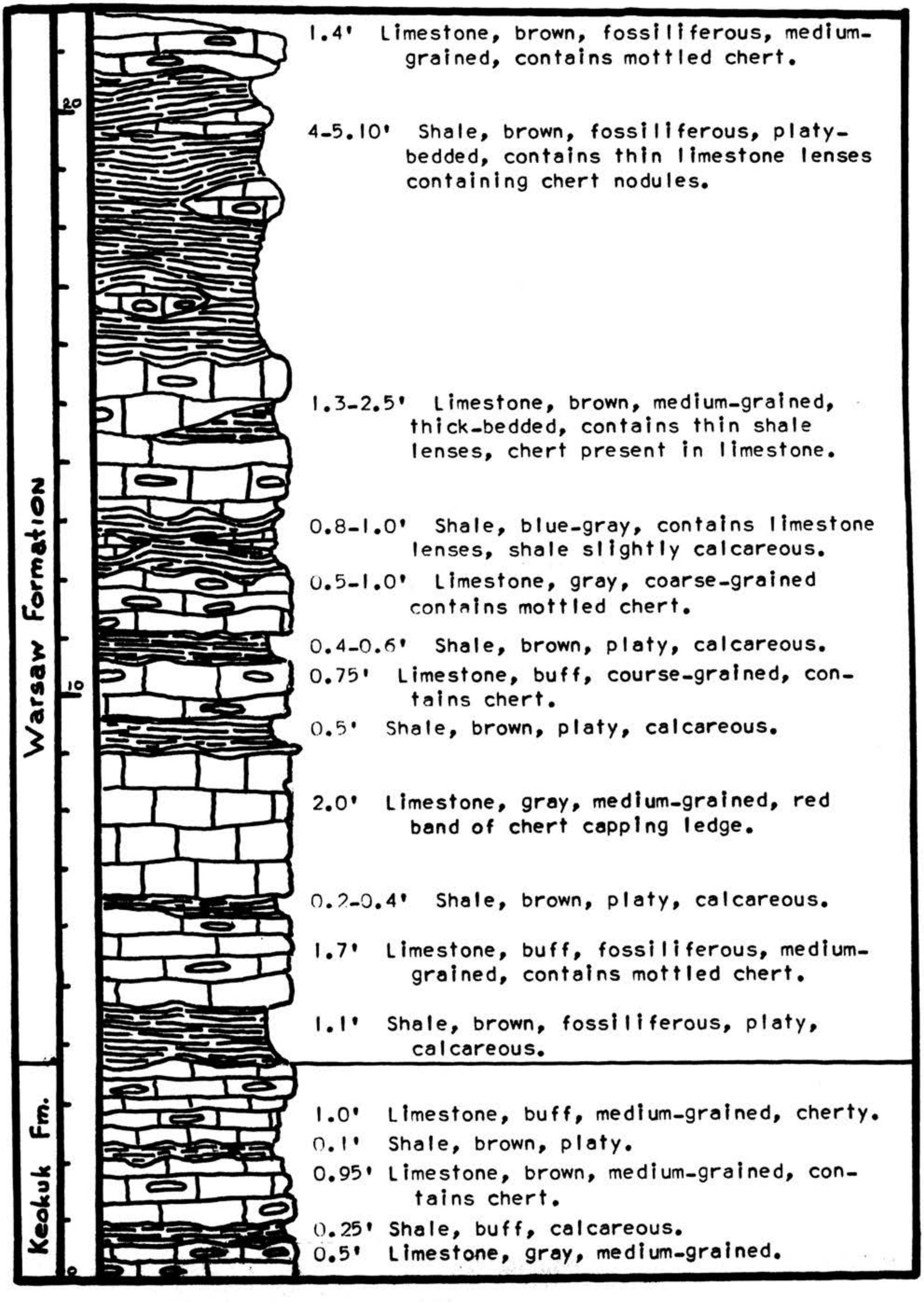



**Figure 2**

**Sylvan Beach Stratigraphic Section.**

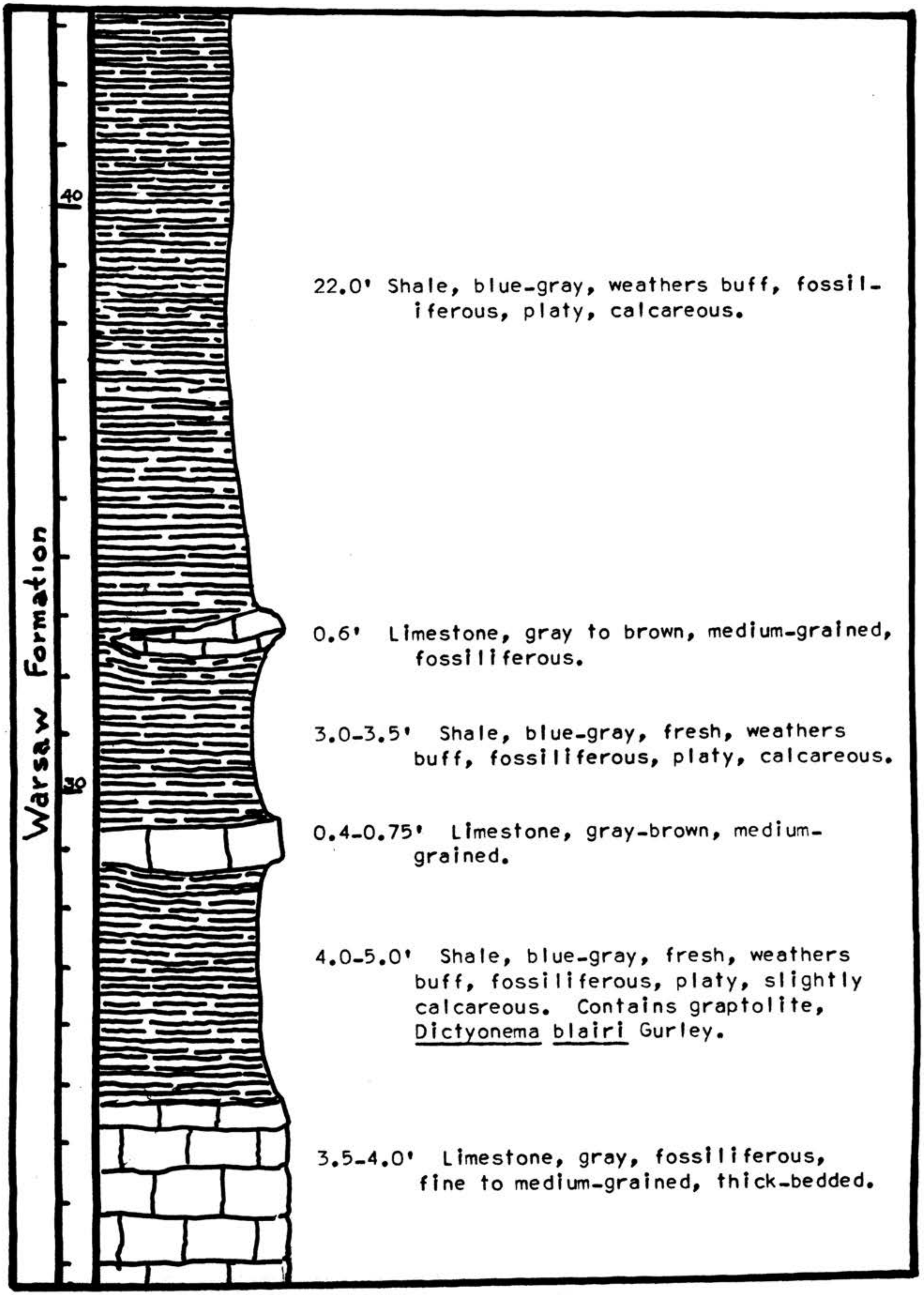



**Figure 3**

**Continuation of figure 2.**

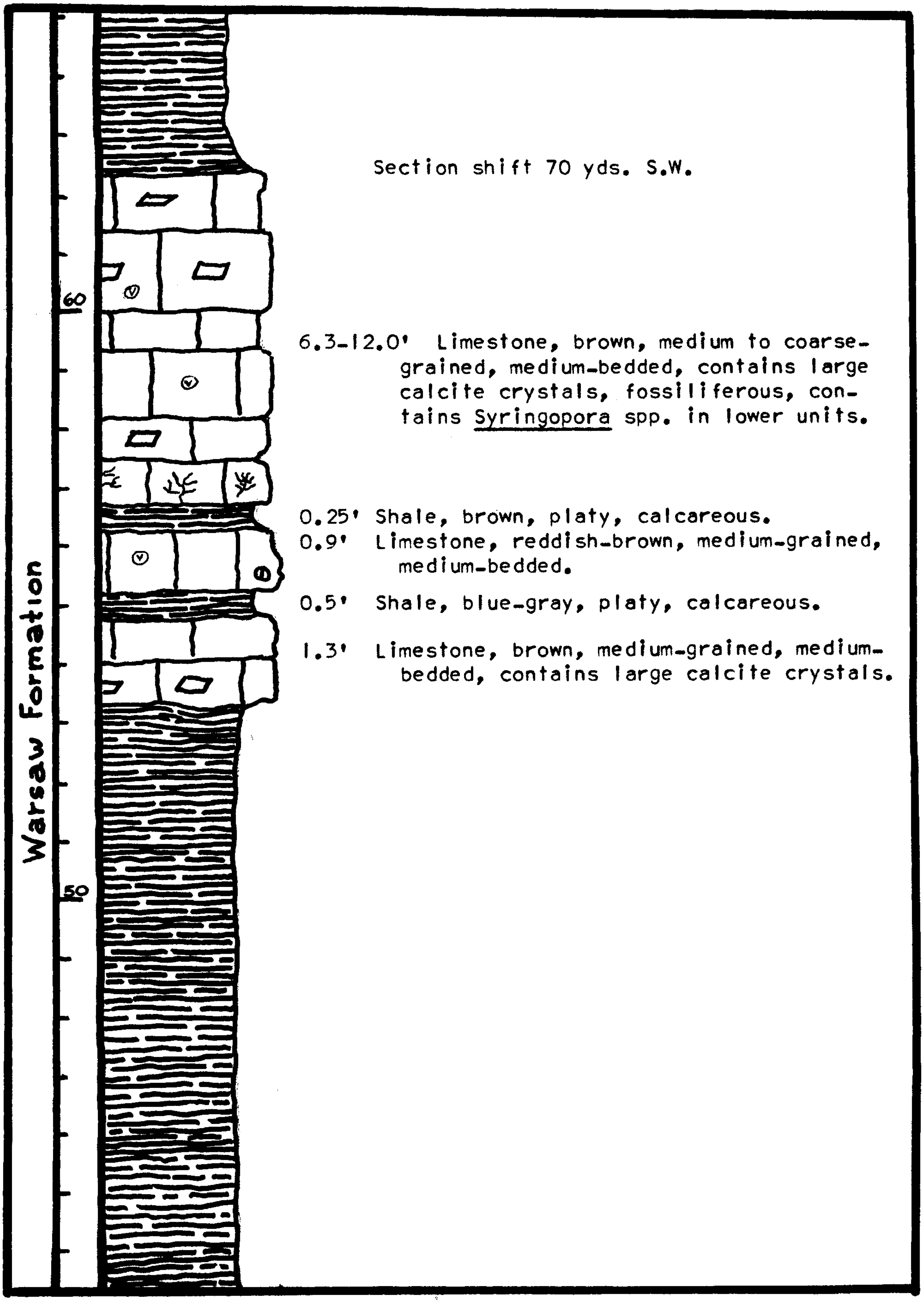



**Figure 4**

**Continuation of figure 2.**

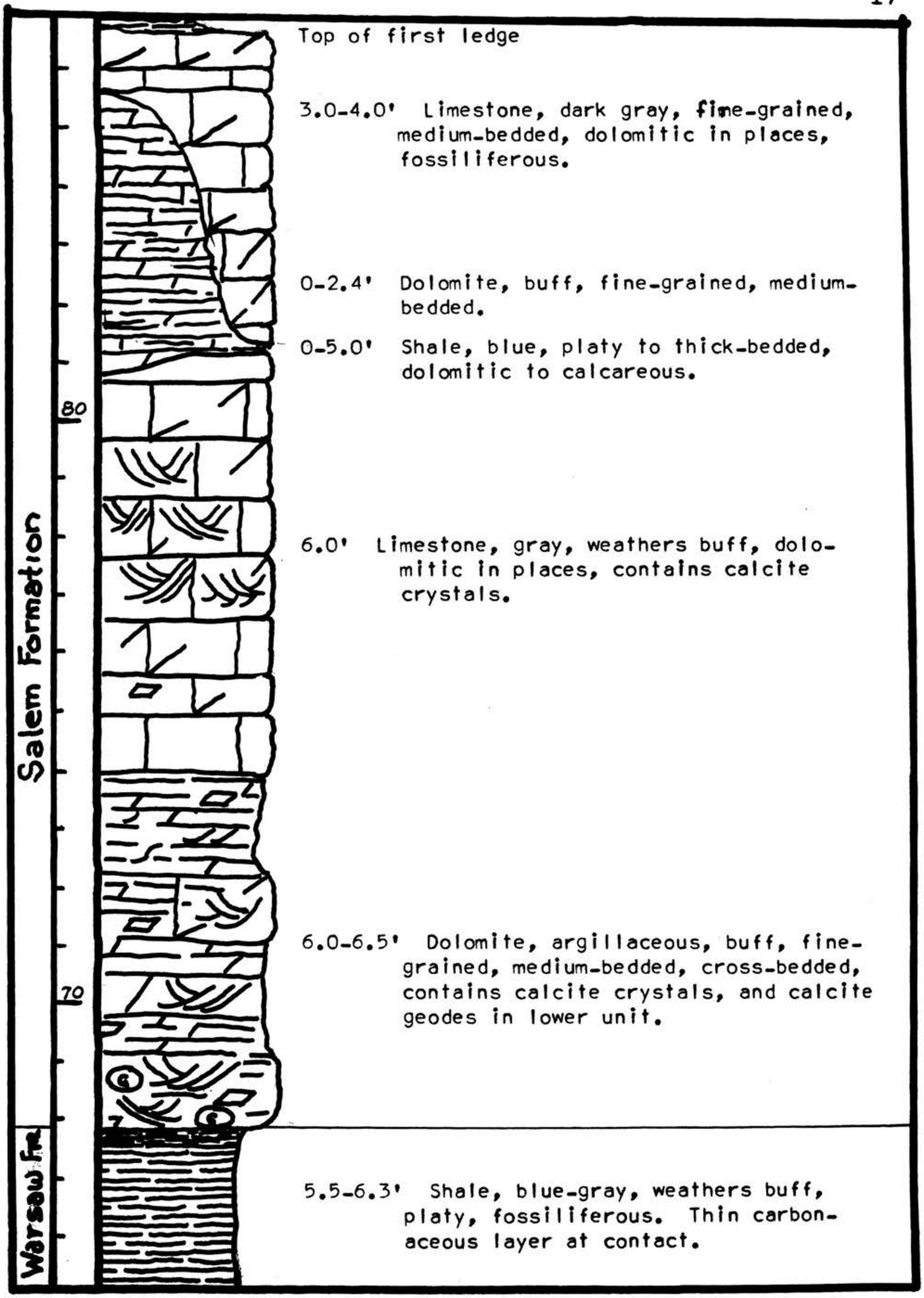



Figure 5

Continuation of figure 2.

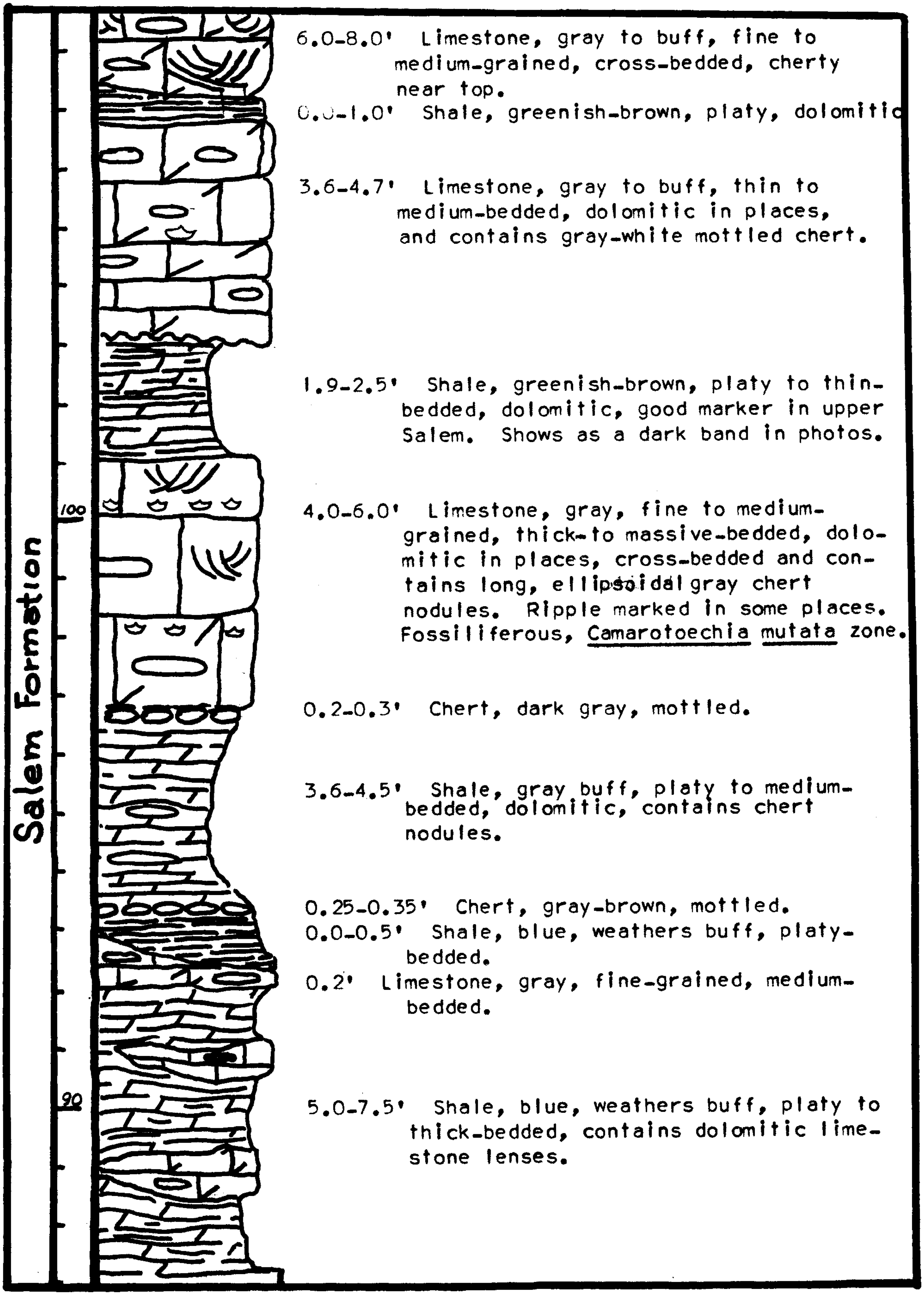



Figure 6

Continuation of figure 2.

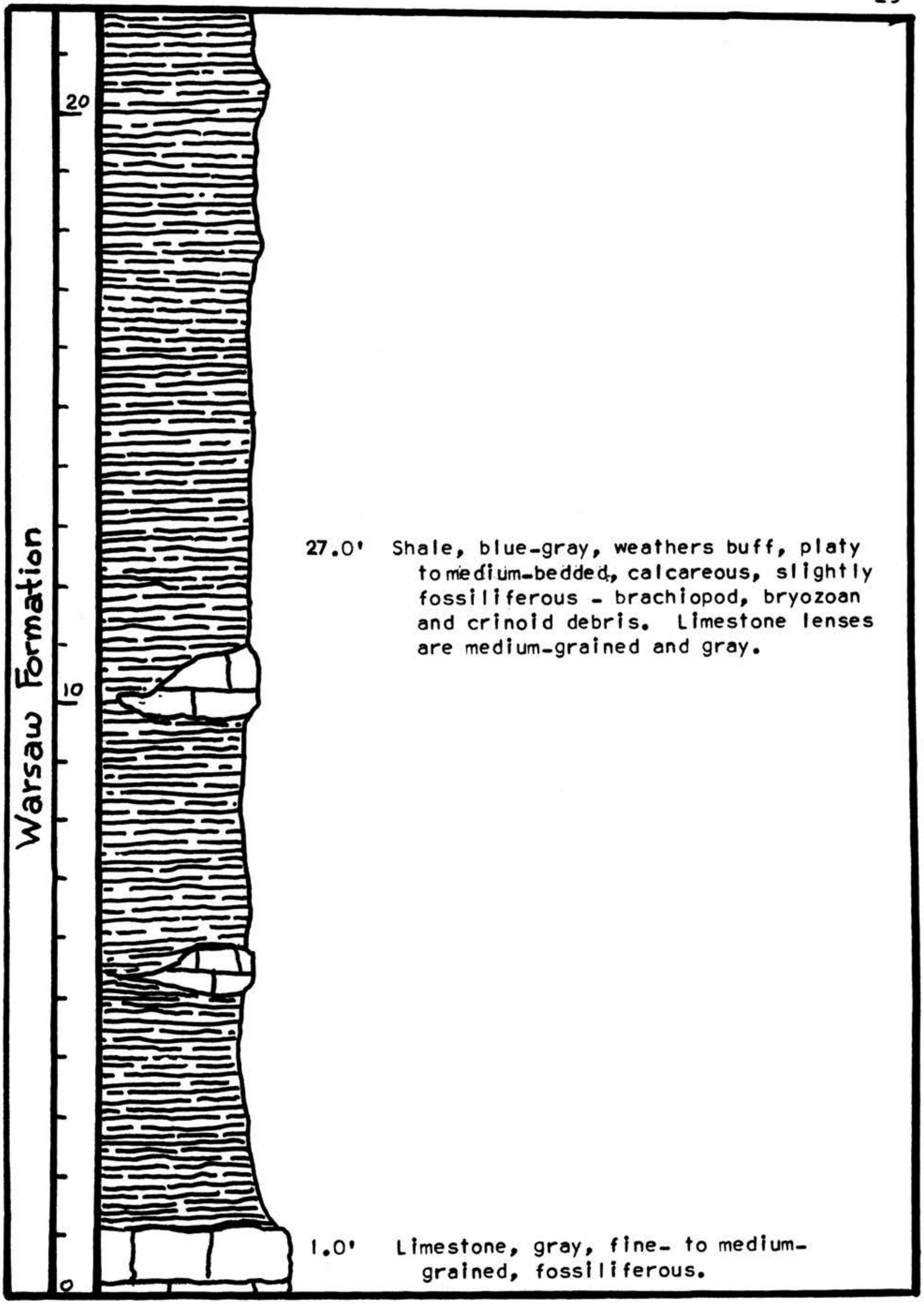



Figure 7

The northeast stratigraphic section.

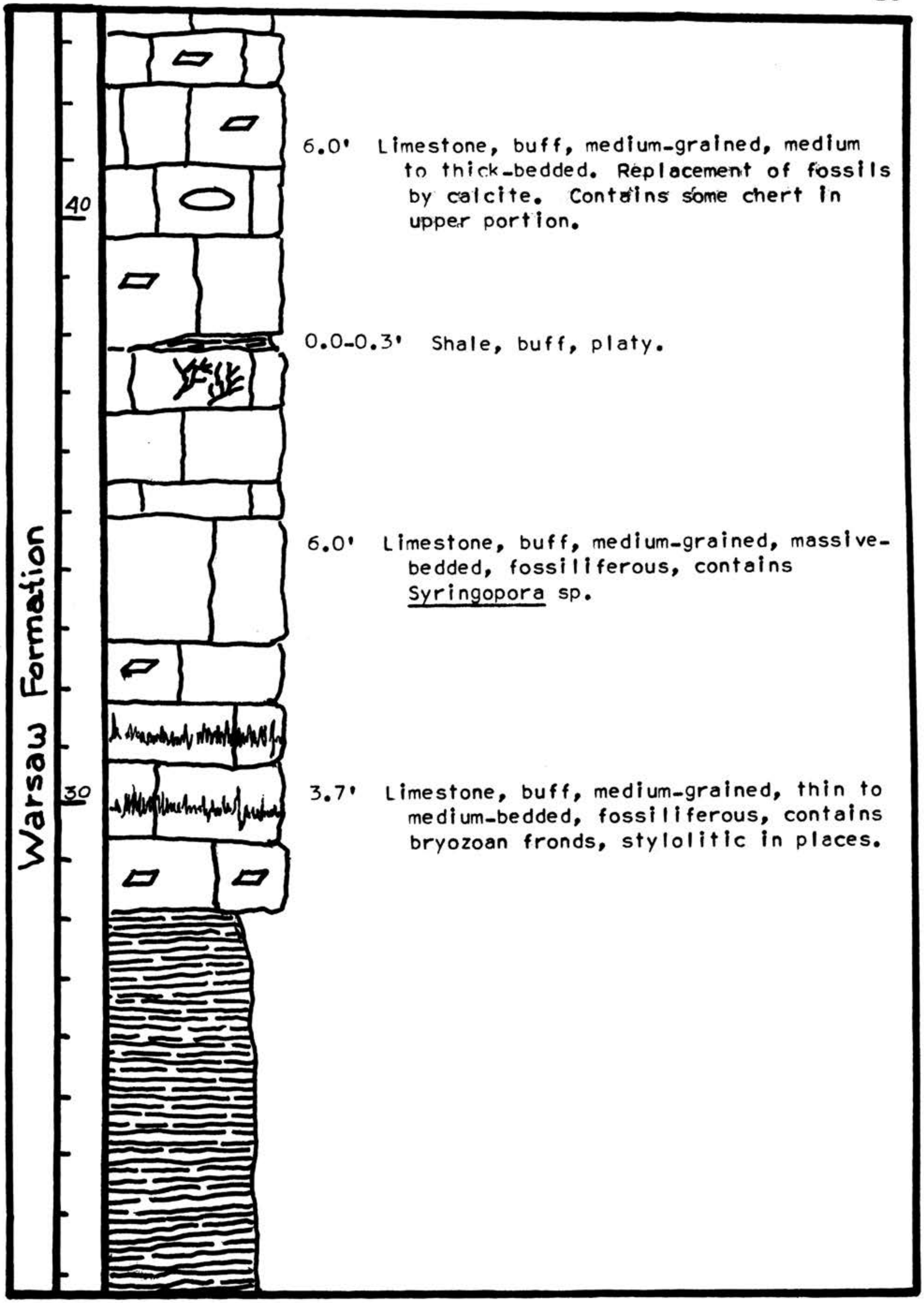



Figure 8

Continuation of figure 7.

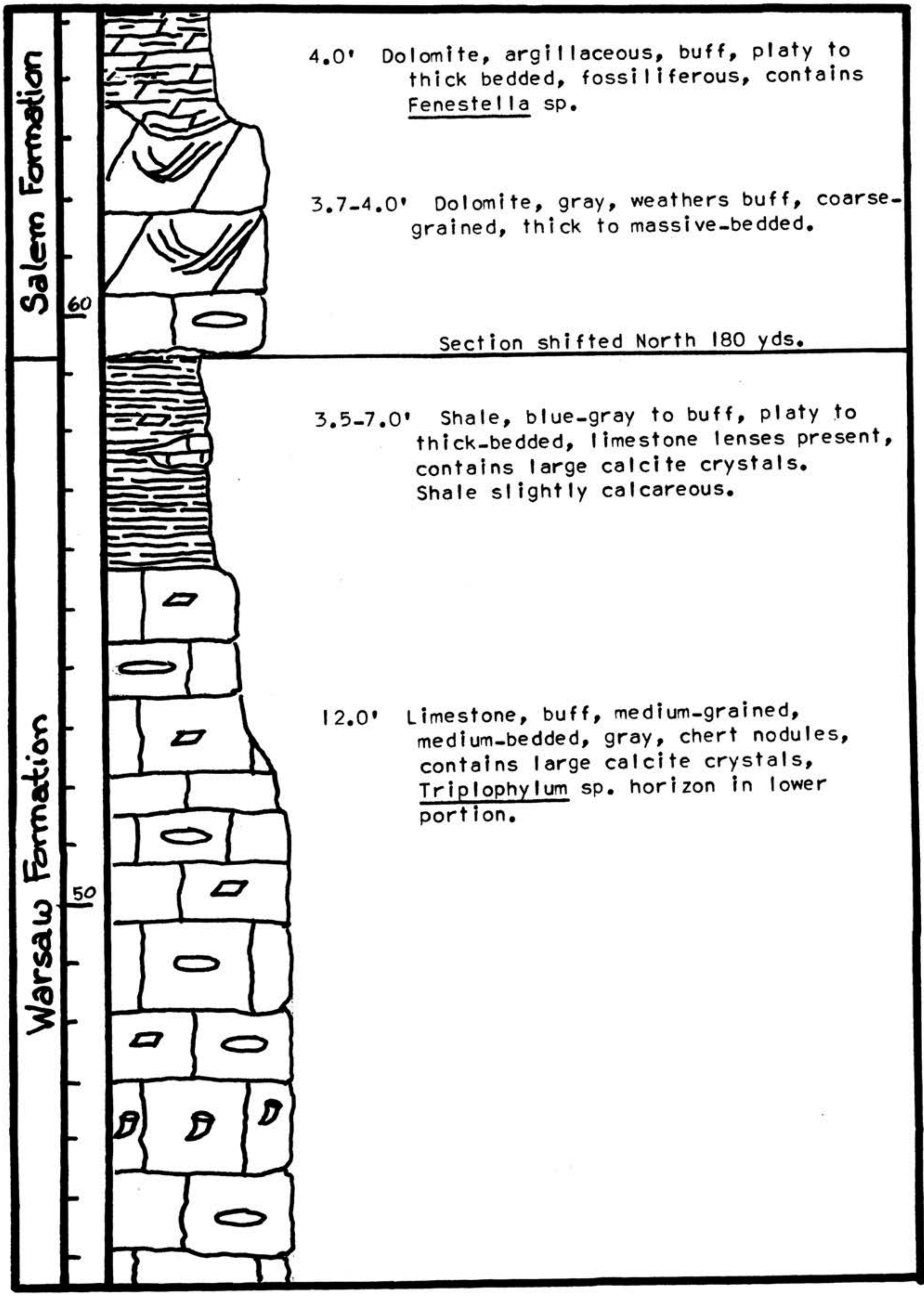
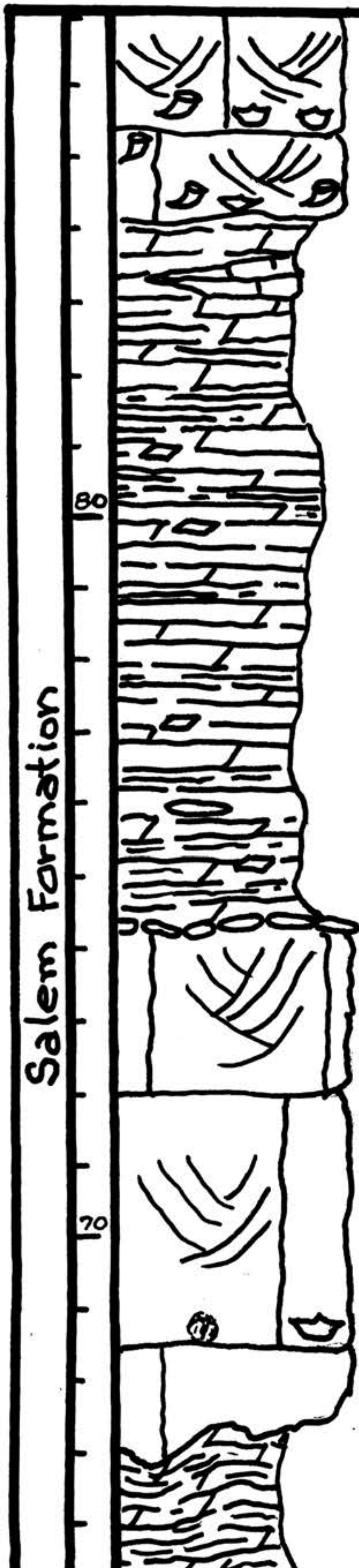



Figure 9

Continuation of figure 7.




17.0' Limestone, gray, weathers buff, fine-grained, thin to massive-bedded, contains gray-mottled chert, predominately cross-bedded. Fossiliferous, contains Rhipidomella dubia, Spirifer pellaensis, Spirifer keokuk in a zone in the lower unit. Upper portion contains breccia similar to St. Louis breccia.

5.5-7.0' Dolomite, blue-gray weathers buff, platy to thick-bedded, argillaceous, contains chert and small calcite crystals. The upper one-half of this unit is the predominate recessive unit on the photographs (Plate X).

0.4' Chert, dark gray nodules.

7.0-7.5' Limestone, weathers buff, medium-grained, massive-bedded; fossiliferous with bryozoan fronds abundant. Pentremites sp., Camarotoechia mutata.

Figure 10

Continuation of figure 7.

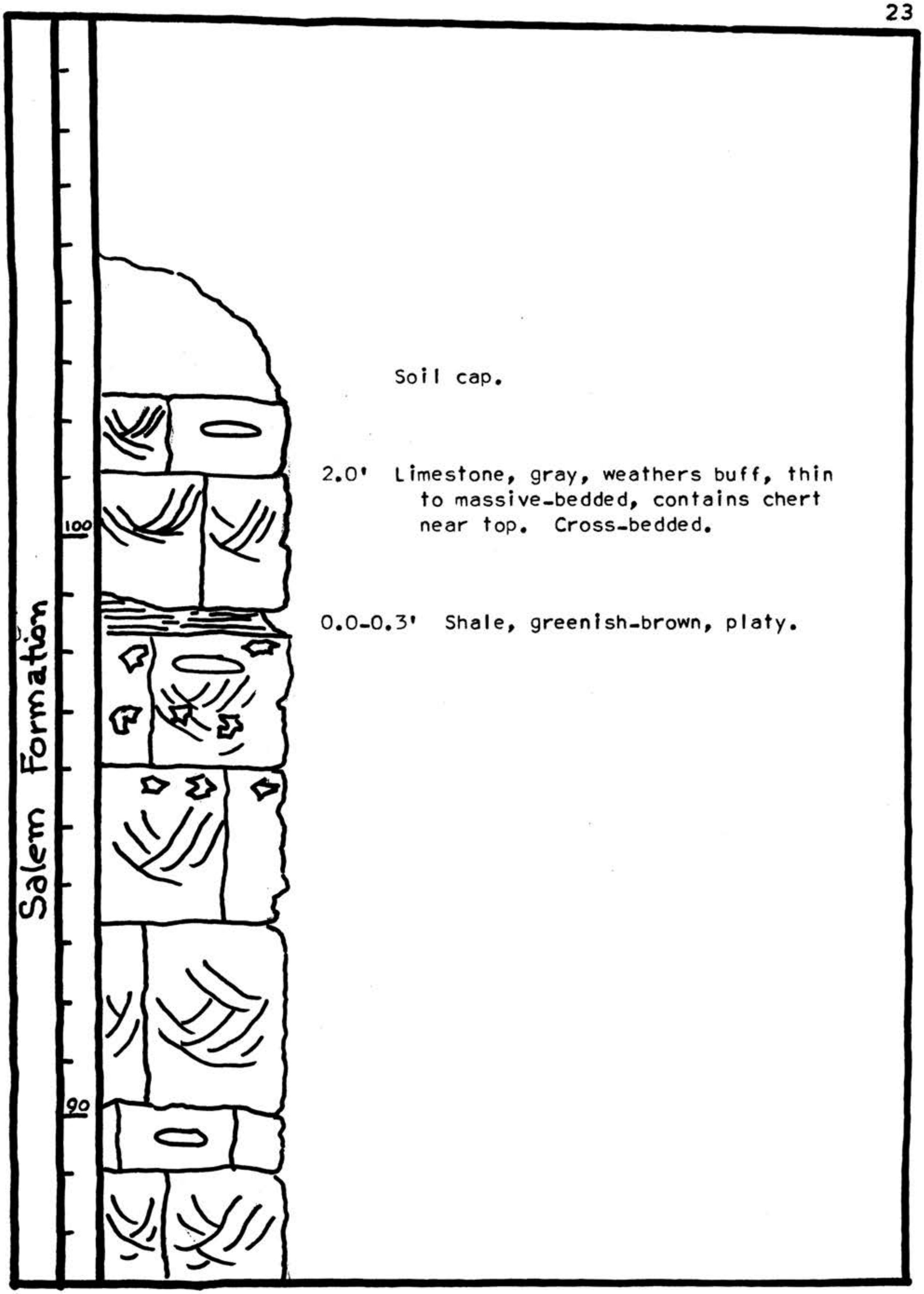



Figure 11

Continuation of figure 7.

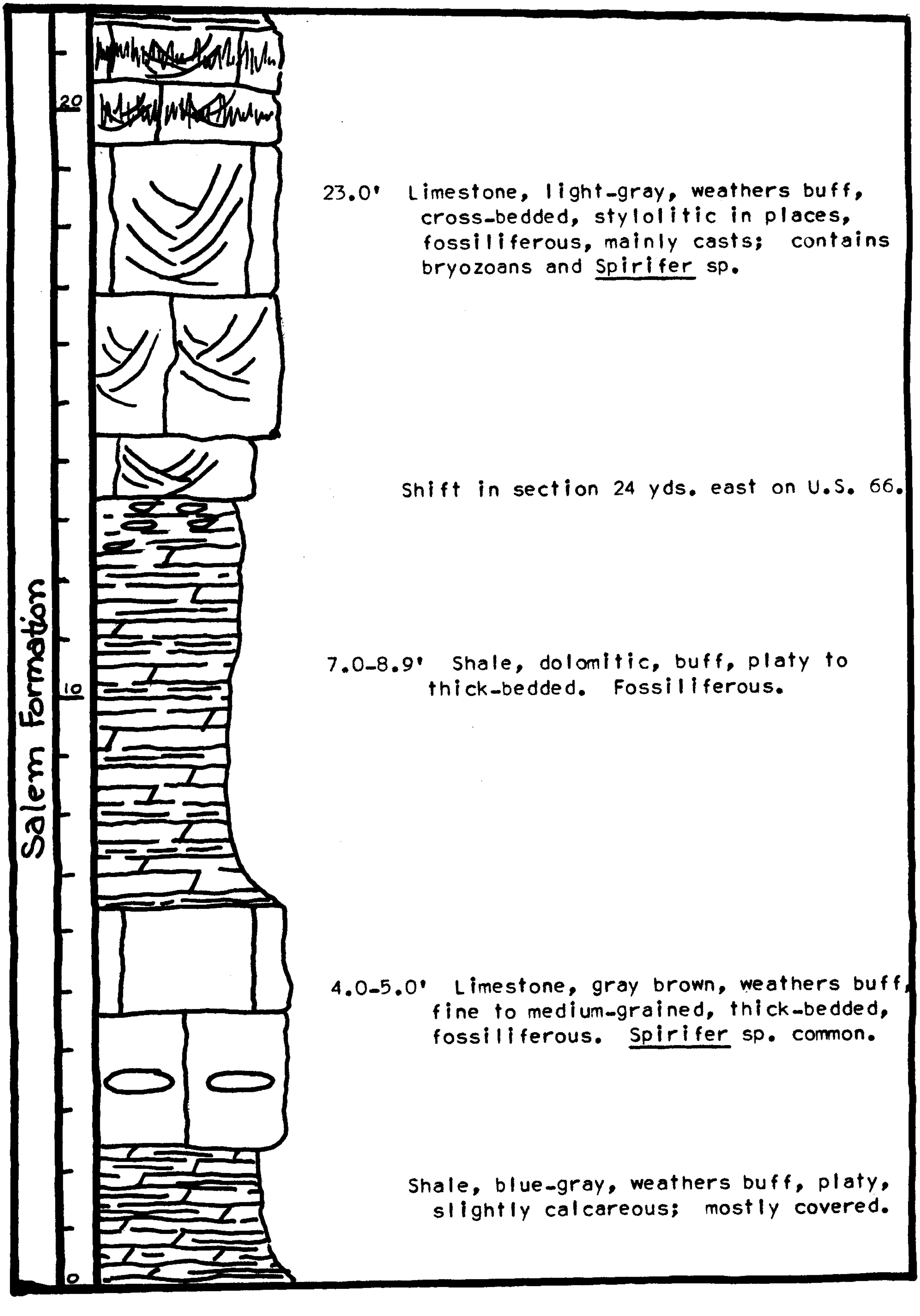



Figure 12

The east stratigraphic section.

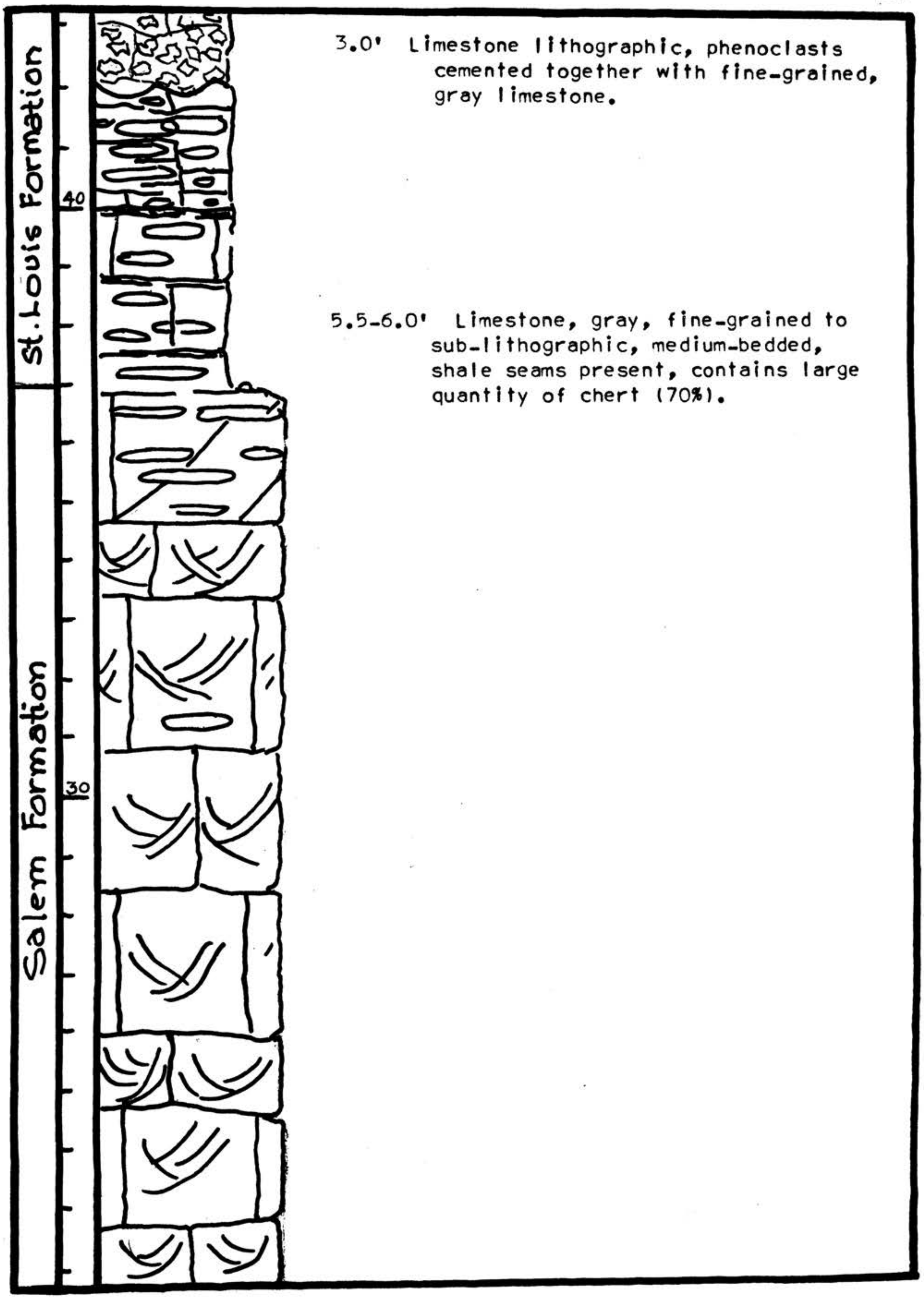



Figure 13

Continuation of figure 12.

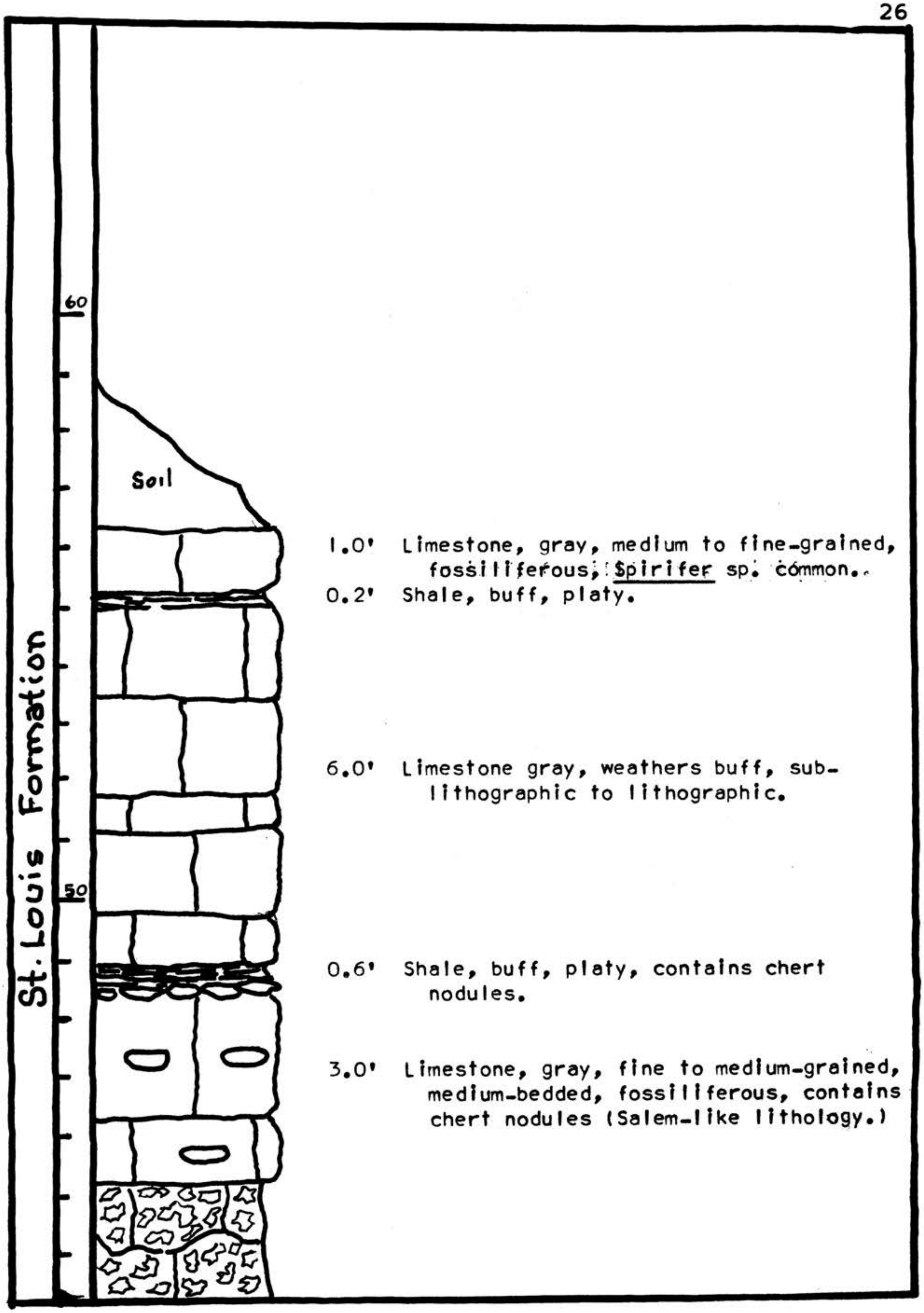



Figure 14

Continuation of figure 12.

The best exposure of the Salem-St. Louis contact in the thesis area is along Ramp Thirteen in the east stratigraphic section (Plate XIII, in pocket).

The terms, "fine," "medium" and "coarse-grained" were used to describe the texture of non-clastics. The boundaries between these textures are the same as the major boundaries used in the Wentworth scale for clastics. The bedding terms "platy," "thin-bedded", "medium-bedded", "thick-bedded" and "massive-bedded" were used to describe the sedimentary units. The terms coincide with the terms described by Payne (1942, p. 1697).

C. Petrology

The lithology of the Warsaw, Salem and St. Louis formations was studied both megascopically and microscopically for this thesis. The megascopic study involved preparing field descriptions of three sections (the measured sections are presented in Chapter III) and studying the fossils and fossil zones in these formations.

Thirty-three thin sections from samples collected at the three sections were studied microscopically. The thin sections were chosen to illustrate the general characteristics of a formation, a particular feature, or a lithologic change within a formation.

In discussing the lithology of the limestones in the thesis area, the writer will use several terms used in R. L. Folks' (1959) classification of limestones. The terms that were used are as follows: biosparite, micrite and biomicrite. A biosparite is a limestone consisting of fossil material (bio), cemented together with sparry calcite (sparite). Sparry calcite is calcite composed of crystals larger than 10 microns. Micrite is the contraction for microcrystalline calcite. Microcrystalline calcite is extremely fine-grained (1-4 microns) calcite often referred to as lime mud. The contraction "micrite" is used as a name for microcrystalline calcite matrix, or for a rock wholly made up of microcrystalline calcite. In thin section it is a brownish color and generally subtranslucent. Biomicrite is a rock composed of micrite and fossil material.

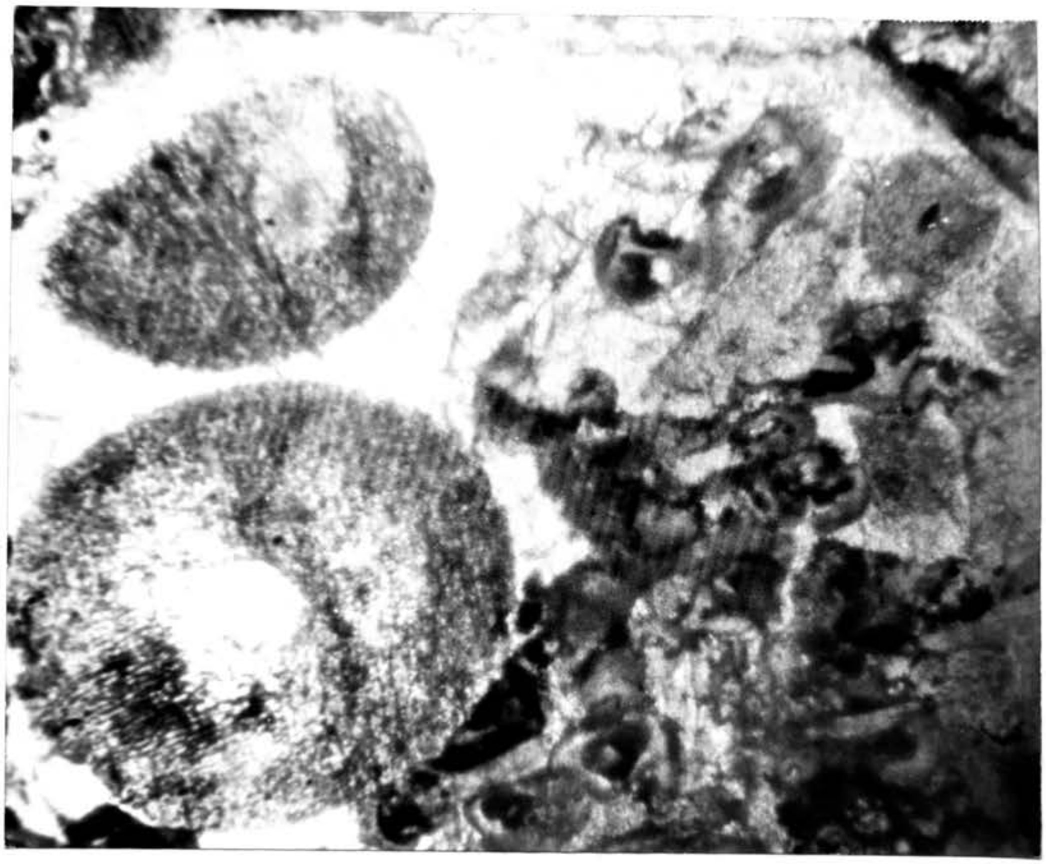
1. Carbonates

a. Limestones

The limestones of the Warsaw Formation are generally dark gray, coarsely crystalline and fossiliferous. The lithology varies considerably within the formation. The limestones are in the lower and upper portions of the formation, and shales predominate throughout the remaining portions. The limestones of the Warsaw is a biosparite containing 70-80 percent fossil fragments, cemented together with sparry calcite (Plate IV). The Warsaw Formation is very fossiliferous and is discussed in the paleontological section later in this chapter.

The limestones of the Salem Formation range from a biosparite (Plate V) in the lower portions to a micrite (Plate

PLATE IV



Photomicrograph of Warsaw biosparite. X 26. The dark material is fossil fragments, mainly crinoid debris. The light material is sparry calcite, which is cementing the fragments together.

VI) in the upper portion. Limestone comprises approximately 60 percent of the formation.

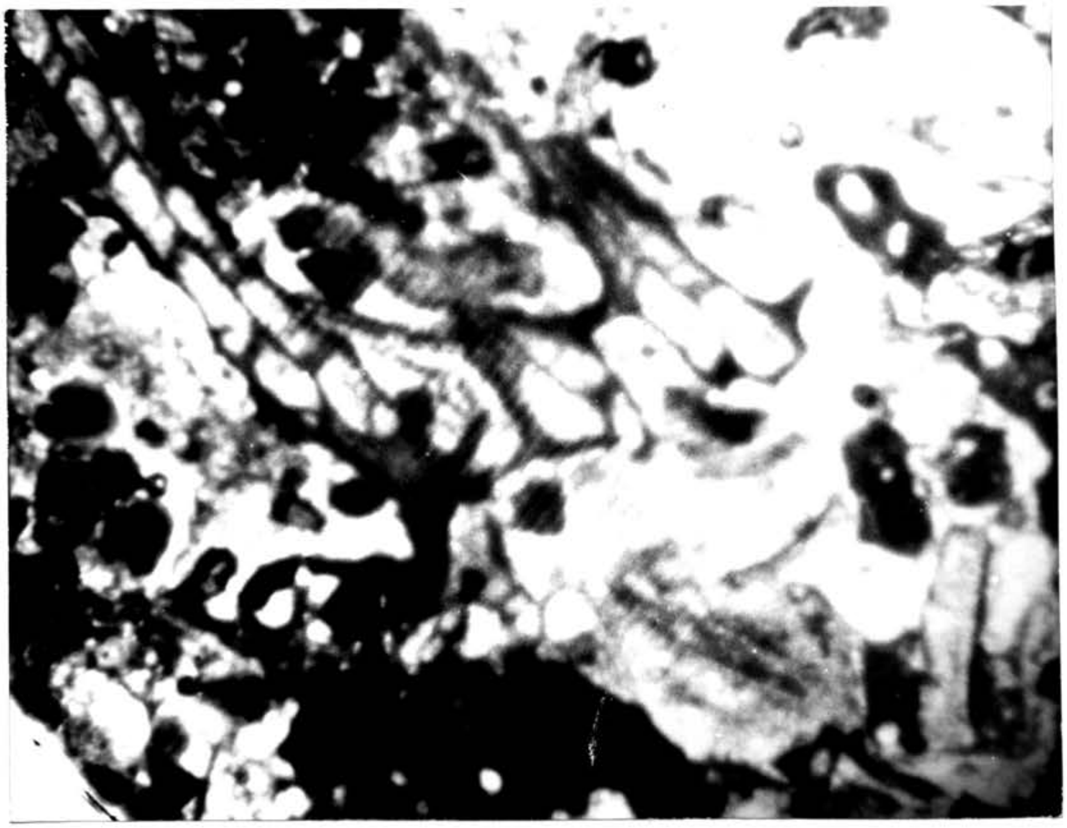
The lithology of the lower Salem is a fragmental-fossiliferous, light gray limestone, dolomitic in places, and with a matrix of sparry calcite. In the lower units large calcite crystals are common in the limestone. In the lower part of the Sylvan Beach section, calcite crystals fill geodes 1.5-2.0 inches in diameter.

The middle units of the Salem Formation are mainly composed of massive beds of crystalline limestones that are highly fossiliferous. This part of the formation has been referred to as typical Salem by some workers. Fenneman (1911) states that this phase has a "striking resemblance in physical character to the well-known Bedford (Indiana) limestone of commerce." The beds are very fossiliferous.

The upper Salem is also very fossiliferous and contains bryozoan and crinoidal debris as well as foraminifers. The limestone is gray, medium-to massive-bedded (2.0-6.0 feet), and contains shale seams as well as chert. Current bedding (Plate VI) and current ripple marks are common in the upper Salem Limestone. In the upper units, the Salem has a very fine texture and is classified as a micrite. A few fragments of limestone breccia, similar to that in the St. Louis Formation can be found in the upper units of the limestone in the northeast stratigraphic section.

The limestones of the St. Louis Formation display many different textures. The most common and characteristic type

PLATE V



Photomicrograph of lower Salem biosparite. X 26. The dark material is fossil fragments, mainly the bryozoan, Fenestella, and the light material is sparry calcite.

within the formation are beds of dense limestone displaying a lithographic texture. These beds often contain intraformational breccia. The lithographic limestone would fit into R. L. Folks' classification as a micrite (Plate VII). The beds of breccia are composed of phenoclasts of lithographic limestone, and they occur in a matrix of fine-to medium-grained limestone (Plate VII). The major dimensions of the phenoclasts range from a fraction of an inch to several inches. According to Grawe (1923, p. 59) the breccias represent subaerial erosion caused by emergence. A full treatment of the many theories of origin of these is beyong the scope of this report. The brecciated zone in the lower part of the St. Louis Formation grades upward into a gray, medium to coarse-grained limestone which contains many fossil fragments (predominantly crinoid columnals). This limestone is similar to that which occurs in the upper portion of the Salem Formation.

b. Dolomites

There are no dolomite beds in the Warsaw Formation in the area under study. However, there is some evidence of small amounts of dolomite within the limestones. This was determined by staining the thin sections that were studied with Alizarin red stain.[1]

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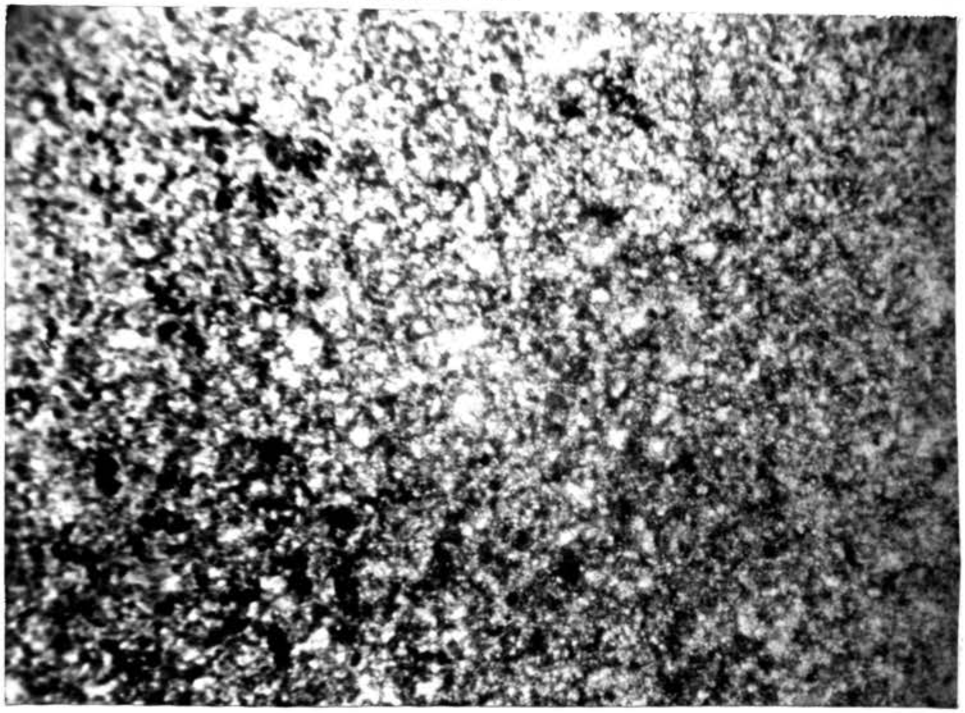
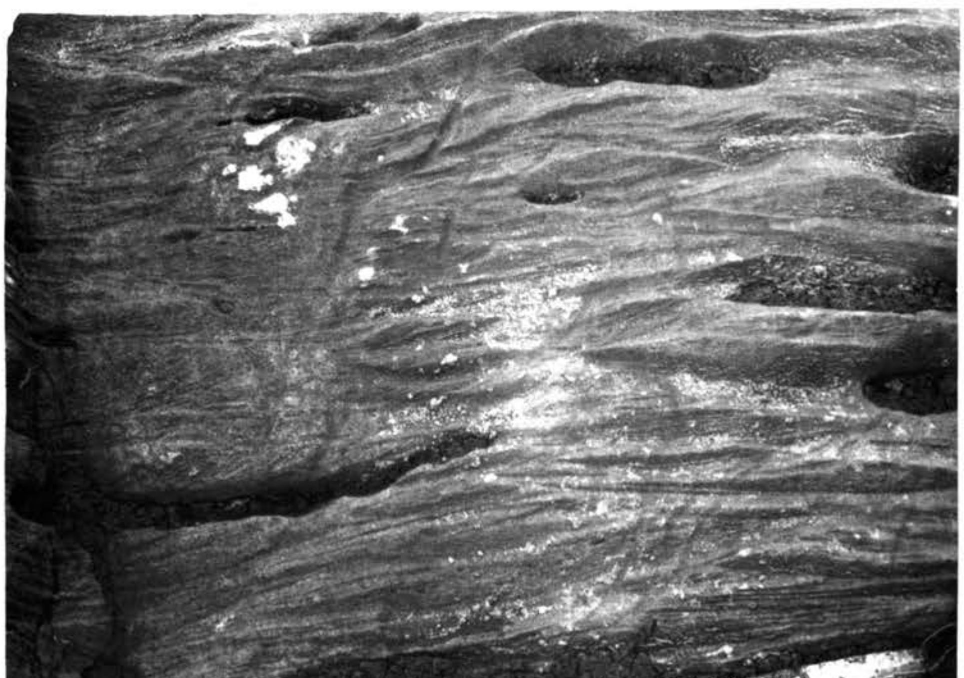
1. This stain is prepared by combining 2.7 milliliters concentrated HCl and 16 oz. water to 1.25 milliliters solid untamped Alizarin Red S dye. Then by immersing the sample into this solution, the stain will affect the calcite but not the dolomite. Thus, one can determine if any dolomite is present in a sample.

PLATE VI

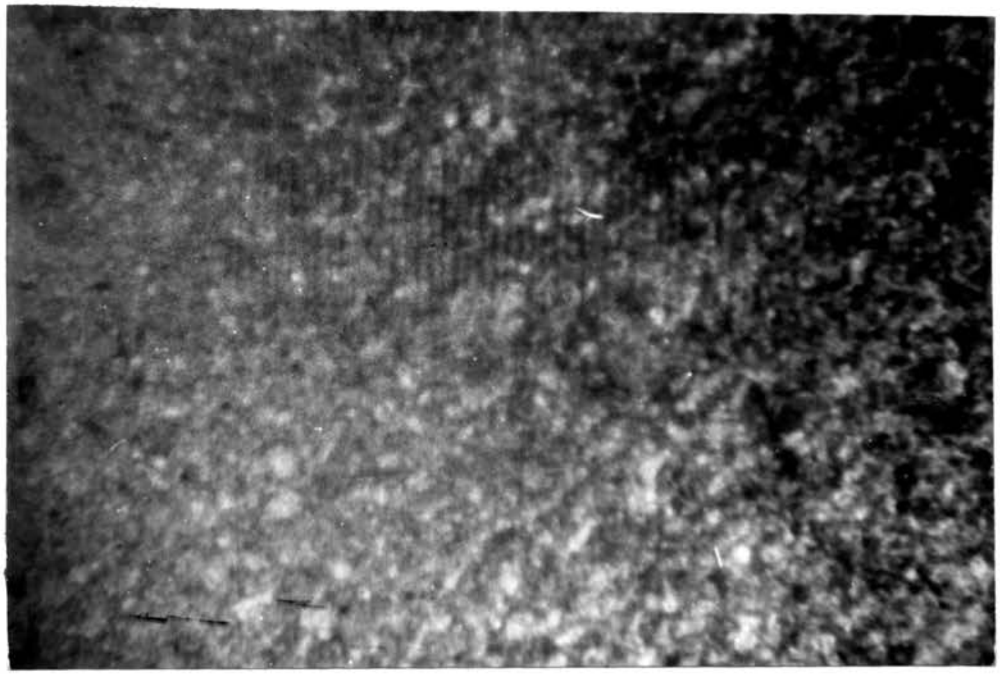


A. Photomicrograph of upper Salem micrite. X 70, crossed nicols. The dark and light material is lime mud.



B. Cross-bedding of the Salem Formation located in the upper part of the Sylvan Beach Section.

PLATE VII



A. Photomicrograph of St. Louis micrite. X 70, crossed nicols. The dark and light material is lime mud.

B. Breccia in St. Louis Formation located in the Meramec Highlands Quarry in the SE¼, SE¼ Sec. 8, T. 44 N., R. 5 E., Kirkwood, Missouri Quadrangle.

The Salem Formation has several argillaceous dolomitic beds. Upon weathering, these beds often break into laminae that present a shale-like appearance. Characteristically, the beds are buff in color when fresh and are fine-grained. The beds also contain large calcite crystals from 0.5-1.0 inch in diameter.

There were no beds of dolomite found in the St. Louis Formation.

2. Shale

In the thesis area the Warsaw Formation is composed of shale and limestones which have already been discussed. The shales of the Warsaw compose approximately 60 percent of that formation. With increasing distance upward from the contact between the Keokuk-Warsaw formations there is an increase in the amount of shale. The middle and upper part of the Warsaw Formation is composed chiefly of shale and thin limestone beds. The Warsaw Formation is usually covered and poorly exposed due to the relative weak mechanical strength of the shale (Plate VIII). The shale of the Warsaw varies in color from light tan to dark gray and bluish gray. In some places it is slightly calcareous and for the most part finely laminated. The laminations are usually obscured by weathering and the dark gray portions assume a light tan color. The uppermost Warsaw shale, which is at the Salem-Warsaw contact is usually dark gray to blue gray and laminated, and more calcareous than the shales farther below.

PLATE VIII

An exposure of Warsaw shale in the Sylvan Beach section.

Within the Warsaw shales, there is abundant evidence of life during the Warsaw time. Bryozoans, mostly of the fenestellid type and including Archimedes, were the most striking abundant forms of life when the Warsaw Formation was formed.

The shales of the Salem Formation (25-30 percent) change from calcareous lenses of shale to argillaceous dolomites. The shales are usually dark gray when fresh, weathering brown after exposure. The units are usually laminated, but in some instances are indurated and bedding becomes massive. As previously discussed, some of the dolomites in the Salem Formation, upon weathering, often break up into fine laminae that present a shale-like appearance. In some places, beds of dolomite were seen to give way laterally to thick lenses of calcareous shale (Figure 5). In many cases the shales of the Salem contain ellipsoidal-shaped chert nodules.

There were very few units of shale found in the St. Louis Formation. The shale occurs in seams separating the limestone units. The "seams" are relatively thin and usually the shale is buff in color and platy weathering. There are small quantities of chert in association with the shale. The shale is calcareous.

3. Chert

Chert is found occurring throughout all of the formations.

The chert in Warsaw Formation generally occurs in the lower portion. The chert of the Warsaw occurs as ellipsoidal-shaped nodules and bands within the limestone; sometimes the chert will cap the limestones. Characteristically, the chert in the lower Warsaw is mottled and has a white tripolitic covering where weathered. Also within the lower portions of the formation there is a band of red chert, highly fossiliferous, containing much crinodal debris (figure 2). In many cases the chert is acting only as a cementing agent for the fossil debris, as much of the fossil material can be removed or dissolved with hydrochloric acid, leaving only the mold in the chert.

Within the Salem Formation there are varying quantities and shapes of chert. In the lower Salem the chert appears as small nodules and in small quantities. In the middle and upper Salem the chert forms long ellipsoidal nodules up to two feet long (Plate IX). One can locate and dislodge chert nodules which have weathered out of the Salem Limestone, which look like "cannon balls", ranging from 6 to 11 inches in diameter. The nodules are banded and are usually dark gray in color. The chert of the upper Salem appears to be primary in origin. The laminae and bedding of the limestone encasing the nodules conform to the outer configuration of the nodules (Plate IX). It seems that if the chert was due to replacement, such a feature would not occur.

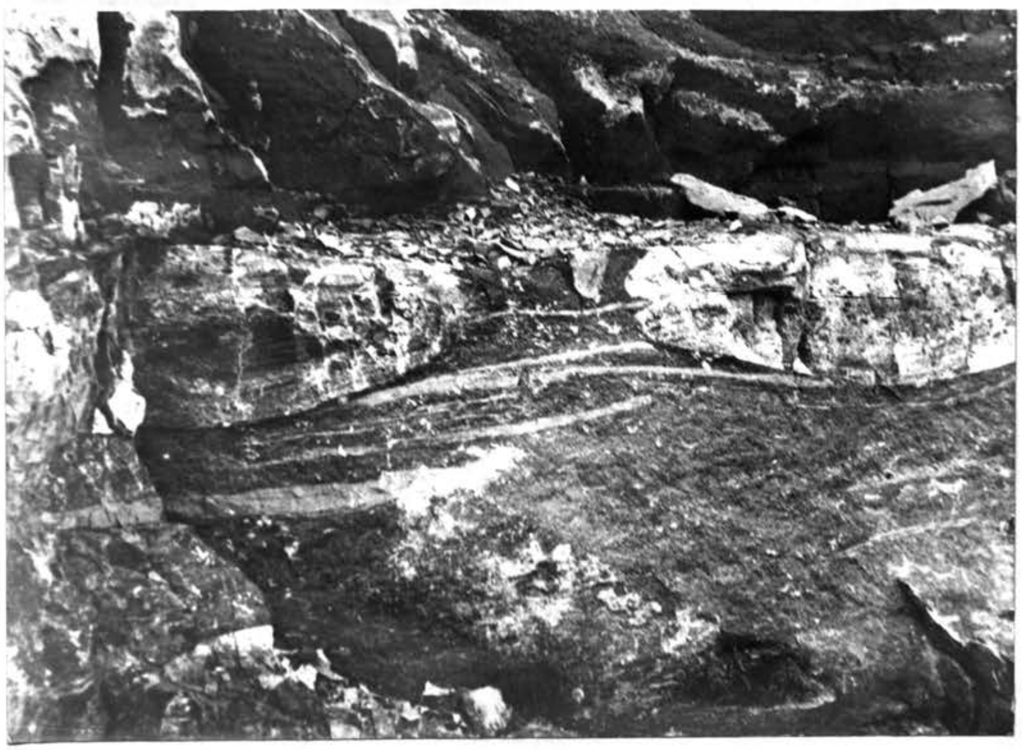
Within the lower portion of the St. Louis Formation in the thesis area, the chert is concentrated immediately above the contact of the Salem and St. Louis formations. The chert is mottled, usually brown, gray and white being the predominant colors. Due to the lithology of the limestone encasing the chert, the writer felt that the chert should be included in the St. Louis Formation. There is a large quantity of chert in the lower portion of the St. Louis Formation. The chert is less common with increasing distance upward from the formational contact.

D. Formational Contacts

The problem of the placement of the boundary between the Keokuk Formation of Osagean age and the Warsaw Formation of Meramecian age has existed for a considerable time among Mississippian stratigraphers. Problems concerning the Osage-Meramec contact cannot be solved at the type sections of either the Osage or the Meramec Series because both sections are incomplete. According to Laudon (1948), at the type section of the Osage (on the Osage River near Osceola, Missouri), the Keokuk, Warsaw, Salem and St. Louis formations are missing. The upper Keokuk beds are exposed at other places in west-central Missouri, and the Warsaw and Salem formations are not represented at all. At the type section of the Meramecian Series, beds of Osage age are not exposed. The type section for the Meramec Series is located on Marshall Road in the S½, SE¼, Sec. 10, T. 44 N., R. 5 E., Kirkwood, Missouri, Quadrangle. This exposure is in the vicinity of Osage Hills (formerly Meramec Highlands). Within

PLATE IX

A. Long ellipsoidal chert nodules in Upper Salem Formation in the Sylvan Beach section.



B. Primary chert nodules in Upper Salem Formation in the Northeast section.

the thesis area, which is approximately one mile southeast of the type Meramecian Series, part of the upper Keokuk is exposed, with the Warsaw Formation of Meramecian age resting conformably on it. According to Laudon (1948), evidence has accumulated that appears to indicate a major break at the end of the Osage epoch. This evidence indicates the desirability of retaining the standard terms "Osage" and "Meramec" and militates against any usage whereby Osagean and Meramecian rocks are classed together as a unit. The name "Valmeyer" was suggested by Weller and Sutton for all rocks of Osage and Meramec age (Laudon, 1948), and this usage has been adopted by the Illinois Geological Survey.

The formational contact between the Keokuk Formation of Osagean age and the Warsaw Formation of Meramecian age is exposed within the thesis area. This contact is in the extreme western part of the area along the Meramec River. The contact is on the east side of the river, south of U.S. Highway 66 (Interstate 44) approximately at the level of the bridge crossing the Meramec River.[2] At this point the rocks of the Keokuk Formation grade conformably into the rocks designated as Warsaw age. Since there is no apparent disconformity in this area on which to base the contact of the two formations, which is also a time break between the Osage and Meramec Series, the contact is arbitrarily placed on a gradational change of lithology. This contact was

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2. Contact placed by R. D. Knight, 1957, p. 13.

placed where the characteristically coarsely crystalline crinoidal limestones of the Keokuk Formation graded conformably into the shales designated as characteristic of the Warsaw Formation. About seven feet above this contact in the Warsaw Formation, there is chert present which is predominantly red. This characteristically red chert has been used as a basis for correlating the formational contact to other measured sections outside of the thesis area (see section on correlation). In this area the Warsaw Formation of Meramec age lies conformably on the Keokuk Formation of Osage age.

In considering the formation contact between the Warsaw Formation and the Salem Formation, we are again dealing with a gradual change of lithology. The Warsaw Formation is characterized by alternating beds of bluish-gray to brownish-gray shales and thin beds of limestone. The shales compose 60-70 percent of the formation. The Salem Formation is predominantly a hard massive to thin-bedded granular to fine-grained, dolomitic, cross-bedded limestone. In determining the contact between the two formations it is a matter of distinguishing between the two different lithologies. In the thesis area a problem arises as to where to put the contact. Should one place it at the top of the last shale and the first limestone of Salem lithology? The writer in making this decision, placed the contact where the predominantly blue calcareous shale of the Warsaw graded conformably into the first massive, buff, argillaceous dolomitic limestone which is designated as Salem lithology (Plate X).

The lithology of the upper part of the Salem Formation consists mainly of fine-grained, buff, cross-bedded limestone containing small quantities of chert. This grades conformably into the overlying St. Louis Formation. A problem again arose as to where to place the contact. For in the upper portion of the Salem Formation the writer encountered small quantities of breccia similar to that in the St. Louis Formation (Figure 11). But since there was only a small amount of the breccia, and a vertical continuation of the Salem lithology the writer did not feel that this was significant evidence on which to place the contact. The contact was placed where the writer encountered the typical lithographic limestones which characterize the St. Louis lithology. At this point there is an abundance of chert which is encased in gray lithographic to sub-lithographic limestone. Also above this contact is the typical St. Louis breccia. But one must be careful to place the contact below this breccia, as breccia is also found at higher levels within the St. Louis Formation. The best exposure of the Salem-St. Louis contact is located along Ramp Thirteen (Plate XIII, in pocket) in the East stratigraphic section.

## E. Paleontology

Fossils are present throughout the formations comprising the Meramecian Series (Figure 15). The fossils are generally

PLATE X


Warsaw-Salem contact in the Sylvan Beach section.

well preserved. The mode of preservation varies. Many of the fossil bryozoans in the Warsaw Shale have been replaced by iron sulphides. Many of the brachiopods of the various formations have retained some of the original shell material, but in other cases are found only to be molds or casts of the original animal. Also, many of the other forms of life in the Warsaw and Salem formations have been replaced by calcite, leaving only a cast of the original form.

It is the intent of this section to present the major fossils of each formation.

The Warsaw Formation is highly fossiliferous. The limestones of the formation are composed mainly of crinoid fragments, bryozoan debris and brachiopod valves. The shales contain, mainly, bryozoan fragments. Among the distinctive bryozoans found in the thesis area, the more common forms are *Archimedes wortheni* (Hall) and *Fenestella fenax* (Ulrich). Of the many brachiopods in the Warsaw, *Camarotoechia mutata* (Hall), *Spirifer bifurcatus* Hall are the ones most commonly found.

Within the lower shale unit of the Warsaw Formation in the Sylvan Beach section (figure 3), the writer found a dendroid graptolite[3] which resembles *Dictyonema blairi* Gurley. *D. blairi* was described by Gurley in 1896; the description was very general and incomplete.

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3. Identification verified by Professor A. C. Spreng (University of Missouri at Rolla) and Mrs. June Ross of the Department of Geology, University of Illinois.

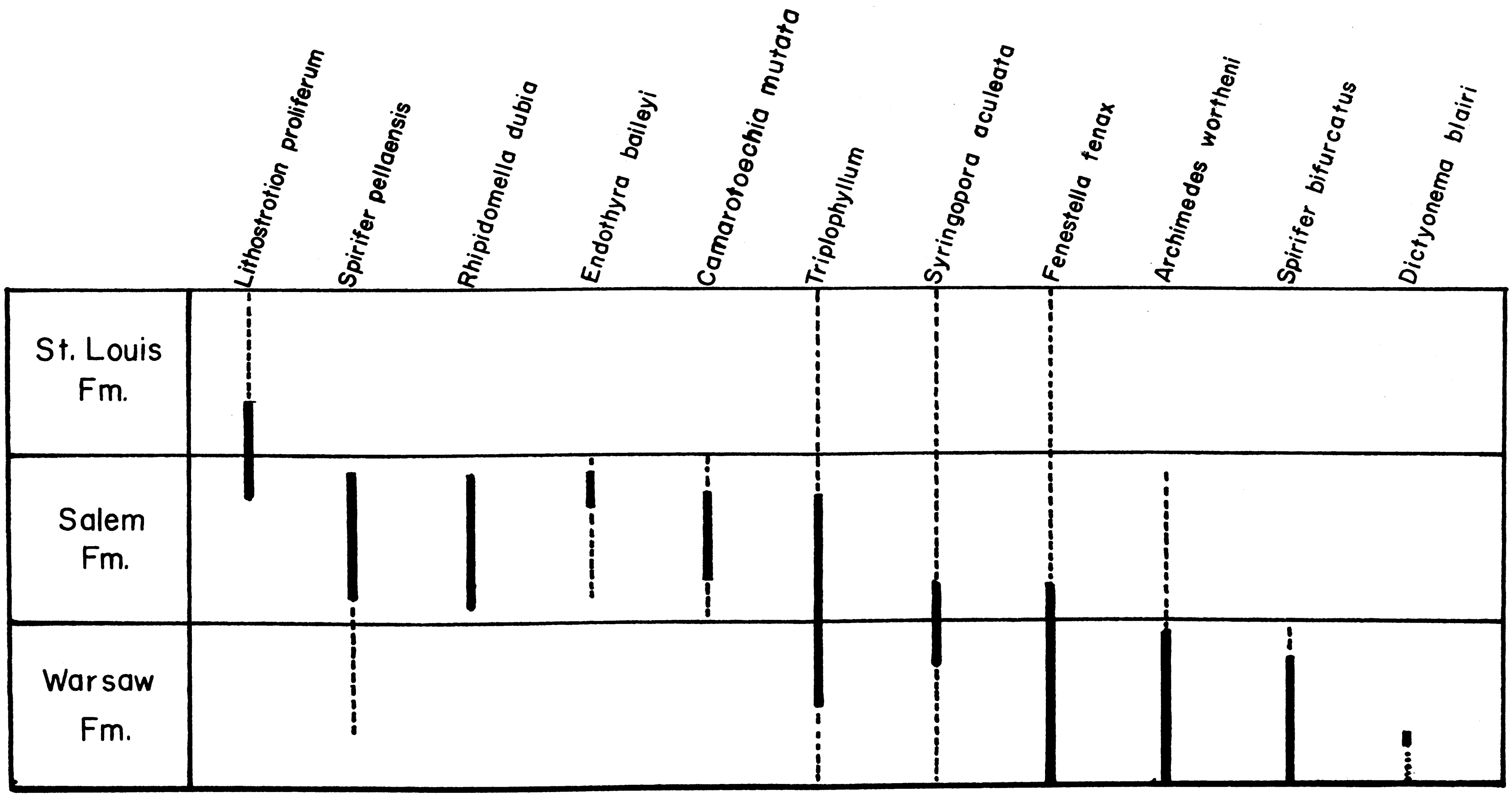


Figure 15

Faunal chart showing the common species in the Warsaw, Salem and St. Louis formations, at the I-244, 44 Interchange, Kirkwood, Missouri.

1. The dark lines indicate the approximate stratigraphic range of the particular species at the I-244, 44 Interchange, Kirkwood, Missouri.
2. The broken lines extensions indicate the range as given by Shimer, 1944.

The description of the graptolite found in the Warsaw Shale is as follows, based on a single colony:

Branches radiate from an area close to the proximal end of the zoarian. The branches are subparallel, usually from 0.4-0.6 mm. thick (flattened), and are arranged transversely, about 19 to 21 in 20 mm. Interspaces are generally no more than 1 mm. wide. Dissepiments are slender, about 0.2-0.3 mm. thick, sometimes perpendicular, but usually oblique to the branch. The meshes vary in shape from quadrangular to oval. The shortest are about 0.7 mm. in length and the longest about 2.3 mm. long. The graptolite is preserved as a flat carbonaceous film (Plate XI).

This description varies only slightly from Gurley's and, therefore, the writer feels that the graptolite found in the Warsaw Shale is _Dictyonema_ _blairi_ Gurley. Gurley described his species from a specimen found at Sedalia, Missouri, in the Chouteau limestone, Kinderhookian Series of Lower Mississippian age. The Chouteau at Sedalia as then identified, generally included some basal Osagean beds also. This was previously the highest occurrence of _Dictyonema blairi_, the upper limit should now be placed in the Warsaw Formation of the Meramecian Series, and since the highest occurrence of genus _Dictyonema_ was in the Lower Mississippian, this should also raise the upper limit of _Dictyonema_ to the middle Mississippian. The specimen was collected 26 feet above the base of the Warsaw Formation (figure 3).

The fossils of the Salem Formation are abundant and many are characteristically small. The most numerous types are brachiopods and corals. Of the many species of brachiopods, Camarotoechia mutata (Hall), Rhipidomella dubia (Hall), and Spirifer pellaensis Weller are the most common ones found in the formation. A biostratigraphic zone which consists almost entirely of Camarotoechia mutata valves occurs in the lower part of the middle Salem Formation, about 35-40 feet above the Salem-Warsaw contact (figure 6). Fenneman (1911, p. 23) referred to this as the Rhynchonella zone. This zone has a maximum thickness of about two feet. Crinoids, corals and microfossils are also found in the Salem Formation. In the lower portion of the Salem, the tabulate coral Syringopora sp. can be found. The corals have been almost entirely replaced by calcite. In the upper portion of the Salem Formation in the Sylvan Beach section the tetracoral Lithostrotion proliferum Hall has been found. The foraminifera Endothyra baileyi (Hall) (Plate XII) is common in the upper Salem.

The St. Louis Formation also contains Lithostrotion proliferum Hall which is stated to be a very distinctive fossil for this formation. Care must be taken in using the fossil alone as an index to the St. Louis Formation, as the same species can be found in the underlying Salem Formation. Within the St. Louis Formation there are areas where the limestone, upon weathering, displays fine wavy, laminated structures which may represent algal colonies (Plate XII). Thin sections made of these show parallel concentric banding

PLATE XI


Photograph of Dictyonema blairi Gurley, found in Lower Warsaw Formation in the Sylvan Beach section.

PLATE XII

A. Photomicrograph of Endothyra baileyi (Hall). X 75.
Found in upper Salem Formation.

B. Algal structures in St. Louis Formation (scale in inches).

and the possibility of cellular structure.

F. Correlations

Within the boundaries of the area under study, one formation belonging to the Osagean Series and three formations of the Meramecian Series of the Mississippian System are represented. These formations can be correlated locally as well as regionally (with some difficulty), based on lithology and paleontological evidence.

It is the purpose of this section to point out the difficulties encountered in making local correlations and the basis on which the correlations were made.

Regionally, the Warsaw Formation can be correlated with the Warsaw of Iowa, Illinois, Kentucky, Tennessee, northern Alabama and northeastern Mississippi. In southwestern Indiana, however, it is correlated with the Upper Harrodsburg (figure 16) (Wilmarth, p. 2276).

Based on its faunal content and stratigraphic position, the Salem Formation of eastern Missouri has been shown to be the correlative of the Salem Formation of Illinois, Indiana and western Kentucky (Wilmarth, p. 2039) (figure 16).

The St. Louis Formation of eastern Missouri is continuous with the St. Louis Formation of Illinois, southern Indiana, Iowa, Kentucky, Tennessee, northern Alabama and southwestern Virginia (Wilmarth, 1938) (figure 16).

The Keokuk Formation of Osagean age is found in the extreme west edge of the thesis area, along the Meramec

River. Here the Keokuk is largely composed of cherty limestone which grades vertically into the Warsaw Formation. Correlating the Keokuk-Warsaw contact is difficult because of the transitional lithologic change from Keokuk to Warsaw. In the lower Warsaw there is a distinctive red chert which could be used locally as a basis for correlating. The writer visited the type localities for the Keokuk and Warsaw formations at Keokuk, Iowa, and Warsaw, Illinois. At this time the writer was unable to find the red chert which is characteristic of the lower Warsaw in the thesis area. There is a difference between the chert of the Keokuk and that of the Warsaw in the type sections. The chert of the Keokuk at the type locality is dark-gray and forms nodules concentrated in the upper portion of the formation, whereas the chert in the Warsaw is mottled buff to white and not as heavily concentrated near the contact. Within the thesis area the writer correlated the Keokuk-Warsaw contact to a section in an abandoned quarry on the south side of the Missouri-Pacific Railroad track in the SE¼, SE¼ Sec. 8, T. 44 N., R. 5 E. of the Kirkwood, Missouri, Quadrangle. There is no sharp contact between the formations in these two localities. The characteristic red chert of the basal Warsaw at the interchange, occurs in the upper part of the section exposure in the quarry, but difficulty arose in placing a definite contact between the Keokuk Formation of the Osage Series and the Meramecian Warsaw Formation (figure 15).

Locally, the lithologic units within the Salem Formation

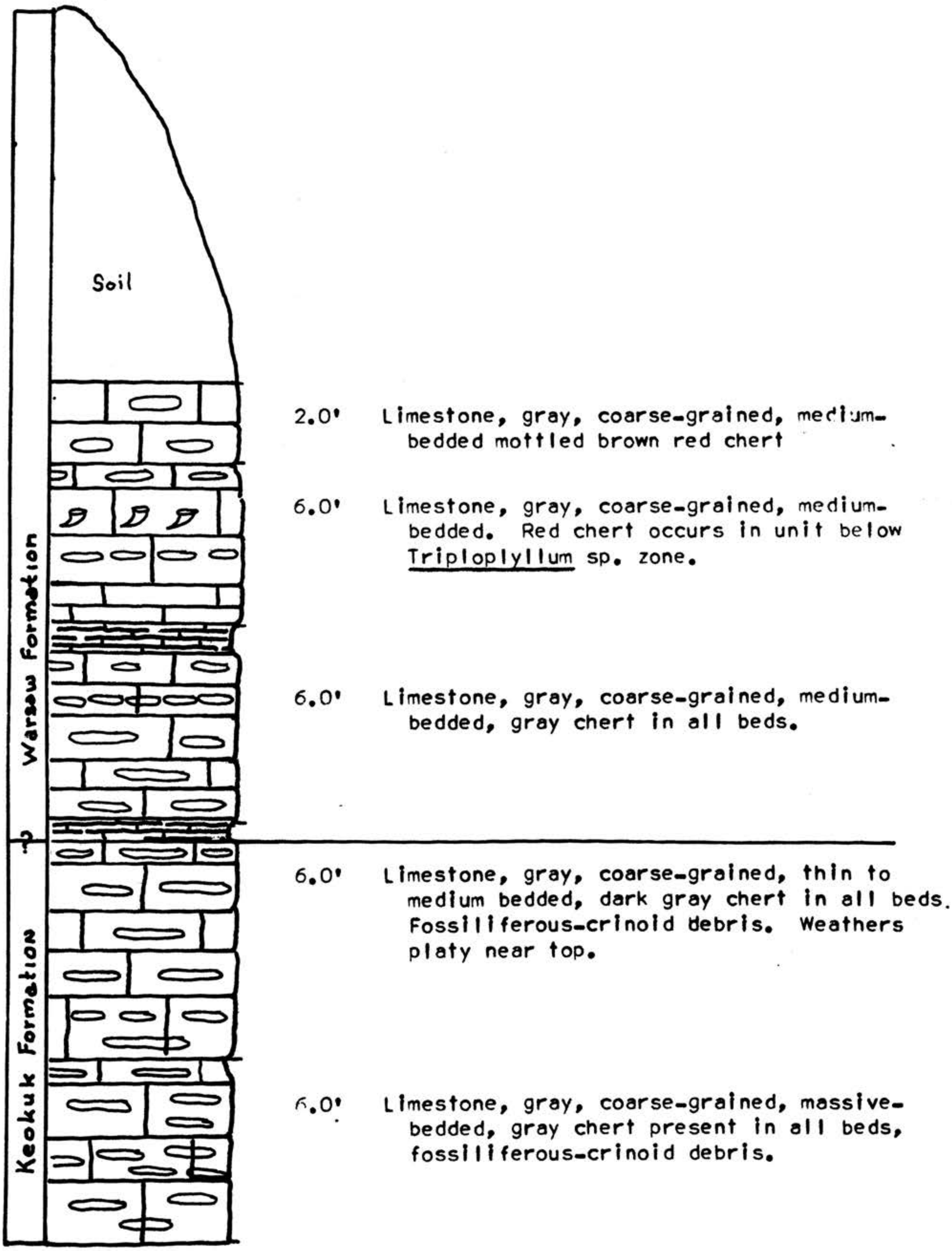


Figure 16

Section in abandoned quarry showing Keokuk-Warsaw contact. Quarry is located in the SE¼, SE¼, Sec. 8, T. 44 N., R. 5 E., Kirkwood, Missouri, Quadrangle.

can be correlated with the adjoining stratigraphic sections within the thesis area and to the Meramec Highland Quarry (figure 17). The writer was also able to correlate the sections within the interchange with sections measured by M. J. Veesaert (1952) which occur three miles north from the interchange, along Marshall Road (figure 18).

The Salem-St. Louis section exposed in the now abandoned Meramec Highlands Quarry is located in the NE¼, SE¼, sec. 10, T. 44 N., R. 5 E., Kirkwood, Missouri Quadrangle, St. Louis County, Missouri. In this quarry the Salem maintains the general appearance and lithology that is shown within the thesis area. There is a vertical variation in the thickness of the units which is shown in figure 17. This is also shown in the section measured by Veesaert (1952) (figure 18). The Salem Formation also contains a biostratigraphic zone consisting almost entirely of Camarotoechia mutata valves, approximately 35-40 feet above the Warsaw-Salem contact. This zone is fairly constant throughout the thesis area. Veesaert (1952, p. 17) also mentions this zone occurring in the sections he measured in the Creve Coeur and Chesterfield quadrangles.

Locally, the lower units in the St. Louis Formation can be correlated, based upon the characteristic lithographic limestone and breccia (figure 17). Veesaert (1952, p. 18) states: "There is an absence of lithographic limestone, so common to the St. Louis, in the Spergen (Salem) and this observation is often helpful in determining an isolated outcrop of the St. Louis." The St. Louis Formation can be correlated to adjoining sections, based almost entirely on the distinct lithologic texture of the formation. This formation is the easiest of the four formations exposed in the thesis area to correlate and recognize. Veesaert (1952, p. 18), also mentions a biostratigraphic zone consisting of Brachythyris altonensis valves occurring about fifteen feet above the Salem-St. Louis contact. This zone was not found in the thesis area, possibly due to the incomplete sections of St. Louis rocks exposed in this area. The St. Louis Formation also contains Lithostrotion proliferum which is stated to be a very distinctive fossil for this formation. Care must be taken in using this fossil alone in correlating the formations, as the same species can be found in the underlying Salem Formation.

The breccia in the St. Louis Formation is also very characteristic of this formation, but care should again be taken in using the breccia as an index for the formation as it does occur in occasionally in the upper Salem.

<table>
<tr><th>system</th><th>series</th><th>INTERCHANGE[1]</th><th>NE MO., SE IOWA[2]</th><th colspan="3">W CENTRAL ILLINOIS[3]</th><th colspan="2">INDIANA[4]</th></tr>
<tr><td rowspan="6">Mississippian</td><td rowspan="5">Meramecian</td><td>St. Louis fm.</td><td>St Louis fm.</td><td rowspan="6">Valmeyerian Series</td><td colspan="2">St. Louis fm.</td><td colspan="2">St. Louis fm.</td></tr>
<tr><td rowspan="2">Salem fm.</td><td rowspan="2">Salem fm.</td><td rowspan="2">Salem fm.</td><td>unamed</td><td colspan="2" rowspan="2">Salem fm.</td></tr>
<tr><td>Sonora fm.</td></tr>
<tr><td rowspan="2">Warsaw fm.</td><td rowspan="2">Warsaw fm.</td><td colspan="2" rowspan="2">Warsaw fm.</td><td rowspan="2">Harrodsberg</td><td>upper</td></tr>
<tr><td>lower</td></tr>
<tr><td>Osagean</td><td>Keokuk fm.</td><td>Keokuk fm.</td><td colspan="2">Keokuk fm.</td><td colspan="2">Keokuk fm.</td></tr>
</table>

1. Missouri Geol. Survey Bull. 40, 1961.
2. Missouri Geol. Survey Bull. 40, 1961.
3. Ill. Geological Survey Guidebook, Series 6, 1964.
4. Ind. Geological Survey Guidebook, No. 7, 1954.

Figure 17.

Regional correlation of Osage-Meramecian formational terms.

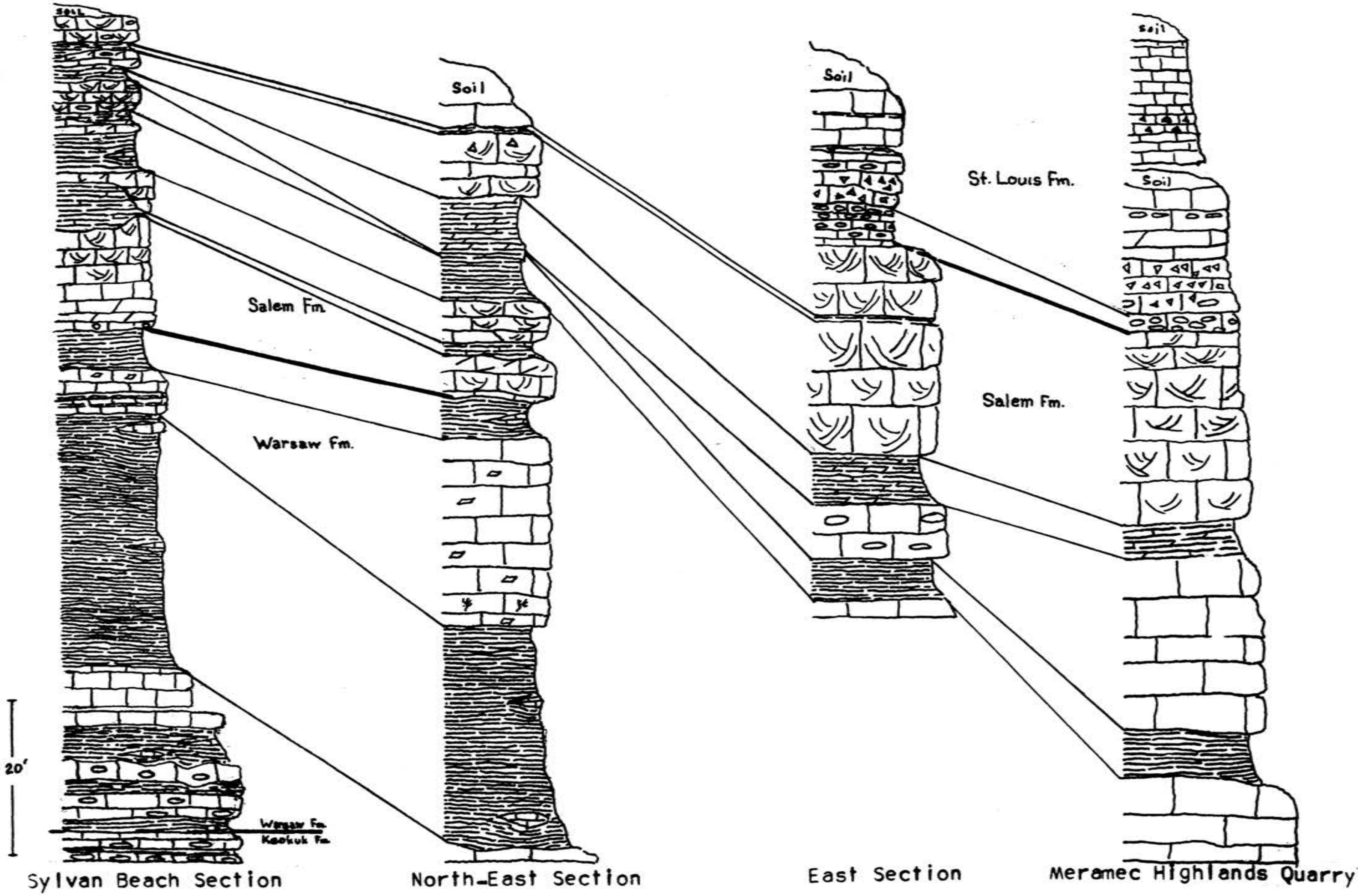


Figure 18

**Local correlation of Osage-Meramecian formations.**

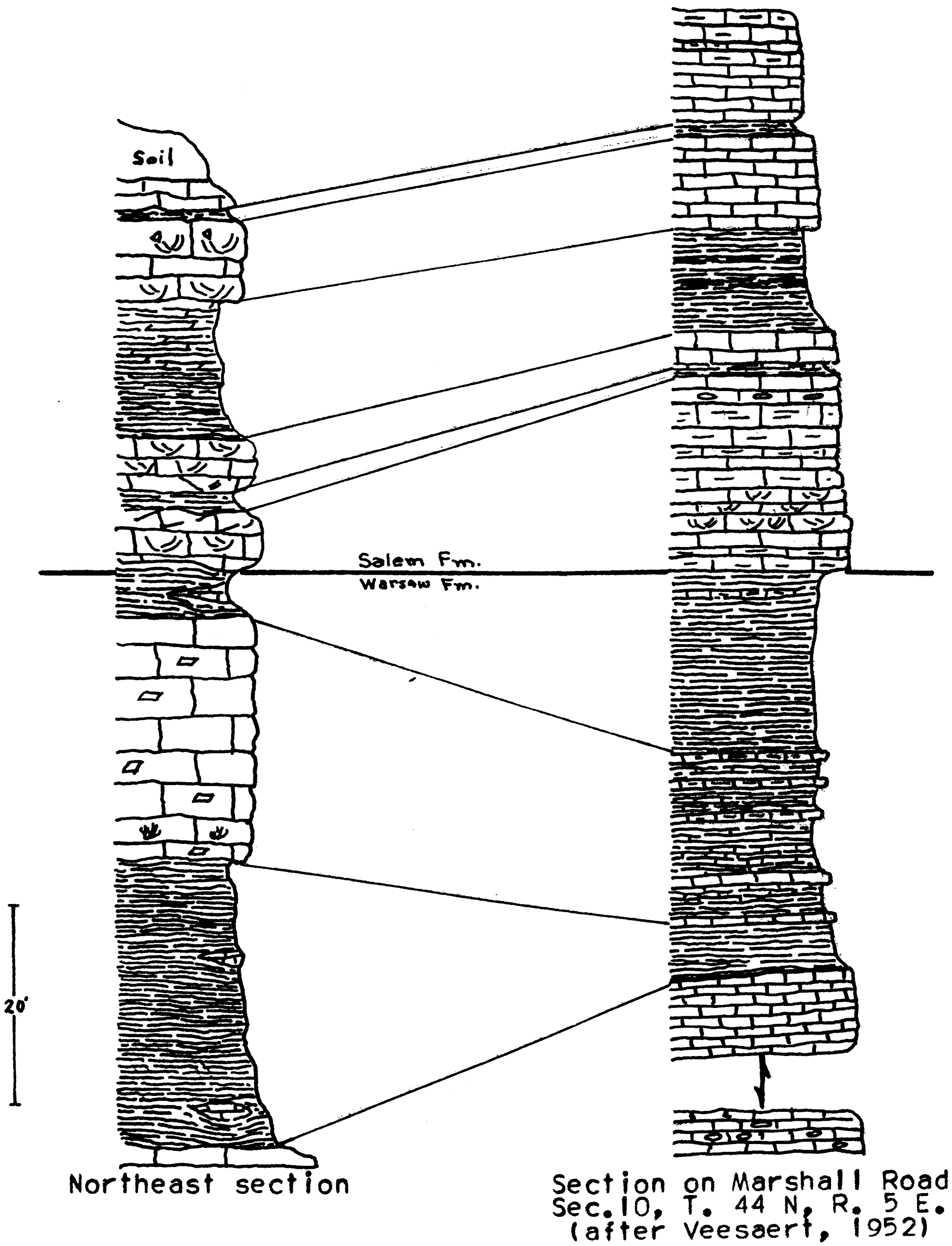


Figure 19

Local correlation of Warsaw-Salem formations.

# CHAPTER IV

# ENVIRONMENTS OF DEPOSITION

## A. Warsaw Time

All of the units composing the Meramecian Series are believed to have been deposited in a marine environment.

J. S. Williams (1957) states that the positive areas of the Appalachians to the north and east contributed sediments during Warsaw time. Warsaw seas extended over all the interchange area (Schuchert, 1955). The major positive source areas were likely a little higher and in the process of being intermittently elevated, in order to produce the alternating beds of shale and limestone in the Warsaw. Because of this, muds and clays were introduced in increasing quantities until these deposits predominanted over the calcareous material. This is shown by the thickness of shale with small interbedded limestone lenses, which comprise most of the Warsaw Formation.

Life of the Warsaw included bryozoans, brachiopods, crinoids, corals, trilobites and graptolites. Bryozoans and crinoids are very abundant. Crinoid remains are so abundant in the limestone deposited that at one time the Warsaw Formation was called the "Encrinital limestone." The life of the Warsaw seemed to flourish during times of carbonate deposition.

At certain times during deposition of the Warsaw Formation, conditions possibly were conducive for the occurrence of graptolites. Ruedemann (1947, p. 23) summarizes the conditions necessary as follows:

> "It is necessary to have stagnate, uninhabitable bottom layers with fouling of the mud by vegetable and animal matter accumulating under deoxygenated conditions, which, in general, implies lack of bottom circulation. This might occur at abyssal depths, but it seems in Lower Paleozoic times to have occurred not uncommonly in shallow, sometimes extremely shallow or lagoon-like embayments of the main ocean where bottom circulation was restricted by submarine barriers."

This seems to hold true for the horizon on which the graptolites were found. Under the conditions set forth by Ruedemann, the conditions conducive for graptolitic shales contain associated forms only as rare, biotic elements of the shale. In association with the graptolites are some bryozoan fragments. The fragments seem to have been replaced by iron sulphides, which also will form under deoxygenated conditions. Aside from the few fragments of bryozoans found associated with the graptolites, no other forms of life were evident in this horizon (figure 3).

There is some possibility that during the times of carbonate deposition in the Warsaw Formation, there were slight currents active. In the limestones, the fossils are cemented together with sparry calcite. This would indicate that these currents carried off some of the muds, and at a later, post-depositional time, the secondary calcite was introduced, cementing the fragments together. Most of the fossils are fragmental; this would indicate some movement necessary to break them up. The fossil fragments are angular and not worn, which would seem to eliminate the possibility of their being transported from any great distance or greatly agitated. It is possible for them to have been transported in a marine environment without having been abraided. It is likely that during the times in which no muds were being deposited, life flourished in the seas, and then during rapid increase of sedimentation, brought about by a rise of the source area, the various forms of life were smothered by the increase of sediments being deposited. Then it is likely that scavengers and fish broke up the organisms in the search of food. Evidence for this is the presence of some shark teeth and a fossil fish found in the Warsaw Formation.

In general the Warsaw seas were muddy, due to the ever present supply of clays and muds. During certain times, sedimentation of the muds must have decreased, providing optimum conditions for life. This would suggest warm, shallow waters of normal salinity, and a plentiful supply of lime.

B. Salem Time

At the beginning of the Salem time the land mass to the north was probably depressed and the removal of this source of mud and clays once again restored conditions conducive to the deposition of predominantly calcareous material. Shifts in the shoreline are recorded in the stratigraphic record as alternate changes from relatively pure limestone strata to argillaceous limestone strata. This may, however, be due to a greater influx of clays and muds during the carbonate deposition.

The Salem sea floor was evidently shallow to emergent, possibly a restricted sea. The presence of evaporites in the Meramecian Series about 100 miles north of the thesis area gives evidence for this (Sloss et al., 1960, p. 30). This also is supported by the cross-bedding and ripple marks which are conspicuous in the limestones of the formation. The presence of broken and rounded fossils gives evidence of re-working, possibly due to the wave action of the shallow sea.

In the Salem Formation there is a slight increase of pore space within the dolomite units. The origin of dolomite and dolomitic limestones is not clear. There is the possibility that much of the dolomite in the Salem is secondary in origin. Pettijohn (1957, p. 424) states "dolomite replacement appears to have been nearly volume for volume rather than molecule for molecule. The latter requires an over-all reduction in volume in the ratio of 100 to 88, with consequent increase in porosity." This would indicate that the dolomite in the Salem Formation is of secondary origin.

Another fact which would indicate secondary replacement is that many of the dolomitic beds are not laterally continuous, which would seem to support this origin. Although there are dolomite beds in the Salem which seem to be secondary, the origin of these beds is not clear.

The chert found toward the top of the Salem Formation possibly was colloidal silica precipitated at the close of Salem time.

C. St. Louis Time

The sedimentary record between Salem and St. Louis time is unbroken. At the beginning of St. Louis time the area was submerged and conditions were essentially the same as those which prevailed at the close of the Salem time.

During intervals of the St. Louis time certain conditions caused the accumulation of calcareous material that eventually gave rise to beds of lithographic limestone. One commonly quoted theory of the origin of the lithographic beds was proposed by Fenneman (1911, pp. 41-42). He feels that the beds were derived from fine calcareous material that was carried in suspension. This material was supposedly separated from coarser calcareous sediments when in nearby areas, portions of the sea bottom emerged slightly. It is also possible that these lime muds were precipitated by chemical processes.

Plumley, *et al*. (1960) classifies the non-fossiliferous lime muds as the extreme case of minimum water agitation. They are characterized by lack of recognizable clastic particles. This is true for the St. Louis Formation as the formation is characterized by the presence of lithographic limestone (microcrystalline calcite). There is evidence that at times there must have been a break in the general quiescent conditions of deposition.

There are occasional argillaceous beds found in the St. Louis Formation that indicate that mud was periodically carried into the sea. Generally, during the deposition of the formation, the sea was clear and free from muds.

Some of the beds in the St. Louis Formation exhibit concentric laminations on weathered surfaces. In examining the structures in thin section, it is possible that this may be of organic origin, possibly algal growths.

Most of the breccias of the St. Louis Formation are composed of phenoclasts of lithographic limestone and a matrix of coarser limestone. A full discussion of the many theories of origin of these rocks is far beyond the scope of this report. Various theories of origin of these rocks hold that the breccias represent subareal erosion caused by emergence (Grawe, 1923, p. 59), sliding of unconsolidated sediments on the sea floor (Rich, 1951, p. 14) and in association with minor folding of the area (Van Tuyl, 1916, p. 22).

In general, the St. Louis seas were quiet, allowing normal deposition of lime muds. There is also the possibility that due to the shallow water conditions and moderate temperatures, the lithographic limestones could have precipitated from the St. Louis seas.

The breccia in the limestone seems to indicate that the general quiescent conditions of sedimentation were occasionally interrupted. The sea of the St. Louis time was also probably very clear, thus allowing light to be transmitted to greater depths permitting the growth of algae.

# CHAPTER V

# ENGINEERING GEOLOGY

In considering the geological engineering problems of the Interstate 244, 44 interchange, the writer consulted with Mr. Gerald Wallace, the highway department geologist of District 6, Kirkwood, Missouri. In talking to Mr. Wallace he pointed out the major engineering problems of the area.

In the preliminary core drilling, several shale layers were encountered in the Salem Formation which would be exposed during excavation of the interchange system. The highway department recommended twelve-foot benches on top of these layers to prevent undercutting and slumping of the limestones above onto the highway.

Another problem affecting the highway system was in the southwestern quadrant. In this area is an old landslide that extended from what is now approximately the south end of the crib type retaining wall, east 300 feet to the bottom of the Meramec River flood plain. The slippage surface was in the upper Warsaw shale and clay. Similar conditions at the top of the backslope prompted the recommendation for the aforementioned retaining wall.

Between old Route 66, Interstate 244, and Geyer Road, there was a problem of the fill material slipping on the Salem shale underlying the fill. It is not known to the writer how this was remedied.

In placing the footings for the Interstate 244 overpass, it was necessary to drill through the lower Warsaw Formation into the upper Keokuk Formation in order to place them on bedrock.

Sink structures were not encountered during the excavation of the interchange.

Most of the surface run-off was channelled underground into drainage tile and this eventually empties into the Meramec River, west of the interchange.

These were the major geological engineering problems within the area under study.

# CHAPTER VI

## SUMMARY

The geology of Interstate Highways 44 and 244 intersection was studied extensively during the summer of 1964. At this time due to construction in the area, numerous artificial exposures were excavated. This provided an excellent opportunity for examining fresh exposures of sediments of Mississippian age and of the Meramecian Series within the type area. The paleontology, petrology, and environmental conditions of deposition of the Warsaw, Salem, and St. Louis formations were studied. A geologic map of the interchange area was also prepared at this time. The field study involved a study of the exposures, collection of specimens and mapping of contacts. These results are presented in Chapter III of the thesis. Difficulty arose in correlating the formations, due to thickening and thinning of the units.

The contact of the Osagean and Meramecian Series was studied, as well as the contacts of the Warsaw, Salem and St. Louis formations. In all cases the lithologies of the formations were gradational and contacts were placed arbitrarily.

The microscopic study was made from thirty-three thin sections made from lithologic samples taken from the area. These studies aided in describing the lithology of the various formations within the Meramecian Series, and lent information dealing with the environment of deposition during the Meramecian time.

The Meramecian Series was deposited during moderately shallow water conditions. There were large quantities of clay and mud being introduced into the Warsaw sea, as indicated by the prominence of shales in the Warsaw Formation. There were intervals during this time when the muds were not dominate, which allowed for carbonate deposition.

The Salem Formation was deposited under shallow water conditions as shown by the prominence of cross-bedding and current ripple marks.

In general, the carbonates of the St. Louis Formation are very fine-grained limestones (micrites), typical of the formation in the area. It is inferred that the limestone was deposited as a lime mud under quiet water conditions.

The presence of intraformational breccia throughout the St. Louis Formation indicates that general quiescent conditions of sedimentation were sporadically interrupted. The occurrence of algal colonies in the formation would indicate moderate, shallow water conditions.

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