THE STRATIGRAPHY OF THE ORDOVICIAN GALENA DOLOMITE IN SOUTHWESTERN WISCONSIN

by

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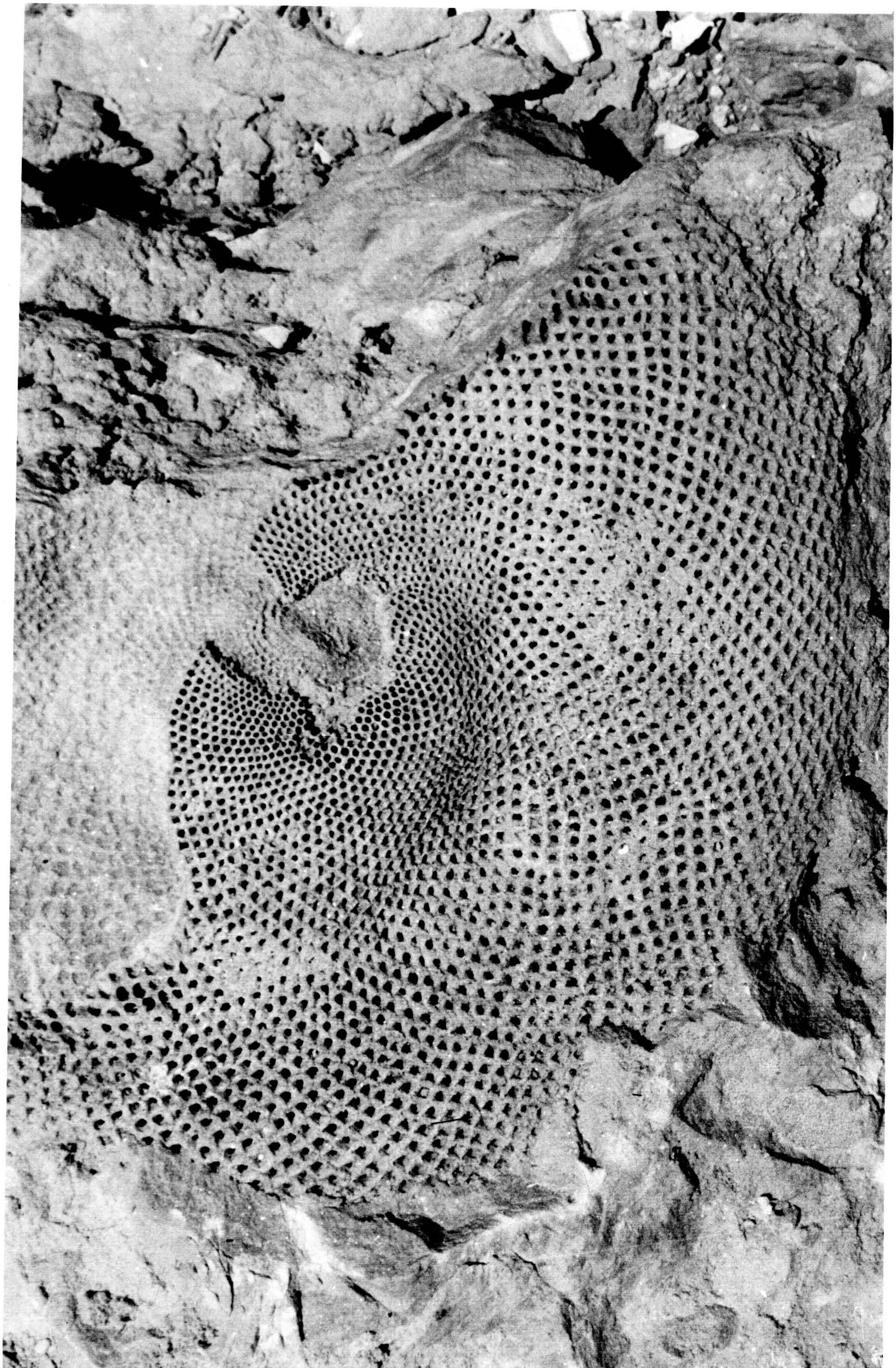

INTRODUCTION

The Galena formation has been examined in Wisconsin by many previous workers mainly in so far as it is related to the mining of lead and zinc in the upper Mississippi River area. In the actual mining region itself, the Galena formation has been studied in almost every mine. However, the geologic emphasis was placed on the origin of the lead and zinc ores, or on listing criteria for prospecting for new mineralized zones. Geologic maps of individual counties were drawn later, but the Galena was not separately mapped and no detailed discriptions were presented of it. It has only been in the last twenty years that any attempt has been made to make a detailed stratigraphic study of the Galena formation with adequate coverage outside its mineralized areas.

During the last few years, excellent papers have been written concerning the Galena in northwestern Illinois and southeastern Minnesota. The stratigraphy and paleontology of the Galena formation and its three recognized members were presented. In both reports the formation was adequately subdivided on the basis of lithologic and paleontologic zones. Although good stratigraphic control was achieved in their respective localities. The two classifications could not be successfully used in adjacent areas. It is because of this lack of correlation in the intervening area between Minnesota and Illinois, that this study of the Wisconsin Galena dolomite section was undertaken.

In the spring of 1957 reconnaissance sections were studied in southeastern Minnesota, Iowa and northwestern Illinois so as to gather background information. Both lateral and vertical variations of the Galena formation were closely checked. The type localities were checked during this time and all criteria for identifying the Prosser, Stewartville and Dubuque members were listed.

It became readily apparent by the end of this reconnaissance period that although the formation was of nearly constant lithology vertically, it was greatly variable laterally. It was therefore felt that the Minnesota and Illinois sections could be correlated if the intervening area and its formational variants were mapped and classified.

With these problems in mind, it is the purpose of this research to study the Galena formation in southwestern Wisconsin in hopes of: (1) Discribing the geologic variants of the Galena formation within the state of Wisconsin. (2) Using these variations for stratigraphic control within the state. (3) Correlating the Wisconsin section with those of Minnesota and Illinois allowing stratigraphic control over the entire outcrop belt of the Galena formation.

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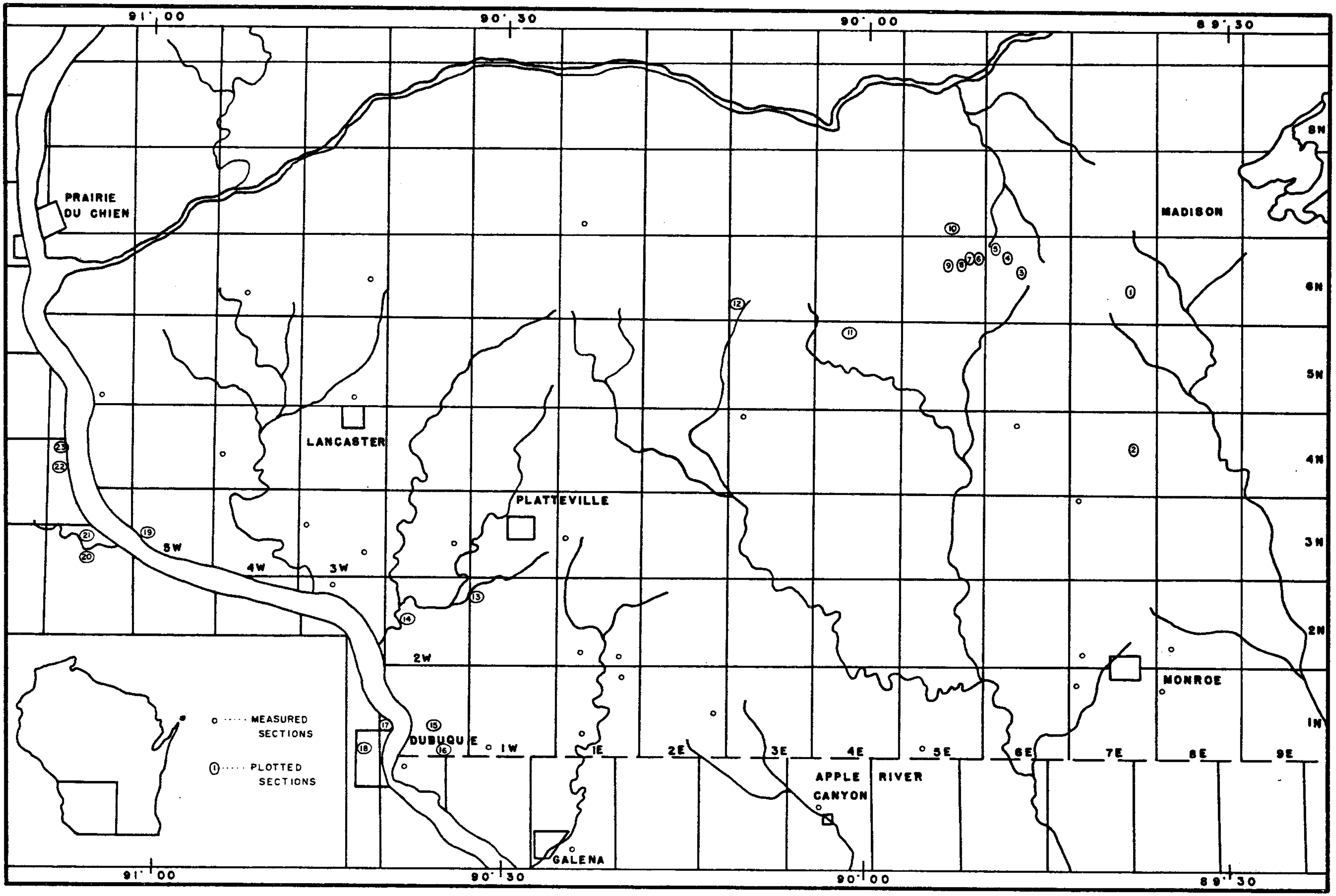
FIELD AND LABORATORY PROCEDURE

During the spring semesters of 1957 and 1058, detailed studies were made of the Galena rocks and their adjacent formations. The majority of the sections studied were in quarries and road cuts, whos localities are listed later in this report. Previous to the study of sections in Wisconsin, it was felt necessary to visit the type sections and examine many reconnaissance sections. The information gained by studying exposures outside this thesis area proved invaluable in later work.

All sections were measured with a steel tape to the nearest fraction of an inch. Samples, both typical and unusual, were collected and detailed notes were made of the lithology, color, texture, weathering characteristics and fauna changes. Each sample was carefully marked for later stratigraphic correlations. Only by this detailed bed for bed examination could knowledge of the individual members in the Galena formation, be gained.

Preliminary field identifications by a 10X hand lens and hydrochloric acid were more carefully varified in the laboratory. All samples were first studied under the binocular microscope and all macrofossils were identified. Insoluble residue studies were then made with the information graphed and plotted. The insoluble materials were checked by both petrologic and X-ray procedures. Additional samples were etched in hydrochloric acid and stained by potassium ferricynide to differentiate the limestone from the dolomite. Many of the cherts and selected samples were cut into thin sections and again examined under the binocular microscope.

All sections studied in the field were recorded in detail, starting at the base of the outcrop. These notes were later plotted into lithologic logs for faster and more accurate correlation. A scale of one inch to ten feet was used for these logs.



Location Map

PREVIOUS WORK AND NOMENCLATURE

The previous work to be analyzed in this thesis will cover all phases of the Galena formation. Unfortunately many of the earlier papers deal with mining possibilities within the formation and are of little value in this report. Written material pertaining strictly to the state of Wisconsin are few, and discribe the Galena formation only in a vague generalities. Therefore, most of the following summaries are in reference to other states but their conclusions must be studied before the Wisconsin section can be understood.

The previous work, to follow, will be placed into two large groups, i.e. Wisconsin literature and Related literature. All work under these divisions will be treated on a chronologic basis.

Wisconsin Literature

The majority of the work concerning Wisconsin is in reports on local quadrangles or from authors working in adjacent states. Only the more recent publications have been of value to this report.

Carter (1910), using both the Galena and Decorah formations as one unit, discribed their average thickness in Wisconsin as being 250' thick. A regional but "obscure" unconformity was also placed at the contact of the Maquoketa and Galena formations.

Studying well cores of Wisconsin, Thwaites (1923) used the Galena-Trenton formation as the datum for his structural geology maps. Mention was also made of finding the Minnesota Prosser member equivalents (Ulrich, 1911) in Wisconsin. Chase (1929) discribes very generally the lithologies of the Prosser, Stewartville and Dubuque members in Wisconsin as well as graphing several cross-sections across the state.

Fosshage (1934), gives an excellent faunal list of fossils from the

New Glarus Quadrangle. Insoluble residue studies were also made in this area but were not used in the report.

Berkeley (1939) measured 180' of Galena formation in the Monroe Township, but was unable to identify any of its members in the field. Schiesser (1946), working in the South Wayne quadrangle, measured 80'-140' of Galena rocks and proposed an unconformity between it and the underlying Decorah formation. Proof for this unconformity was based on sections where their contacts were at the level of the present soil zone. These fragments of Galena rock mixed with soil suggests very strongly an origin by the presently operating erosional agents.

Kay (1932) also placed a local disconformity at the Galena-Decorah contact in the area of Grant County. His proof was based on a "red arenaceous shale zone" at the base of the Prosser member. He also (1935) states that no Dubuque member equivalent is found in Wisconsin.

The annual Tri-State Geologic Field Conference Reports (1948, 1952, 1956) give excellent outcrop localities and occasional graphs of sections. Detailed discriptions or discussions of the Galena formation are not included in any of these reports. The Kansas Geologic Society Guidebook (1935) also gives this same type of information. Excellent sections shown in these reports allow rapid reconnaissance of the variations within the Galena formation.

By far the most important work done on the Galena rocks of Wisconsin is in the report by Agnew (1956). His subdivisions of the Galena formation are planned for use in well core identifications. The Galena formation is first divided into a "cherty zone" and a "noncherty zone". Further subdivisions were made into seven units, which were correlated on relative amounts of chert and bedding characteristics. It was also shown that the base of the Prosser member becomes more shaly and less cherty as it is traced into southern Minnesota, and that the Galena formation changes from dolomite to limestone north of the Wisconsin River. Using paleontologic evidence, the Stewartville member is correlated with the Trenton age and the Dubuque member to Richmond age. A disconformity is placed between these two members on this basis. The unconformity placed at the base of the Prosser (Kay, 1932) is discribed as an error in geologic interpretation and incorrect.

Related Literature

The first geological report concerning the Galena formation of the upper Mississippi Valley is by D. D. Owen (1844). During his investigations of this area he refers to the upper Magnesian limestone from which lead is being mined. This formation presently would include all formations between the Maquoketa shale and the St. Peter sandstone. A report by Locke (1842) was also included in Owens' paper and listed many fossils from this formation. Conrad (1844) discribed this fauna collection as having Trenton affinities.

James Hall (1851) was the first to call the Galena formation by its present name. From a trip through the lead region in 1841 Hall proposed the name "Galena" for the lead bearing dolomitic rock near the town of Galena Illinois, and placed it as Niagran in age.

In an Iowa paper, Winchell (1895), discribed the Galena formation as being "a phase of the Trenton, intensified in this area and fading out in all directions." Using paleontologic evidence, Winchell refutes Wallcotts' (1879) correlation of the Utica shale in New York to the Silurian, Maquoketa-Galena formation of the upper Mississippi River area.

Calvin and Bain (1899) after their studies in Dubuque County, Iowa, concluded that the Galena rocks were not in themselves a true stratigraphic formation, but only a dolomitized portion of the upper Trenton. This idea, later supported by many other Iowa geologists, was based on the increasing vertical separation between the green shales (Decorah) and the base of the Prosser member as it is traced into Minnesota. Evidence of the *Receptaculites* zone crossing from Galena into Trenton rocks was suggested but no localities for observation were listed. There has been no other geologist since Calvin and Bain to prove or suggest this idea. This report is also the first to give a detailed discription of the total Galena section. Special reference was made to a "Cap Rock" lying immediately above the upper *Receptaculites* zone (Stewartville member). The cap rock is a very dense two and a half foot bed of dolomite. A gastropod zone was also noted as lying 80' to 100' below the Maquoketa and Galena contact.

Savage (1902) referring to the report of Calvin and Bain (1899) discribed all the Galena formation lying above the chert zone. He is also one of the first geologists not to place the Decorah rocks as part of the Galena formation. Calvin in this same year (1902) discribed the normally dolomitic Galena formation as being limestone in northeastern Iowa and strongly resembling the Niagran limestones of the southern part of the state. The upper *Receptaculites* zone was placed 60' below the Maquoketa contact and a gastropod zone placed 20' below this.

Studying the geology of northwestern Illinois, Calvin (1905) presents an excellent paleontologic zonation of the Galena formation. The following are the faunal zones and their heights above the base of the Galena: lower *Receptaculites* -- 60'; *Ischcadites* -- 110'; small gastropod -- 145'; upper *Receptaculites* --160'; large gastropod -- 170'; and the top of the Galena formation at 225'. Unfortunately, Calvin concluded at the end of the report that the fossils in the Galena are found in colonies, not zones.

One of the most important reports dealing with the paleontologic aspects of the Galena and its correlatives was presented by Ulrich (1924) on the Kimmswick of Illinois. Fifty-two genera and 45 species of fossils were found to be common to both the Kimmswick and the Prosser. Ulrich and Scott (1933) correlate a large gastropod zone near the top of the Prosser with the base of the McCune limestone of Missouri. The top of the Kimmswick was also correlated to the Fusispira zone lying midway in the Prosser member. Interpreting the migration paths of the fossils common to both the Kimmswick and Prosser, Ulrich suggests that although they are of the same age the fossils of each formation originated in different faunal provinces. That is, the fauna assemblage of the Prosser formation shows affinities to a northern or Russian province while the Kimmswick shows eastern or Appalachian affinities. It is also concluded that the depositional basins of each formation were never interconnected.

Knappen (1926) reporting on the geology of Illinois, says that correlation within individual members of the Galena formation is impossible due to uniform lateral and vertical lithologies. An average thickness of 150' is given for the Galena rocks in this area as well as an excellent fauna list. Commenting on the geologic history, he visualizes the Galena as being a continuation of the Platteville sea with extremely uniform conditions over all of Galena time.

Stauffer and Thiel (1932-1933) found that the base of the Prosser became more argillaceous and its basal contact less defined when traced from Fillmore County, Minnesota, northward. It was also found that in southern Minnesota that the Prosser member was limestone while the overlying Stewartville member (Ulrich, 1911) was dolomite. No mention of a Dubuque member (Sardeson, 1907) was made, however, discriptions of the "Transition beds" (Sardeson, 1887) at the base of the Maquoketa shale were surprisingly similar to what might be expected if this member were present.

The best report on the paleontology of the Galena formation was written by Kay (1935). Using fossils, Kay, correlates the Minnesota Dubuque member (transition beds) with the Collingwood of Michigan, the Stewartville with the upper Cobourg and the Prosser with the Sherman Falls and Hull formations. An unconformity was also placed between the Dubuque member and the Maquoketa shale. Excellent classification are presented for each of the three members as well as thickness variations over southern Minnesota.

Reporting on the taxonomy of the Galena dolomite, Keyes and Sardeson (1937) proposed that the original naming of the Galena, by Hall (1851), was not formally correct. They then suggest that the name Charette limestone (Broadhead, 1860) be used in place of Galena, Kimmswick or Receptaculites limestone (Shumard, 1873) for future stratigraphy in this area.

Du Bois (1945) doing subsurface geology accounts for the disappearance of the Stewartville and Dubuque members as well as the thinning of the Prosser in southern Illinois, by a large regional unconformity at the base of the Maquoketa shale. Using electric logs and the fossil identifications by Bays, correlation is made of the Stewartville to the McCune limestone and the Prosser to the Kimmswick.

Willman and Reynolds (1947) also working in Illinois give excellent discriptions of the Galena formation. The thickness of the Dubuque member was measured at 45' with its base being defined as the lowest shale parting. The 35' of Stewartville was found to have at its base the upper Receptaculites zone and to be generally, massively bedded. The Prosser member was differentiated into 40' of noncherty dolomite, followed by 100' of cherty dolomite and the basal contact. The best structural horizons were placed at the top and base of the chert zone, respectively 100' and 8' above the base of the Prosser. A persistant

2" shale bed lying 15' above the top of the chert zone was discribed as possibly having a bentonitic character.

An important abstract prepared by Weiss (1953) on Fillmore County, Minnesota, makes several important sedimentation observations within the Galena formation. Cyclic limestone and shale beds were noted at the base of the Prosser and a corrosion zone was discribed at the top of the member. The Stewartville was found to be dolomitic and having a felthpathized shale at its base. Interbedded limestones and shales were discribed as being the dominant lithology of the Dubuque member with some of the shales being felthpathized. The felthpathized shale was interpreted as bentonite. Because of the difficulty of several authors (Agnew, 1956; Nelson, 1922;, Willman, 1947) in identifying these shales as true bentonite, it is felt by this author, that they are using the term with a metabentonite conotation.

Agnew, (1955) gives an excellent discription of lithologic changes in the Galena of Iowa. This report is one of the few to study this formation in the subsurface. Thicknesses were shown to vary from 230' in the northeast to 130' in the southeast and 100' in the southwestern parts of Iowa. None of the three formational members were identifiable in the subsurface and the basal contact became obscure and known as the "False Decorah" in southwestern Iowa. The basal portion of the Prosser was found to have slight amounts of sand in southwestern Iowa, and incorperating one half of the total formation in the northwest. A regional unconformity with the Maquoketa shale is common over the entire state. Phosphatic pebbles at the base of the Prosser in southwestern Iowa suggests another unconformity.

BLUE / GREY / DRAB / BUFF SHALE / FLINT / SANDY	LOCAL TERMINOLOGY
UPPER MAGNESIAN LIMESTONE ★ / ARENACEOUS, CHERT / ARENACEOUS	D. D. OWEN 1839
NIAGARAN	W. O. LOCKE 1840
★ / GALENA	J. HALL 1851
BLUE LS. / FLINT-BEARING LS. / ARENACEOUS LS. / CAP ROCK	J. V. PHILLIPS 1854
GALENA – TRENTON	W.H. NORTON 1897
★ / TRANSITION BED SIL.	F.W. SARDESON 1897
DECORAH FM / GALENA STAGE GALENA LIMESTONE	S. CALVIN 1906
DECORAH FM. / JULIAN FORMATION	C. KEYES 1922
★ / GALENA FORMATION GALENA DOLOMITE	G. M. KAY 1929
DECORAH FM / GALENA GROUP PROSSER FORMATION / STEWARTVILLE FM. / DUBUQUE FM.	G. M. KAY 1939
DECORAH FM / GALENA DOLOMITE PROSSER MEMBER / STEWARTVILLE MBR / DUBUQUE MBR.	A. F. AGNEW 1950
DECORAH FM / CHERTY UNIT: D / C / B / A NONCHERTY UNIT: P / STEWARTVILLE / DUBUQUE	A. F. AGNEW 1956

Taxonomy of the Galena Formation

STRATIGRAPHIC NOMENCLATURE

The Galena dolomite, formally named by James Hall (1851, p. 146) was discribed as a grey to drab, friable, thick bedded dolomite, being extremely vuggy and cherty in parts. The true vertical extent and definition of its contacts was not discribed in the original paper and writters since then have placed its limits at variable points. Subdivision of the Galena has also progressed in varying degrees, depending on the state in which the unit was being studied and to what use, commercially or academically, the classification was to be used. The subdivisions used in adjacent states, were largely made possible by the increase in argillaceous material and consequent better fossil preservation south and west from the Wisconsin arch.

In the area discribed in this thesis, neither the Illinois divisions, based on lithologic differences, or the Minnesota divisions, discribed largely on faunal distribution can be used. Rather, it appears more desirable to combine favorable portions of each where they can be applied. The term Galena dolomite will be used with the stratigraphic time-rock value of a formation and will pertain to the dolomitic sedimentaries lying between the top of the Ion member of the Platteville formation and the base of the Maquoketa shale. The divisions Prosser, Stewartville and Dubuque members will be recognized and subdivision of the Prosser member into five units will be suggested.

DEFINITION OF CONTACTS

Prosser member

The Prosser member of the Galena dolomite was described by Ulrich (1911, p. 257), from its type section at Prosser Ravine, Wykoff, Minnesota, as a medium to coarse grained, medium to massively bedded dolomite, with abundant chert nodules and bands. The basal contact was placed at the bottom of the *Nematopora* bed (Ulrich and Winchell, 1897, p. 83) and the upper contact at the top of the *Fusispira* bed (Ulrich and Winchell, 1897, p. 83). Agnew (1956, p. 295) placed the base of the Prosser member in the lead-zinc district at the top of the *Prasopora* zone. This zone is reported to extend from East Dubuque Illinois to Rockford, Illinois (Templeton and Willman, 1952, p. 17). However, it was not found in the Wisconsin section except in the extreme southwestern part of the state and could not be used. In field studies, the Ion and Prosser members were found to grade transitionally into each other as they were traced toward the Wisconsin arch. The fauna assemblages, that are present, are sparse, thus making lithologic gradations the only practical means of separation. This lithologic transition covers a three to five foot interval where the typical grey, argillaceous dolomite of the Ion member fades into the non-argillaceous, buff dolomite of the basal Prosser. Separation of the Prosser was therefore placed at the last visible evidence of non-argillaceous dolomite, and all lower argillaceous beds were placed in the Ion member of the Decorah shale.

Lower noncherty unit--The lower noncherty unit is a four to ten foot, buff to tan dolomitic sequence of rocks. It is defined at its base by the basal contact of the Prosser, and at its top by the first indication of chert nodules or chert beds.

Lower cherty unit--Overlying the lower noncherty unit is a ten to fifteen foot unit of dolomite, characterized by abundant chert beds and nodules. Its base is identified by the "Base of Chert" (Agnew, 1956, p. 217). This horizon extends with excellent lateral continuity and is used by many stratigraphers as a datum for mapping. The upper contact is placed where the chert becomes sparse and the fossil *Receptaculites* becomes abundant.

Lower Receptaculites unit--Immediately above the lower cherty unit is a 15' section of rock containing numerous molds of the fossil Receptaculites. It is normally a thick bedded, sparsely cherty, tan to buff dolomite. The upper contact is based on the re-appearance of chert beds and chert nodes and the gradual decrease of Receptaculites.

Upper cherty unit--The upper cherty unit consists of interbedded, massive to medium, cherty to non-cherty, tan dolomitic rock. The upper contact is defined by the "Top of Chert" (Agnew, 1956, p.297) and is the second horizon used for a datum on geologic maps. The last visible bed containing chert is classified as the top of the upper cherty unit.

Upper noncherty unit--The upper most unit in the Prosser member is a sequence of yellow to buff, massive to medium bedded, noncherty, sandy dolomitic rocks. Although locally rich in gastropod fauna, no zoneation based on fauna such as in the lower Receptaculites unit is possible in this thesis area. The basal contact is placed at the top of the chert and the upper contact of the upper noncherty unit (top of Prosser member) is placed at the lowest bed containing Receptaculites.

Stewartville member

The contact of the Stewartville and Prosser members has been held in disagreement between many authors for several years. Ulrich (1911, p. 27) discribed the base of the Stewartville, in Minnesota, as the last evidence of the Maclurea zone (Ulrich and Winchell, 1897, p. 83). In the Wisconsin sections this faunal zone could not be accurately identified due to a sparse fauna population. The base of the Stewartville was therefore placed at the lowest bedding plane, above which abundant Receptaculites are found (Kay, 1935, p. 565). This method of defining a contact is felt to be exceedingly unreliable because the Receptaculites are found throughout all of the Galena formation, and in several localities the base of the Stewartville contains almost no Receptaculites. As there is no lithologic break between these two members in the WIsconsin area, the means of separation would be more ideal if defined at the top of the upper cherty unit. (Locally in the southwestern portions of Wisconsin, a two to four inch argillaceous zone is found at the contact of these two members.)

Dubuque member

The first discription of the Dubuque member was published by Sardeson, (1907, p. 193) from its type section at Dubuque, Iowa. It is discribed as a light grey to buff, fine grained, thin bedded dolomite with abundant shale partings. The basal and upper contacts were exceedingly difficult to locate in the Wisconsin area. What few outliers do exist are usually capped by the Maquoketa shale and the talus derived from the Maquoketa normally covers both contacts. The base of the Dubuque member, when found, was placed at the lower most indication of shale partings (Agnew, 1955, p. 172). The upper contact (top of Galena dolomite) was not found exposed in the Wisconsin area, but in other states it is placed at the base of the Depauperate zone of the Maquoketa shale (Agnew, 1956, p. 300).

LITHOLOGY

The lithology of the Galena dolomite is in nearly all respects similar throughout all three members. This constant lithology both vertically and laterally, as compared with the more typical argillaceous beds present in Minnesota and Illinois prevents any detailed subdivisions of the Galena dolomite in this state. In many sections the variation is between cherty and noncherty beds, or on relative abundance of Receptaculites and shale partings. Generally, the Galena dolomite is extensively mottled in the Prosser and Stewartville members as yellow sandy pods inveloped in a matrix of more dense, tan dolomite. This mottling is due primarily to differential ground water solution allowing the larger dolomite crystals to remain as the yellow sand. Beals (1953, p. 292) suggested that mottling is due to redistribution of magnesium by ground water. The localization of the pods is due to the supply of magnesium finally becoming exhausted. Throughout all of the Galena, but primarily in the basal portions of the Prosser, scattered nodules and beds of pyrite and marcasite are found. Usually these minerals are replaced as pseudomorphs of limonite. No correlation between sections on this basis was possible. Calcite nodules are found interbedded with the dolomite and locally carbonate coatings are found on the faces of exposures, where ground water intersects the surface. Thin, one to six inch argillaceous beds are also found throughout the Galena dolomite, however, no lateral continuity was indicated. A bentonitic origin has been stated for many of these argillaceous beds by Weiss and Bell (1956, p. 70). The argillaceous zones found in the Wisconsin area do not correlate with these mentioned bentonites, nor do they show any concentrations of montmorillonite, suggesting volcanic origin. The weathering characteristics of the Galena dolomite produce an exceedingly vuggy and porous rock. Normally tan to buff in a fresh sample, the dolomite becomes light yellow upon weathering. The large rhombohedral crystals of dolomite are released as a yellow sand, which is the characteristic outcrop expression.

Occasionally, very dense, pure dolomite on limestone zones are encountered (plate 1). These zones strongly resemble sandstone in textural characteristics, however, laboratory examination shows them to be composed entirely of fine grains of calcite in dolomite.

Chert beds and nodules also weather rapidly on exposure to the atmosphere. Although porcelaneous to granular in the fresh sample, they become exceedingly chalky and soft after several years of weathering. Bedding in the Galena dolomite ranges from massive to very fine. Agnew (1956, p. 268) used this variation in bedding as one of the main criteria for subdividing the formation. It was noted, however, that the bedding characteristics of this dolomite are more closely associated to the amount of ground water penetration, and amount of cover, than it is to the inherent lithologic variations.

Some limestone units are seen in the extreme southwestern portions of the state, and a limestone-dolomite contact has been shown to extend from Patch Grove, Wisconsin to Guttenberg, Iowa, (Kay and Atwater, 1935, p. 102). This contact gradually climbs up through the Galena section as it is traced northwestward into Minnesota and Iowa. Bell and Weiss (1953, p. 69) have discribed cyclic sedimentation, as well as corrosion zones, in the Prosser member of Minnesota, however, no indication of such features was found in Wisconsin.

Lower noncherty unit

The basal part of the Prosser member was found to contain a four to ten fo mapable unit over the entire Wisconsin area. This unit is characterized by buff to tan, thick to thin, noncherty dolomite. All the rocks are extremely mottled with pods of yellow sandy dolomite surrounded by a matrix of dense to medium dense dolomite. The lower half of this unit has many small 1/8 to 1/32 inch microbeds of multi-shaded dolomite. These small beds are shown in a polished section as wavy, irregular layers which grade imperceptibly into each other. They are composed mainly of dolomite which has small amounts of argillaceous and iron impurities. It is felt that these impurities cause the shaded bedding. Small beds of pyrite and marcasite nodules are found locally and sporadic galena nodules may be found. In the western part of the state, calcite nodes and occasionally calcite coatings are found over the outcrop, where the decending ground water was forced to flow laterally by the impermeable shales of the Ion member.

Lower cherty zone

This unit of the Prosser member, is characterized by a thick to thin, tan to buff dolomite. The rock is easily weathered and on first appearance resembles a very soft sandy rock. The fresh samples are more dense and coarsely grained. Numerous chert nodules up to 6 inches in size are present, as are equally thick chert beds. Occasionally, discontinuous chert bands appear which resemble a boudinage structure. Microbedding, such as in the former unit, is again present, however, a slight decrease is noted when traced vertically toward the top of the unit. Although variations between each bed can be seen, if studied in great enough detail, it was found impossible to correlate any single bed laterally.

Lower Receptaculites zone

Above the lower cherty unit is a sequence of primarily massively bedded, sparsely cherty, tan dolomite. It is nearly identical to the underlying unit, but can be easily distinguished by the near absence of chert and the predominance of the fossil, Receptaculites and fucoids. Within this unit there are zones of fucoidal dolomite which are overlain by a two to three inch layer of dense pure limestone. Calcite molds of fossils are commonly found which appear to be made up of fragmentary remains of crinoids and brachiopods. Templeton and Willman (1952, p. 24) discribed a similar detrital limestone at the top of the Kimmswick limestone in southern Illinois, with which this unit is a lateral correlative.

Upper cherty zone

The upper cherty unit has been subdivided by Agnew (1956, p. 268) and Templeton and Willman (1952, p. 10) into four and five units respectively. Their classifications are based mainly on lithologic variations, and, although they could be recognized in the extreme southwestern portion of Wisconsin could not be used over the entire area. This unit was noted to have in its lower 1/3 many oscillations between nodular cherty beds and noncherty beds. Many of the noncherty portions also contained similar dense, pure dolomitic beds, as discribed in the previous unit. The upper 1/3 of this sequence, becomes increasingly more cherty with the noncherty portions becoming thinner. The chert bands and beds also increase upward through the unit. Locally, abundant Receptaculites are found in the central portions, but zonation such as was accomplished in the lower Receptaculites unit was not found practicable. Scattered within this unit are several zones containing very argillaceous material. In some areas these zones were found to be the result of solution action allowing slumping and mixing of the dolomite. A sample, analyzed by Dr. S. A. Tyler (personal communication, 1958) from the Guttenberg section, showed highly polished, black grains similar to those found in the Cretaceous deposit of Iowa and Minnesota. It was suggested that these grains were possibly deposited in a fracture filling, during erosion of these cretaceous rocks.

Upper noncherty unit

Immediately overlying the top of the chert is a yellow to buff, massive to medium bedded noncherty dolomite. It is normally granular and upon weathering is extremely sandy and soft. Shale beds from one to four inches thick, were found in all the sections measured, but correlation with each other was impossible. The bentonite bed discribed by Agnew (1956, p. 268) was not found in any portion of southwestern Wisconsin. Gastropod zones, and occasionally brachipod zones are found in several sections near the basal and upper portions of the unit. Also a few Receptaculites may be identified.

Stewartville member

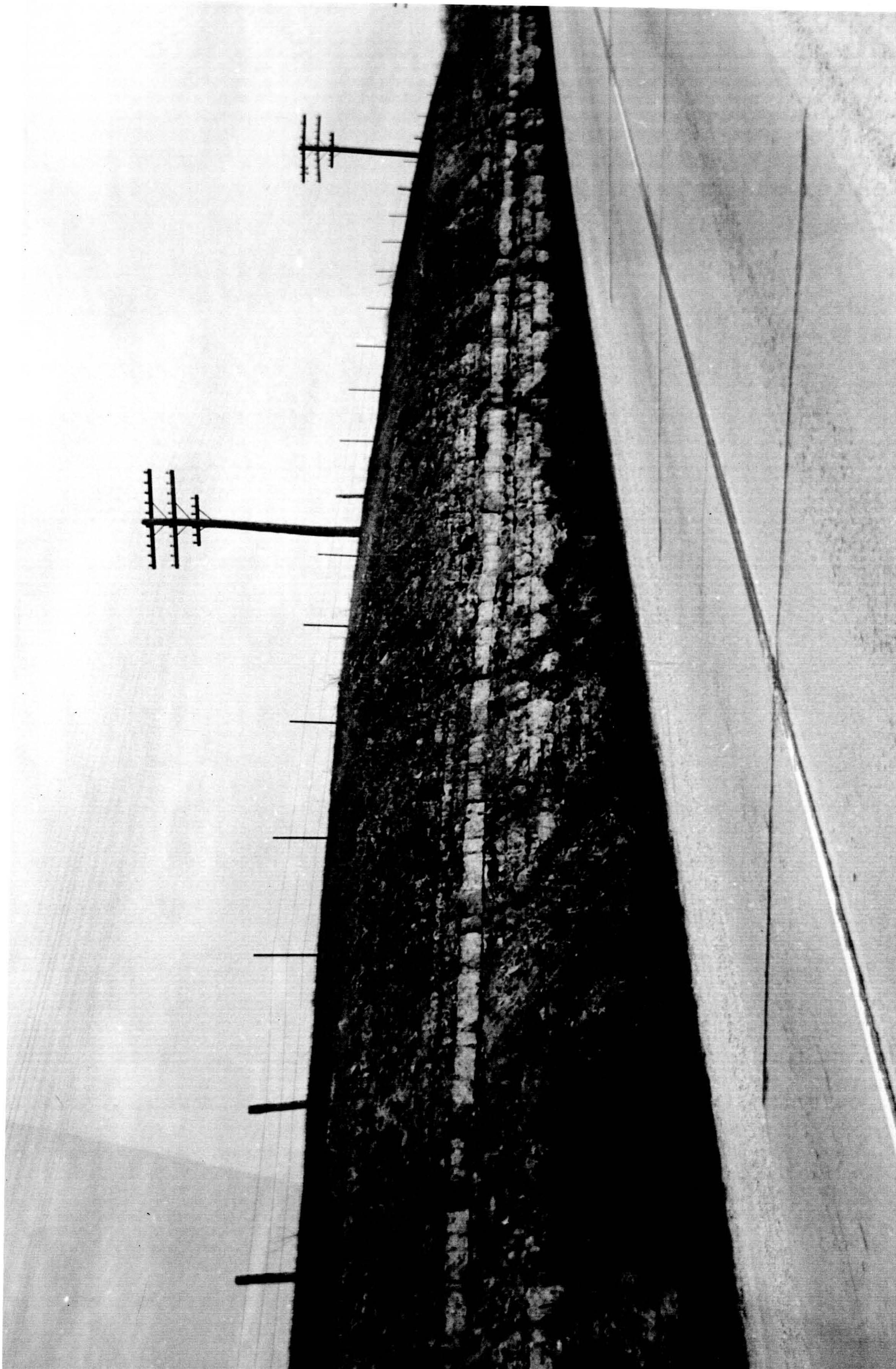
The lithology of the Stewartville member is strikingly similar to the upper noncherty unit of the Prosser. It is generally, a yellow to buff, fine to medium textured dolomite. In the basal 1/3 of this unit, it is thick bedded and grades vertically into fine to medium beds near the top. Fresh samples of this rock show the majority of the unit to be very soft and semifriable. Near the top, however, it becomes more dense. A few beds with microbedding, such as were discribed from the lower Prosser, are found but are not as excellently developed. Upon weathering, the Stewartville member becomes exceedingly vuggy and porous except for a three foot layer about ten feet above its basal contact. This dense, smooth portion of the unit is commonly called the "cap rock" in the lead-zinc district. When traced eastward this zone becomes obscure and can not be identified accurately. Two bentonitic shale beds have been reported from Minnesota by Weiss and Bell (1956, p. 69) and a "felthpathized shale" at the base of the Stewartville was discribed by Weiss (1953, p. 272) from the same area. No evidence was found in this thesis area of bentonitic shales, but a six inch shale zone was found at the base of the Stewartville in the Turkey River and Sinsinua sections. The data obtained, after laboratory examination, suggests possible correlation with the "felthpathized shale" mentioned above. The Stewartville member is noted mainly for its abundance of Receptaculites and gastropods in the basal ten feet of the member. When traced eastward across the state, these fossils gradually decrease in number, but as the rest of the fossils in the Galena formation also decrease at the same ratio, these fossil zones can still be identified if examined closely.

Dubuque member

As previously mentioned, the Dubuque member was difficult to study in the Wisconsin area. The few sections seen, were characterized by light grey to buff, fine grained, sandy dolomite. The member is medium bedded in the basal portions and becomes thinly bedded upward. Shale partings are found between the bedding planes and range from 1/32 of an inch to six inches in thickness. Agnew (1956, p. 298) discribes the Dubuque member as becoming more shaly and calcareous upward through the section. The regional disconformity with the Maquoketa shale has been discribed by Du Bois (1945, p. 14) as becoming more intense to the south in Illinois.

ILLUSTRATION 3.

Plate 1. Outcrop of the upper noncherty unit in the Prosser member, two miles west of Blue Mounds. Note dense 16 inch bed of limestone lying between beds of porous dolomite. Outcrop is plotted in section 7, appendix.



FAUNA

The preservation and abundance of fossils in the Galena formation of Wisconsin, is remarkably poor when compared with the Minnesota and Iowa equivalents. This characteristic is partly explained by the greater abundance of argillaceous material as the formation is traced outward from the Wisconsin arch. This argillaceous lithology is generally considered more favorable for fossil preservation, although it is not related to relative abundance prior to lithification. It is the concerted opinion of most of the geologists who have studied the Galena dolomite, that the area adjacent to the Wisconsin arch was a broad shallow basin deepening southward and westward. During Galena time this sea was presumably clear and relatively free from argillaceous inflow. It is also generally agreed that the lack of fossils in the dolomitic phase of the Galena dolomite, is due to the distruction of all but the larger sized fossils, by the processes of dolomitization. It is felt however, that another solution may be equally adequate to explain this faunal absence. It is evident that the fossil most commonly present in the dolomitic rock is the sponge Receptaculites, and with it are gastropods such as Fusispira, Hormotoma and Maclurites, also in abundance, are horn corals, calcitized crinoid stems, and fucoids. As the formation is traced west into the argillaceous phases in Minnesota and Iowa, the brachiopods and trilobites become the dominant fauna and Receptaculites crinoids and horn corals become minor. Environmentally, this relationship is common, with the sponges, corals and crinoids preferring clean, quiet, shallow water and the brachiopods and trilobites being adapted to a more muddy environment. It is also noted that the zones rich in gastropods where usually found as local lenses or pods. Similar examples of this colony type distribution of gastropods was discribed by Calvin (1905, p. 94) from Iowa. These fossil pockets occasionally showed the larger Fusispiras to be lined up horizontally with their bases pointing the same direction. When thin sections and insoluble studies were made across one of these pockets, no textural difference was noticed that suggested lessening of the dolomitization processes within the pod. Rather, it is felt that this local abundance of gastropods was probably due to current or wave action concentrating the shells in small depressions. The horn corals and Receptaculites, which are normally attached to the bottom, are rarely found close together and were probably entombed in situ.

An abundance of fucoids is found in the Ion and lower half of the Prosser. Although many of these fucoids are poorly preserved, several localities produced excellent multi-branching types. The molds are found near the tops of the coarse to medium crystalline dolomitic beds, and are often overlain by a dense, thin, fine grained limestone. Upon weathering, the fucoid beds commonly show impressions of arcs of circles around a central point. This type of structure is interpreted by Twenhofel (1950, p. 619) as markings made by plants growing on the bottom of water bodies. As the plant was swung around by water movement the contact of the branches with the sediment causes these arcuate impressions The dense pure layer covering the fucoids is interpreted as a rapid inflow of clastic sediment causing rapid burial of the fucoids.

Thin section studies and staining of the samples also showed several features which might support this explanation. The dense massive beds sparsely scattered throughout this formation were found to be composed almost entirely of fine grained, clastic limestone with several of the samples showing fragments of brachiopods, and small gastropods (see plate 2). The clean sharp contacts of these limestone beds with the surrounding dolomite have been interpreted by some authors as being evidence of diagenetic, rather than, selective dolomitization. If this is true, the fossils, especially the brachiopods, can be accounted for by their being brought into this area from an environmental locality more favorable for animal and plant life. The face that the limestone are clastic with fragmentary fossils suggests transportation at least to some degree. The previously mentioned fucoid remains, in the dolomitic rocks overlain by clastic limestone, also indicates inflow of these limestones from some adjacent area.

Such a solution, as suggested above, need not assume primary precipitation of dolomite, but rather, that the original carbonate was dolomitized prior to, or at the same time as, lithification. The absence of fossils, in this and other similar dolomitic formations, may indicate an ecological environment adverse to animal life, not distruction by epigenetic dolomitization. (Cline, personal communication, 1958).

The following list gives the types of fossils identified from the Galena dolomite of Wisconsin, Minnesota and Iowa. The names followed by an asterisk indicate fossils identified in this thesis study.

GASTROPODA:

Fusispira subbrevis (Ulrich and Scofield)*

Fusispira subfusiformis (Hall)*

Hormotoma major (Hall)*

Hormotoma subangulata (Hall)*

Lophospira minnesotensis (Ulrich and Scofield)

Maclurina sp.

Maclurina cuneata (Whitfield)

Maclurina manitobensis (Whiteaves)

Maclurites crassus (Ulrich and Scofield)*

Michelinoceras sociale Hall*

Murchisonia gracilis Hall

Owenella sp.

BRACHIOPODA:

Dalmanella sp.*

Dalmanella porrecta (Sardeson)*

Dalmanella testudinaria Dalman

Lingula iowensis Owen*

Lingulepis walcotti Resser

Oxoplecia calhouni Wilson

Platystrophia trentonensis McEwan*

Pseudo lingula iowensis (Hall)

Rafinesquina deltoidea (Conrad)*

Rhynchotrema capax (Conrad)*

Zygospira recurvirostris (Hall)*

BRYOZOA:

Nematopora ovalis Ulrich

CRINOIDEA:

Cheirocrinus sp.

PORIFERA:

Ischadites iowensis (Owen)*

Receptaculites oweni Hall*

TRILOBITA:

Bumastus milleri (Billings)*

Illaenus americanus Billings*

ILLUSTRATION 4.

Plate 2. Thin section of limestone found in the Stewartville member. Note the lack of dolomite crystals even though this bed bounded on both sides by thick sections of dolomite.

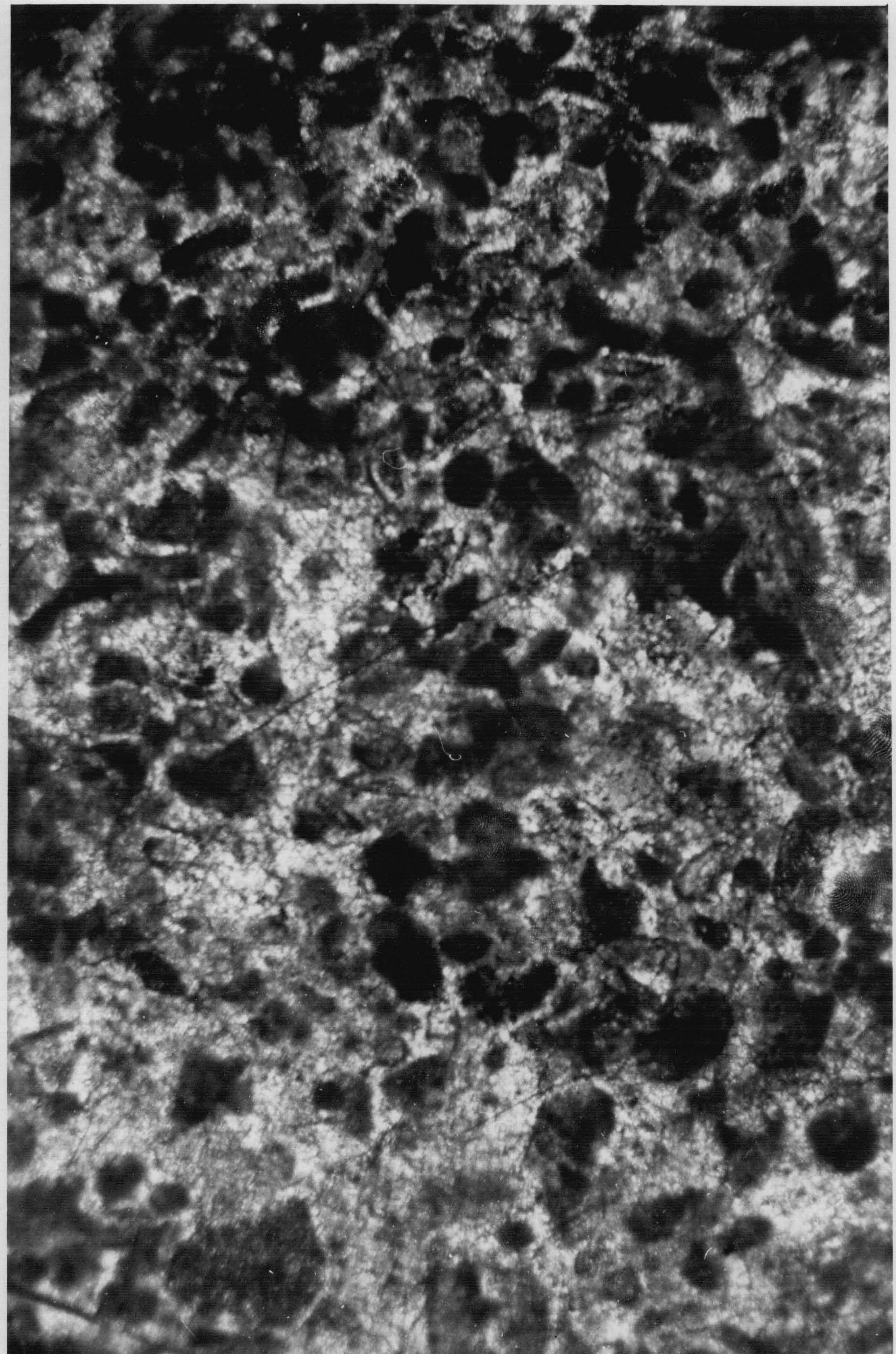
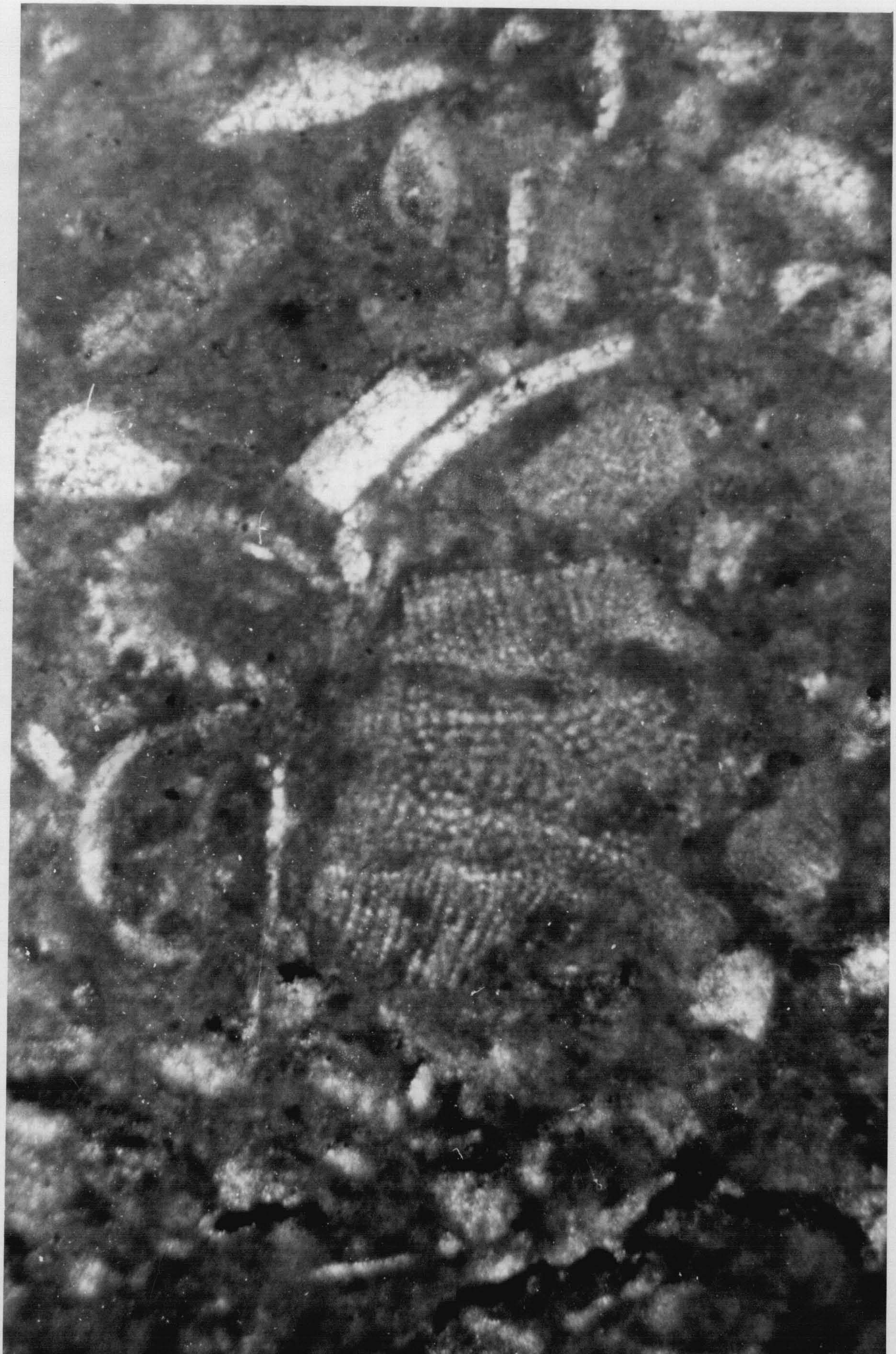


ILLUSTRATION 5.

Plate 3. Thin section of limestone found in the Prosser member near Dodgeville Wisconsin. Note the abundance of unaltered fossil fragments. This bed was also bounded by dolomitic rocks.



THICKNESS

In all reports concerning the Galena dolomite of Wisconsin, Iowa, Minnesota and Illinois, the formation is discribed as averaging from 220' to 230' in thickness. Weiss and Bell (1956, p. 67) report that the Prosser member thickens from 40' in western Minnesota to 51' in the eastern part of the state. Agnew (1955, p. 1709) using subsurface well logs, shows the Galena dolomite to thin to 130' in southwestern Iowa, and the Dubuque member to thin from 35' to 15' as it is traced from Dubuque to the northern Iowa state line. The thinning and gradual disappearance of the Dubuque and Stewartville members in Illinois has been reported by Du Bois (1945, p. '5) but was accounted for by a regional unconformity at the top of the Prosser. Other than in these few reports, the members of this formation are discribed as if they were of constant lateral thickness. However, field studies in the Wisconsin area showed the Galena dolomite to thin rapidly as it lapped up on the Wisconsin arch. Several sections separated by cover, were checked for stratigraphic position by an alidade to insure accuracy. The following are the variation in thickness of units and members as the formation is traced from Cassville to Dodgeville to Blue Mounds, Wisconsin.

	Cassville	Dodgeville	Blue Mounds
Lower noncherty	10'	8'	8'
Lower cherty	20'	12'	10'
Lower *Receptaculites*	13'	16'	15'
Upper cherty	75'	67'	55'
Upper noncherty	35'	30'	28'
Stewartville	45'	40'	*
Dubuque	42'	*	25'?

The preceeding chart shows that the Prosser member thins readily as it is traced from west to east across Wisconsin. The maximum thinning is seen to take place in the two cherty units, although, a decrease is noted in the other units as well. The date needed to support a similar situation in the Stewartville and Dubuque members is lacking due to removal of these units by erosion in the eastern part of the thesis area. Well records were checked at the United States Geological Survey office in hopes that they might eleviate this problem. It was found that neither the well logs or the well cuttings were detailed enough to pick individual members and units and therefore were not used. A comparatively recent well, drilled atop Blue Mounds, showed 25' of grey, shaly dolomite lying between a tan to yellow dolomite and the Maquoketa shale. This might be interpreted as the Dubuque member and evidence for its thinning to the east. (see chart i).

INSOLUBLE RESIDUES

In the laboratory studies, an attempt was made to correlate on the basis of insoluble residues. Two sections were chosen 1/4 of a mile apart and were correlated visually by walking the various contacts along road cuts. Forty gram samples were then selected from each correlated bed and disolved in a 1N solution of hydrochloric acid till effervenscence stopped. After washing the ratio of insoluble to original material was calculated and the insoluble constituants studied under the petrographic and binocular microscope. The results were then matched with the visual correlations. The results of this study proved to be meaningless and future correlation by insoluble materials was abandoned. The above results are what might be expected, owing to the small amount of argillaceous material in the Wisconsin phase of the formation. Future work of this kind might prove valuable however, if studied in the states adjacent to Wisconsin and where the argillaceous-carbonate ratio increases.

It was noticed, in the residues studied, that of the constituents composing the insoluble residues, many of the samples contained considerable amounts of quartz and feldspar. Both these minerals were checked by petrographic and X-ray procedures for varification. Further studies showed these two minerals to have been formed from allogenic and authi genic processes (see plate4). The clastic quartz was identified only in the shaly beds and varied from angular to rounded, white to pink or yellow, and from clear to frosted. Occasionally the quartz gains were seen to contain inclusions of a black fiberous mineral. However, no rock fragments were found which would indicate the composition of the parent rock. The feldspar was identified in only one sample, which was at the shaly basal contact of the Stewartville member, at Turkey River, Iowa. In this case the feldspars were pink, semi-angular and ranged up to 1/4 inch in size.

Evidence of authigenic quartz and feldspar was found scattered throughout the rocks lying below the top of the chert. Also some scattered feldspar grains were found as high as the top of the Dubuque member. Both the authigenic quartz and feldspar were present as clear, perfectly formed crystals of remarkably uniform size (plate 5). The amount of quartz was also noted to increase until a maximum was reached at the top of the Ion member.

The source of silica for the quartz might be derived from the chert, as the crystals are found only below the top of the chert. The Na. and Al. in the feldspar could be easily obtained from the overlying shales or from surface erosion. Because of the similarity in size, clearity and crystal forming nature, these two authigenic minerals, are felt to have formed contemperaneously. Descending ground water was most likely the transporting agent for the silica, Na. and Al. ions.

Other mineral accessories, included pyrite, sphalerite, galena and magnetite. Only magnetite was noted to be of any concentration, and then, only in the sample previously mentioned from Turkey River, Iowa. This sample was analyzed to contain as much as 1% magnetite. Also associated with this sample were the large grains of detrital quartz and feldspar mentioned previously. Studies of other shaly beds showed no similarity to the above zone, and correlation into Wisconsin sections was impossible. It is thought, that future work is warrented, in hope that this or other detrital beds might have lateral continuation so their source and depositional conditions be explained.

ILLUSTRATION 6.

Plate 4. Insoluble residue from a typical lower Prosser dolomite. Note the clear crystals of feldspar and fragments of quartz. Actual size, .09 - .04 mm.

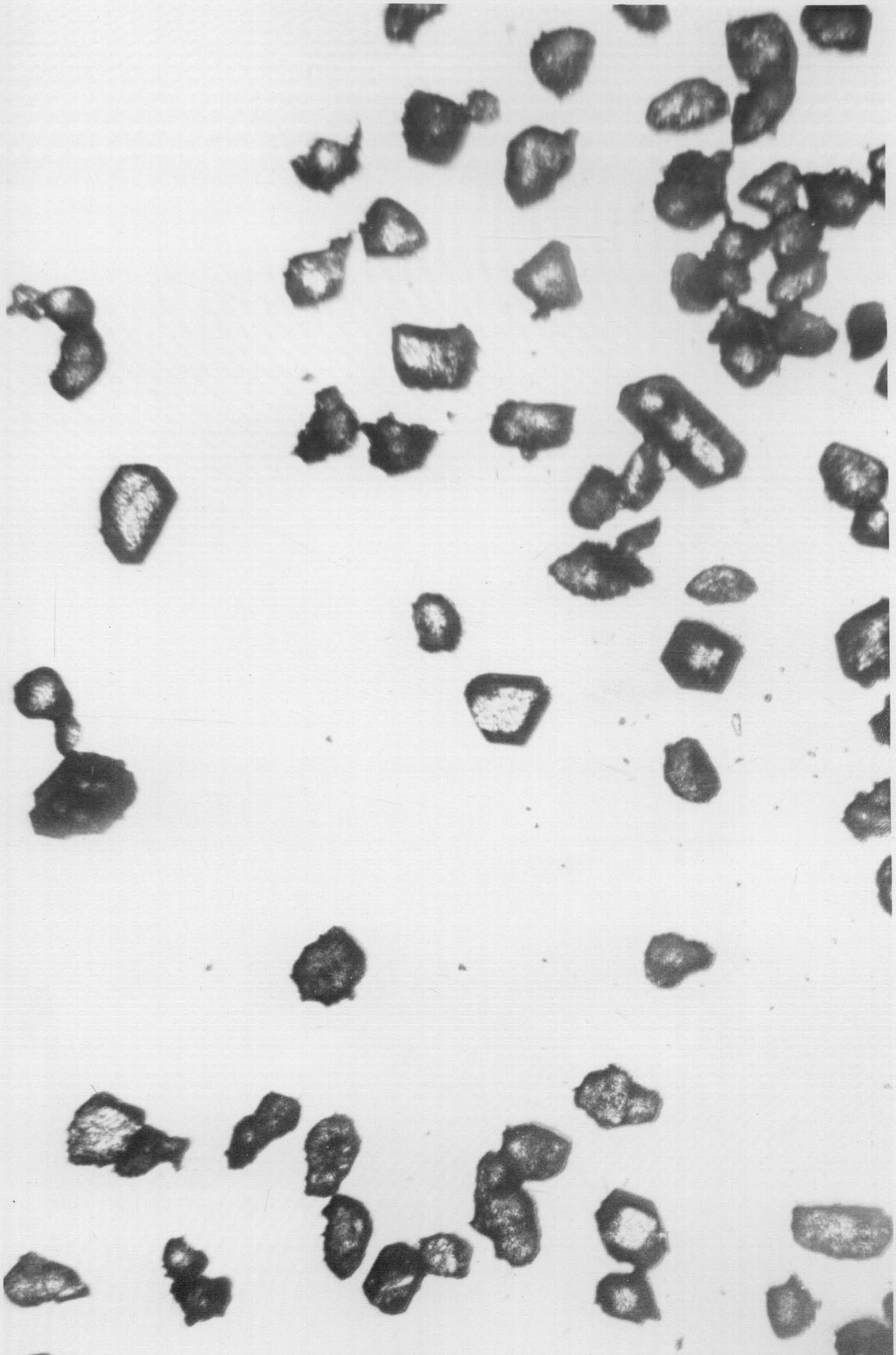
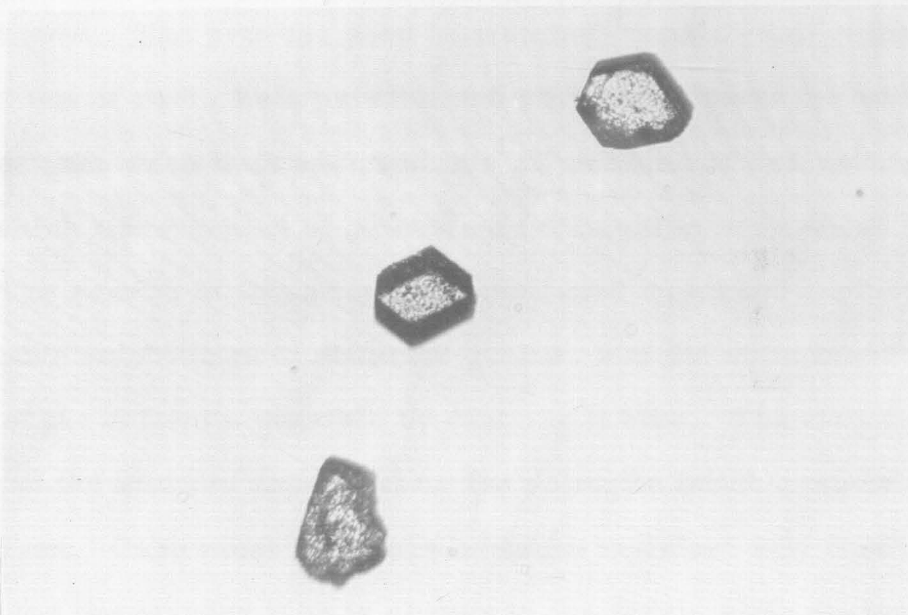
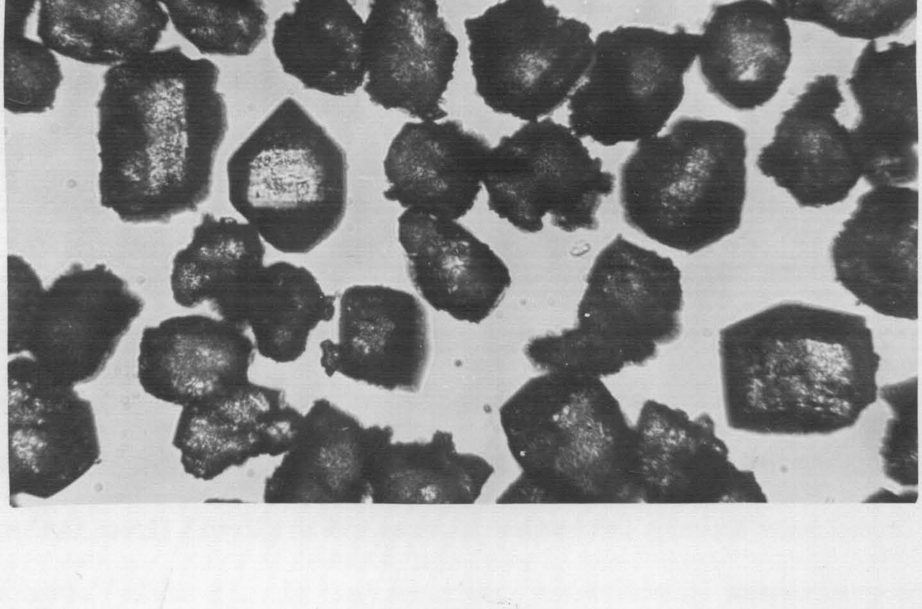


ILLUSTRATION 7 & 8.

Plate 5. Authigenic feldspar crystals found in a typical Prosser member dolomite. Note clearity and lack of abrasion. Actual size, .09 - .04 mm.

Plate 6. Authigenic quartz crystal. Note the uniform size of all the particles. Actual size, .09 - .04 mm.





DOLOMITIZATION

To aid in the evaluation of the possible causes under which the dolomite was formed, many selected samples were stained, etched and thin sectioned. The process used in staining, consisted of cutting 1/4 inch sections of rock, both parallel and perpendicular to the bedding. These sections were then emersed in a 1N solution of hydrochloric acid to which a few grains of potassium ferricynide were added (Lamar, 1950). The results of this procedure produced an etched surface, showing comparative solubilities of different grains, and the stain made identification of the dolomite possible by staining it blue. The chemical reaction of the stain is dependent on the dolomite latice containing ferrous iron. Care must therefore be taken to select only fresh samples for the ferrous iron is change to the ferric state during weathering.

The following paragraphs are some of the general features brought out by studies of thin sections, etched surfaces and staining.

Texture

During the laboratory studies it was seen that the majority of the rocks in the Galena formation are composed of pure dolomite. However, occasionally mixtures of fine grained, nonclastic calcite and dolomite were found. When the dolomite was sparse the grains were seen as isolated euhedral crystals normally .5 mm in size. These crystals were disseminated in a fine, anhedral matrix of calcite (plate 7). As the dolomite became more dominant, the crystals become slightly less euhedral until finally a mosaic of anhedral grains was found in pure dolomite beds (plate 8). In one section, evidence of secondary overgrowths on the dolomite rhombohedrans was seen, indicating at least two periods of dolomitization in this locality (plate 9).

Porosity

Porosity caused by volumetric reduction during dolomitization of calcite has been proposed by many authors. Evidence to support or disprove this, could not be found during this investigation. During the study of the dolomites, it was noticed that the iron in the dolomite crystals in vugs, was always changed to ferric iron. The same effect was noted in the yellow mottled portions of the rock. This may be interpreted as ground water action, producing the cavities or, as ground water passing through the area after the cavities had already formed.

Chert

The chert samples, studied in thin sections, showed dolomite being replaced by silica (plate 10). If this is the case, then most of the chert in the Galena dolomite must have been post-dolomitization.

Origin

In presenting the conditions important in producing dolomitization, it is first necessary to account for the addition of magnesium ions into the system. Addition from some source outside the depositional area is possible, but it would seem most logical to gain it from some material already within the local area.

Many theories for the formation of dolomite have been presented in the literature, and the data observed in the Galena dolomite fits part of many of these. Dr. A. G. Fisher's ideas concerning the conditions necessary for dolomitization seem to fit this situation best, and will therefore be the basis on which this particular dolomite is explained (Princeton, personal communication, 1958). Working on limestone fabrics, Fisher has found that the type of carbonate, forming a sediment, will be determined mainly by the temperature of the water and the type of fauna present in this environment. The crinoids and corals were found to produce shells of high magnesium calcite (10-20% Mg.), and the brachiopods, to produce shells of low magnesium calcite (0-7% Mg.). Generally, it was seen that the higher the temperature the more magnesium the shell was able to contain. If this data is correct, then an environment of shallow, warm seas, plus a fauna capable of producing high magnesium calcite, could produce the needed magnesium for dolomitization. The amount of dolomite produced would also be dependent on the abundance of animal life, prior to diagenisis. The triggering action necessary to cause the original calcite to break down and release its magnesium, has been suggested to be a changing of the PH, and the forming of reducing conditions below the depositional interface. Under these conditions the high magnesium calcite is much more unstable than the low magnesium calcite and would redissolve releasing magnesium ions. The presence of ferrous iron within the dolomite also supports this idea.

ILLUSTRATION 9.

Plate 7. Thin section of a dolomitic limestone from the lower Receptaculites unit of the Prosser member. Note euhedral crystals of dolomite in a limestone matrix.

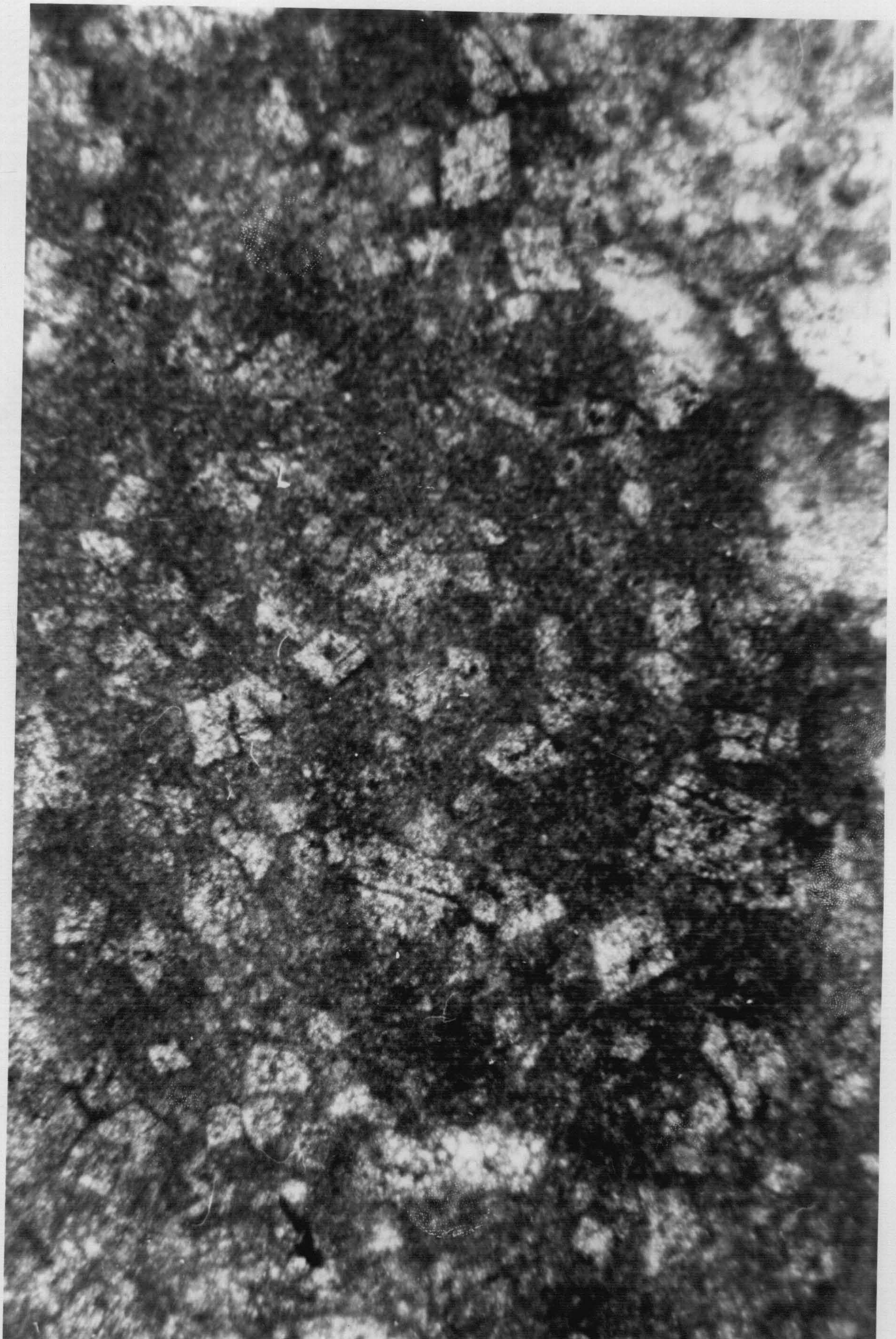

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ILLUSTRATION 10.

Plate 8. Typical dolomitic texture of the Galena formation. Note the mosaic of anhedral grains found in dolomitic rocks as compared with the scattered euhedral grains of dolomite seen in the limestones (plate 7).

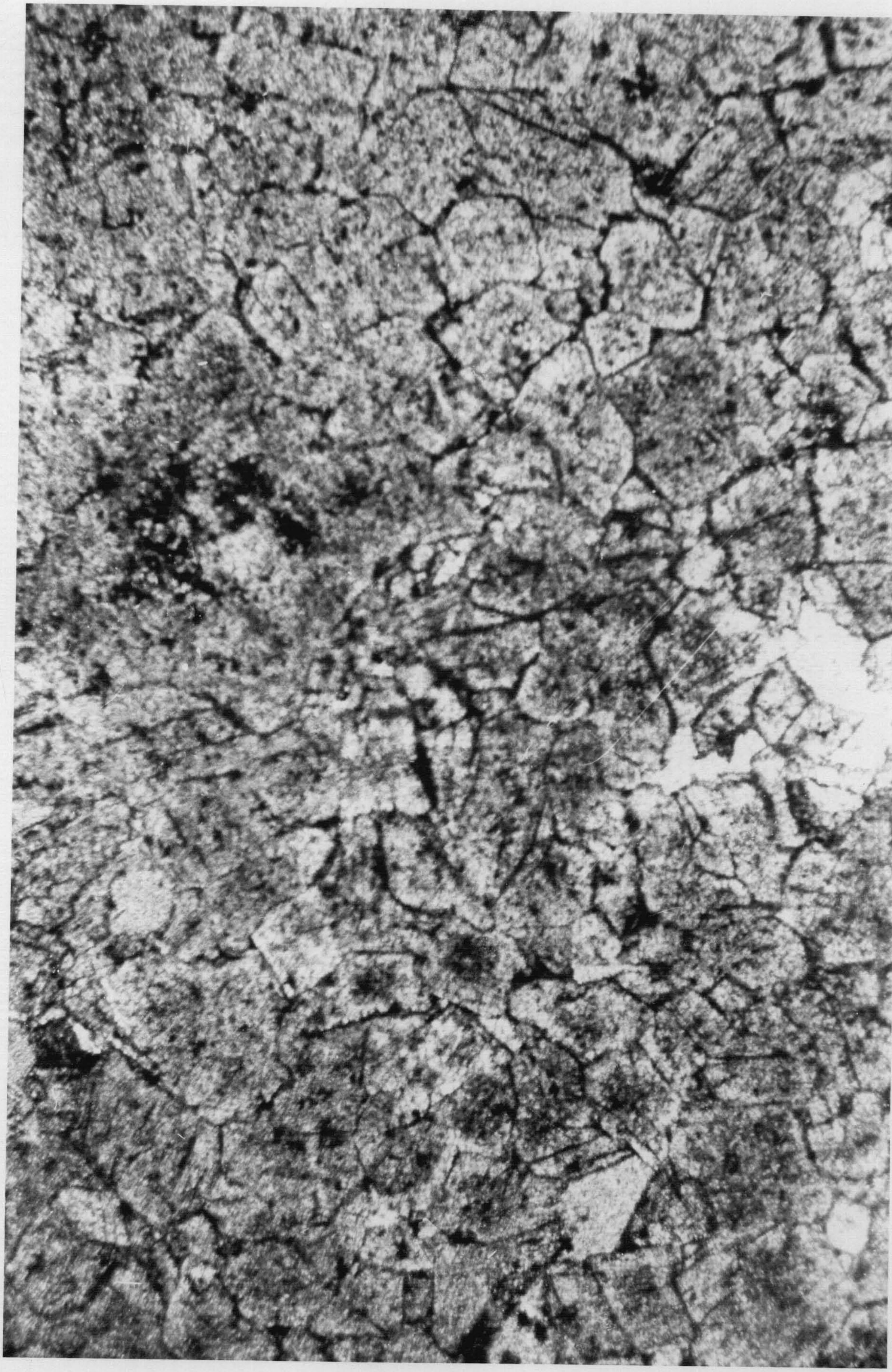


ILLUSTRATION 11.

Plate 9. Secondary overgrowths on a dolomite crystal. Impurities within the crystal are mainly iron oxide .

ILLUSTRATION 12.

Plate 10. Chert nodule found in the upper cherty unit of the Prosser member. Note the chert replacing portions of the dolomitic host rock.

HISTORY

From the evidence found during the course of this study, the following conditions typify the depositional and environmental history during Galena time. Because there is no indication of an unconformity at the base of the Prosser, and also that the contact of the Ion and Prosser are essentially transitional, it is felt that the Galena sea is mearly a continuation of the Decorah-Platteville submergence. Also, the massive nature and uniform lithology of the entire Galena dolomite shows no indication of depositional interruption at any time during its formation.

The shore line of this sea most likely lay to the north and possibly northeast of Wisconsin, and during lower Prosser time this adjoining land mass was elevated enough to supply quartz sands in western Minnesota and Iowa.

The Wisconsin arch although present, was not out of the water in southern Wisconsin during any part of Galena time. However, while the Prosser and Stewartville sediments were being deposited this arch was high enough to cause thinning of the sediments over it. The sea during this same time was shallow, clear and warm, and the ecological conditions were such that corals, crinoids, sponges and a few plants were the only living organisms found in appreciable amounts. The brachiopods and gastropods preferring the deeper muddier waters were found to the south and west.

The lack of bedding in the dolomite suggests some sort of current or wave action which mixed the small amounts of argillaceous material equally throughout the carbonates. In Dubuque time the area submerged and allowed increasing amounts of mud to be interbedded with the carbonate sediments. Because of the cyclic nature of these two lithologies, an oscillating basin may be indicated. Environmental conditions also shifted with the deepening of the depositional basin allowing brachiopods to become more common. The Wisconsin arch also lowered in Dubuque and part of Stewartville time and thinning of these members became lessened.

At the end of the deposition of Galena sediments, the sea retreated from much of the upper Mississippi valley leaving a marked unconformity when the Maquoketa sea follded the area. Because the basal Maquoketa shales show no evidence of reworked Galena sediments and also the fact that the thickness of the Dubuque member is exceedingly uniform from Minnesota to Illinois, this period of erosion is thought to be only minor.

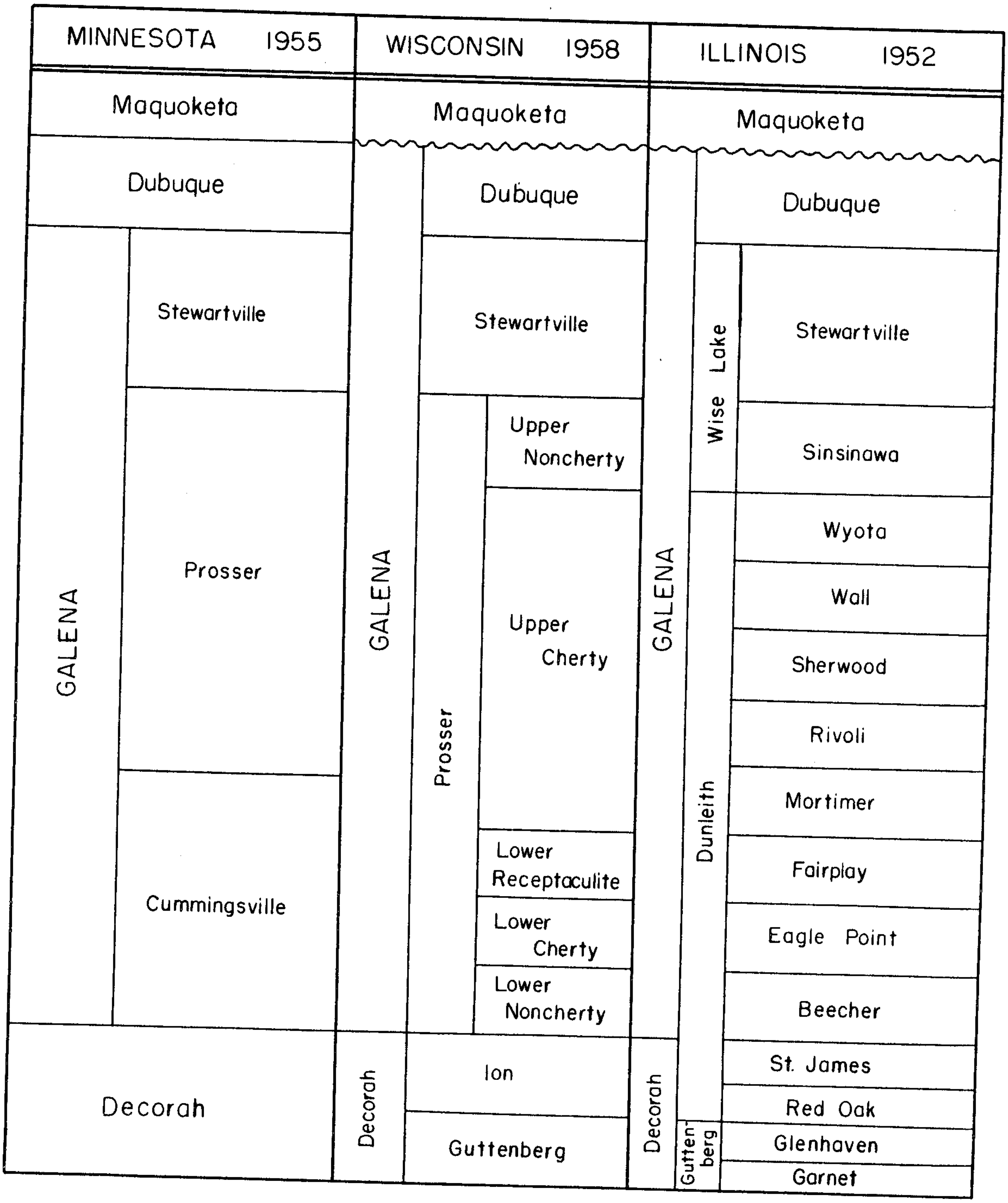
SUMMARY OF CONCLUSIONS

1. The base of the Galena formation in Wisconsin can not be determined by the previously defined Prasopora zone. A lithologic change based on the last visible evidence of shale is therefore presented as the contact.
2. The contact of the Stewartville and Prosser members is impossible to accurately locate due to the absence of the upper Receptaculites zone in many areas. If subdivision into the customary three members is necessary the contact is more feasibly placed at the top of the upper cherty unit.
3. Correlation with the faunally zoned Minnesota section is not possible over most of the Wisconsin area.
4. Correlation of the Wisconsin section with all of the recognized subdivisions of the Galena formation in Illinois is impossible except in the extreme southwestern portion of the state.
5. A diagenetic origin for the dolomite of the Galena formation in Wisconsin is proposed.
6. The absence of nearly all fossils except horn corals, Receptaculites and fucoids in this dolomite may be due to the environmental conditions necessary for diagenetic dolomitization being adverse for other types of animal life.
7. The chert in the Prosser member of the Galena dolomite was probably developed after dolomitization.
8. The limestone beds, within this dolomitic sequence of rocks, are detrital in origin.
9. No evidence of bentonitic shales was found in this area.
10. The entire Galena formation thins over the Wisconsin arch, Most of

this thinning is accounted for in the upper cherty unit.

11. The Galena dolomite is a shallow, clear water deposit, showing continuous deposition throughout its entirety.

12. Because of the lithologic transition between Decorah and Galena sediments, it is suggested that they were both deposited during one invasion of the sea.



Correlation Chart

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APPENDIX

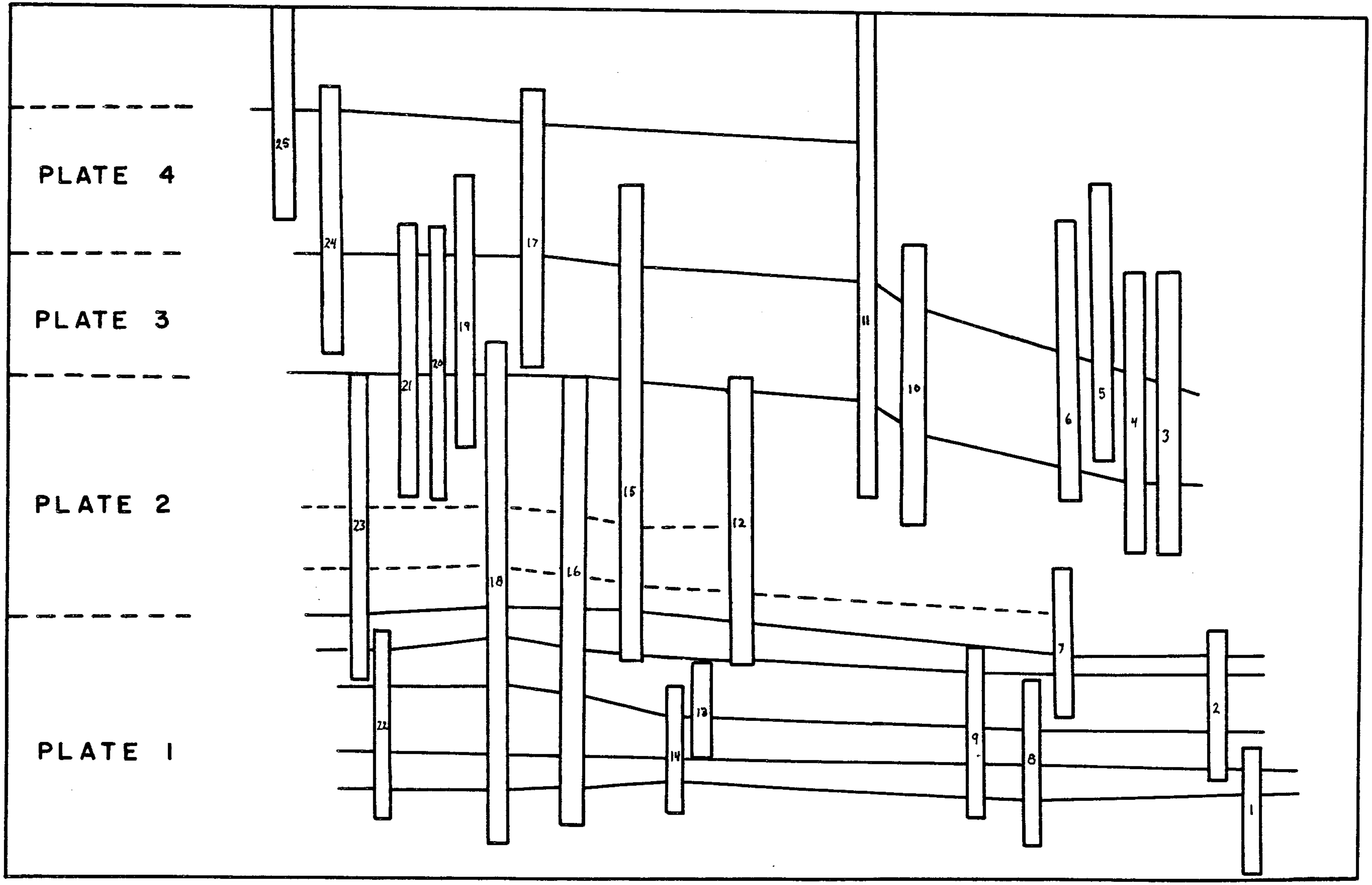
PLATE 4
PLATE 3
PLATE 2
PLATE 1
1
2
3
4
5
6
7
8
9
10
11
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15
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20
21
22
23
24
25

Index Map

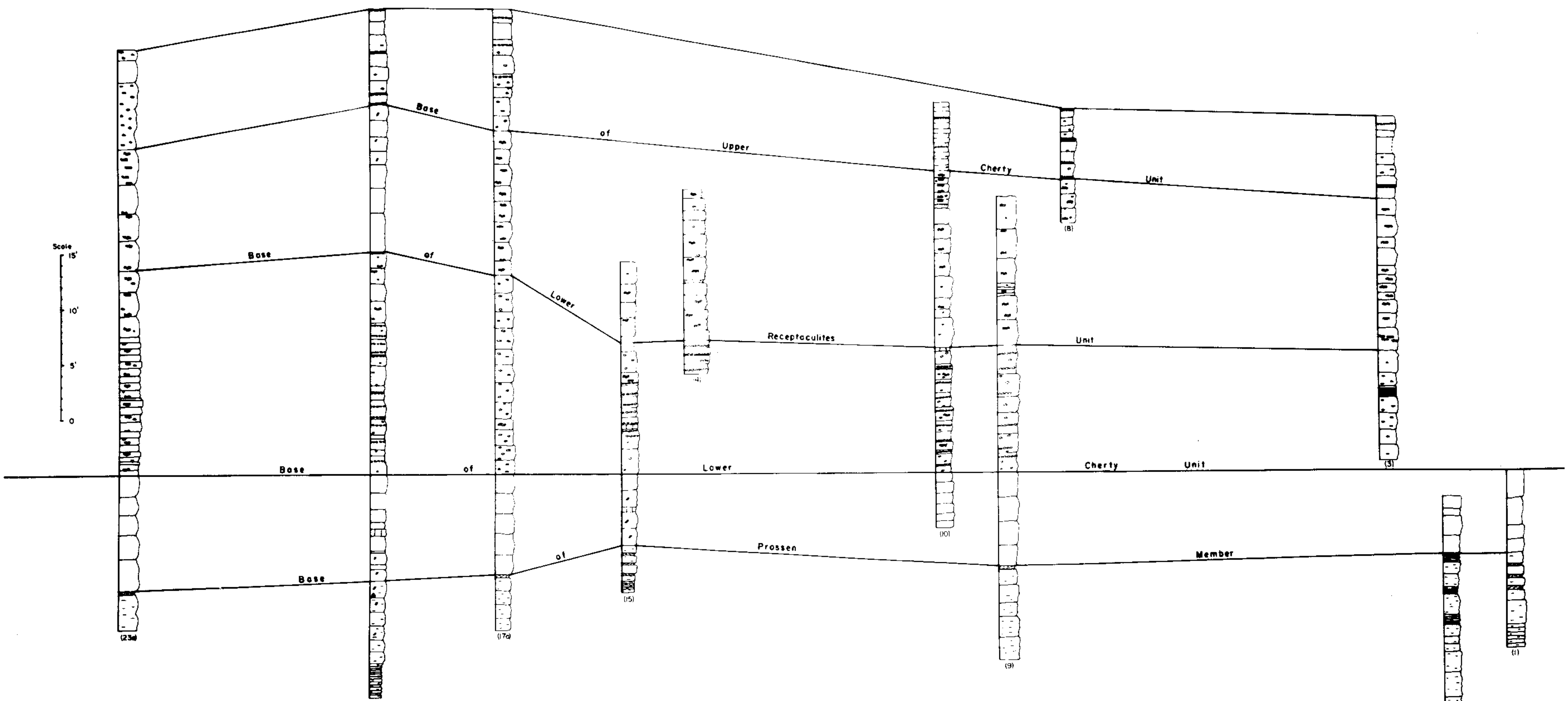
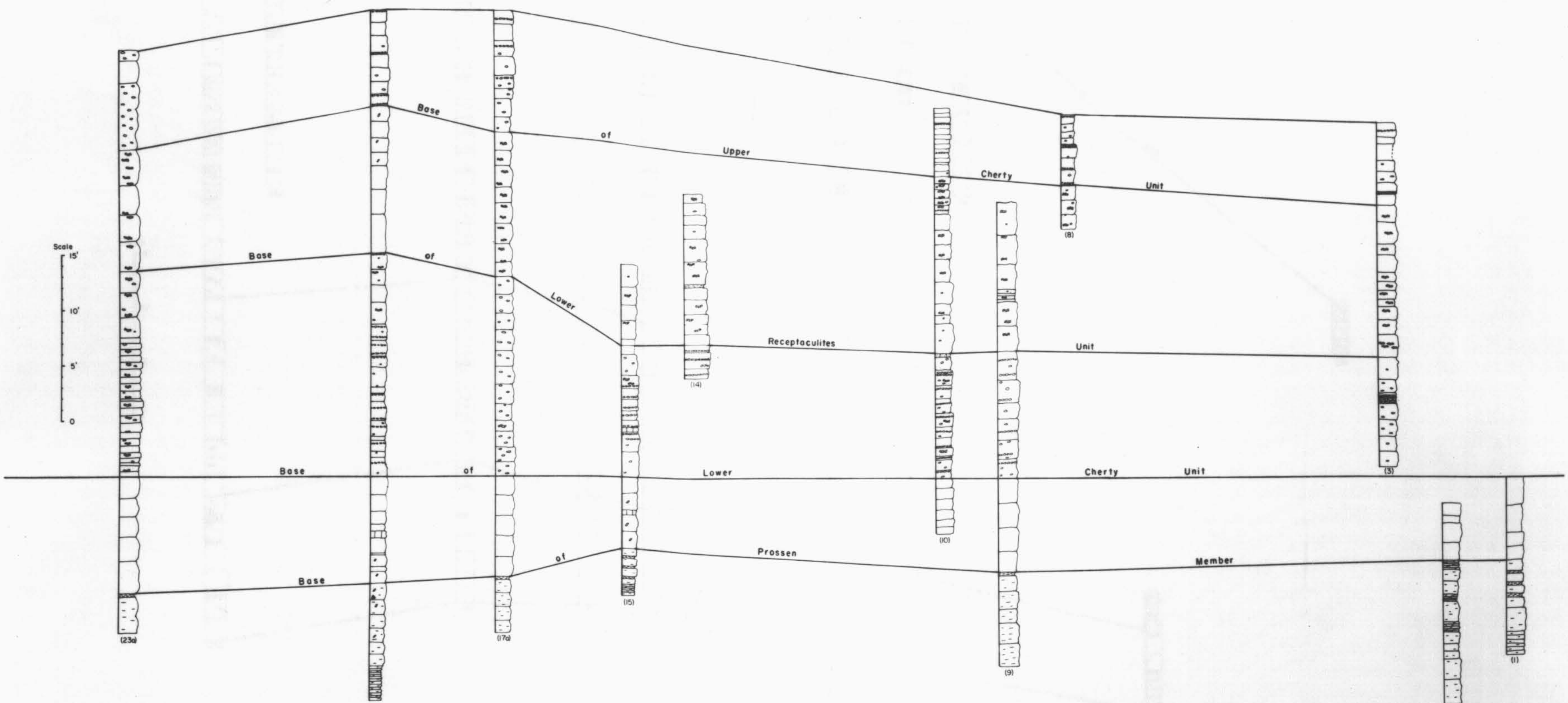

Base of Upper Cherty Unit
Base of Lower Receptaculites Unit
Base of Lower Cherty Unit
Base of Prossen Member
Scale
15'
10'
5'
0
(23a)
(17a)
(15)
(4)
(10)
(9)
(8)
(3)
(2)
(1)

Plate 1


Scale
15'
10'
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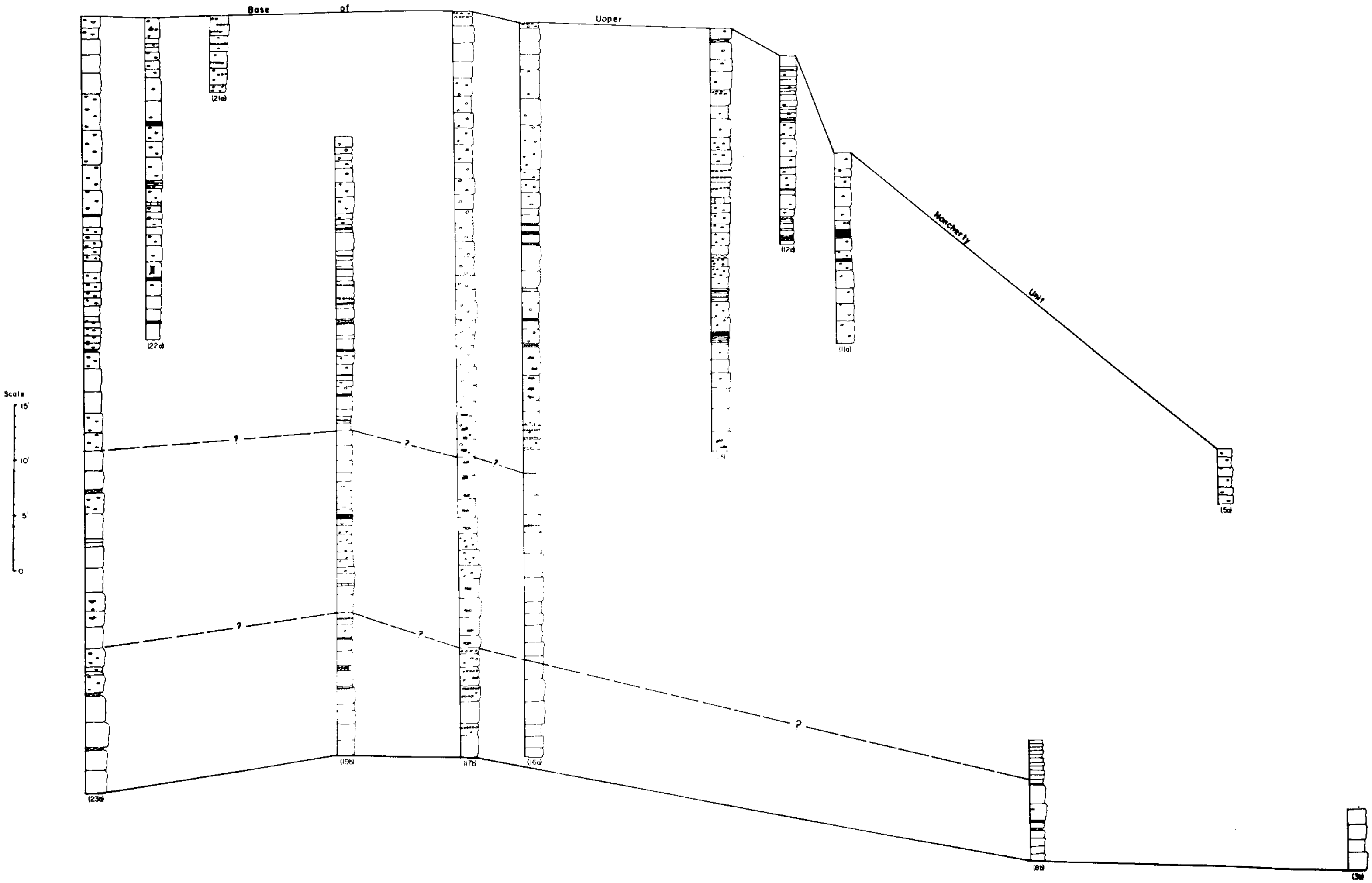
0
Base of Upper Cherty Unit
Base of Lower Receptaculites Unit
Base of Lower Cherty Unit
Base of Prossen Member
(23a)
(17a)
(15)
(14)
(10)
(9)
(8)
(3)
(2)
(1)

Plate 1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5'
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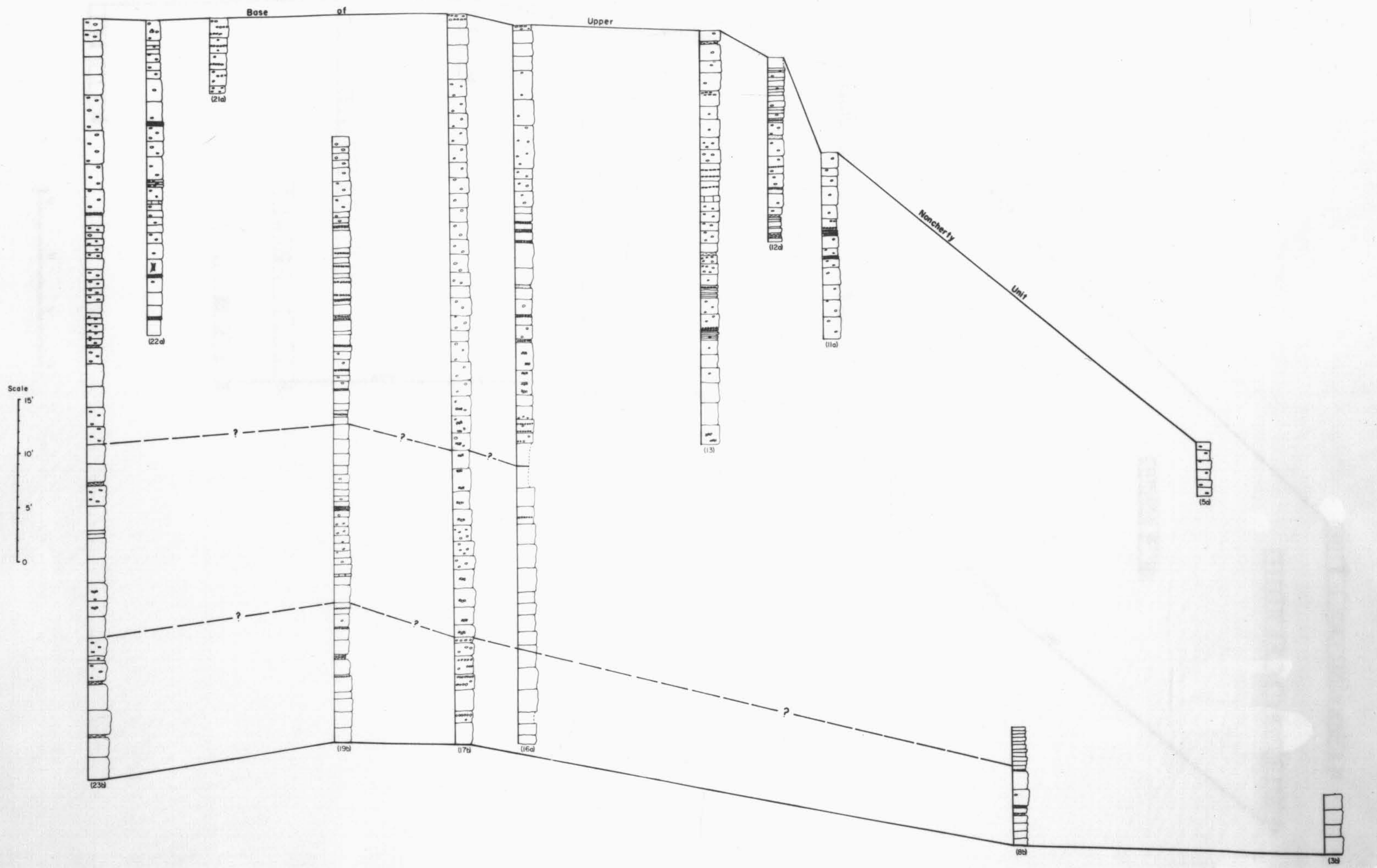
(22d)
(21a)
(19b)
(17b)
(16a)
(12d)
(11a)
(5a)
(8b)
(3b)
?

Plate 2


Base of Upper Nancherty Unit
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(22a)
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(13)
(12a)
(11a)
(5a)
(8b)
(3b)
?

Plate 2

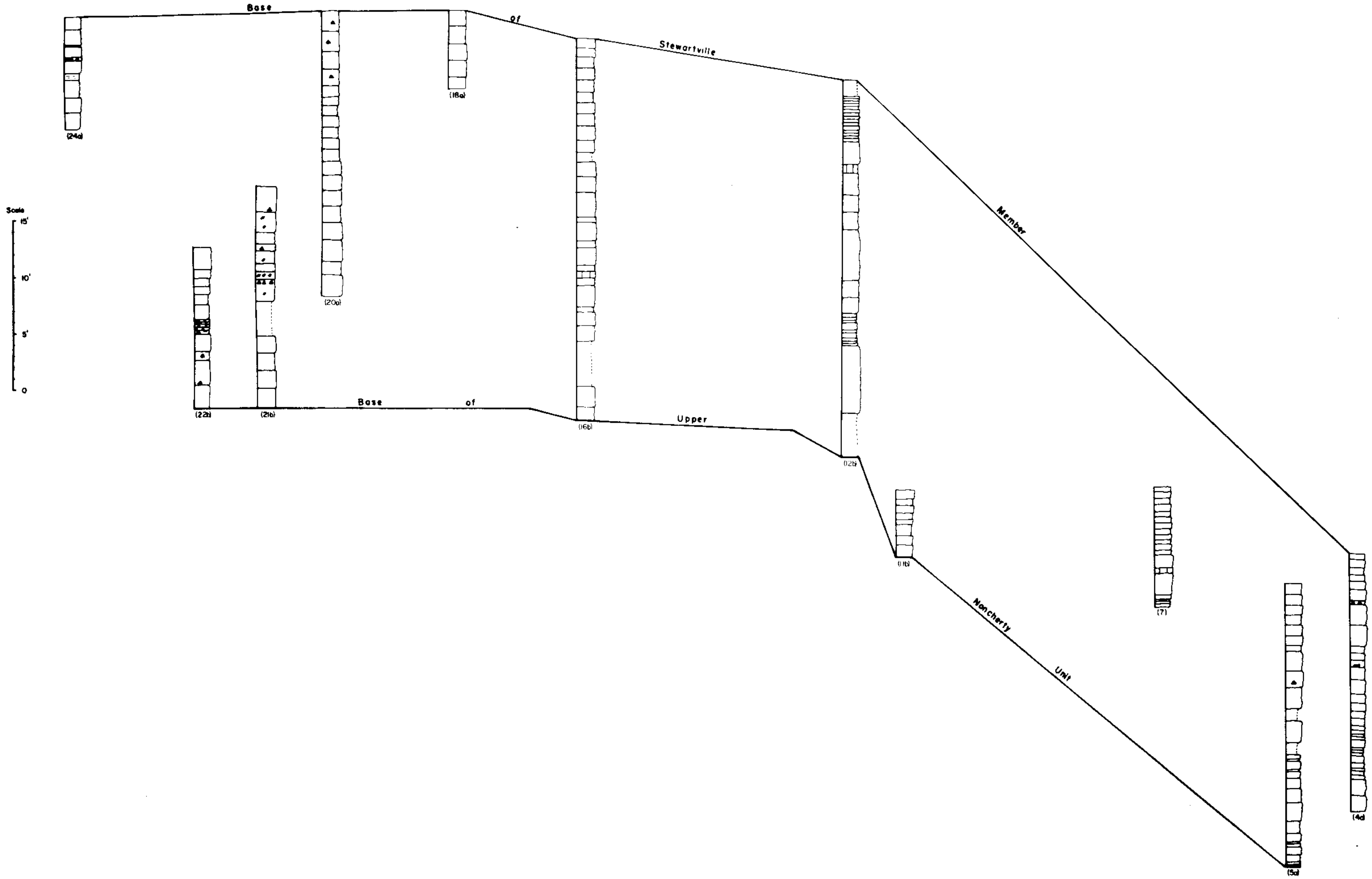
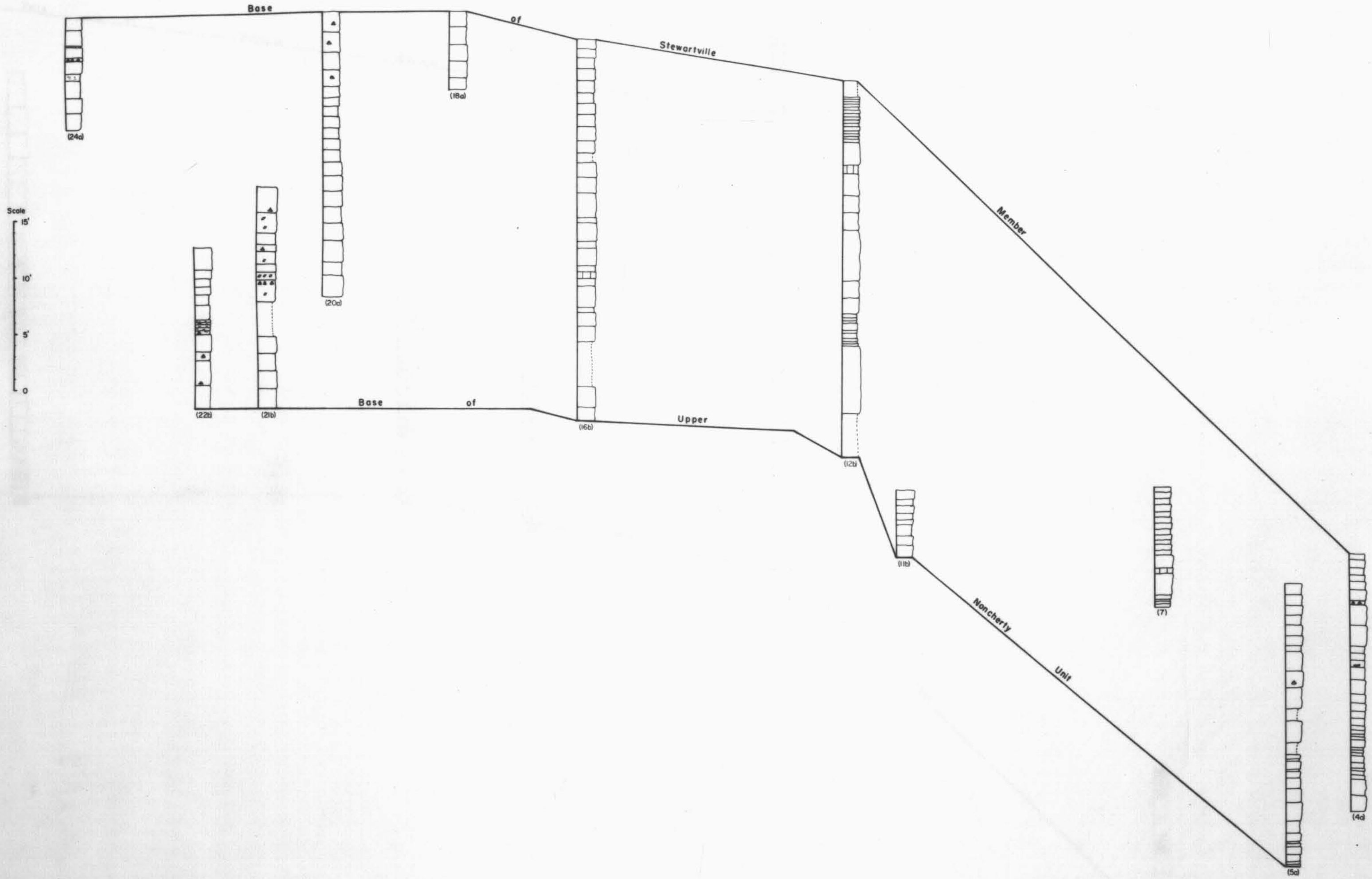

Base
of
Stewartville
Member
Base
of
Upper
Noncherty
Unit
(24a)
(20a)
(18a)
(16b)
(12b)
(22b)
(21b)
(11b)
(7)
(5d)
(4d)
Scale
15'
10'
5'
0

Plate 3


Base of Stewartville Member
Base of Upper Noncherty Unit
Scale
15'
10'
5'
0
(24a)
(22b)
(21b)
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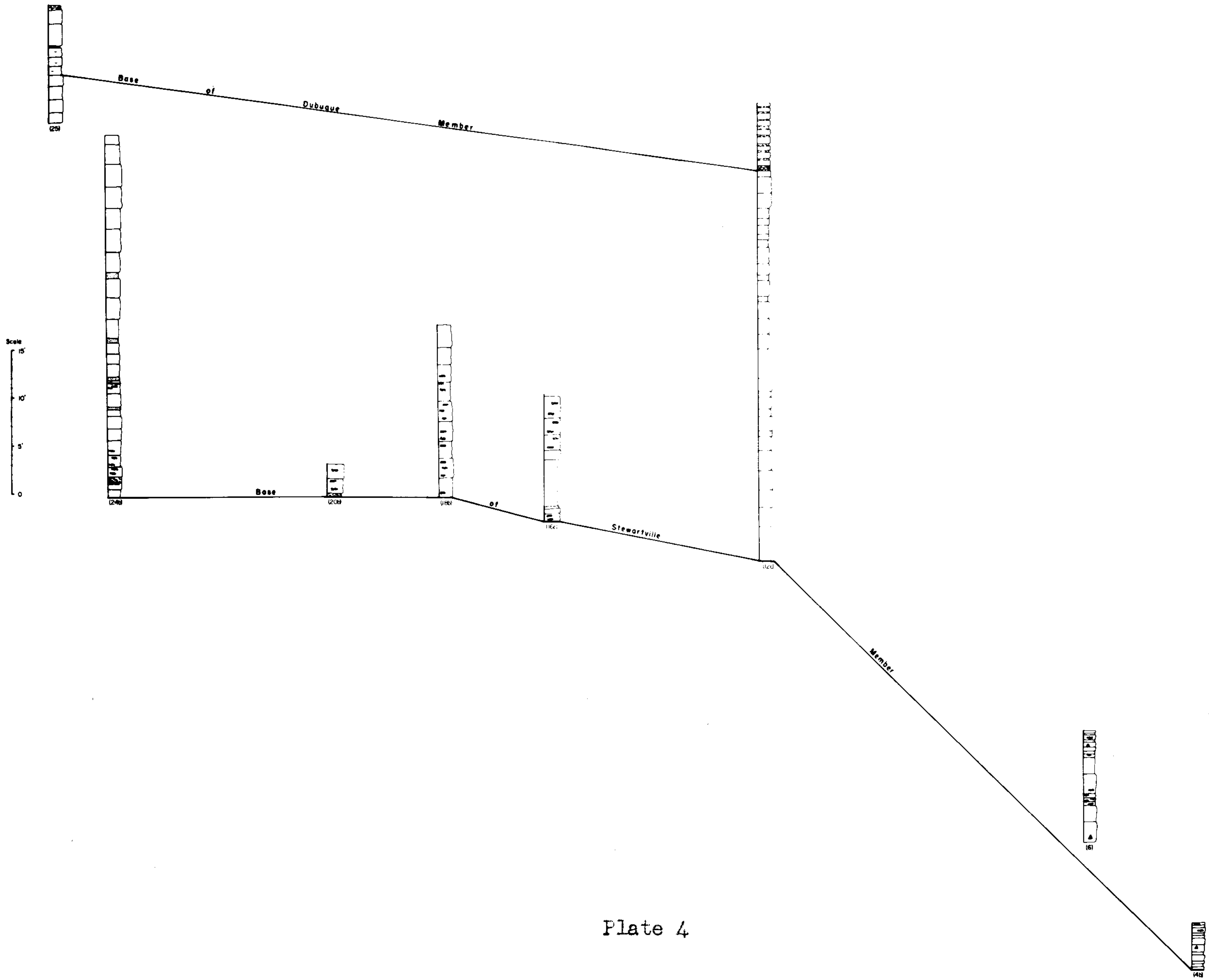
(12b)
(11b)
(7)
(5a)
(4a)

Plate 3


Base of Dubuque Member
Base of Stewartville Member
Scale
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10'
5'
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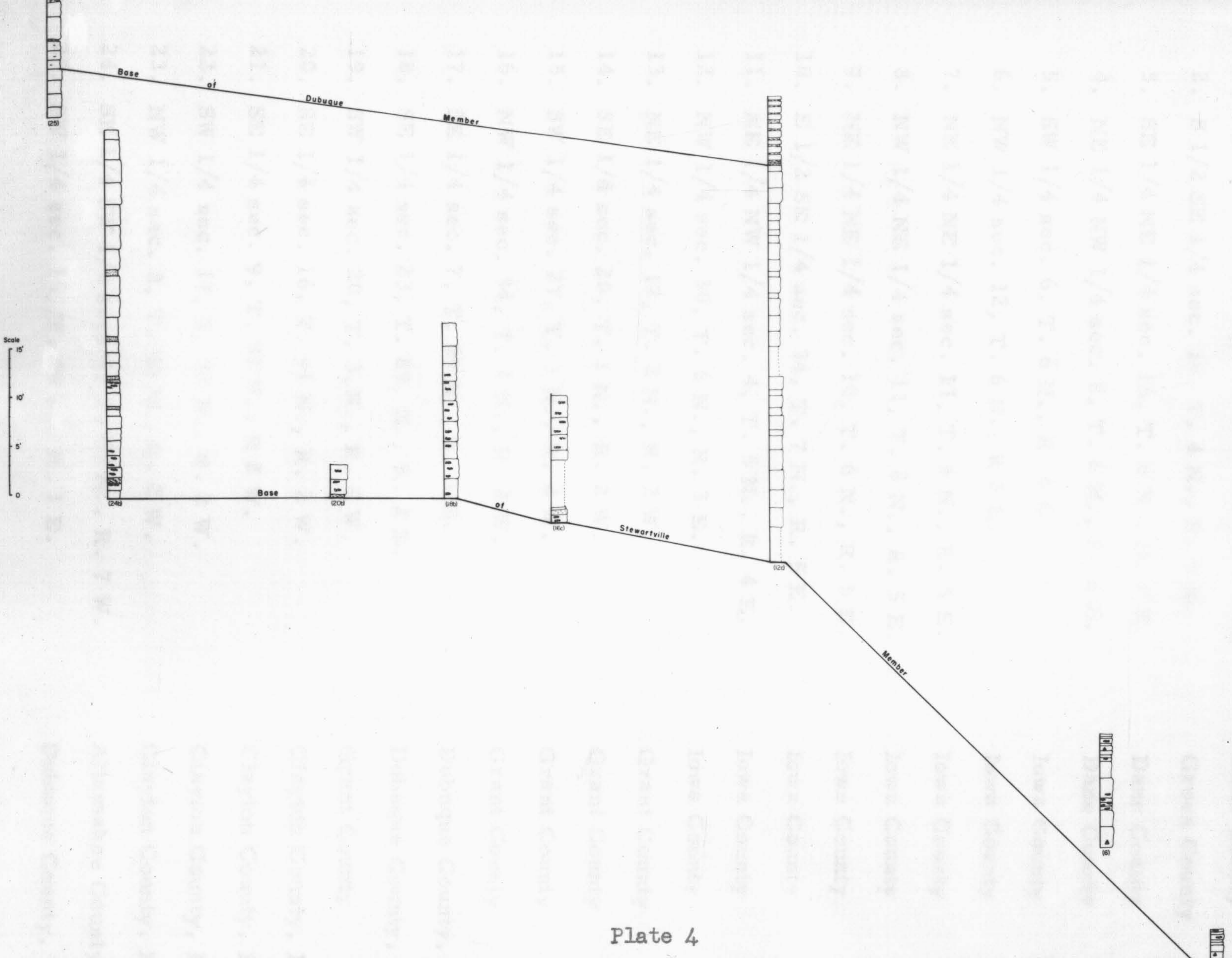
(25)
(24b)
(20b)
(18b)
(16c)
(12d)
(6)
(4b)

Plate 4


Scale
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10'
5'
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(25)
(24d)
(20d)
(18b)
(16c)
(12d)
(6)
(4b)
Base of Dubuque Member
Base of Stewartville Member

Plate 4

LIST OF LOCATIONS

1.	NE 1/4 NE 1/4 sec. 23, T. 6 N., R. 7 E.	Dane County
2.	S 1/2 SE 1/4 sec. 14, T. 4 N., R. 7 E.	Green County
3.	SE 1/4 NE 1/4 sec. 16, T. 6 N., R. 6 E.	Dane County
4.	NE 1/4 NW 1/4 sec. 8, T. 6 N., R. 6 E.	Dane County
5.	SW 1/4 sec. 6, T. 6 N., R. 6 E.	Iowa County
6.	NW 1/4 sec. 12, T. 6 N., R 5 E.	Iowa County
7.	NE 1/4 NE 1/4 sec. 11, T. 6 N., R. 5 E.	Iowa County
8.	NW 1/4 NE 1/4 sec. 11, T. 6 N., R. 5 E.	Iowa County
9.	NE 1/4 NE 1/4 sec. 10, T. 6 N., R. 5 E.	Iowa County
10.	E 1/2 SE 1/4 sec. 34, T. 7 N., R. 5 E.	Iowa County
11.	NE 1/4 NW 1/4 sec. 4, T. 5 N., R. 4 E.	Iowa County
12.	NW 1/4 sec. 30, T. 6 N., R. 3 E.	Iowa County
13.	NE 1/4 sec. 12, T. 2 N., R. 2 W.	Grant County
14.	SE 1/4 sec. 20, T. 1 N., R. 2 W.	Grant County
15.	SW 1/4 sec. 27, T. 1 N., R. 2 W.	Grant County
16.	NW 1/4 sec. 34, T. 1 N., R. 2 W.	Grant County
17.	SE 1/4 sec. 7, T. 89 N., R. 3 E.	Dubuque County, Iowa
18.	SE 1/4 sec. 23, T. 89, N., R. 2 E.	Dubuque County, Iowa
19.	SW 1/4 sec. 20, T. 3,N., R. 5 W.	Grant County
20.	SE 1/4 sec. 16, T. 91 N., R. 2 W.	Clayton County, Iowa
21.	SE 1/4 sec. 9, T. 91 N., R 2 W.	Clayton County, Iowa
22.	SW 1/4 sec. 17, T. 92 N., R. 2 W.	Clayton County, Iowa
23.	NW 1/4 sec. 8, T. 92 N., R. 2 W.	Clayton County, Iowa
24.	SE 1/4 SW 1/4 sec. 4, T. 97 N., R. 7 W.	Allamakee County, Iowa
25.	SW 1/4 sec. 16, T. 89 N., R. 1 E.	Dubuque County, Iowa

Approved by L. R. Laudon

Date 6-1-58