SUBSURFACE GEOLOGY AND STRATIGRAPHIC ANALYSIS OF THE BAYPORT FORMATION IN THE MICHIGAN BASIN

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ABSTRACT

SUBSURFACE GEOLOGY AND STRATIGRAPHIC ANALYSIS
OF THE BAYPORT FORMATION
IN THE MICHIGAN BASIN

By

Yaghoob Lasemi

Rocks of the Bayport formation have been analyzed to determine the sedimentation and stratigraphic relation of this almost unexamined formation of the Michigan Basin. Samples from 202 wells, which are the basic tools for the analysis of this formation, were studied to present a picture of the environments of deposition. The formation is subdivided into three units on the basis of lithology and fossil-rich zones. Isopach and lithofacies maps of the formation and isopach-limestone/dolomite ratio maps of the subdivisions are bases for determining the sedimentation processes. The rocks of the upper and lower units were deposited in intertidal or lower supratidal environments. These two units are composed of predominantly microcrystalline dolomite which is deposited under a warm climate with high evaporation. Dolomitization occurred shortly after deposition of the lime or aragonite muds.

The middle unit was deposited after a major transgression and is characterized by ostracodal biomicrosparite

or calcareous sandstone in the lower and upper parts and by a biosparite with normal marine fossils in the middle. Secondary dolomitization in a few places has produced medium-coarse crystalline dolomite with clear crystals. The lithology indicates that the formation was deposited in a stable environment.

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INTRODUCTION

The Bayport formation is of Upper Mississippian age and forms a part of the Grand Rapids Group in the Michigan Basin area. Studies to date regarding the formation either have been restricted geographically or covered regionally in very little detail as part of a broad stratigraphic interval. None of the studies gives adequate information of the regional picture and depositional environment of this formation. The present study attempts to analyze the lithology and distribution of the Bayport formation to identify and describe any facies present and their depositional environment. Observations have been made concerning rock types, contact relationships with adjacent units, dolomite distribution, clastic ratios, sand-shale ratios, and facies relationships.

Well cuttings from the Department of Geology, Sample Library and the Michigan Geological Survey have been the basic data source. Very few mechanical logs exist for this stratigraphic interval and none was available for the wells for which there are samples.

Also because the stratigraphic position of the Bayport is higher than most oil and gas targets, no coring has been done and cuttings have not been collected for most of the wells. However, the writer examined samples from 202 wells which served as a reasonable data base for a structural and stratigraphic regional framework study of the Bayport formation.

PREVIOUS WORK

Rocks of the Bayport formation have been described by several early workers including Lane (1899, 1906, 1908), W. M. Gregory (1912), Smith (1914), Alen *et al.* (1917), Newcombe (1933), Eddy (1936), and Martin (1937).

Lane (1906) defined the Bayport as being the upper part of the Grand Rapids Group, and consisting of light-colored high-grade limestone and white sandstone. Newcombe (1933) indicated that the Bayport formation includes alternating limestone, dolomite, sandy limestone and sandstone, with a thickness range of 0-100 feet. Cohee (1951) displayed isopach and structure maps of the Carboniferous System of the Michigan Basin including the Bayport formation. McGregor (1953) described the general lithology of the Bayport formation as light to dark gray shale, bluish limestone and dolomite with some chert and a few lenses of sandstone. He displayed isopach, sand-shale ratio, percent carbonate and percent evaporite maps of the Grand Rapids Group (Michigan plus Bayport formations) but did not treat the Bayport individually or in detail.

Bacon (1971) made the most detailed study to date of the Bayport formation but restricted his study to the

Wallace Stone Company Quarry at Bayport where he concluded that the formation was deposited in a sabkha environment.

REGIONAL STRATIGRAPHY

The Bayport limestone[1] (referred to as "formation" herein) was named by Lane (1899) for outcrops at Bayport, Huron County, where it is quarried. It lies locally with disconformity upon the Michigan formation which consists of shales, anhydrite, gypsum, sandstone and dolomite.

Rocks of Pennsylvanian age (Parma sandstone and Saginaw formation) unconformably overlie the formation and fill the irregular surfaces which are the result of the post-Bayport erosional unconformity. The formation was divided by the writer into three units throughout the Michigan Basin. The lower unit (A) is very irregular in thickness and is predominantly dolomite with chert and interbedded sandstone. The middle unit (B) is a fossiliferous limestone with diverse fossils and can be traced in all places in the Basin. It has been used as a marker bed to correlate the rock units of the formation. The upper unit (C) is similar to the lower unit, consisting of dolomite, chert and sandstone lenses. Details of these units will be considered later.

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[1]This study shows that the Bayport limestone (as described by Lane) contains considerable amounts of dolomite, sandstone, and shale also. Therefore the name formation has been used herein.

The Bayport formation is believed (Newcombe, 1933, and Weller *et al.*, 1948) to be Meramecian in age and equivalent to the lower part of Maxville limestone of Ohio, St. Genevieve and St. Louis limestone of the Mississippi Valley section. Oden (1952) studied the brachiopods of the Bayport and pointed out that they are the same species that have been found in the St. Louis and St. Genevieve limestones (chert is also present in the St. Louis limestone). According to Kay *et al.* (1965, p. 240-244), the Meramecian Sea spread over the Cincinnati Arch and warm, shallow water extended from West Virginia to the Mississippi Valley area and Michigan. The fossiliferous limestone of the middle (B) unit is present along the margin of the Basin inferring that this unit of the Bayport at least, was connected to correlates in Ohio, Indiana and Illinois. The Chester Series is not believed to be represented in the Basin because of non-deposition or post-Mississippian erosion. The correlation table of the Bayport formation is shown on page 7.

Table 1. Correlation table of the Bayport formation (Modified from Weller, J. M. *et al.*, 1948).

Standard Sec. Upper Miss. Valley	Michigan		Illinois Monroe Co.	Ohio South Central
Chesterian			Chesterian Series	
Meramecian			St. Genevieve ls.	Maxville ls.
	Grand Rapids Gr.	Bayport ls.	St. Louis ls.	
		Michigan Fm	Salem ls.	
			Warsaw ls.	
Osagian			Keokuk-Burlington ls.	Waverly Gr.
	Marshall Gr.		Fern Glen fm.	
Kinderhookian	Coldwater Sh.			
	Sunbury Sh. Bera ss.			
	Bedford Sh.			Ohio Sh.
	Antrim Sh.			

DETAILED STRATIGRAPHY

The Bayport formation was subdivided into three units with control based on the middle unit (B) fossiliferous limestone. This limestone is traceable throughout the Michigan Basin.

Description of Unit A (Lower)

The A-unit consists of brown to light brown and buff microcrystalline dolomite. It contains a few anhydrite nodules at the base and some pore-filling gypsum crystals present in the dolomite. The dolomite is cherty in most places and quartzose sand grains are embedded in the dolomite in some localities. Occasionally near the center of the Basin, the unit is composed of a gray-dark gray limestone (micrite). The dolomite is interbedded with quartzose sandstone which is in the range or zero to several feet in thickness. The sandstone is grayish white, fine to medium grained, sub-angular to rounded with some frosted quartz grains. It is mostly friable but in some places cemented by dolomite or earthy gypsum. The sandstone is lenticular and the thickness changes rapidly from a few inches to several feet in a few miles. Both sandstone and dolomite have spots filled locally by glauconite. Thin beds of greenish gray to gray and dark-gray shale are also present in the unit, mostly in the western part of the Basin. In the south, east and a few places in the north, the middle or lower part of the unit is replaced by a sequence with upward decreasing grain size from medium-coarse grained, sub-angular-rounded quartzose sand, to fine-grained sand, silt and finally blue-gray silty clay. This is a very local feature and may change to dolomite in the adjacent section or township. Greenish-gray claystone is also present in a few places interbedded with dolomite.

Except for a few silicified ostracods and some stromatolites in the dolomite, no other fossils have been found in the unit. In a few places near the base of the unit are quartz pebbles and dolomite pebbles or coarse-grained sandstone, possibly indicative of a disconformable relationship with the underlying Michigan formation. The contact is usually readily chosen and A-unit lithology is contrasted to the anhydrite, gypsum and micaceous shale of the Michigan formation. In a few places the unit is absent and the middle unit rests with clear disconformity on the Michigan formation. The upper contact is conformable and sharp and is overlain by the fossiliferous limestone of the middle unit.

Description of Unit B (Middle)

This unit in most places starts with fine sandy grayish-brown to tan, finely crystalline limestone with an assemblage of fossils. Other than for a few fine-grained, angular quartz grains the limestone is quite pure in most places showing little insoluble residue. However, it does become shaly to the west and northwest in the Basin. Near the top of the unit fine quartz sandy limestone reoccurs and thin beds of gray to dark gray shale are also present as tongues comprising up to 20 percent of the unit. The limestone is interbedded with light brown medium sucrosic dolomitic limestone or dolomite in some localities. In the latter instance the criterion for distinguishing the B-unit from the A- and C-units would be the occurrence of a few undolomitized crinoidal stems in the B-unit. The limestone contains a fossil zone, persistent throughout the Basin, consisting predominantly of crinoids, ostracods, foraminifera (*Endothyra*), echinoid spines, occasional bryozoan brachiopods and corals. There is no evidence of transportation of the fossils. These fossils which form the framework of the rock are cemented by a gray brown, finely crystalline sparry calcite (biosparite of Folk, 1959).

Chert is less than in the lower unit and when present consists of white-gray and gray-brown nodules which, on outcrop, often show fossil fragments or bulbous entities (algal according to Bacon, 1971) which serve as nuclei. Also burrow-like tubes often penetrate the nodules as well as the host rock and the possibility of worm borings being present also cannot be ruled out. Glauconite also is present in the limestone and frequently in the center of the chert nodules, where vugvlar at the center, or in the tubes, suggesting a reducing condition provided by the organic nuclei.

The unit in other places, mostly in the north, south and east parts of the Basin, starts with a grayish-brown to light brown, finely crystalline sparry calcite facies with ostracods (biosparite). This facies changes to crinoidal limestone upwards. At the top of the unit, the same ostracodal limestone as at the bottom of the unit is present (for example, T19N-R7W-24). In a few places, there is no middle fossiliferous limestone and the whole unit is composed of ostracod limestone which is quite pure, yielding only traces of insoluble residues.

Description of Unit C (Upper)

The C-unit is partially or entirely eroded along a post-Mississippian erosional unconformity (Fig. 4). When present, it is composed of gray to dark gray limestone (micrite) interbedded with brown to light brown dolomite micrite (landward) and finally grading into light brown to buff limy dolomite or dolomite micrite. The dolomite is partly quartz sandy and pyritic and has a few pore-filling gypsum crystals. Both dolomite and limestone are cherty but most of the chert is present in the dolomite.

Lenses of gray to gray brown, fine to medium grained subangular to subrounded quartzose sandstone are present in the unit and are mostly friable and in some places cemented by dolomite, calcite or earthy gypsum. There are also some frosted quartz grains in the sandstone. Thin beds of gray to greenish gray and brownish red shale are also present as tongues in the unit. The lower contact is conformable with the middle unit, and the upper contact occurs at the pronounced pre-Pennsylvanian disconformity. The Parma ss. or Saginaw formation of Pennsylvanian age fills the irregular surface of the Bayport and quartz, chert and dolomite pebbles occur at the contact in most places.

DISTRIBUTION AND THICKNESS

The irregular pattern of the total Bayport isopach (Fig. 5) distribution is partly because of post-Mississ-ippian erosion. Attempts were made to use the wells which had at least parts of Unit C in the construction of the isopach map. However, those wells showing clearly anomalous thicknesses for Unit C along the disconformity were eliminated and the isopach maps for Unit C and total Bayport were reconstructed from more meaningful data. In order to assure full thickness development in Units B and A, only those wells showing Unit C as present were used to generate these maps.

Unit A Isopach

The isopach of A-unit (Fig. 2) indicates several local basins which were present at the time of deposition, or produced by subsidence at the time of deposition. These basins are in approximate north-south and east-west directions, and in both ovate and elongate shapes. The thickest parts of the unit show the area of maximum sub-sidence in respect to adjacent shallow shelf area at the time of deposition. The isopach lines show that the

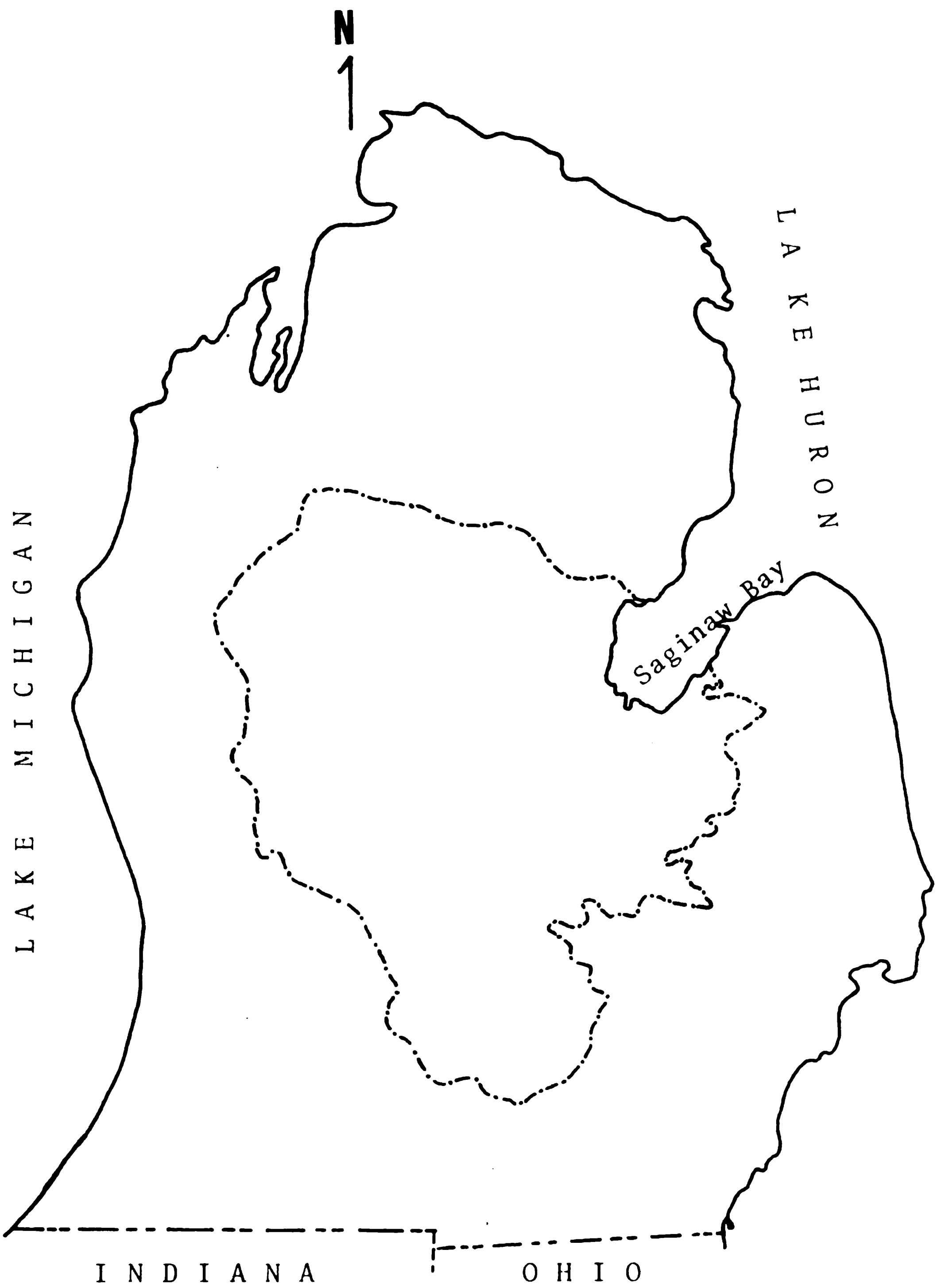

Figure 1. Index map of the study area.

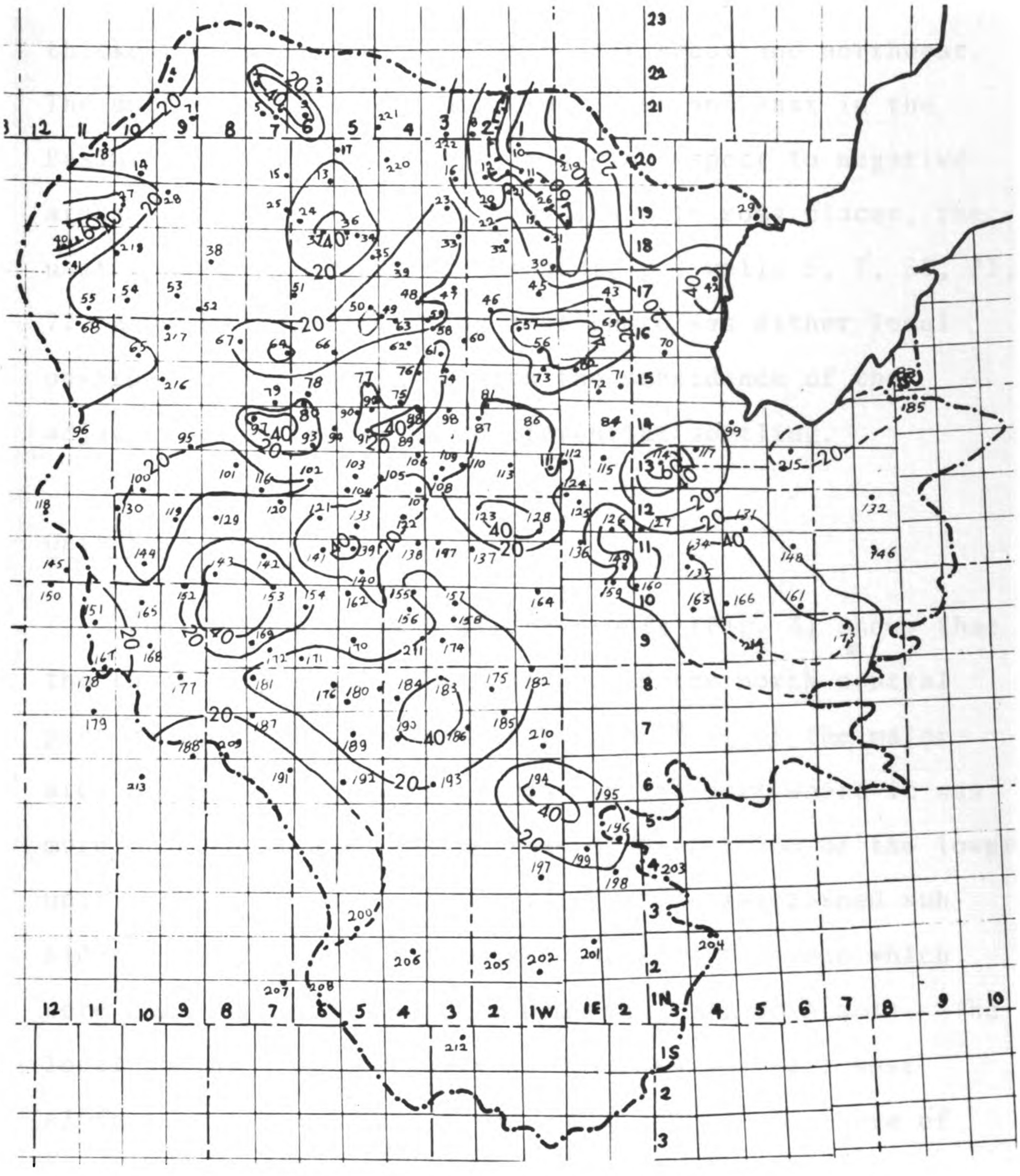

Figure 2
Isopach Map
of
Unit A of
Bayport Formation
in the
Michigan Basin

scale
5 0 10 20 30 mi.

Contour interval 20 ft.

Y. Lasemi July 1975

•16 Control well

40 Thickness line

Bayport subcrop

thickest areas are to the north, northeast and northwest. The unit thins to the south, southeast and east in the Basin. These were the high areas in respect to negative areas of the subsiding local basins. In some places, the unit thins and finally is absent (e.g., wells 5, 7, 38, 71, 72, Appendix A), indicating that there was either local upwarping contemporaneous with the subsidence of the adjacent areas, or simply differential settling.

Unit B Isopach

The isopach pattern of the B-unit (Fig. 3) shows that the thickest parts of the unit are in the north central part of the Basin, indicating the shifting of the major area of subsidence to the north central part where it was more of a shelf area at the time of deposition of the lower unit. While some of the subsiding areas maintained subsidence after A-unit time others shifted to areas which were shallow at the time of deposition of the A-unit. The local basins show generally north-south and east-west elongation. The major "highs" were similar to those of the A-unit, to the south, the southeast, east, northeast and northwest. The same general randomness of isopach closure is apparent here as in Unit A.

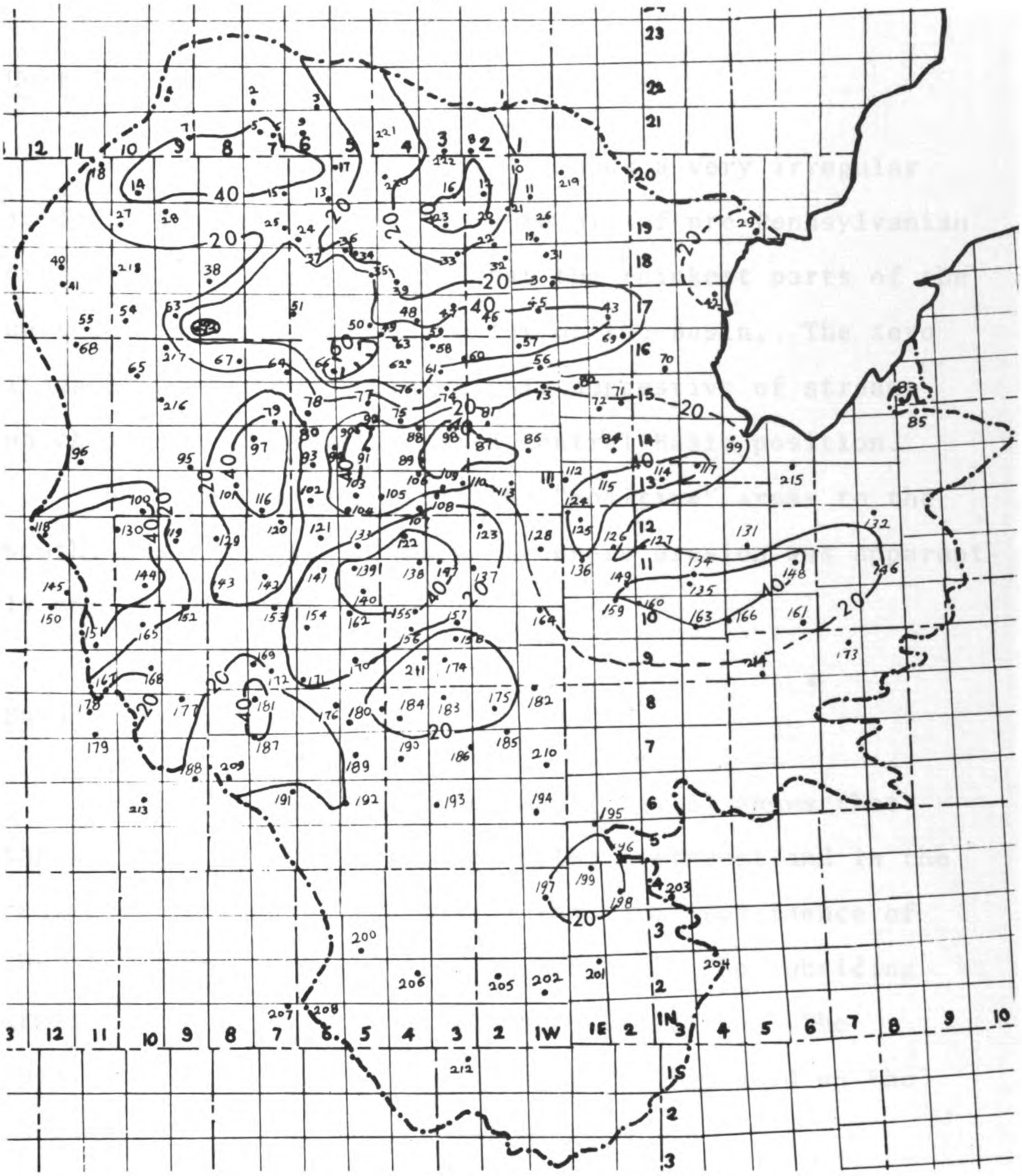

Figure 3
Isopach Map
of
Unit B of
Bayport Formation
in the
Michigar Basin
scale

5 0 10 20 30 mi.

Contour interval 20ft.

Y. Lasemi July 1975

• 16 Control well

40 Thickness line

Bayport subcrop

Unit C Isopach

The C-unit isopach (Fig. 4) shows a very irregular isopach pattern obviously as a result of pre-Pennsylvanian erosion. The isopach shows that the thickest parts of the unit are in the north and center of the Basin. The zero isopach indicates patterns highly suggestive of streams which appear to radiate from a central Basin position.

The C-unit is absent in the "positive" areas to the south, east, northeast and west, where erosion was apparently more pronounced.

Bayport Isopach

The total Bayport isopach map (Fig. 5) shows that the thickest areas are in the north, northwest and in the center of the Basin, indicating the major subsidence of the formation at the time of deposition. The subsiding areas are almost in the north-south direction. The "positive" areas are in the same areas displayed on the isopach maps of the individual units.

The total Bayport isopach does not compare favorably with any one of the subdivision isopach maps, pointing to the general randomness of the general thickness patterns. Thus it appears that there is no definite reflection of any pre-existing intrabasinal structures, faults or folds, that are believed (Prouty, 1972) to have developed earlier in about pre-Meramecian time. The isopach maxima (two)

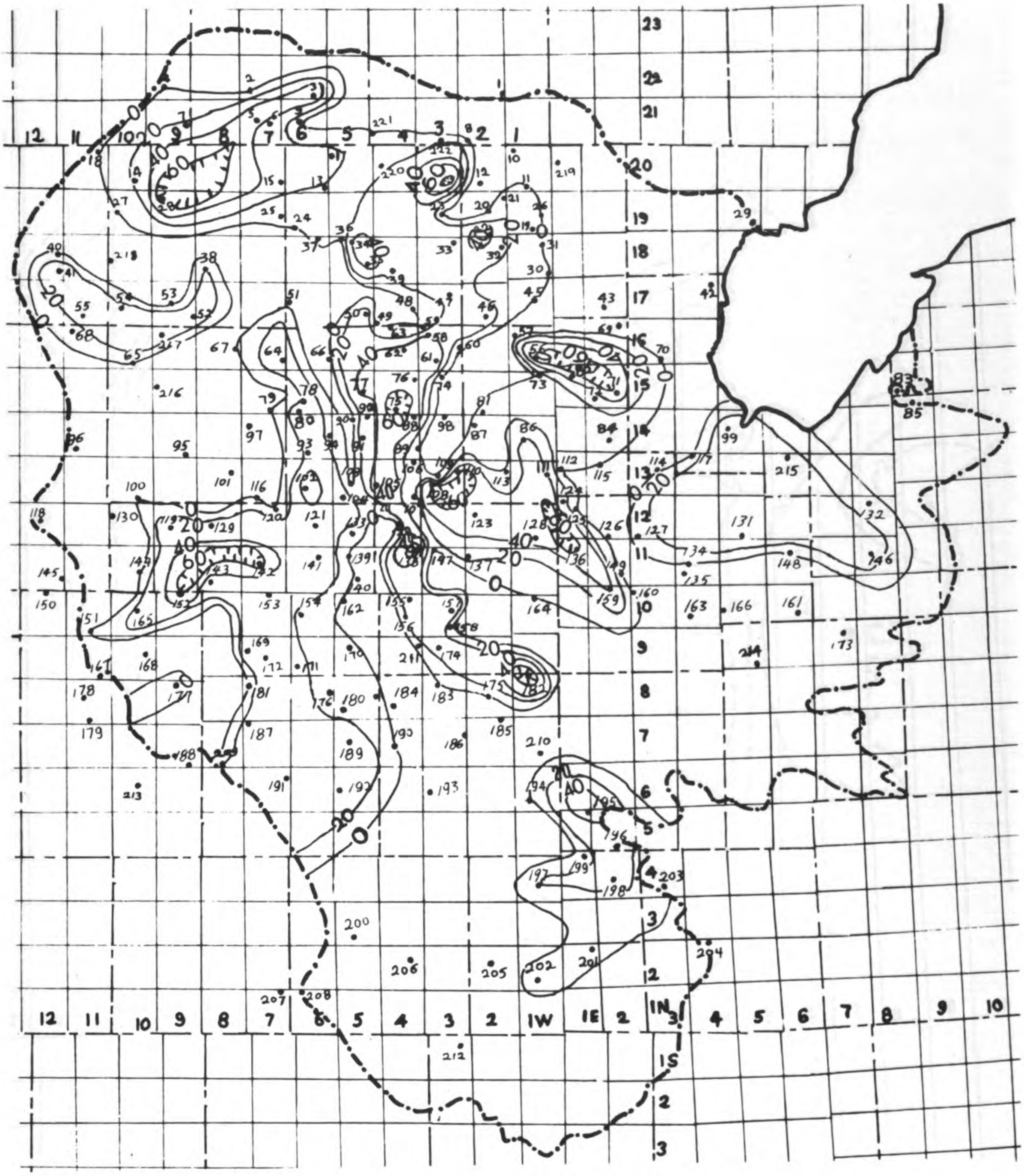

Figure 4
Isopach Map
of
Unit C of
Bayport Formation
in the
Michigan Basin
scale
0 5 10 20 30 mi.

Contour interval 20 ft.
Y. Lasemi July 1975

•16 Control well

0 Thickness line

Bayport subcrop

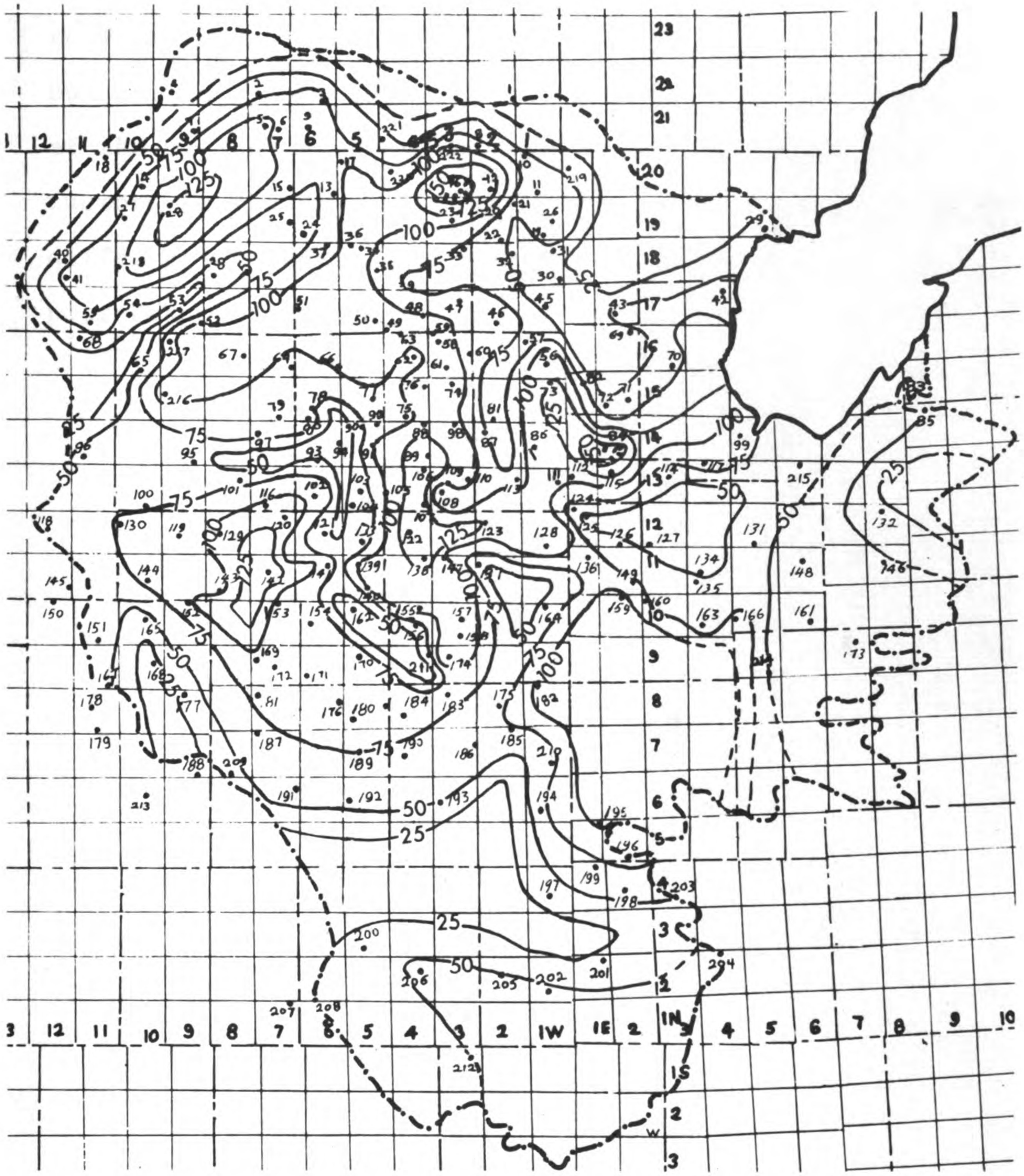

Figure 5
Isopach Map
of
Bayport Formation
in the
Michigan Basin

scale

0 5 10 20 30 mi.

Contour interval 25 ft.

Y. Lasemi July 1975

●16 Control well

50 Thickness line

Bayport subcrop

conform generally to the central basinal depocenter area but are not truly centered nor is there a single "closure" at the present structural center. The most important factors in the Bayport isopach are likely a combination of differential basinal settling and distribution related to post-Bayport erosion.

LATERAL RELATIONSHIPS

To determine the compositional features of the total Bayport formation, the triangle facies map (patterned after Krumbein, 1948; Krumbein and Sloss, 1963; and Sloss, Krumbein and Dapples, 1949) of this unit has been constructed using clastic ratio (sandstone and shale divided by non-clastic) and sand-shale ratio (total sand divided by total shale) lines. The major rock types of this formation are carbonates (dolomite and limestone) with minor amounts of clastics. Therefore the limestone-dolomite ratio maps of the subdivisions of the formation have been constructed to show the lateral relations of these two rock types.

Bayport Facies

For the correct interpretation of the facies of the total unit, only those wells have been used which have at least parts of the C-unit present (in addition to Units B and A). A lithofacies map of the total unit was prepared to assist in interpretations. The map (Fig. 6) shows that the formation is mainly carbonate, with varying amounts of clastics, not exceeding 80 percent in any one area. The map indicates that in small areas (northwest, east and

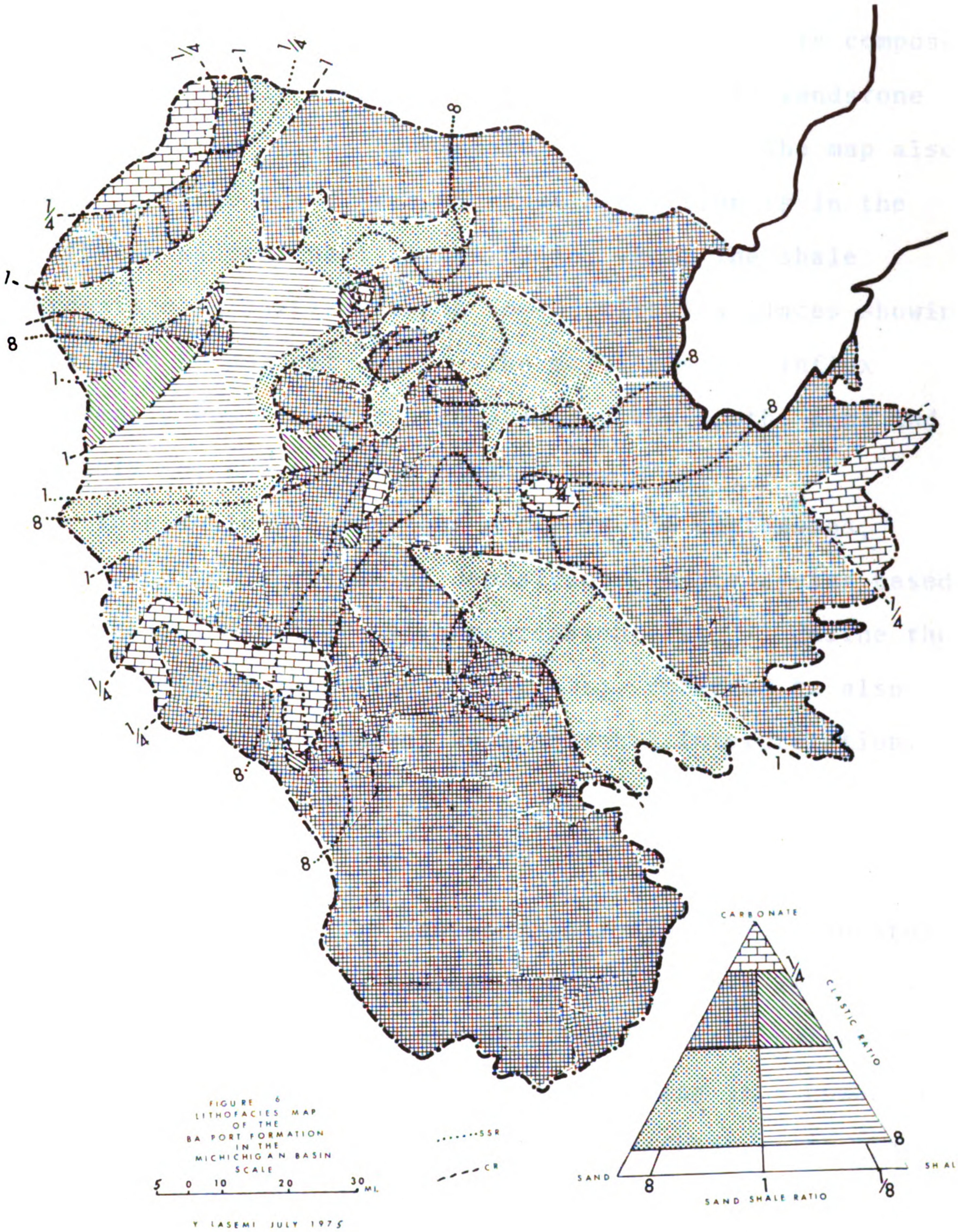

FIGURE 6
LITHOFACIES MAP
OF THE
BA PORT FORMATION
IN THE
MICHICHIGAN BASIN

southwest) the formation includes more than 80 percent carbonate (clastic ratio less than 1/4). Most of the area in the south, east and center of the Basin is composed of carbonates with less than 50 percent quartz sandstone (clastic ratio 1-1/4, sand-shale ratio > 1). The map also shows that the major area of shale deposition is in the northwest central part of the Basin, where the shale percentage is mostly between 50-80, with few places showing less than 50 percent shale. The major clastic influx apparently was from the high areas to the south, east and possibly northwest of the Basin.

Thin shale alternations occur in the carbonates, indicating small cycles of deposition. Major cycles based on regression-transgression-regression (Fig. 7) define the three facies of the Bayport (Fig. 11), referred to also under Geologic History and Environmental Interpretation.

Unit A Facies

Figure 8 shows the facies relationship of carbonates of this unit. The map indicates that the unit is mainly dolomite forming broad unbroken areas near the periphery of the Basin. More basinward and occurring in a number of disconnected "pockets," the dolomite interbeds with limestone and becomes mainly or entirely limestone at the center of these pockets, a relationship to be discussed later.

At some shoreward localities to the east and south in

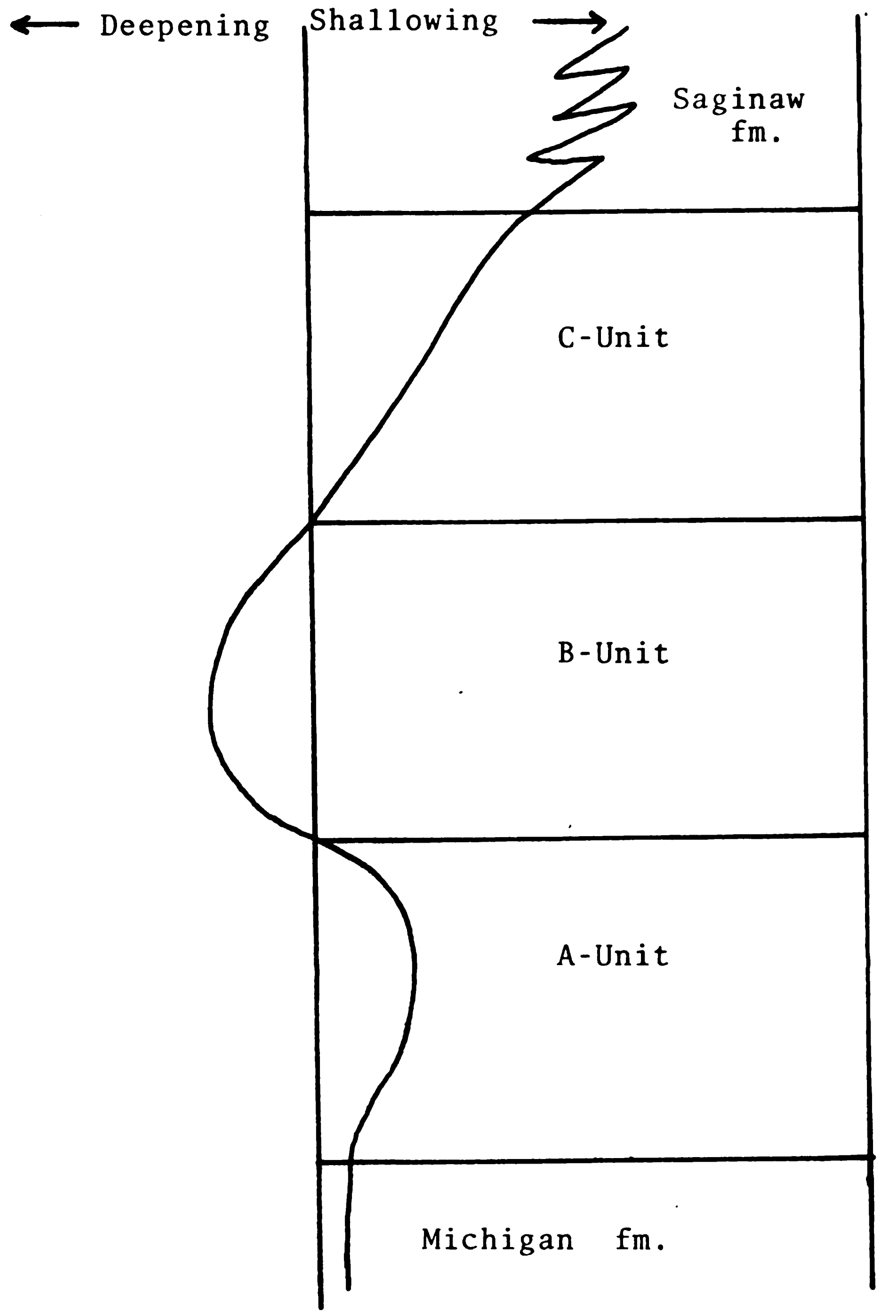

Figure 7. Regressive-transgressive cycles--Bayport formation.

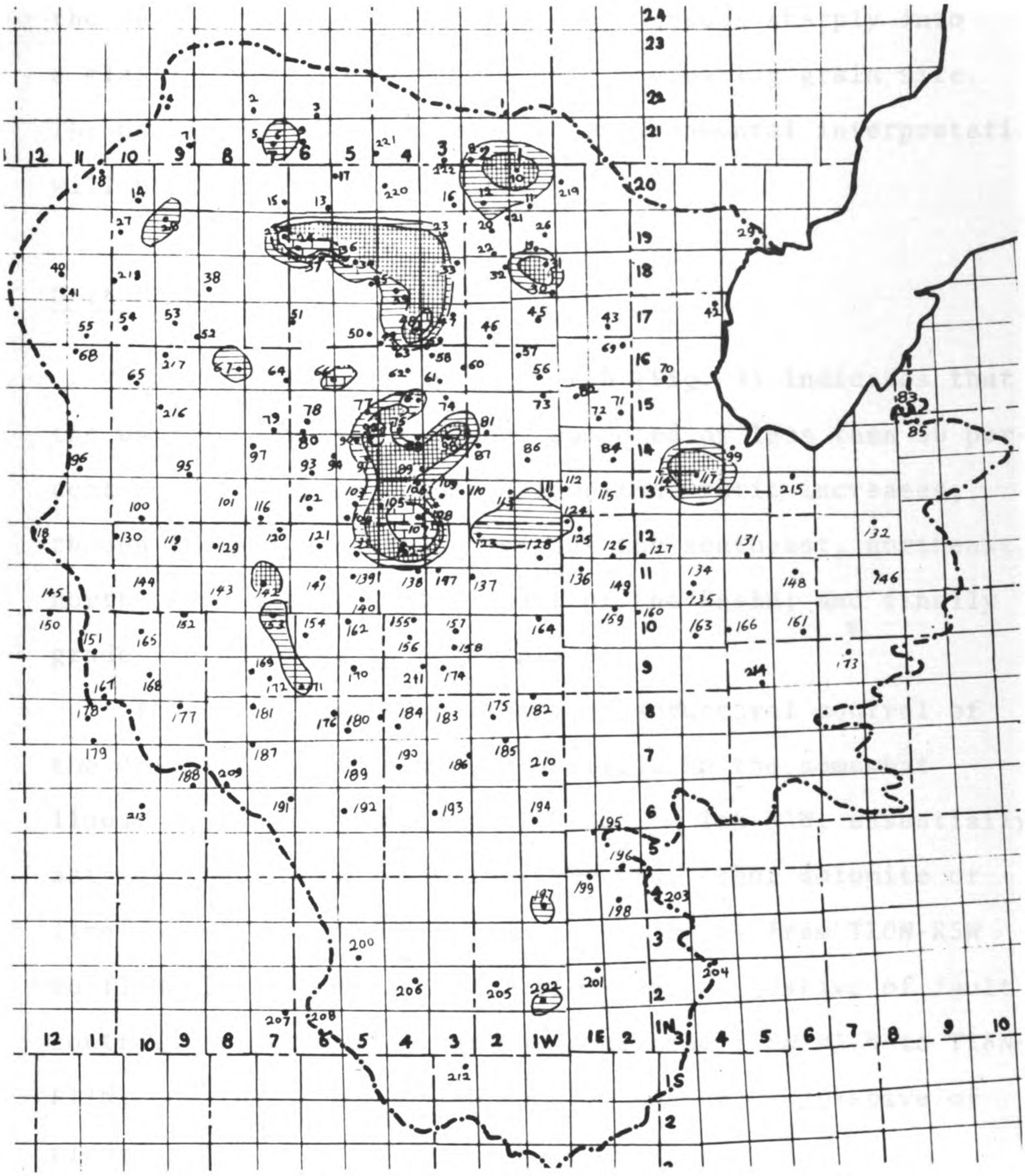

Figure 8
ls.–dol. ratio map
of
Unit A
of
Bayport Formation
in the
Michigan Basin
scale

5 0 10 20 30 mi.

Y. Lasemi July 1975

•16 Control well

Ratio line

Bayport subcrop

ls. [8 | 1 | 1/8] dol.

ls / dol ratio
» 8 ls
1–8 ls.–dol.
1– 1/8 dol.–ls.
« 1/8 dol

the Basin, typical A-unit lithology grades sharply into a clastic sequence showing upward decreasing grain size. The meaning of this sequence in environmental interpretation will be described later also.

Unit B Facies

The lithofacies map of Unit B (Fig. 9) indicates that the unit is mainly limestone, composed of less than 50 percent dolomite. The dolomite/limestone ratio increases, though in isolated areas, towards the southeast, northeast, northwest and east central part of the Basin; and finally grades to dolomite in a few places.

There are some suggestions of structural control of the dolomite distribution, especially in the somewhat linear strip occurring from T1N-R3E to T6N-R1W, essentially astride the Howell Anticline. Several other dolomite or lime-dolomite areas show linear trends, as from T10N-R5W to T12N-R1E, and T10N-R5E to T11N-R3E, suggestive of fault control. Some other occurrences as from T18N-R12W to T18N-R11N, and T19N-R1W to T19W to T19N-R2E are suggestive of plunging fold axes, but could be coincidental.

Unit C Facies

Figure 10 shows the facies distribution of the C-unit as it relates to the post-Bayport pre-Pennsylvanian disconformity. The blank area of the map shows the places

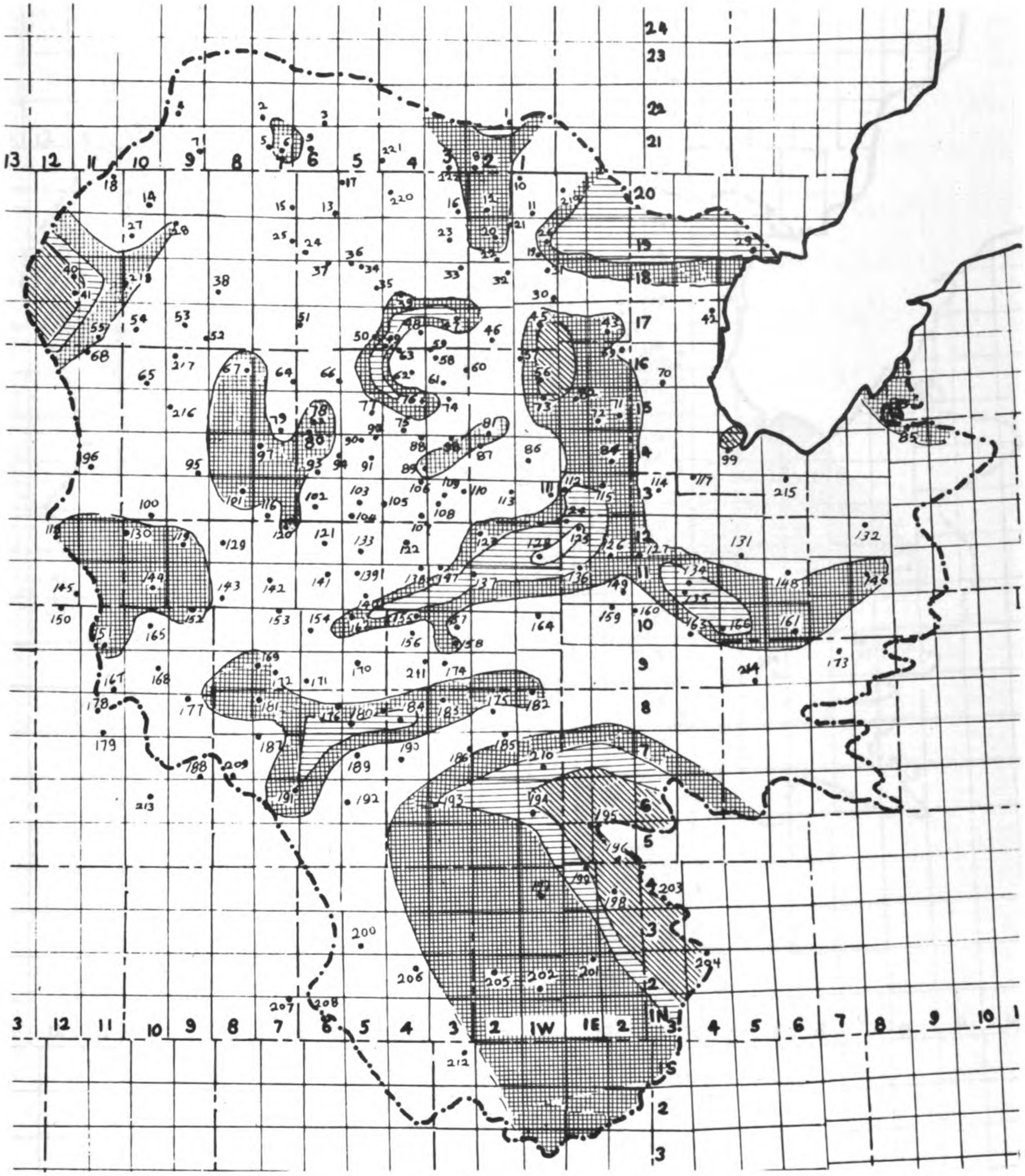

Figure 9
ls. — dol. ratio map
of
Unit B of
Bayport Formation
in the
Michigan Basin
scale

5 0 10 20 30 mi.

Y Lasemi July 1975

•16 Control well

Ratio line

Bayport subcrop

ls. | 8 | 1 | 1/8 | dol.

ls. / dol. ratio
»8 ls.
1–8 ls. – dol.
1 – 1/8 dol. – ls.
« 1/8 dol.

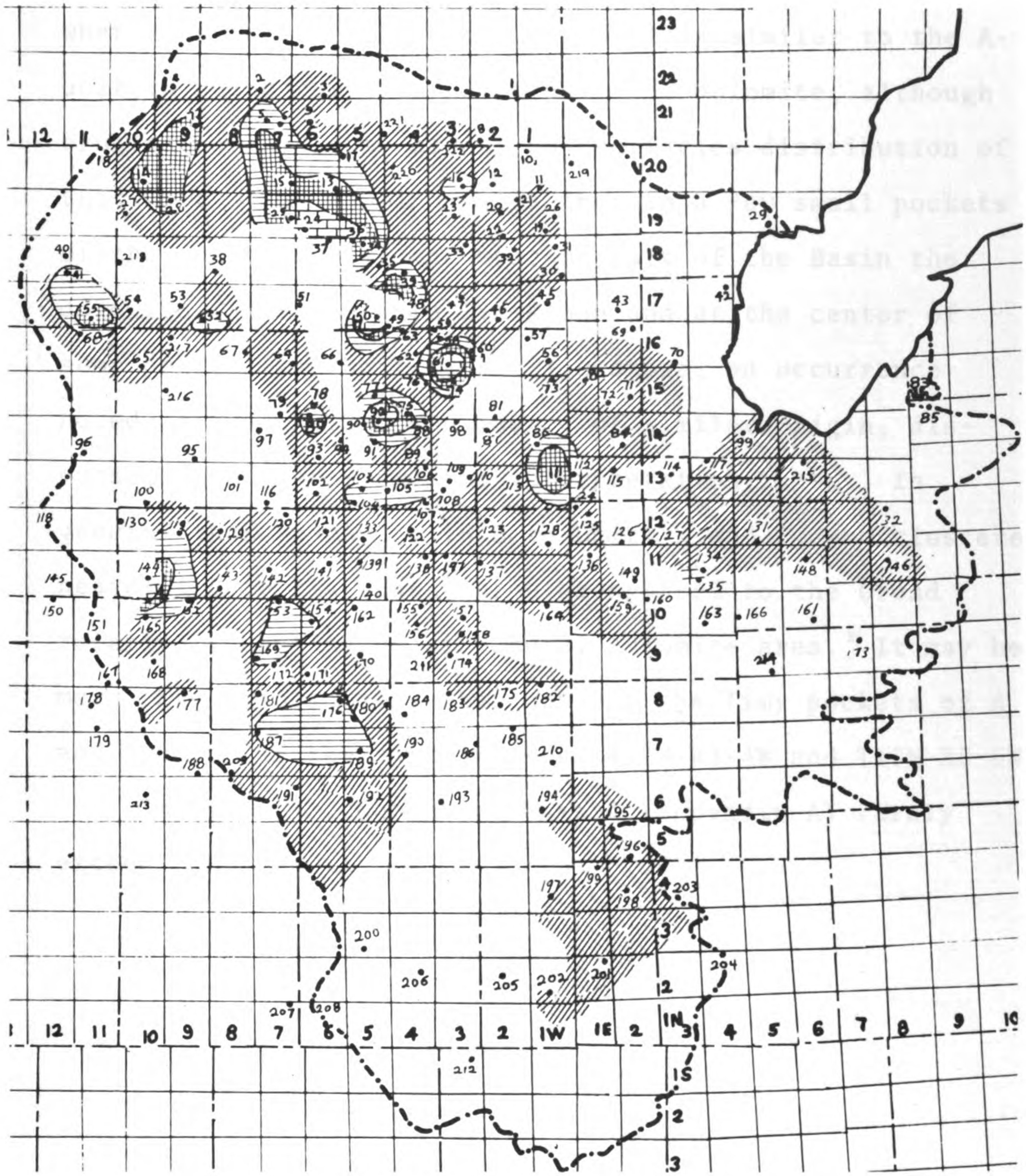

Figure 10
ls./dol. ratio map
of
Unit C of
Bayport Formation
in the
Michigan Basin
scale

5 0 10 20 30 mi.

Y. Lasemi July 1975

•16 Control well
Ratio line
Bayport subcrop

ls. [8 1 1/8] dol.
ls. / dol. ratio

» 8 ls.
1 – 8 ls. – dol.
1 – 1/8 dol. – ls.
« 1/8 dol.

where the unit is eroded. This unit is similar to the A-unit in being composed principally of dolomite, although erosion has had some effect on the facies distribution of this unit. The map indicates that in a few small pockets of the north central and western part of the Basin the dolomite interbeds with limestone and at the center of some pockets the unit is all limestone, an occurrence noted in Unit A, and considered of similar origin, discussed under Environmental Interpretation later. In general these pockets, in both Units A and C, are clustered nearer the central Basin area as opposed to the broad relatively continuous peripheral dolomite area. It may be more than coincidental that some of the limy pockets of A and C occur in the same areas as T17N-R3-4W and T19N-R5-6W.

The clastic content of Unit C (Appendix A) rarely exceeds 50 percent.

GEOLOGIC HISTORY AND ENVIRONMENTAL INTERPRETATION

The sedimentologic association of the Bayport formation would appear to represent the condition of a stable shelf, as proposed by Sloss *et al.* (1948). Lithologic associations of the formation reveal the types of environments that were present during Bayport time.

Bacon (1971) studied the 18-foot section of the Bayport formation in the Wallace Stone Company quarry at Bayport, Michigan. It appears that this section is composed of the upper part of Unit A and part of Unit B of the Bayport subdivisions used herein. Bacon apparently applied the model of Butler (1969) for sabkhas of the southern Persian Gulf, concluding that the entire Bayport has been deposited in a sabkha environment, based on the single section. The study herein is directed towards a sedimentary environmental study of the total Bayport formation in the regional sense and will test several models by different investigators in search of a clear picture of the depositional history of the formation.

Unit A

Deposition of the lower unit began with a slightly less restricted environment in the Michigan Basin area. This terminated the gypsym deposition of the hypersaline lagoon of the Michigan formation. The environment of deposition is suggestive of a tidal flat. Clastics of decreasing grain size upward grade laterally into carbonates. This is particularly noticeable in the south, east and northeast part and into the central Basin area. This type of sequence, referred to as intertidulite by Klein (1971) are deposited in the intertidal environment by tidal processes. The clastic sequence when present is about 5 to 30 feet thick, and has a sharp contact with the Michigan formation or occurs within lower or upper part of the unit. The sequence starts below with fine to medium and coarse quartzose sand and grades upward to fine sand, very fine sand, silt and finally to silty clay. The upper contact is sharp with Unit B or upper part of Unit A. According to Klein, a gradation into finer sediments across the tidal flat shoreward and the textural distribution occurs as a result of high and low tide level. If the tidal flat environment progrades seaward upward gradation to finer will occur. Paleotidal range can be determined from the upward fining sequence of tidal flat clastics. The sand at the bottom represents the low tide; the transition sediment, which is from suspended load and bedload, represents mid-tide; and the clay indicates high tide (Klein, 1971). The sequence shows local progradation of the sea at the time of deposition.

The carbonate of Unit A also represents deposition mainly in a tidal flat environment. The dolomite is micritic and in the most part associated with pore-filling gypsum crystals. Quartz sandstone beds are generally cemented by earthy gypsum. Except for occasional ostracods, fossils are rare in the dolomite. Bacon (1971) recognized algomat associated with dolomite in the Wallace Stone Company Quarry at Bayport. Investigations in recent tidal flat environments by Illing *et al.* (1965), Curtis *et al.* (1963), Lucia (1968), Butler (1969), Shinn (1965) and Deffeyes *et al.* (1965) indicate similar sedimentation in intertidal and lower supratidal environments. Dolomites of intertidal and supratidal origin have been recognized in ancient records by several investigators including Lucia (1972), Laport (1967), Armstrong (1970), Fisher and Rodda (1969), Campbell (1962), Gardner (1971) and many others. Micritic dolomite of A-unit of the Bayport formation is also interpreted as intertidal or lower supratidal carbonate, as does Bacon (1971) at Bayport. The amount of chert increases in this unit which is additional likely evidence of tidal flat sedimentation of the dolomite. The silica may have been deposited either inorganically from the quartz sands brought to the environment by the streams, or organically by silica-precipitating organisms. Gardner (1971) concluded that the chert in the Bois Blanc Formation of the Michigan Basin deposited extensively along the periphery of the Basin. Fisher and Rodda (1969) also showed that, like dolomite, chert is present in a belt marginal to carbonate evaporite lagoon in Texas.

In several disconnected areas of the north central part of the Basin (Fig. 8) the dolomite is interbedded with a gray to dark gray micrite and finally grades to limestone. This limestone, which corresponds to the deeper part of the Basin, indicates conditions of subtidal (marine) environment, which remained undolomitized. The environment of deposition of the dolomite was likely in warm waters with high evaporation rate. The evaporation produced a fluid of much higher Mg-Ca ratio because of the formation of gypsum (Adams and Rhodes, 1960, Deffreyes *et al.*, 1965, and Butler, 1967).

The dolomitization may have occurred according to the seepage refluxion model proposed by Adams and Rhodes (1960). According to this model, the loss of water by evaporation increases the concentration and specific gravity of the remaining brine along with precipitation of gypsum. The heavy hypersaline water seeps slowly downward through the slightly permeable carbonates. During this process the MG^{++} replaces Ca^{++} and high magnesium calcite recrystallizes as dolomite. The limestone of the lower unit and those interbedded with dolomite in the north central part of the Basin are similar to dolomite in having micritic texture, inferring that the dolomite is penecontemporaneous with the limestone and that dolomitization occurred shortly after deposition of the lime or aragonite mud. The hypersaline brine with high Mg-Ca ratio, either could not reach some parts of the lime mud, or evaporation was not high enough to produce high Mg^{++}-Ca^{++} ratio, because of water depth. The latter possibility is strengthened by the occurrence of the limestone in isolated patches which may have been "pockets" or depressed areas of deeper water on the sea floor. This is supported by comparing the A-unit isopach (Fig. 2) to A-unit limestone/dolomite ratio map (Fig. 8). Examples of reasonable correlations between isopach "highs" (low topography) and increased limestone content may be observed in T13N-R3 and 4E, and T20N-R1 and 2W of both maps. Isopach "lows" (higher topography) correlates rather well with increased dolomite areas.

Clastic deposition exceeds carbonate in some areas. The quartzose sand often has dolomite cement which may be the result of dolomitization of pre-existing calcite cement (Blatt *et al.*, 1972, p. 491).

Unit B

A major transgression occurred after a quick rise of sea level in early B-unit time. The B-unit, which is deposited in a marine environment, consists of dominantly limestone with a diverse and normal marine fossil assemblage. At the beginning, quartz sand deposition was predominant in many places, and with additional transgression the environment became suitable for carbonate deposition in which invertebrate forms flourished. In the other parts of the Basin sedimentation began more quietly with lime muds. The only fossil in this limestone is well preserved ostracods with thin shells and no ornaments, indicative of a deeper marine environment (Heckel, 1969). This is now a biomicrosparite with the ostracods in a very finely crystalline sparry calcite cement. As there has been no transportation to wash away the microcrystalline ooze matrix, the sparry calcite cement may have been the result of recrystallization of the microcrystalline calcite or inversion of aragonite ooze (Folk, 1959). The ostracod biomicrosparite or calcareous sandstone of the lower part grades upward to a gray-brown-tan, generally finely crystalline fossiliferous limestone (biosparite). As there is no evidence of transportation and sorting of the fossils, the microcrystalline calcite ooze, primarily deposited as a cement, may also have altered to finely crystalline sparry calcite after recrystallization. In some localities recrystallization has affected both the cement and the fossils such that the entire rock is a medium to coarsely crystalline limestone in which, except for a few crinoid stems, all fossils have been destroyed. The fossil assemblage of this unit contains crinoids, foraminifera (*Endothyra*) ostracods, echinoid spines, bryozoans, corals and brachiopods, all of marine habitat.

The middle part of the B-unit indicates the time of maximum stand of the sea level which brought the circulation of normal sea water to other basins, as in Illinois, Indiana, Ohio and the Appalachian area. According to Matthews (1974, p. 257), rising water creates more living space between the bottom and surface of the water, while at the same time clastic influx is ceased by trapping in the extuaries and alluvial environments. Since the rising water was not fast, the character of the carbonate deposition did not change and the organisms could flourish along with rising sea level. The presence of thin beds of shale or quartz sand in the limestone indicates fluctuations at the time of deposition. The presence of ostracod limestone and calcareous sandstone near the close of Unit B similar to those of the lower part of the unit, indicates gradual lowering of the sea level. Near the top of the unit in the Cheney Quarry at Bellevue, Michigan, is a zone of cup corals. The same coral zone, apparently, was recognized by Bacon (1971) in the quarry at Bayport, inferring a warm shallow marine environment near the end of Unit B. The presence of fossil fragment serving as nuclei in the chert nodules of Unit B infers a secondary origin for the chert. Glauconite is found also rather commonly with the organic nuclei of the chert and as casts in limestone, inferring a reducing condition for the environment. Both chert and glauconite suggest a quiet environment with no clastic material at the time of deposition.

In some places the limestone has been dolomitized (Fig. 9) resulting in a medium-coarse crystalline mosaic of saccharoidal dolomite or dolomitic limestone. In some localities the dolomite rhombs are large and can easily be seen under the binocular microscope (e.g., T4N-R1W-Sec. 22). The dolomite rhombs are yellowish brown, transparent and sometimes are interlocking medium-coarse sucrosic, sparry crystals. The transparent crystals are similar to those of limpid dolomite of Folk and Land (1975).

Several observations can be made concerning dolomitization in the B-unit. A few of the lime-dolomite beds have linear traces which may reflect some known structures (which may be faulted), as indicated earlier under Lateral Relations. Oil production from linear structures in the Ordovician and Devonian long have been attributed to fractures and dolomite porosity, with dolomitization clearly epigenetic in origin. Linear structures in Mississippian limestones similarly could be faulted with the faults serving as channelways for secondary dolomitization. The isolated patterns of dolomite-rich (Mg^{++}-rich) rocks of the B-unit, apparently are unrelated to thickness (Fig. 9) or proximity to the ancient shorelines and therefore appear related to faults and fractures with dolomitization being epigenetic.

Some of the magnesium may be related to post-Bayport erosion and descending groundwater. The localized distribution of magnesium-rich areas (Fig. 9) could then be related to the loci of fault channelways and localization of high Mg^{++}-charged descending groundwater. This high-magnesium water source could have originated in standing bodies of water, as lagoons, where fresh water may be mixed with sea water -- hypersaline or normal (Folk and Land, 1975), which causes the Mg/Ca ratios to remain high, but lowers the salinity and crystallization rate. This diluted solution is then transported to the limestone of the B-unit. The non-dolomitized area of Unit B indicates that either the magnesium-rich solution was not available, or by the time it reached the B-unit, the magnesium was already consumed, and the crystalline limestone was not dolomitized.

Another possible source for the origin of the dolomitizing fluids could be groundwater/seawater mixtures (Folk and Land, 1975; Badiozamani, 1973). Such a process may have yielded the "limpid" dolomite that would appear to characterize the B-unit.

Unit C

Because of similarity of carbonate associations of the C-unit with that of the A-unit it is considered here that they were developed under similar conditions and had parallel histories. The only apparent difference in the two is the sucrosic dolomite (like that in Unit B) found occasionally in Unit C. The sucrosic dolomite may have been formed by one or more of the methods described for dolomitization of the B-unit.

Bayport Clastics

As indicated before, the sandstone of the Bayport formation is quartzose and may be either well cemented or friable. The grains are usually subangular to rounded, but occasionally show high sphericity, indicating possible reworking of the grains prior to deposition, or they may have been derived from older formations. The infrequent highly spherical frosted quartz grains probably were handled by wind at some stage in their history.

Typically the Bayport quartzose sands vary appreciably in their concentration. When sand grain movement was in the form of collective movement, carbonate sedimentation ceased; on the other hand the individual movement of sand grains might not have any effect on carbonate deposition (Payne, 1942).

The quartz grains of the B-unit are in the form of angular, very fine grained sand or silt, indicating that the grains could be carried by suspension or by saltation during stormy seasons.

The shale of the Bayport is greenish gray, dark gray and black. Though the clay minerals were not investigated qualitatively, the green color could well reflect the rather common glauconite in the Bayport, or simply the inferred reducing conditions with iron in the ferrous state. The dark to black color of the shale represents finely disseminated carbonaceous material, or otherwise finely disseminated pyrite or marcasite observed commonly as fine euhedral crystals in the carbonate groundmass. Also, secondary crystal masses are found commonly throughout the carbonates as fillings of vugs and other porosity. For the thin shale partings in the limestone, Heckel (1969) suggested either a rapid influx of fine clastics to the environment, where both carbonate and skeletal material were depositing slowly, or a cessation of carbonate deposition for a longer period of time. Of the two the latter might more closely fit the situation for the shale in the Bayport, as the carbonate is shaly in some areas, especially to the west in the Basin. The shale-limestone alternations may also reflect sea level fluctuations as a part of smaller cycles within the major cycles inferred by the transgressions and regressions that defined the three units of the Bayport formation (Fig. 7). The lagoonal environment of the Michigan formation gave way to the tidal flat deposition of the A-unit. Then after a local progradation, the major transgression occurred and resulted in the more open, marine B-unit. At the end of B-unit time progradation (recession) occurred with a return to a similar condition to the A-unit in C-unit time.

The source of the clastics in the Bayport poses a problem because of the patchy occurrence of some of the shale and sand bodies. The sand-shale ratio of the Bayport lithofacies map does not show a clear regional directional trend, inferring irregular distribution by currents along tidal flats. Unit A sandstone near the base (Fig. 11, A-A') represents one of the more continuous bodies indicating likely a sheet sand along the recessive shorelines, with the source to the east. Probably the same sand crosses the basin along the north-south profile (B-B'). Concentrations of sandstone and the principal shale body occurs near the west side of the structural basin, suggesting a possible source from that direction. The north-south section (B-B') shows similar clastic concentrations to the north and south. Thus it would appear that the clastics may have been derived ultimately from peripheral highlands. This departure from the more typical eastward source in earlier Mississippian time probably represents the general uplift of the Basin that culminated in the post-Bayport disconformity.

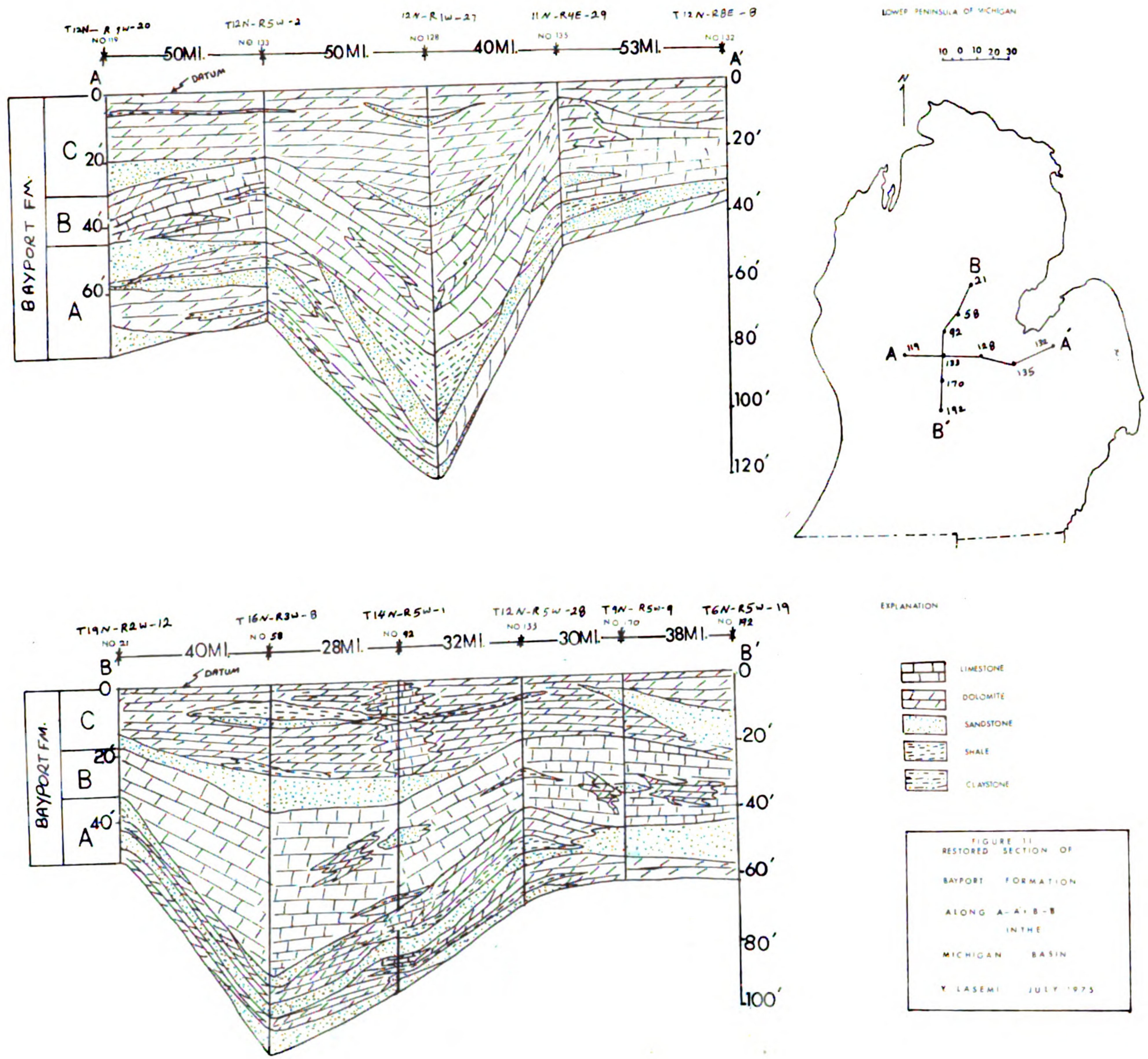

FIGURE 11
RESTORED SECTION OF
BAYPORT FORMATION
ALONG A-A'-B-B'
IN THE
MICHIGAN BASIN
Y. LASEMI JULY 1975

STRUCTURE

The presence of an erosional unconformity on top of Bayport formation is well-recognized by residual chert, quartz pebbles, coarse sand and occasional dolomite pebbles at the base of Pennsylvanian rocks. In most places, the upper unit is all eroded (Fig. 4). This figure shows the zero isopach of the upper unit, which is suggestive of stream channels radiating from the center of the Basin. In some localities the entire Bayport is missing along the erosional unconformity. A local erosional unconformity is suggested for the lower contact with the Michigan formation, as in a few places (such as in the northeastern part of the Basin) the Bayport formation rests on the Marshall sandstone.

Figure 12 is a structure contour map constructed on the base of the Bayport. The map shows that the deepest part of the Basin is in the north central area where three synlines are elongate in a northwesterly direction. It is of interest to note that the Bayport formation in its entire distribution conforms with the general northwest elongation characteristic of all the previous Paleozoic systems in the Basin -- despite the obvious shifting of the Basin structural center in post-Osage time (Prouty, 1972) from the general Saginaw Bay area to the present

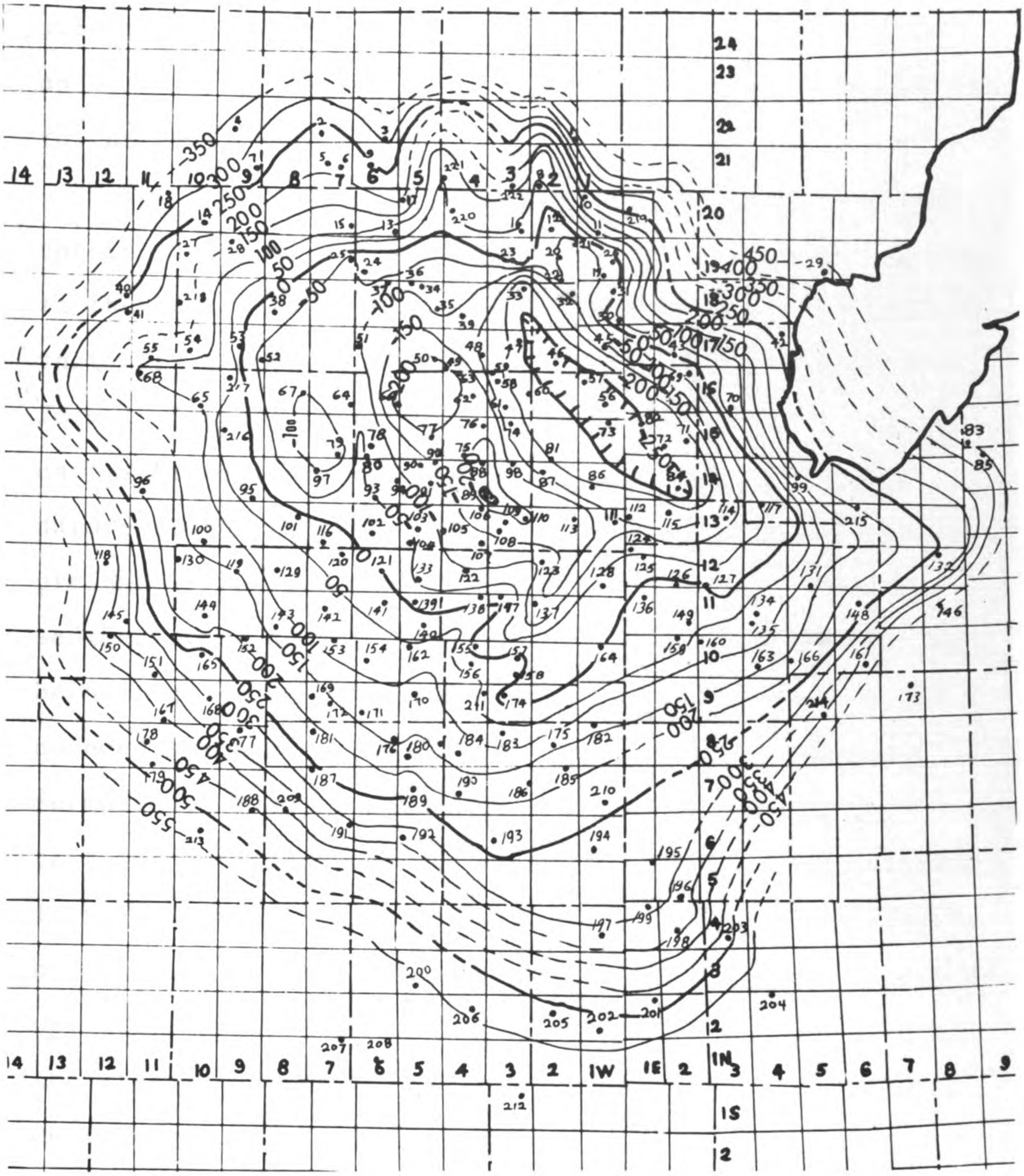

Figure 12
Structure Contour Map
of base of
Bayport Formation
in the
Michigan Basin
scale
5 0 10 20 30 mi.
Contour interval 50 ft.
Y. Lasemi July 1975

•16 Control well

0 Contour line

structural center of the Basin. The Bayport depocenter as defined by the isopach high (Fig. 5) conforms generally to the structural center.

The Howell Anticline is defined by sharp offset of the isopleths in T3N-R4E to T5N-R2E where a fault (perhaps in the left lateral sense) is inferred. It is noteworthy that this structure does not show pronounced anticlinal form in Bayport time. Ells (1969) has shown in a northeast-southwest section across the fold the offlapping nature of the Coldwater, Marshall and Michigan formations, presumably because of post-Marshall erosion. Bayport sedimentation occurred in a structure that apparently had been largely, but not entirely, truncated such that pronounced structural relief does not show in the Bayport formation. Evidence has been presented (Prouty, 1972) that the anticline was likely formed, and perhaps faulted, in post-Osagean (Mississippian) time. The post-Marshall pre-Bayport erosion interval apparently resulted from this uplift. Another observation from the structure map shows the steeper east side of the Michigan Basin. This could well be one of the better lines of evidence to support the contention of Prouty (*op. cit.*) that the principal stresses forming the faulted structures such as the Albion-Scipio, Howell, Pinconning, North Adams, Deep River and other dolomite and fracture producing oil fields, as well as the shifting of the Basin center from the Saginaw Bay general area westward to its present central position, resulted from stresses from the east to southeast (presumably orogenic stresses from the developing Appalachians) in post-Osagian time.

The marginal area of the Bayport basin shows a number of gentle folds plunging generally towards the basin center. A rather pronounced exception is a relatively sharp northeast structure near the central basinal area from T10N-R4W to T13N-R2W.

SUMMARY AND CONCLUSION

The Bayport formation is subdivided into three units, for more detailed stratigraphic, sedimentologic and environmental interpretation. The lithologic observations indicate that the formation was deposited in a rather stable tectonic environment. Deposition of the lower unit (A) began after cessation of the predominantly evaporite deposition of the Michigan formation. The evaporite lagoons gave way to carbonate flat deposition by a slight rise of sea level, which caused more circulation of the sea water over wide areas. Hypersaline conditions returned occasionally to the point of gypsum precipitation as crystals, pore fillings or very thin beds. In this case the brine of high Mg/Ca ratio caused dolomitization of already deposited lime or aragonite muds.

The major transgression at the beginning of the middle unit (B) provided an excellent environment for development of organisms. This was the time when the Basin was probably connected to the adjacent basins and open circulation of sea water produced essentially similar environments regionally. The gradual regression at the close of the B-unit provided almost the same environment of deposition as the lower unit. Thin beds or lenses of sandstone and shale in the carbonate indicate that there have been occasional fluctuations at the time of deposition.

The penecontemporaneous (stratigraphic) dolomite of the A- and C-units was distributed mostly throughout the Basin, interrupted by a few isolated limestone areas, which are believed to reflect pockets of deeper, less saline waters. Dolomitization in the B-unit is the converse of the A and C units in that the dolomite represents localized areas in a wide-spread limestone unit. These isolated, but somewhat geometric, patches strongly suggest fault and fracture control. The dolomitizing process in this case was epigenetic, and the magnesium-rich replacing fluid is believed to have its origin in a fresh water-sea water mixing environment, such as a lagoon, or perhaps where groundwater and sea water could admix.

After deposition of the C-unit, the entire area rose above sea level by positive epeirogenic movements or negative eustatic movement and then was sugjected to severe erosion. Streams cut through the formation and eroded the upper unit in most places. It is not resolved whether the entire Chesterian series was eroded along this disconformity or whether it was deposited at all. In some areas, the entire Bayport was eroded away.

The major area of subsidence apparently was in the north central part of the Basin, while the major positive areas were located in the south, east and northwest. These higher marginal areas may have accounted for the somewhat peripheral occurrence of the Bayport clastics. The structural center and depocenter of the Basin conform rather closely to the present Basin center, suggesting relatively stable conditions since directly post-Osagian structural changes. The Bayport structure contour and isopach maps reveal evidence of these earlier movements, including the likelihood of extrabasinal stresses.

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APPENDICES

APPENDIX A

-- Unit not present

Blank Units are not differentiated

APPENDIX A

Well data used for mapping of the total Bayport fm. and subdivisions.

Well Sequence No.	Permit No.	Location TP-RG-S	Unit C ls/dol ratio	Unit C clastic ratio	Unit C ss/sh ratio	Unit C thick-ness	Unit ls/dol ratio	Unit clastic ratio
1	5222	22N-2W-36 ne ne se	--	--	--	--	.37	.08
2	9210	22N-7W-29 c s/2 se ne	--	--	--	--	9	.11
3	9968	22N-6W-35 c s/2 nw nw	0	.8	∞	55	∞	0
4	997	22N-9W-28 ne ne ne	--	--	--	--	∞	.6
5	8726	21N-7W-16 c 5 w	1.5	1	8	52	∞	.9
6	8468	21N-7W-23 c s/2 se ne	.3	2.7	6.3	15	4.2	.03
7	7381	21N-9W-24 sw se se	2.2	.6	∞	26	∞	.05
8	4595	21N-2W-32 cnw nw	--	--	--	--	1.4	.27
9	8014	21N-6W-16 cs/2 sw sw	--	--	--	--	∞	.2
10	14500	20N-1W-8 nw nw ne	--	--	--	--	∞	.16
11	8587	20N-1W-33 ne se ne	--	--	--	--	∞	.25
12	5065	20N-2W-28 sw se se						
13	8438	20N-6W-36 cn/2 ne sw	3	1.5	1.4	20	∞	.14
14	12648	20N-10W-27 se se nw	2.5	.9	∞	20	∞	.38
15	7473	20N-7W-25 n/2 ne ne	1.1	1	4	30	∞	0
16	16254	20N-3W-26 se se	.52	.61	3	84	17.5	.05
17	11444	20N-5W-7 cs/2 se nw	.27	1.6	4.5	36	∞	.54
18	124	20N-11W-11 nw nw	--	--	--	--	∞	3
19	3856	19N-1W-34 nw ne ne						
20	14123	19N-2W-15 se se ne	--	--	--	--	3.2	.52

ss/sh ratio	thick-ness	ls/dol ratio	clastic ratio	ss/sh ratio	thick-ness	ls/dol ratio	clastic ratio	ss/sh ratio	thick-ness	Elev. of A Base
∞	13	0	2.6	1.3	57	.13	1.4	1.4	70	+394
1	10	0	1.6	∞	40	.5	.9	∞	50	+225
0	25	--	--	--	--	.8	.45	∞	80	+320
∞	24	0	3.1	.27	31	2	1.5	.74	55	+335
7.3	51	1	.25	1	15	4.4	.96	7.6	118	+189.7
.5	46	.2	.6	0	19	1.8	.3	1	80	+208.3
0	40	--	--	--	0	9.8	.2	5	66	+277.3
2.7	34	.24	1.3	4.5	46	.7	4	.7	80	+48
.5	20	0	.47	.6	50	.5	.37	.6	70	---
1.8	12	1.6	.66	5.3	27	3.2	.46	4.4	39	+239
1	11	0	3.9	76	68	.6	2.5	30.3	79	+118.4
--	--	--	--	--	--	.02	1.4	9	130	-29.7
.3	31	0	6.8	10.3	39	4.7	1.25	3.5	90	+71.6
2.5	50	--	--	--	15	14.5	.5	4.8	85	+242.7
0	38	0	.33	2	12	2.9	.29	3.5	80	+134.4
0	39	0	1.7	∞	27	1.1	.5	4.1	150	+42.5
.62	37	0	1.8	2	17	1.68	1	1.93	90	+205
∞	12	0	1.73	∞	26	.3	2	∞	38	+325
						0	1.1	3	69	-46
2.4	20	.11	.66	3	46	.46	.62	2.8	66	-50.5

21	4265	19N-2W-12 se se ne	0	.36	11.8	17	∞	.05
22	14627	19N-2W-34 se ne ne	0	1.4	12.0	40	∞	0
23	3666	19N-3W-15 ne nw nw	--	--	--	--	10.5	.04
24	8365	19N-6W-29 cs/2 nw sw	--	--	--	--	∞	.1
25	10009	19N-7W-24 c n/2 ne ne	13	.28	.5	10	25.5	.13
26	5740	19N-1W-23 se se nw	--	--	--	--	1.1	1
27	16286	19N-10W-20 nw nw ne	--	--	--	--	∞	0
28	15193	19N-9W-8 se ne se	2.6	.63	∞	77	8	.26
29	16884	19N-5E-26 se se nw	--	--	--	--	.5	.26
30	3885	18N-1W-36 nw sw nw	--	--	--	--	--	--
31	3781	18N-1W-11 se sw se	--	--	--	--	--	--
32	12658	18N-2W-12 sw sw se	0	.62	∞	22.6	∞	.14
33	2372	18N-3W-2 c se se	0	.44	12.4	30.7	20.6	.03
34	3591	18N-5W-3 c sw sw	2.5	4.7	11	51.2	∞	.15
35	1449	18N-5W-24 nw se sw	.08	.1	.76	45	∞	.08
36	11625	18N-5W-5 c ne	--	--	--	--	∞	.3
37	5200	18N-6W-2 nw ne nw	∞	.25	0	16	∞	.5
38	10336	18N-8W-29 cn/2 nw nw	0	1.5	1	20	∞	.25
39	17086	18N-4W-28 nw nw sw	2.5	.01	0	25	7.8	.14
40	13403	18N-12W-13 se se sw	--	--	--	--	--	--
41	4424	18N-12W-25 sw sw sw	.26	1	∞	45	0	0.1
42	3690	17N-4E-12 sw nw ne	--	--	--	--	∞	1.1
43	4796	17N-2E-28 nw nw nw	--	--	--	--	1.3	.14
45	16197	17N-1W-15 se se se	--	--	--	--	.06	.12
46	8738	17N-2W-28 se se se	0	11.6	3.6	33	∞	1.1
47	10046	17N-3W-11 s s/2 sw se	0	2.3	∞	28	.79	1.1
48	16695	17N-4W-24 sw sw sw	--	--	--	--	∞	.15

4.6	16.25	0	2.1	8.4	34.75	.76	.62	31	58	-68.8
0	7	0	.2	∞	10	.28	.78	13	57	-54
∞	40	.02	.43	∞	27	1.6	.17	∞	67	+21
∞	33	∞	26	7.6	27	∞	.93	8.6	60	-39.3
1.3	30	∞	.37	1.2	20	31	.25	1	60	-55.4
16	50	0	.9	∞	90	.22	.01	44.6	141	-5
0	15	0	1.5	.6	40	.93	.77	.6	55	+162
11	28.5	.36	1.6	∞	19.5	2.6	.62	9.5	125	---
1.1	18	.07	.49	.8	13	.3	.35	.9	31	+423.5
--	--	0	2.5	∞	35	0	2.5	∞	35	+58
--	--	1.4	.26	∞	25				25	-12.6
∞	6.4	0	5.6	5.8	14	.35	.9	11.2	43	-83
∞	22.3	0	.73	1.47	21	.59	.34	3.4	74	-235
∞	17.8	1	1.5	∞	35	3	1.7	21	104	-90
0	40	0	9	3.5	10	1	.2	1	95	-99.4
0	35	∞	.8	.2	40	∞	.53	.13	75	-93.3
3	20	0	6.5	1.7	49	4	1.3	1.5	85	-75
0	10	--	--	--	0	1	.87	.75	30	-21.7
1.5	20.25	.33	3.9	22.75	29.75	2.6	.54	10.7	75	-143.6
--	--	0	4.9	53	65	0	4.9	53	65	+261
∞	11	0	∞	∞	29	.16	1.7	∞	85	+182.7
∞	25	0	.74	∞	43	.46	4.8	∞	68	+270
∞	35	0	.05	∞	20	1.3	.1	∞	60	+12.4
∞	35	0	0	0	4	.06	.11	∞	39	---
.22	36	0	4	7	20	2.5	2.78	1.7	89	-282.3
16.5	39	0	.42	2	15	.27	1.2	15.7	82	-248.4
3.3	33	∞	1	.66	20	∞	.37	1	53	-153.6

49	3662	17N-4W-31 sw sw sw	--	--	--	--	.6	.25
50	2474	17N-5W-26 nw se se	∞	.75	∞	28	∞	.4
51	4637	17N-6W-18 c n/2 sw nw	--	--	--	--	∞	.57
52	12066	17N-9W-25 c ne	∞	2.7	6.3	30	∞	.73
53	12865	17N-9W-16 ne sw se	--	--	--	--	∞	.28
54	2419	17N-10W-20 c ne se	0	.69	.76	25	∞	1
55	12469	17N-11W-28 sw ne se	2.3	.62	∞	35	7.6	.15
56	4724	16N-1W-27 nw sw ne						
57	2977	16N-1W-7 sw sw nw	--	--	--	--	∞	1
58	7225	16N-3W-8 se nw nw	0	.47	1.6	48	∞	.04
59	3900	16N-3W-6 E/2 ne	--	--	--	--	34.15	.33
60	16665	16N-3W-13 se se ne						
61	5090	16N-3W-28 se se nw	11.4	2.8	∞	47	∞	.18
62	3677	16N-4W-23 sw ne nw	.1	.6	3.2	42	∞	.2
63	3676	16N-4W-5 sw nw ne	--	--	--	--	10.5	.1
64	5109	16N-7W-25 sw nw se	0	.9	∞	34	∞	.3
65	17018	16N-10W-33 nw nw ne	--	--	--	--	--	--
66	9924	16N-6W-25 se se se	--	--	--	--	23.5	.4
67	10387	16N-8W-13 c N/2 nw sw	--	--	--	--	3.1	.5
68	15300	16N-11W-5 sw se sw	0	.16	0	7	∞	.8
69	4890	16N-2E-11 ne se nw	--	--	--	--	9.5	.57
70	3247	16N-3E-35 se se se	--	--	--	--	--	--
71	5201	15N-2E-23 nw nw sw	0	8.1	∞	55	2.88	.2
72	4606	15N-2E-29	0	.86	∞	32	5.2	.98
73	4932	15N-1W-2 ne nw nw	--	--	--	--	0	.16
74	12335	15N-3W-3 sw ne ne	--	--	--	--	14.2	.27
75	13673	15N-4W-33 ne se nw	.7	2.8	5	65	∞	0.09

∞	24	0	.59	∞	39	.36	.44	∞	63	-203
∞	40	.04	1.3	∞	39	2.7	.74	∞	107	-201.9
0	22	0	2.3	0	5	9.3	.74	0	27	-98.7
3.6	7.0	--	--	--	? 0	∞	1	3.4	100	-76.8?
.57	? 25	?	?	?	?	?	?	?	25	+128.8
∞	6	0	1.5	3.2	14	.14	.92	1.76	45	+126
∞	15	0	.03	∞	15	1.2	.32	∞	65	+102.6
						.46	2	10.6	120	-288
4	20	0	.96	∞	50	.4	.97	16.2	70	-286.7
1	52	0	1.8	∞	20	1.58	.47	2.85	120	-191
1	47	0	.3	.84	37	1.5	.5	.94	84	-183
						.08	.97	5.6	80	-224.4
∞	36	0	.9	∞	28	2.6	.84	∞	111	-164.4
∞	48	--	--	--	0	1.8	.4	5.7	90	-171.5
∞	52	0	6.5	∞	30	5.2	.6	∞	82	-196.8
∞	16	0	1.1	∞	42	.3	.8	∞	92	-44.6
--	--	0	1.3	9	27	0	1.3	9	27	+108
.1	70	∞	.9	.4	30	31.5	.5	.2	100	-210
1.4	25	.3	.25	.2	30	.84	.35	.7	55	-93.6
7	9	.03	.52	1.7	24	.27	.52	2.37	40	+91.8
∞	15	0	2.33	1.3	20	1.35	1.1	2	35	-40
--	--	0	.2	.66	9	--	--	--	9	+74.7
∞	24	--	--	--	--	1.32	2	∞	79	-253.7
23.8	25	--	--	--	--	.05	.9	53	57	-203.7
∞	21	0	2.4	16.4	37	0	1	18.4	58	-288.3
10	31	0	.08	3.68	16	2.2	.42	5.4	47	-188.5
0	16	0	∞	2	9	2.2	1.8	3.8	90	-19.4

76	12124	15N-4W-12 c N/2 nw sw	0	2.5	∞	52.5	3.7	.04
77	6038	15N-5W-23 ne se nw	.54	.87	∞	44	∞	.1
78	5495	15N-6W-32 se sw ne	1	.11	∞	20	1.1	.01
79	13654	15N-7W-35 nw se nw	--	--	--	--	∞	.18
80	3713	15N-6W-28 se se nw	.36	.11	0	29	1.9	.8
81	19098	15N-2W-33	0	.4	1.5	8.6	2.3	.13
82	2060	15N-1E-11 sw se	--	--	--	--	--	--
83	19515	15N-9E-31 se se nw	--	--	--	--	5	.24
84	3664	14N-2E-27 ne sw nw						
85	18882	14N-9E-10 nw ne sw	--	--	--	--	4.5	.09
86	16696	14N-1W-20 ne sw sw	.12	.46	1.5	40	∞	.18
87	13044	14N-2W-8 nw sw ne	--	--	--	2	∞	.15
88	16520	14N-4W-1 nw ne ne	.87	.63	7.6	49	∞	0
89	4540	14N-4W-25 nw nw ne	--	--	--	--	6.9	0
90	11199	14N-5W-3 sw nw sw	--	--	--	--	∞	.1
91	11930	14N-5W-14 sw ne nw	0	.56	∞	25	∞	0
92	16678	14N-5W-1 nw ne ne	∞	.36	9	37.5	∞	.66
93	17738	14N-6W-33 ne sw sw	0	.2	0	20	∞	.1
94	11864	14N-6W-13 se sw nw	0	0	0	13	∞	.77
95	11955	14N-9W-35 c sw						
96	2916	14N-11W-29						
97	11305	14N-7W-7 se nw ne	--	--	--	--	--	--
98	2962	14N-3W-3 ne ne nw	--	--	--	--	∞	.36
99	7086	14N-5E-17 nw nw nw	0	.44	2	39	.24	.26
100	3095	13N-10W-35 c se nw	--	--	--	--	17.2	1.4
101	13005	13N-8W-11 se ne se	--	--	--	--	4	7.4
102	13414	13N-6W-28 nw se sw	0	.93	15.6	58.5	∞	0

∞	40.5	.5	10	.4	23	1.3	1	2.8	116	-179.5
∞	25.8	.4	.6	7	21.2	1.44	.5	29.9	91	-186
0	24	--	--	--	--	1	.05	20	44	-53
1.8	44	--	--	--	--				44	-116.4
2.9	37.5	0	1.1	.9	18.5	.6	.6	1.2	85	-54.8
.58	22.4	0	3.2	1	21	.8	.68	4	52	--
--	--	.02	3	∞	85	?	?	?	85	--
∞	36	0	.49	∞	28	1	.34	∞	64	+456
						1.54	1.5	5	160	-279
∞	30	0	.56	∞	23	1.1	.25	∞	53	_441.7
0	36.2	0	12.5	1.24	33.8	1.25	.82	1	110	-197.6
∞	30	0	1.26	.76	19	2.5	.4	1.4	51	--
0	25.2	0	4.4	1.4	39.8	1.67	.82	2.2	114	-234
0	46	1.6	.16	∞	17	4.4	.04	∞	63	-259
68	39.5	.37	.74	3	16	5.7	.23	3.8	55.5	-142.4
0	36	.22	2.5	8.3	39	1.5	.58	11.3	100	-130.6
1.75	27.5	∞	1.6	3.4	25	∞	.68	3.4	90	-151
0	10	0	.85	2.2	25	.3	.4	1	55	-53
0	23	--	--	--	--	1	.37	0	36	-57.6
						11	.78	1.2	65	+23.6
						.17	1.5	8.4	60	+194.6
--	--	0	.47	∞	65				65	-99.6
1.68	25	∞	24	8.6	25	∞	1.6	5	50	-142.5
1.2	26	0	0	0	15	.06	.3	1.7	80	+196.5
3.3	43.7	0	1.9	3	33.3	1.38	1.6	3.2	77	+134
.4	42	0	8.6	.07	29	1	7.8	.24	71	+3
0	15.5	0	1.7	∞	21	.4	.77	23.4	95	-25

103	7450	13N-5W-21 c E/2 ne ne	--	--	--	--	20.9	.41
104	12679	13N-5W-32 nw nw se	.17	.53	∞	34.5	25.7	.05
105	3654	13N-4W-19 w/2 S nw	.44	1.2	∞	50	∞	.02
106	3935	13N-4W-1 nw ne nw	0	.83	2.7	101	∞	0
107	12634	13N-4W-36 nw sw ne	--	--	--	3	17.3	.53
108	8751	13N-3W-20 c w/2 nw se	.64	.26	1.6	53	∞	0
109	3423	13N-3W-16 se se ne	--	--	--	--	∞	.06
110	12532	13N-3W-12 sw nw sw	0	1.1	38	68	∞	.06
111	3231	13N-1W-11 se nw se	3.4	.26	8	56.3	25	.18
112	6156	13N-1E-15 c s/2 nw nw	--	--	--	--	1	.15
113	4694	13N-2W-12 c nw se se	0	1	∞	21.2	∞	8.4
114	1303	13N-3E-15 ne sw	--	--	--	--	--	--
115	5422	13N-2E-9 sw sw ne	--	--	--	--	1.6	.12
116	3133	13N-7W-32 c se ne	--	--	--	--	∞	0
117	20114	13N-4E-4 ne ne sw	--	--	--	--	∞	.06
118	17295	12N-12W-10 se sw sw	--	--	--	--	4.3	.59
119	3519	12N-9W-20 sw sw se	.2	.3		38	6	.7
120	3729	12N-7W-2 c ne se	--	--	--	--	6.2	.31
121	5037	12N-6W-14 c sw	0	.3	∞	30	∞	0
122	1403	12N-4W-15 c se nw	--	--	--	--	∞	.05
123	3439	12N-2W-8 nw ne nw	.59	.93	∞	54.6	4.1	.26
124	17752	12N-1E-4 se se sw	.17	.11	∞	23	1	.31
125	8417	12N-1E-11 c E/2 ne nw	--	--	--	--	∞	.27
126	12783	12N-2E-34 se se se	--	--	--	--	--	--
127	5472	12N-3E-31 nw nw sw	--	--	--	5	7.5	.53
128	774	12N-1W-27 E/2 sw	0	.2	∞	49	∞	0

6	31	0	1	∞	14	2.6	.55	11.4	45	-79.4
∞	22.6	0	2	3.65	13.9	.97	.46	10	71	-20
0	32	3	4	6.6	20	2.4	.24	2.8	102	-118
0	32	.88	1.5	2.8	12	.6	.58	2.7	145	-196
.3	25	16	.63	2.8	25	7.6	.54	.98	50	-133
0	16.4	0	2.1	17.7	19.6	1	.4	4.1	91	-159
2.6	32	0	1	∞	12	5	.34	14.6	44	-179.7
∞	20.9	0	∞	∞	18.1	.89	.78	52	109	-213
4.4	30.9	.1	2	11.7	18.8	.88	.38	8	106	-137
∞	31	0	7.3	21	25	.87	8.8	25	56	-170.6
2	30	0	1.7	1.5	29.8	1	.91	2.7	81	-95
--	--	0	.81	∞	71				71	-113
4.4	34	0	2.25	1.25	13	1.2	.37	1.2	67	-174
0	42	0	1.3	7.8	25	3.8	.26	7.8	67	+33
.74	44	1.75	5.2	1.47	34	22.5	.68	1.37	78	-67.6
∞	51	0	.1	∞	19	1.1	.42	∞	70	+392
4	12	0	2	19	30	.3	.74	16	80	+150
6.5	38	0	∞	∞	5	6.2	.5	10	43	+24.3
0	7	0	4.1	∞	18	.26	.64	∞	55	+9.7
∞	44.5	0	.47	∞	23.5	2.6	.17	∞	? 68	-96
∞	29	0	.82	11	42.4	.64	.69	31.2	126	-109
∞	42					.5	.23	∞	65	--
3.9	34	0	6	∞	12	15.7	.6	15	46	-43.4
--	5	0	.86	17	58				63	+6.9
∞	24.6	0	3.8	∞	23.4	2	1.3	∞	48	+3
0	31	0	5.6	.7	40	.66	.54	1.1	120	-32

129	400	12N-8W-20 ne sw	--	--	--	4.5	∞	0
130	17332	12N-10W-7 sw se se						
131	37	12N-5E-33 se ne	0	.16	∞	28	∞	0
132	2315	12N-8E-8 ne sw sw	0	.1	∞	16	∞	0
133	16315	12N-5W-28 ne sw ne	.06	.05	0	18	∞	.04
134	15199	11N-4E-20 ne ne ne	--	--	--	--	--	--
135	---	11N-4E-29 sw sw nw	--	--	--	--	.44	1.2
136	5005	11N-1E-11 ne ne	0	1	9	60	.93	.03
137	3680	11N-2W-7 nw nw nw	0	3.7	19.5	26	.56	.06
138	12394	11N-4W-2 ne nw ne	.05	.8	∞	75	13	.2
139	4439	11N-5W-10 se ne nw	--	--	--	--	∞	.45
140	---	11N-5W-27 ne ne ne	--	--	--	--	∞	0
141	3739	11N-6W-11 c nw sw	0	.6	∞	32	∞	.16
142	4769	11N-7W-17 sw sw se	6.8	.7	∞	73	∞	.2
143	4565	11N-8W-29 se nw ne	0	.36	∞	30	∞	0
144	8149	11N-10W-23 sw se se	--	--	--	--	4.5	.28
145	13168	11N-12W-25 se se sw						
146	13044	11N-8E-21 ne ne ne	0	.54	∞	30	6.5	.03
147	4569	11N-3W-5 c N/2 nw	--	--	--	--	13.3	.52
148	3722	11N-6E-10 se sw nw	--	--	--	--	9.3	.7
149	7688	11N-2E-26 ne se se	--	--	--	--	12.8	.1
150	16957	10N-12W-3 ne ne sw	--	--	--	--	--	--
151	12688	10N-11W-34 ne nw se	--	--	--	--	5.5	.38
152	3496	10N-9W-3 nw ne ne	.5	1.32	∞	59	5.6	0
153	12864	10N-7W-3 nw se nw	.16	.17	∞	34	34.6	0
154	---	10N-6W-20 se se nw	.78	0	0	15	15.2	.09

0	17	0	.4	∞	3.5	6.8	.05	∞	25	+82
						.02	.33	18.1	77	+170
0	7	0	1.5	∞	30	.19	.51	∞	65	146.5
0	14.7	0	1.25	∞	6.3	.85	.16	∞	37	+259
0	22	0	.76	.62	30	.66	.27	.5	70	-46.4
--	--	0	.7	∞	46				46	+80.4
∞	44	∞	3.3	1	16	.6	.4	1.9	60	+56.6
∞	40	--	--	--	--	.31	.52	9.3	90	+19.7
3	31	?	?	?	?	.43	.67	14	57	-157
∞	50	0	4	∞	9	.11	1	∞	132	-19.3
0	50	0	3.9	.77	44	3.8	1.2	8.4	94	-14.7
0	23.6	0	1.8	27.3	26.4	2.5	.5	27.3	50	+35
∞	29	0	.07	4	34	.6	.43	10.4	95	-42.7
∞	25	0	8	∞	27	3.9	.85	∞	125	+56
0	19	0	.77	∞	48	.38	.41	∞	97	+121
∞	50	∞	2.2	15	33	1.8	.7	23	83	+163
						.04	.94	47.5	70	+320.8
∞	21	0	4	∞	10	.73	.45	∞	61	+469
.89	48	0	.25	1	7	3.7	.48	.9	55	-11
∞	53	0	∞	∞	17	9.3	1.2	∞	70	+229
.37	37	0	.1	0	24	1.3	.1	.19	61	+47.4
--	--	0	.17	∞	33				33	+356.7
∞	9	0	1.48	∞	35	.36	1.13	∞	44	+363.5
0	20	0	0	0	20	1.47	.5	∞	99	+194.6
0	17.8	.22	1.4	27.6	39.2	.62	.44	33.7	91	+73.6
.75	32	0	.96	8.1	26	1.4	.27	4.2	73	+70

155	3819	10N-4W-2 c sw sw	0	.84	∞	32.6	2.4	.38
156	12041	10N-4W-22 se sw se	0	.05	∞	19.9	∞	.04
157	13120	10N-3W-14 c n/2 nw	0	1.3	∞	78	∞	.25
158	4707	10N-3W-26 sw sw nw	--	--	--	--	5.5	.16
159	11700	10N-2E-3 nw nw nw	0	1.8	5.6	40	∞	.37
160	19998	10N-3E-7 nw nw nw	--	--	--	--	∞	1
161	1954	10N-6E-26 sw ne sw	--	--	--	--	4.5	0
162	19639	10N-5W-8 nw nw ne	--	--	--	--	4	.4
163	12536	10N-4E-29 c n/2 nw ne	--	--	--	--	∞	.83
164	13237	10N-1W-3 c nw nw						
165	7992	10N-10W-15 ne ne nw	0	.4	11.6	13.5	1.2	.06
166	3104	10N-5E-19 nw nw sw	--	--	--	--	.9	.1
167	4834	9N-11W-35 se sw se	--	--	--	--	∞	.2
168	9776	9N-10W-14 c N/2 ne ne						
169	13554	9N-7W-7 se sw nw	.32	.4	∞	28	2.6	.27
170	11939	9N-5W-9 nw nw ne	0	.7	∞	29	∞	.14
171	13906	9N-6W-30 ne se nw	--	--	--	--	∞	0
172	11587	9N-7W-21 ne sw sw	.09	.21	5.7	30	∞	0
173	9669	9N-7E-11 sw se ne	--	--	--	--	--	--
174	2331	9N-3W-9 nw sw sw	0	.66	∞	31	∞	0
175		8N-2W-22 nw nw nw	--	--	--	--	∞	.4
176		8N-6W-13 se se nw	.4	0	0	17	7.1	0
177		8N-9W-4 sw ne se	0	1.5	∞	12.5	9.6	.09
178		8N-11W-16 sw sw nw	--	--	--	--	∞	.06
179		8N-11W-34 sw sw ne	0	1	∞	8	1.3	.19
180		8N-5W-29 nw nw se						
181		8N-7W-14 ne se se	--	--	--	--	3	.1

∞	40.4	0	1.3	∞	36	.93	.58	∞	109	-10.7
∞	21.1	0	.2	∞	3	.95	.05	∞	44	+10.6
∞	18	0	.19	∞	21	.28	.77	∞	117	+11
∞	28	0	2.26	2.3	32	1.64	.7	3	60	+7.6
.52	39	0	1.4	6.5	26	1.1	.95	3	105	+15.6
0	14	0	6.5	1.4	42	1.2	3.5	.98	56	+78
0	21.9	0	.95	∞	34.1	.83	.42	∞	56	+420
0	35	0	∞	2.3	10	4	.8	.53	45	--
8.8	34.8	0	3.7	6.9	31.2	2.8	1.6	7.6	66	+140
						0	1.46	∞	57	+4
0	18.5	--	--	--	--	.54	.18	2.7	32	+262
∞	29	.06	.7	2.4	48	.34	.4	1.6	77	+152
∞	25	0	.09	∞	33	6.3	.13	∞	58	+404.3
						.05	.4	7	83	+297
∞	34	0	1.2	37	35	.64	.4	49.4	97	--
∞	25	0	1.3	∞	16	.91	.52	∞	70	--
0	22.2	.66	.79	∞	23.8	2.5	.38	∞	53	--
0	18	0	.2	.64	17	.55	.14	2.28	65	--
--	--	0	3.9	∞	44				44	--
0	53?	0	4.9	4.5	33	2.2	.5	6.9	117	-19.8 ?
∞	30	0	.8	1.1	29	1.4	.57	2.6	59	+145
0	15.4	.08	.98	∞	30.6	1	.26	∞	73	+147.5
∞	17.5	0	1	∞	5	1.6	.49	∞	35	+352
∞	27	0	.33	∞	25	1.35	.17	∞	52	+440
∞	34	0	0	0	20	.4	.18	∞	62	+485.3
						.15	1.2	∞	62	--
∞	30	0	25.3	∞	28	2.5	1	∞	58	--

182	2341	8N-1W-4 nw nw ne	0	.59	∞	62	3.5	.44
183	13586	8N-3W-9 nw nw se	--	--	--	--	3.6	.78
184	12514	8N-4W-28 nw ne sw	0	0	0	9.6	.32	0
185	11803	7N-2W-2 ne sw nw						
186	17980	7N-3W-13 se se nw	--	--	--	--	--	--
187	11027	7N-7W-6 ne nw se	.43	.5	4	30	18	1.1
188	3090	7N-9W-35	--	--	--	--	∞	.2
189	20200	7N-5W-16 sw sw ne	.71	1.4	32	28.5	∞	.13
190	9869	7N-4W-21 c S/2 se sw	--	--	--	--	--	--
191	3154	6N-7W-12	0	.08	3	26.5	1.3	.03
192	3390	6N-5W-19 ne ne nw	0	.82	∞	32	∞	.72
193	5042	6N-3W-19 se se	0	0	0	17	1.1	1
194	3376	6N-1W-29 ne sw ne	--	--	--	--	--	--
195	1198	5N-1E-1 ne nw se	.2	.65	13.6	56	0	.62
196	14034	5N-2E-34 se se se						
197	9987	4N-1W-22 c N/2 sw sw	0	.48	∞	20	1.8	.07
198	792	4N-2E-21 ne nw nw	0	2.2	∞	24	.04	.23
199	20566	4N-1E-2 se sw nw						
200	564	3N-5W-28 sw sw						
201	9477	2N-1E-1 sw se sw	0	.07	0	7.5	2.7	.0
202	4837	2N-1W-28 ne se nw	0	1	∞	13	3	1.2

.14	13	0	∞	.66	20	.17	.97	2	95	+127.5
∞	25	.03	.23	∞	40	.38	.49	∞	65	+77
0	26.4	.05	1.3	∞	47	.15	.47	∞	83	+127
						.1	.55	2	77	+190
--	--	0	.36	∞	40				40	+181.7
∞	40	0	0	0	15	.8	.57	14.5	85	+256
∞	24	.28	3.6	.22	45	5	.93	.47	69	+458.6
∞	17	.08	.18	3.5	29.5	.73	.44	14.3	75	+222.6
--	--	0	.67	1.64	45				45	+192.4
∞	15.5	0	.6	.66	30	.17	.24	.89	72	+301
∞	20	0	1	∞	7	.55	.8	∞	59	+348
12	13	0	5.6	∞	20	.15	.88	46	50	+239
--	--	0	1.5	∞	50				50	+279
∞	17.5	0	1.4	∞	34.5	.1	.83	31.8	108	+229
						0	.56	8.7	70	+346
∞	20	.5	0.6	∞	5	.6	.28	∞	45	+342.7
∞	21.7	0	.47	2.5	18.3	.02	.74	15.2	64	+342.3
						0	.35	1.7	64	+292
						0	.9	27.4	42	+646
0	7.5	--	--	--	--	.6	.03	0	15	+483.4
∞	10	.14	1	∞	35	.16	.88	∞	58	+575

APPENDIX B

APPENDIX B

Data from geologist log,
only used for total isopach and structure contour maps.

Well Sequence No.	Permit No.	Location TP-RG- S	Elevation of Bayport Base	Thickness
203	967	4N-3E-28 se sw	+507	50
204	---	2N-4E-4 se se ne	+775.6	51
205	24518	2N-2W-16 ne ne ne	+524	50
206	2767	2N-4W-16 c se sw	549	65
207	7011	1N-7W-2 ne ne ne	809.6	29
208	24485	1N-6W-22 nw sw ne	806	38
209	24619	7N-8W-34 c se cw	404	41
210	24315	7N-1W-27 se se nw	247	60
212	21842	1S-3W-11 c sw sw	+747	50
213	248	6N-10W-15 se se ne	546.3	41
214	---	9N-5E-35 se w/2 se	348	50
215	8746	13N-6E-3 nw nw ne	+ 20.4	69
216	5656	15N-9W-18 ne sw ne	+ 33	103
217	10612	16N-9W-8 c s/2 sw nw	+ 65.3	90
218	11140	18N-10W-19 c n/2 ne sw	+192.5	95
219	16158	20N-1E-16 ne ne nw	+273.4	40
220	24239	20N-4W-20 c nw	+ 68.8	80
221	24530	21N-4W-30 nw se nw	+ 56.8	28
222	9063	21N-3W-34 c s/2 sw nw	+121.8	100

APPENDIX C

APPENDIX C

Description of Wells Used in Restored Sections

Depth (ft)	
	Well Sequence No. 119, T12N-R9W-20 SWSWSE Permit No. 3519
670-680	Limy dolomite, gray brown (some sandy), dense; limestone dark brown dense 30%; shale, red, silty 10%; few chert, white, gray and black.
680-690	Limy dolomite, buff, dense; limestone as above 10%; some chert as above.
690-700	Sandstone, white, fine-medium grained, sub-rounded to rounded; dolomite very finely crystalline; 10%.
700-710	Limestone,dolomitic, brown, sucrosic, fine-medium grained, 80%; limestone, white-tan, fine-medium crystalline with ostracods and crinoids.
710-720	Limestone as above, fine quartz sand with few white chert; dolomite as above 20%; sandstone, white fine grained 40%; shale, red and greenish gray 10%.
720-730	Sandstone, white, fine-medium grained sub-angular-rounded; shale greenish gray 10%.
730-740	Dolomite, buff-dark brown, dense, 90%; sand as above.
740-750	Sandstone, white, medium-coarse grained, rounded-sub-rounded and some frosted grains, 90%;dolomite, as above 10%.
	Well Sequence No. 121, T12N-R6W-14 C SW Permit No. 5037
875-885	Dolomite, light brown, v. finely sucrosic and dense with white gray chert; sandstone, gray, fine to medium grained, angular 40%; few grains gray and black shale.
885-895	Same as above with 20% sandstone.
895-905	Dolomite, light brown, sucrosic, sand 10% as above.
905-910	Limestone, light brown-tan, medium crystalline with few crinoids.
910-915	Limestone, as above, sandy 40%; sandstone, gray, fine-medium grained, sub-angular.
915-920	Sand, as above; 50% dolomite, light brown, limey, v. finely crystalline.
920-930	Sandstone, fine grained, sub-angular 90%; dolomite, light brown.
	Well Sequence No. 128, T12N-R1W-27 E/2SW Permit No. 774
620-630	Dolomite, brown, very finely crystalline, dense with yellowish gray chert; sandstone, gray, well cemented in gypsum 10%; few gypsum crystals and pyrite.

630-650 Same, with both cemented and friable sand.
650-660 Dolomite, brown, very finely sucrosic, sandy; few white chert; sandstone, grayish white, medium grained, subangular-well rounded, cemented by dolomite 40%.
660-670 Dolomite, brown, dense-very finely crystalline-dense; limestone, gray brown-tan, 10%; sandstone, gray, medium grained, sub-rounded 10%.
670-680 Limestone as above, fine-medium crystalline with few crinoids.
680-700 Limestone as above with crinoids, foraminifera (*Endothyra*), ostracods and echinoid spines.
700-720 Clay, blue gray, soft, silty.
720-730 Sandstone, white, fine grained, subangular-rounded, few frosted; dolomite, brown, dense, with few white chert, 30%.
730-740 Dolomite as above, 30%; sandstone, gray, fine-medium grained, subrounded.

Well Sequence No. 135, T11N-R4E-29 SW SW NW Permit No.?

470-490 Dolomite, light brown, limy, medium sucrosic.
490-500 Dolomite, medium-coarse sucrosic 70%; limestone, gray-tan, very sandy 20% with few crinoids.
500-510 Limestone, gray brown, very finely crystalline with ostracods; sandstone, gray, fine-medium grained, angular 40%.
510-518 Limestone, as above, 50%; sandstone, white, fine-medium grained, some cloudy and rounded.
518-524 Clay, gray-blue, soft.
524-530 Sandstone, gray, fine-medium grained, sub-angular to sub-rounded, 40%; dolomite, light brown, micro-crystalline.

Well Sequence No. 132, T12N-R8E-8 NE SW SW Permit No. 2315

375-391 Dolomite, brown, dense-very finely crystalline, few white chert; dolomitic limestone, light brown, finely sucrosic 20%; sandstone, medium-coarse grained, subrounded, 10%.
391-395 Limestone, crinoidal, gray brown-tan, medium crystalline with eginoidal spines and crinoids; some chert, gray brown.
395-405 Limestone as above, some finely sand.
405-412 Sandstone, gray, fine-medium grained, angular-rounded, 50%; limestone, gray brown, dense, 10%; dolomite, brown, dense 40%.

Well Sequence No. 21, T19N-R2W-12 SE SE NE Permit No. 4265

852-859 Dolomite, brown, dense-very finely crystalline, very cherty; some pyrite; shale, gray 5%; sand, gray, medium grained, angular 5%.

859-869 Dolomite, as above, and buff sandy, dense; sandstone, gray, fine-medium grained, subrounded to rounded, some frosted, 40%; chert, white.
869-874 Limestone, gray-tan and gray brown, slightly crystalline, sandy, crinoidal, *Endothyra*, ostracod, and echinoid spines; some white chert.
874-877 Limestone, as above; sand, gray, fine grained, angular and cloudy 10%; shale, gray 5%.
878-881 Limestone, as above, sandy, and gray brown, finely crystalline limestone with ostracods; sand, 10%.
881-890 Limestone as above and gray 50%; dolomite, brown, dense 30%; sandstone, white, fine-medium grained, rounded and frosted.
890-898 Sandstone, as above, 90%; dolomite, brown, dense.
898-902 Sandstone, as above; dolomite, tan, dense 10%.
902-906 Sandstone, white, fine-coarse grained, rounded, some frosted; dolomite, light brown, dense, sandy 10%; some black and gray shale.
906-910 Dolomite, brown, dense, 80%; sand, as above.

Well Sequence No. 58, T16N-R3W-8 SE NW NW Permit No. 7225

880-900 Dolomite, light brown and buff, dense to finely crystalline, very cherty; shale, gray 30%; sand, white, angular 10%.
900-915 Dolomite, limy, brown, dense with white chert; shale, black 20%; sand, as above 10%.
915-925 Sandstone, yellow, fine-medium grained, angular-subangular; dolomite 10% as above; shale 10% as above.
925-930 Sand as above 60%; limestone, gray brown-tan, finely crystalline with crinoid; little shale.
930-950 Limestone, as above with *Endothyra*, crinoids, ostracod, echinoid spines.
950-980 Same, finely sandy; sand, gray brown, angular, fine-medium grained 10%; some gray shale.
980-990 Dolomite, limy, dense-very finely crystalline 50%; sand, white, medium grained, rounded.
990-1000 Same, with 80% sandstone.

Well Sequence No. 92, T14N-R5W-1 NW NE NE Permit No. 16678

900-920 Limestone, light brown-gray brown, very finely crystalline; few chert; shale, gray-greenish gray 10%.
920-930 Limestone, dark brown, finely crystalline; sand, white, fine-medium grained 10%; some greenish gray shale.
930-940 Sandstone, white, medium grained, subrounded, 75%; limestone, gray to tan, sandy; grayish green shale, 5%.
940-950 Sand as above 50%; limestone, as above; some shale.
950-960 Limestone, white-tan, finely crystalline with crinoids and other fossils; glauconite casts; sandstone, as above 20%.

960-965 Limestone, as above, sandy, 80%; shale, gray-green, gray and red.
965-980 Limestone, microcrystalline, gray brown-light brown; sandstone, fine-medium grained, subangular-subrounded 40%; shale 10% as above.
980-990 Same, limestone sandy; sand 60%; shale 20%.

Well Sequence No. 133, T12N-R5W-28 NE SW NE Permit No. 16315

870-880 Dolomite, light brown-gray brown, finely sucrosic; white, sandy limestone 10%; shale, black 10%.
880-890 Dolomite, brown, dense, very cherty with silicified ostracods; limestone, gray brown with crinoids, finely crystalline, 20%.
890-910 Limestone as above, with crinoid, ostracod, specules; shale, black 10%.
910-920 Dolomite, buff, microcrystalline with few ostracod in dolomite; shale, black 20%.
920-930 As above, dolomite 30%; shale 20%; sandstone, gray, medium grained, cemented by dolomite and gypsum 50%.
930-940 As above, 40% dolomite 30% shale, 30% sand.

Well Sequence No. 170, T9N-R5W-9 NW NW NE Permit No. 11939

630-640 Dolomite, light brown, dense 40% with yellowish white chert; sandstone, white and gray, fine-medium grained, subangular-rounded, some cemented by gypsum.
640-650 Dolomite, brown, finely crystalline, white and yellow chert; limestone, gray, dense 10%.
650-660 Limestone, crinoidal, gray-tan, finely crystalline; white-gray chert.
660-670 Limestone, sandy as above, 20%, yellow brown, ostracods; limestone, very finely crystalline; sand, gray, medium grained, angular 30%.
670-680 Limestone as above 40%; sandstone, white, medium grained, well rounded-subrounded, cemented by earthy gypsum.
680-690 Sand as above, 30%, some earthy gypsum; dolomite, light brown, dense.

Well Sequence No. 192, T6N-R5W-19 NE NE NW Permit No. 3390

365-375 Dolomite, yellow brown, dense, some white chert.
375-385 Sandstone, gray, medium grained, subangular to rounded; dolomite 10% as above.
385-390 Dolomite, light brown, finely sucrosic; sandstone, white, medium grained, subrounded-well rounded 70%.
390-417 Limestone, gray brown, fine sandy with few crinoids and ostracods 40%; sandstone, white, medium-coarse grained, subangular-well rounded, some cemented by calcite.

417-424 Dolomite, light brown-buff, dense 50%; sandstone, gray, medium grained, subangular to subrounded, some cemented by earthy gypsum.