The strata consist largely of thin conglomerates, light greenish gray gritstones, and green and red shales. A fine grained grit of light greenish gray color is characteristic of the formation. This grit becomes shaly by vertical and horizontal gradations, sometimes maintaining its characteristic tint and sometimes changing to a deep reddish brown color. The green and red colors are bright and distinct when the rock is wet and contrast strikingly in drill cuttings. The conglomerate near the base of the formation described by Lane[107] as the "peanut conglomerate" occurs regularly in wells in the "Thumb" district. The red color so common in the Lower Marshall of eastern Michigan disappears locally in the western part of the State, particularly in southern Kent and adjoining counties. In some places the absence of red Lower Marshall agrees rather closely with the structural position of the locality, the synclines containing a preponderance of red strata and the anticlines practically none. In northwestern Michigan where the Marshall thins, the red micaceous beds are absent and instead there is a pink tinted sandstone member in the upper part of the formation. This may be explained by lateral change in the color and texture of the Lower Marshall and the small amount of Napoleon in western Michigan; removal of Lower Marshall red micaceous sandstones by the Napoleon sea gradually invading the land along its western shore line, thus adding red color to the beds; or coloration of the Napoleon sandstone beds from the western source of sediments in the iron-bearing regions, as suggested by Thomas[108].

The Napoleon sandstone has been extensively described in early reports and papers by Winchell[109], Rominger[110], and Lane[111], and the examination of well cuttings has added much new data in the past few years. The rock is mostly white sandstone with impurities of pyrite which form brown stains. The light greenish tint of many of the sand grains is characteristic and some of the grains consisting of undecomposed feldspar are pink in color. Often the matrix[112] binding the sandstone grains consists of kaolinitic material which has been determined as gibbsite (Al_2O_3) $(3H_2O)$. The grains are angular and in local beds they are relatively uniform in size, although where cross bedding has been found the grain size is not so regular.

The sandstone is open textured and an important water bearing formation wherever it occurs. Under sufficient cover the beds contain a brine strong with salts of bromine, iodine, and chlorides of calcium and magnesium. Small quantities of heavy oil and some gas have been found in the reworked beds for a long time thought to be in the upper part of the Napoleon. The formation is usually superimposed by dolomitic limestones of the Michigan series, and the greenish color of the associated shale is significant in correlation.

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[107] Lane, A. C., Geological Reports on Huron County: Geol. Survey of Michigan, Vol. VII, p. 19 (1900).

[108] Thomas, W. A., Op. cit., p. 494.

[109] Winchell, Alexander, First Biennial Report of Progress of the Geological Survey: Michigan Geol. Survey, pp. 88-91 (1861).

———, Proc. Am. Philos. Soc., Vol. 11, pp. 57-83 (1869).

———, Proc. Am. Philos. Soc., Vol. 12, pp. 385-418 (1870).

[110] Rominger, C., Geology of the Lower Peninsula: Michigan Geol. Survey, Vol. III, Pt. 1, pp. 69-101 (1876).

[111] Lane, A. C., Geological Report on Huron County: Geol. Survey of Michigan, Vol. VII, Pt. II, pp. 16-18; 86-98 (1900).

———, and Seaman, A. E., Notes on the Geological Section of Michigan: Michigan Geol. Survey, Ann. Rept. of State Geologist for 1908, pp. 79-83 (1909).

[112] Thomas, W. A., Op. cit.

Commonly in the north central area of the "Thumb" district, the interval[113] between the green glauconitic layer and the eroded top of the Napoleon sandstone is about 15 feet. The glauconite bed either rests between two layers of hard limestone or is associated with a single layer which is sometimes present alone. A thin series of shales separates the limestones from the top of the Napoleon. This interval represents the "break" described by Thomas[114].

The Marshall formation ranges from less than 150 feet to over 560 feet thick, the thickest section being found in eastern Clinton and Gratiot counties and the Saginaw Bay region. The exact amount of Lower Marshall is not easily determined but the Napoleon sandstone generally contains from 80 to 100 feet of strata, although over 200 feet of Napoleon has been correlated in wells. The Marshall formation thins rapidly toward the central part of the State and is generally less than 250 feet thick west of Isabella County.

The Grand Rapids series has two members, the Lower Grand Rapids or Michigan formation, and the Upper Grand Rapids or Bayport limestone. During the deposition of the series, there was an emergence in the early stages and a general transgression of the sea at the close. The Michigan formation is typical of the Michigan synclinal basin area. The beds were deposited on an uneven surface resulting from extensive denudation at the close of Marshall time, and at the end of the Mississippian period intensive erosion again took place, cutting deeply and removing large quantities of the materials laid down. A series resulted which is extremely irregular and contains a wide variety of deposits. The concentration of sediments and chemical precipitates in local basins shows a close relation to structure. The thickest Michigan formation beds are found in the synclinal areas.

The Michigan formation marks the return of conditions favorable to evaporation and apparently isolated seas were predominant. The Basin seems to have been cut off from outside connections for considerable periods of time, and numerous thick deposits of anhydrite and gypsum were the result. Bedded salt has not been reported from the formation, although veinlets of salt have been observed.

A bed of hard, brown to buff, impure, dolomitic limestone usually occurs at the base of the Michigan formation and separates it rather sharply from the underlying Napoleon sandstone. The formation consists largely of gray, greenish gray, and dark gray shales which are frequently bituminous in the lower members. Sandstones occur locally in some areas and those near the base of the series which consist largely of reworked Marshall sands serve as an important reservoir of natural gas in the central part of the State. Red sandstones and shales are also found locally, especially in thick sections of the formation and in structural "lows." Several types of gypsum and anhydrite occur in bedded deposits and disseminated nodules of varying sizes. Gypsum and anhydrite are generally most abundant in the lower part of the formation and occurrences of these minerals have been discussed in detail by Grimsley[115].

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[113] Kirkham, Virgil R. D., Personal communication.

[114] Thomas, W. A., Op. cit.

[115] Grimsley, G. P., The Gypsum of Michigan and the Plaster Industry: Geol. Survey of Michigan, Vol. IX, Pt. 2 (1904).

———, Origin of Gypsum with special reference to the Origin of Michigan Deposits: Kansas Acad. Sci., Trans., Vol. 19, pp. 110-117 (1903).

Exposures of Michigan formation rocks are not usually well preserved because of the readiness with which they slack and weather. The beds come nearest the surface in Kent, Arenac, Iosco, and Ogemaw counties. Gypsum is extensively quarried and mined in the vicinity of Alabaster, Iosco County, and Grand Rapids, Kent County, and the color of the raw mineral product varies from cream white to pink and red and the texture from needle-like to granular. In the south part of the State in Jackson County, Michigan series beds are thin or entirely absent, and the Bayport limestone locally rests directly upon the Marshall sandstones. Where the entire Grand Rapids series is absent, the Parma sandstone of Pennsylvanian age has been found locally to be in direct contact with the Marshall with scarcely a perceptible break.

The area where Michigan formation rocks come to the surface (see fig. 2) has an arcuate rectangular outline with the long direction trending northwest-southeast in the central part of the State. The belt narrows and widens and is locally interrupted to the southeast by the overlap and removal of beds caused by the pronounced arch in the vicinity of Howell. This area includes about half of the southern peninsula and the outcropping belt of soft non-resistant rocks exercised important control upon the localities of intensified pre-glacial erosion.

Drill cuttings from the Michigan formation are easily distinguished by the greenish gray color and the presence of sulfates. Cores often show fractures cemented with selenite (a mineral form of gypsum) and evidently a large amount of adjustment in the beds has taken place as the result of solution. The solubility of the gypsum is illustrated by the fluted appearance of the weathered surface where it is exposed. Breccias or recemented fractured beds are common throughout the formation.

The thickness of the Michigan formation varies widely over small areas and is closely related to structure. The formation may be locally absent but generally it is from 50 to over 550 feet thick and the thickest sections are largely in the central part of the State. The stratigraphic position of the series is not well determined, but Lane[116] considers the rocks of this age to include Keokuk, a part of the Kinderhook, and possibly the lower St. Louis of the Illinois section. Beds which are directly equivalent have not been found in Ohio and the time of emergence is considered to be about the close of Osage. Much further paleontologic study of the faunas in the Michigan formation rocks must be carried on before the problems of correlation can be definitely settled.

The Bayport limestone is mapped with the Michigan formation as a member of the Grand Rapids series, but it constitutes a distinctly separable formation although often variable in color, texture, and composition. It contains white to light gray, dark gray, and bluish limestone, magnesian limestone, and dolomite. Lenses of sandstone and sandy, nodular cherty beds are locally present and in places show greenish colors near the contact with the underlying Michigan formation. The sand content increases toward the base and the rock passes into a white, firm to poorly cemented, coarse grained sandstone. Intraformational breccias and conglomerates with limestone pebbles have been observed in cores. There is abundant evidence that the Bayport was extensively reworked by the Pennsylvanian sea and numerous isolated remnants and

[116] Lane, A. C., and Seaman, A. E., Notes on the Geological Section of Michigan: 10th Ann. Rept. of State Geologist, p. 84 (1909).
Lane, A. C., Geological Report on Huron County: Geol. Survey of Michigan, Vol. VII, p. 16 (1900).

layers of material from other beds resulted. Limestone beds are frequently interspersed with sandstone resembling the typical Parma sandstone above.

The maximum thickness of the Bayport is about 100 feet but it usually contains from 40 to 60 feet of strata. Exposures occur in Jackson, Eaton, Huron, Tuscola, Arenac, and Kent counties, and large quarries are in operation at Bayport, Huron County, and Bellevue, Eaton County. The beds are highly fossiliferous in the upper part of the section, and there are some thin strata high in calcium carbonate. The contact of the limestone with the white Parma sandstone above is not always sharp, but usually there is sufficient contrast to separate the formations.

The Bayport limestone is probably equivalent in age to the upper part of the St. Louis, and the St. Genevieve limestone of the Mississippi Valley section. The beds can also be compared approximately with the lower part of the Maxville of Ohio. Recent determinations[117] of bryozoa and brachiopod species suggest Warsaw affinities, but this may possibly be explained by the long range of many species occurring in typical Warsaw beds. For the time being, the Bayport is provisionally correlated with upper St. Louis and St. Genevieve and may be as old as Warsaw.

PENNSYLVANIAN

The Pennsylvanian rocks of Michigan have been studied only in very limited areas. They have been isolated by erosion from the large basins of coal deposition in other states and except in a few small areas are also deeply buried by glacial material. Because of these conditions, the beds cannot be definitely traced from adjoining states and faunal evidence by which they may be correlated is meager. The approximate correlations of the Michigan rocks with the Pennsylvanian and Permian of Ohio and Indiana are shown in Table VII.

The system has three members called the Parma, Saginaw, and Woodville in ascending order. The Parma sandstone which is the basal member was deposited upon an irregular land surface. It is sometimes absent or poorly developed. The Saginaw formation is the thickest series in the Pennsylvanian and in numerous places contains beds of coal which are locally workable. The Woodville sandstone is usually present at the top of the coal measures and is probably an emergent type of deposit, forerunner to conditions of evaporation under which gypsum was formed.

The Parma sandstone is typically exposed in Jackson County and is named from Parma, a small town west of Jackson. The rock is white, quartzose, glistening sandstone, locally coarse to conglomeratic. The small milky white pebbles have been compared to "split peas," the white color is characteristic although coaly terrestrial material has been found, and the rock is here and there stained with iron. Its stratigraphic position to the Bayport limestone below is an important aid in identifying the Parma. Reworked Bayport material may be found within the formation, and this locally contributes a greenish color.

The Parma has been recognized in numerous wells throughout the State, and this shows that it was deposited widely. The thickness is variable and seldom attains over 100 feet except where the sand has filled deep valleys in the pre-Pennsylvanian land surface. About 50 feet of Parma sandstone is usually present.

[117] Kelly, W. A., Personal communication.

TABLE VII.—*Pennsylvanian and "Permo-Carboniferous?"*

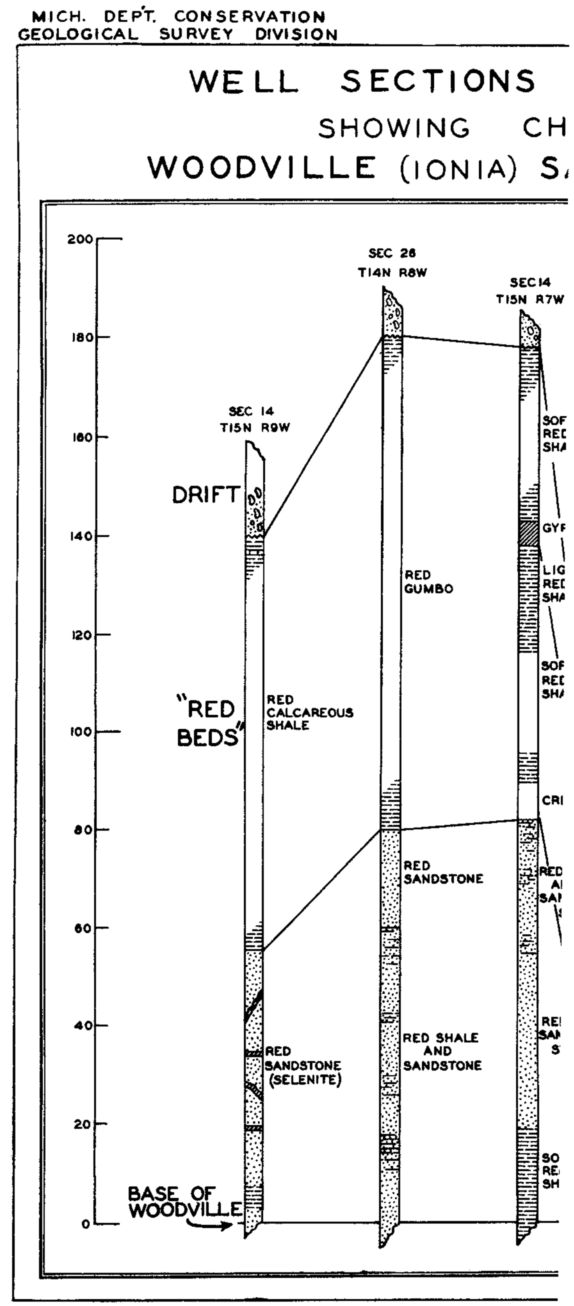
Michigan	PERMIAN. Ohio		Indiana	Illinois
Red Beds (?) (These strata of unknown age may range anywhere from Conemaugh to Permian or possibly higher in the column. The basal sandstone member is probably exposed at Ionia)	Dunkard	Washington		
		Greene		
	PENNSYLVANIAN			
	Monongahela			
	Conemaugh			
Woodville (Ionia)	Allegheny			
Saginaw (Grand Ledge Fauna=Lower Mercer of Ohio)	Pottsville			
Parma		Connoquenessing (?)	Mansfield (?)	

Fauna has not been found to aid correlation, but the relation of the Parma to the overlying Saginaw formation would place the age as Pottsville. The position of the beds in the stratigraphic column may be equivalent to the Mansfield of Indiana and the Connoquenessing (Massilon)[118] sandstone of Ohio, but this is entirely inferential. The exact correlation of the Parma will be in doubt until some faunal occurrences are found within the formation or closely associated beds to more closely fix its age.

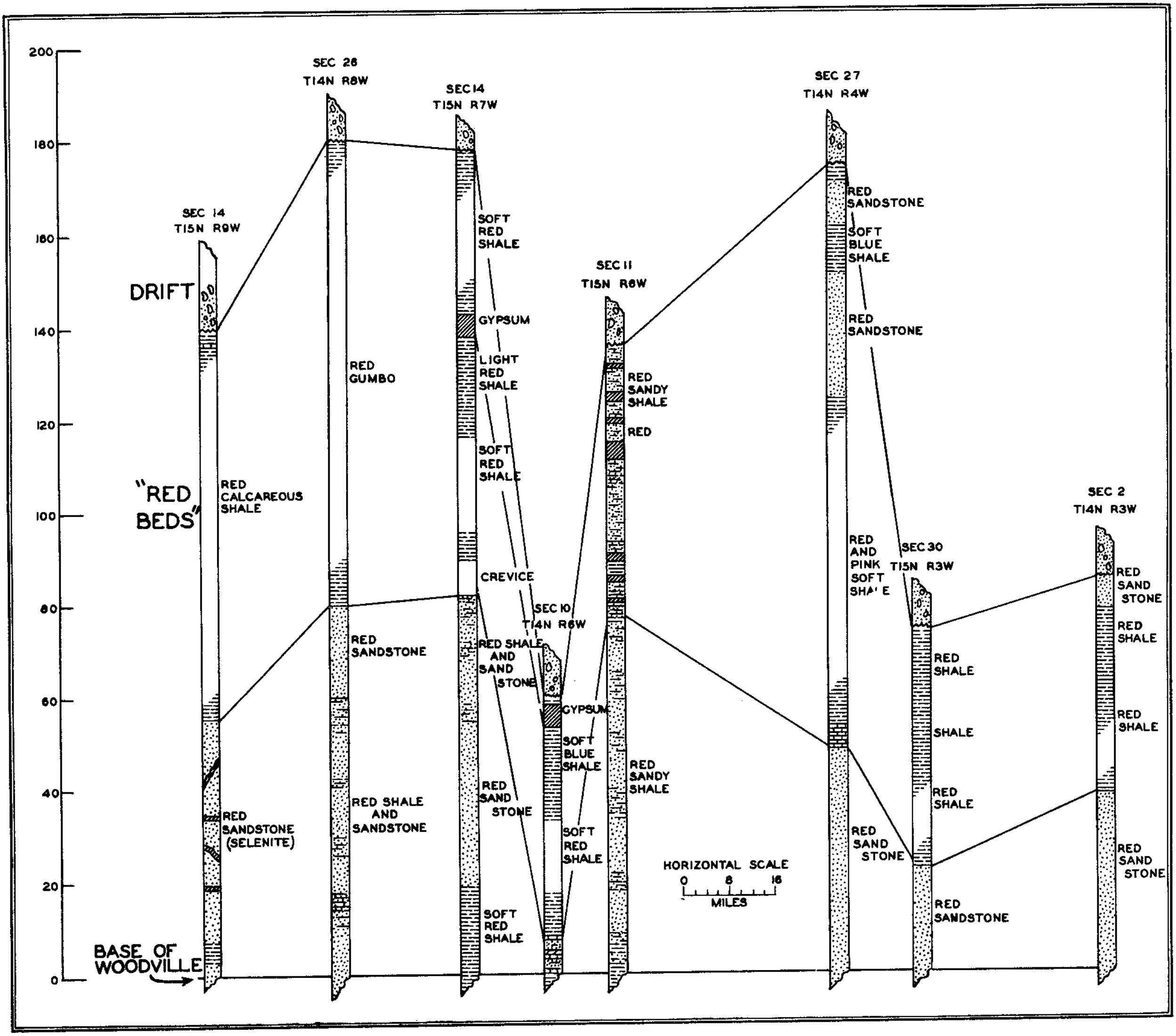
The Saginaw formation contains the coal bearing measures of the Michigan Basin and is composed of many beds of shale and sandstone. These beds are usually lenticular and so limited in extent that they cannot be traced from one locality to another. The shales are light to dark gray and black and some of the beds have been termed "fire clay." The sandstones are generally white to light gray and somewhat micaceous, the mineral being the light colored muscovite. Seams of siderite (black band ore) and nodules of siderite, pyrite, and sphalerite are present. There are a few thin limestone members in the Grand Ledge area where the most extensive Pennsylvanian fauna in the State has been found.

The widespread occurrence of the "Red Beds" and the basal sandstone (Woodville or Ionia?) has limited the territory underlain by the Saginaw formation to an arcuate belt around the center of the State, and thereby restricted its areal extent. Where exposed beneath the drift, the total amount of strata is exceedingly variable due to wearing away by ice action and erosion. The greatest reported thickness is about 500

[118] Stout, Wilber, Personal communication.



WELL SECTIONS ACROSS CENTRAL MICHIGAN
SHOWING CHARACTERISTICS OF THE
WOODVILLE (IONIA) SANDSTONE AND THE "RED BEDS"



feet. The best exposures are in Jackson, Genesee, Saginaw, Bay, Shiawassee, Ingham, Eaton, and Arenac counties, and various mine openings in these areas and in Huron and Midland counties have added to the information concerning these rocks. (See fig. 2).

The age of the formation has recently been discussed in detail by Kelly[119], who added several new species to the sparse assortment of fossils which occur in black shales and thin limestone beds of the Grand Ledge region, Eaton County. He confirms the findings of White[120] and the writings of Lane[121] by maintaining that the general correlation should be with the upper part of the Ohio Pottsville. Faunal evidence is reviewed which indicates that the Michigan forms were not derived from the Ohio forms and that "the Michigan Basin may have been connected with that of Indiana and Illinois." A quotation from J. Marvin Weller states that one species (*Spirifer boonensis*) characterizes horizons in Indiana and Illinois which are probably nearly equivalent to the Lower Mercer limestone of Ohio.

The Woodville[122] sandstone in its originally described locality at the Woodville mine in sec. 36, T.2S., R.2W., Jackson County, has not proved to be the highest member of the coal measures, as defined. A more typical section is found between Lyons and Ionia, Ionia County, where a heavy sandstone high up in the series is exposed. This member is a red or brown, fairly coarse grained, cross-bedded sandstone with white or greenish gray spots and streaks. An upper red sandstone similar to that which occurs near Ionia has been traced by well records across the central counties of the State. The name of Woodville applying to a sandstone, which at its type locality is only a lenticular, restricted bed, probably should be dropped. A better name for the apparently persistent basal pink or russet colored sandstone of the "Red Beds" section would be the Ionia sandstone, suggested by Lane[123] in 1909.

A maximum thickness of 95 feet is recorded at Ionia but this much sandstone is not common. Some of the variations in the formation are indicated in Figure 6, which shows the probable correlation of a number of wells across the central part of the State. The area underlain by the Ionia sandstone is not mapped, but it probably includes a narrow belt which parallels the inner boundary of the Saginaw formation.

Fossils have not been found in these sandstone beds, but Lane[124] suspected the possibility of their being "Permo-Carboniferous" (?) in age, or lower Conemaugh, at the earliest. He believed that the local absence of the sandstone was due to the fact that it rests disconformably on the Saginaw formation below.

"PERMO-CARBONIFEROUS" (?)

The return of aridity and other conditions favorable to evaporation is indicated by a series including red shale, red to greenish sandy shale, sandstone, and gypsum. These beds occur above a thick basal sandstone and are widespread in the central part of the State. The basal sandstone

[119] Kelly, W. A., Lower Pennsylvanian Faunas from Michigan: Jour. Paleont., Vol. IV, No. 2, pp. 129-151 (June 1930).

[120] White, David, Letter quoted in Coal of Michigan: Geol. Survey of Michigan, Vol. VIII, Pt. 2, p. 45 (1902).

[121] Lane, A. C., and Seaman, A. E., Notes on the Geological Section of Michigan: Ann. Rept. of State Geologist, pp. 87-89 (1909).

[122] Winchell, Alexander, Geology, Zoology, and Botany of the Lower Peninsula: Geol. Survey of Michigan, First Bien. Rept., pp. 114, 115; 126, 127 (1861).

[123] Lane, A. C., and Seaman, A. E., Op. cit., p. 89 (1909).

[124] Lane, A. C., and Seaman, A. E., Idem, p. 89 (1909).

member is probably equivalent to the Ionia sandstone or Woodville as first defined. The beds are found directly beneath the glacial drift throughout an area of about seven counties and attain a maximum reported thickness of 180 feet. Exposures have not been found and the beds remain unnamed because of their comparatively recent discovery and the difficulty of correlation due to the apparent absence of faunal material. Many of the layers are soft and the samples secured from drilling operations are usually poor.

The series is provisionally given the very generalized name "Red Beds" for identification purposes, with full appreciation that the term will probably be inadequate. The physical characteristics of the beds seem to compare rather closely with the Permian "Red Beds" of the southwestern sections of the United States, but this does not in any way imply a proposed correlation with any particular section. In fact, these strata could include beds from Pennsylvanian to Triassic in age and still possess practically the same lithological properties as described. The conditions which characterize "Permo-Carboniferous" deposition were apparently present in the restricted Michigan "basin." However, these conditions may have existed prior to the time that they prevailed in the typical southwestern "Red Beds" region. This conception was proposed for other sections of the eastern United States by Case[125] upon discovery of "Permo-Carboniferous" vertebrates in Conemaugh beds of Ohio.

There is no definite evidence at the present time to indicate that these beds should be separated in age from the previously described Woodville (Ionia) sandstone. The red color of the sandstone suggests aridity and possibly other climatic conditions favorable to dessication. Perhaps deposition was almost continuous so that no pronounced breaks occur in the entire red series. Well samples from new drillings and cores may bring about a better solution of this problem in the future.

The Woodville and "Red Beds" have been mapped as one complete unit in the region penetrated by the drill in central Michigan. The shape of the area underlain by these beds is roughly elliptical with the major axis almost due north and south. (See fig. 2) This area is apparently asymmetrical to the depositional "basin" and confined to the northwest side. However, it is probable that because of their soft, plastic character and the resemblance to certain types of red lake clay and boulder clay these beds have not been recorded in many wells. The exact limits of the area underlain by "Red Beds" is, therefore, not very accurately defined.

PLEISTOCENE

The Pleistocene deposits of Michigan which make up the surface material of a large part of the State have been extensively described[126]. The work of ice in sculpturing the hard rocks and molding surface features, acting as an agent for transporting incoherent rock debris, and serving as a barrier for impounding great inland fresh water lakes, is the deter-

[125] Case, E. C., Permo-Carboniferous Conditions versus Permo-Carboniferous Time: Jour. Geol., Vol. 26, pp. 500-506 (1918).
——————, Carnegie Inst. Washington, Pub. 283, pp. 187-193 (1919).
——————, Michigan Acad. Sci., 20th Ann. Rept., p. 82 (1918).

[126] Leverett, Frank, and Taylor, Frank B., The Pleistocene of Indiana and Michigan and the History of the Great Lakes: U. S. Geol. Survey, Mon. 53 (1915).
——————, Surface Geology and Agricultural Conditions of Michigan: Michigan Geol. & Biol. Survey, Pub. 25 (1917).
——————, Moraines and Shore Lines of the Lake Superior Region: U. S. Geol. Survey, Prof. Paper, 154-A (1929).
Russell, I. C., and Leverett, Frank, Ann Arbor Folio: U. S. Geol. Survey Folio 155 (1915).
Sherzer, W. H., Detroit Folio: U. S. Geol. Survey Folio 205 (1916).

mining factor in the origin of the surficial deposits of Michigan. The resulting material is known as *drift* and may be either stratified or unstratified. Boulder clay, lake clay, sand, and gravel are very widely scattered and irregularly distributed. These weathered materials dumped by the receding glacier during the various interrupted stages of its existence form a mantle or cover of variable thickness over most of the southern peninsula. The greatest known thickness is about 884 feet in southeastern Wexford County, but the thickness generally is from 100 to 300 feet. The areas of thick drift conform closely to the regions of high pre-glacial relief, but in some cases old drainage channels have been filled with glacial deposits. Here the drift is abnormally thick.

The ice advanced over the region because of several successive cold stages and retreated during relatively warm periods. The recognizable deposits in Michigan from two of these stages are the Illinoian and Wisconsin drift sheets. The Illinoian drift was subject to a considerable amount of weathering prior to the Wisconsin stage, and the lime removed by solution was reprecipitated in the spaces between the grains. The resulting boulder clay, or till, as it is sometimes called, is consequently somewhat hardened and is usually termed "hardpan" by water well drillers because it is difficult to penetrate. The color is generally blue gray and thus contrasts distinctly with red to brown boulder clay which is more common in the younger drift. In addition to the leached clay which resulted from weathering processes during the interglacial period, dark black humous soils formed in swampy places. These interglacial soils contain remains of leaves, plants, and animals revealing the climatic conditions of the time. Evidence of erosion of the Illinoian drift prior to the Wisconsin stage is available from the topographic relief shown in wells penetrating the entire thickness of the Wisconsin drift sheet. The deposits of Wisconsin drift are less consolidated and do not show the same extensive effects of weathering as the earlier deposits. Locally, they are somewhat hardened by the action of solutions which filter through the sand and gravel and by the precipitation of lime, iron oxide, etc., cement the pebbles together. This cemented gravel, sometimes termed "crag," is similar in appearance to concrete. It has been found along hillsides, in gravel pits, and in wells.

The origin of the Wisconsin drift sheet has a complex history. The great mass of ice which covered the region was adjusted and controlled in movement by the depressions which existed prior to its formation. Because of this conformity to the larger valleys, the ice moved over the country in lobes or tongues which in this particular area occupied the basins of Lake Michigan, Lake Huron, Lake Erie, and Saginaw Bay. These lobes have been called the Michigan, the Saginaw, and the Huron-Erie lobes. The deposits from melting at the ice margin or front of the ice lobes were laid down when the ice fronts stood for some time at certain positions. At the junction of two lobes the quantity of material resulting from melting of the ice was much larger, and the deposits were, therefore, much thicker in these localities. Usually the interlobate areas, as they are called, correspond with the pre-existing pre-glacial topographic ridges and account for the rough correspondence of thick glacial deposits to the preexisting topography.

The principal surface features produced by the glacial deposits are called terminal moraines, kames, eskers, drumlins, ground moraine, and outwash. The terminal moraines are knolls or ridges consisting of boulder clay and more or less of sand and gravel. They are formed at the margin of the ice by the accumulation of debris from melting. Kames are modified types of terminal moraine and are usually sharp knolls or steep conical hills within the moraine. The material is sand and gravel rather than boulder clay. Eskers or "hogbacks" are steep, winding, snake-like ridges, consisting of the sand and gravel deposited by streams flowing within or at the base of the ice mass. Drumlins are inverted canoe-shaped hills of boulder clay, extending parallel to the ice movement, and were probably molded beneath the ice. Their exact origin is still in doubt. Ground moraine consists of the low hills and plains of till formed beneath the ice, when the retreat was sufficiently rapid to prevent the building of terminal moraine. Outwash is usually represented in the landscape by a comparatively level plain and is made up of sand and gravel deposited by the sheet-like bodies of running water or braided streams which flowed from the front of the ice. Sometimes the deposits of outwash have a "pitted" surface because of the subsequent melting of buried blocks of ice. The continuity of these glacial features is determined by the position of the several ice lobes when they were formed. The various morainic systems have been traced out in detail and given local names. They are fully described and shown by means of maps in the comprehensive reports on the glacial geology of Michigan[127].

Surface deposits indirectly caused by the continental glacier were laid down in the glacial lakes formed when retreats and advances of the ice diverted and choked drainage so as to impound the water. These lakes attained different forms and sizes near the close of Wisconsin glaciation as the ice lobes retreated into their respective basins. The elevations at which their waters stood were closely related to the numerous changes in outlet. At different times the lakes were drained by the Fort Wayne outlet and the Wabash River; the Chicago outlet and the Illinois River; the Imlay outlet westward across Michigan and thence to the Chicago outlet; the Grand River outlet across Michigan to Lake Chicago which then occupied the southern end of the present Lake Michigan; the Ubley outlet across the "Thumb" to Lake Saginaw, and the Grand River outlet to Lake Chicago; the Trent outlet across Ontario and the Mohawk outlet across New York to the Hudson River; and the North Bay, Ottawa River outlet to the St. Lawrence. As the lakes stood at different levels, individual beaches, bars, barriers, and offshore features were formed and remain now as evidence of their former presence.

The Lakes were known in the order of their formation as Lake Maumee, Lake Arkona, Lake Whittlesey, Lake Wayne, Lake Warren, Lake Lundy, Lake Algonquin, and the Nipissing Great Lakes. The elevations at which they stood were not in direct relation to the order of existence, but a general oscillation took place in the direction of lower levels. This complication arose from the distribution of the topographic features of the region, the deepening of the outlets, a differential uplift of the land, and the shifting back and forth of the ice fronts.

The deposits of the glacial lakes were governed by the position of the shores. The basins of the lakes are left as comparativly level expanses underlain by different types of lake clays and silts. Near the former beaches, parallel ridges exist which represent the shore features generally common to all lakes. These features may be traced for miles as ridges of assorted sand and gravel with distinctive slopes which give further evidence of their origin.

[127] Op. cit.

Chapter IV

HISTORICAL GEOLOGY

DIFFICULTIES IN TRACING THE EVOLUTION OF THE SYNCLINAL BASIN

The geologic history of the Michigan synclinal basin from its beginning to the present is difficult to trace with any degree of continuity. The deep burial beneath glacial drift and the isolation from other depositional provinces allow only very broad generalizations from the usually accepted methods of tracing faunal evolution and strand line displacement. Surface outcrops are few and far between. The proper solution seems to rest with careful examination of well records, accurate determination of the sections thus disclosed, and correct interpretation of their relation to the regional setting. The early correlations will require frequent revision until regional aspects are more fully understood, and the methods of correlation must necessarily become more exact by the rigid application of micro-paleontology, micro-lithology, heavy mineral studies, and the close examination of chert residues. Until these detailed studies have been pursued, it will be necessary to rely on a more cursory examination of well record data in outlining the geologic history of the region.

PALEOZOIC ERA

CAMBRIAN PERIOD

LAKE SUPERIOR TIME

The earliest time of the Paleozoic era recorded in the rocks of Michigan is revealed by the clastic series of the Cambrian period. The origin of the structural downwarp giving rise to a basin of sedimentation occurred a long time prior to this era, but the continued sinking by the addition of sandy sediments was apparently accelerated. The land areas which were probably present to the west and also to the northeast must have had considerable relief, and weathering processes were relatively active. This is shown by the coarse texture of the material deposited and the content of undecomposed minerals. The conglomerate which in many places occurs at the base of the Lake Superior sandstone indicates that there was a rugged shoreline which was gradually worn down as the sea advanced. When the iron-bearing rocks became more thoroughly submerged, less ferruginous material was introduced into the sea, and the upper part of the Cambrian rocks indicates this condition by the absence of red color. A lapse of the processes of deposition and erosion in the Cambrian is suggested by the local absence of Trempealeau beds in eastern Wisconsin and northeastern Illinois. During the closing stages of Lake Superior time, (the Jordan of Wisconsin in part) a considerable portion of the sea probably withdrew and the land was elevated. The terrestrial conditions which resulted were possibly associated with arid climate, as three-sided faceted pebbles (dreikanter) which are considered by many as characteristic of desert erosion have been found.[1] According to Ulrich[2], marine connections existed repeatedly and perhaps continuously throughout the Cambrian between the seas of the upper Mississippi Valley and those of certain western and southwestern states.

ORDOVICIAN PERIOD

OZARKIAN TIME

A period of warping and extensive erosion took place during the interval between Cambrian and Ozarkian (Lower Ordovician) times. In northern Michigan, the Ozarkian sea contained a large quantity of lime and magnesia which was precipitated on the sands then present along low tidal flats. A quantity of oolitic dolomite resulted, and in the central part of Michigan a close adjustment between downwarping and deposition probably resulted in the laying down of an abnormal thickness of these sediments.

CANADIAN TIME

Depositional and faunal evidence from without the Michigan Basin province indicates that at the close of the Ozarkian, the land was again uplifted and subjected to subaërial erosion. Widespread seas inundated the region in Canadian time and the relief of the land areas was unstable as indicated by the irregular deposition of sandstones and cherty dolomites. The oolitic character of many of the cherts shows that the land area at infrequent intervals had a low relief, thus causing the formation of oolites by accretion of lime. The periodic sinking of the "basin" resulted in the deposition of an unusual thickness of these rocks in central Michigan. Only the very border deposits of this sea are revealed in the northern part of the State.

ST. PETER TIME

At the close of Canadian time and prior to the deposition of the St. Peter sandstone, the land was again deeply eroded. The irregular surface upon which the sandstone was deposited is well shown throughout the Mississippi Valley region, and particularly near Milwaukee, Wisconsin, where the St. Peter rests directly upon the Eau Claire formation of Cambrian age. The occurrence of residual soil and a basal St. Peter cherty conglomerate in other contiguous states is further evidence of this erosion surface. The presence of this conglomerate suggests the long continued work of large sized streams. The clean white sandstone indicates emergence and rather complete assorting by both wind and wave action. The sea probably transgressed over a shore area largely covered with dunes of windblown sand which were piled up by winds similar in type to those causing the present dune region along the eastern shore of Lake Michigan. Recent drilling in the interior of the Michigan "basin" has shown the St. Peter sandstone to have great thickness and unusual physical characteristics, comparable to subsurface occurrences in north central Illinois. This discovery gives evidence that the St. Peter sea not only advanced on the Wisconsin land mass from the south, but also occupied the Michigan Basin for a longer time than surrounding areas. The adjustment of downwarping to deposition load also took place as in previous periods. The low relief of the land and the completeness of dust removal by the wind is shown by the absence of coarse conglomerates and the purity of the fine grained sandstones. The thick deposits left in the deeper basins farther from shore are fine textured sandstones with only thin partings of shaly material. Climatic factors which favored rapid disintegration probably explain the scarcity of shales in these rocks.

[1] Hussey, R. C., Personal communication.
[2] Ulrich, E. O., Notes on New Names in the Table of Formations and on Physical Evidence of Breaks between Paleozoic Systems in Wisconsin: Trans. Wisconsin Acad. Sci., Arts & Letters, Vol. 21, p. 106 (1924).

TRENTON—BLACK RIVER TIME

Trenton-Black River time marked the return of climatic conditions favorable to lime deposition, and the seas transgressed far beyond the present limits of the low-lying Archean land mass to the northwest. Animal life thrived in these seas and relatively uniform conditions are indicated by the physical characteristics of the rocks. The maximum extent of the Trenton sea is not known, but the Limestone Mountain outlier in Keweenaw County suggests that it probably covered the entire Lake Superior region. The general direction and location of the northern shore line is suggested by the rate of thinning to the northwest. (See fig. 4).

DECORAH TIME

During Decorah time, a structural disturbance or slight uplift must have occurred to the northwest, but apparently the coarse sandstone beds to the north were not exposed to erosion because the material brought in was entirely calcareous shale. The Decorah beds thicken to the northwest and thus furnish evidence that their source was possibly from that direction.

Soon after Decorah time, the submergence probably was more widespread, and waters covered a vast expanse in north central Canada. The Wisconsin area then emerged, but the subsequent seas, including the upper Mohawkian of which there are no existing deposits farther west in Wisconsin, occupied the greater part of the Michigan synclinal basin.

CINCINNATIAN TIME

Preceding early Cincinnatian time, a slight elevation of the area made the sea shallower, and the waters of the Appalachian trough probably entered by a northeast connection. Climate in the east, assisted by abundant vegetation, favored complete land decay, and the widespread deltas which resulted were composed largely of bituminous muds. These beds are represented in Michigan by the Collingwood shale which covered a large part of the "basin" and spread westward beyond Newberry in the northern peninsula. As the dark colored mud was brought in, the basin gradually subsided. The toxic conditions caused in part by shallow waters changed as the water gradually deepened. With this deepening and clearing of the water, abundant life forms thrived. The sea came in again from the north and south, and many of the gray shale beds were probably derived from the weathering of limestone rocks which made up the shores of the neighboring land masses. The fossiliferous beds and thin limestones evince the tempering of climate. At the time of the Richmond invasion, the basin of deposition was not entirely isolated because floating faunal forms indicate currents and a connection to the eastward.

The area was somewhat restricted to the south and any connections with adjoining basins in that general direction were only temporary. Near the close of Richmond time, residual red clays were forming in southeastern Michigan on the adjacent land mass, probably by the weathering of limestone. A gradual continental uplift took place and caused these transition beds to be deposited locally. Because of the ample supply of iron in the residual soils, these red and green shales were laid down well into the next period and are widespread throughout the northeastern United States.

SILURIAN PERIOD

CATARACT TIME

The Lower Silurian or Medinan began with an extensive transgression of the sea which deposited the Manitoulin beds. The Manitoulin sea encroached from the north, and the shores consisted largely of limestone. The composition of the waters must have been fairly uniform because the physical characteristics of the Manitoulin rocks are comparatively uniform throughout the area of the Michigan Basin.

Toward the end of Cataract time, the quantity of finely divided detrital material forming on the land increased. The Cabot Head shale was formed from the deposition of muds which consisted of highly oxidized red and green sediments. The colors resulted from the influences of climate and the nearby pre-Cambrian rocks which contained large quantities of iron. The red color alternates with green and gray, and the lighter color suggests that the ferruginous sediments originating in the north were reduced by the deoxidizing influence of marine conditions originating in the south.

NIAGARAN TIME

In middle Silurian or Niagaran time, the sea transgressed widely, a general deepening of basins took place, and the deposition of limestone and dolomite indicates that the climate was warm. Shallows must have existed temporarily during the formation of the Byron beds, which are locally argillaceous and contain "sun cracks" and ripple marks. The transgression took place from the north and probably originated in the Arctic[3] and Hudson Bay regions. Local connections may have been made with the St. Lawrence trough but the relations are not definite. The Burnt Bluff formation was laid down in a period when the deepest part of the Michigan synclinal basin was far north of its present location. The members of the formation thin rapidly into the central part of the southern peninsula, and this convergence supports the faunal evidence of northern origin. Local conditions of deposition and possibly later chemical changes brought about the lateral gradation of limestone into dolomite that is so common.

Shaly beds found in the Niagaran in wells in lower Michigan are lacking in the northern region where it is exposed. Possibly the Rochester formation, considered to have been removed[4] by erosion in many regions beyond the confines of the Michigan "basin," is preserved in the southern

[3] Ehlers, G. M., Unpublished manuscript.

[4] Williams, M. Y., The Silurian Geology and Faunas of the Ontario Peninsula and Manitoulin and adjacent Islands: Canada Geol. Survey, Mem. 111, p. 70 (1919).
Chadwick, G. H., Stratigraphy of the New York Clinton: Bull., Geol. Soc. Am., Vol. 29, pp. 355-359 (1918).

peninsula under the cover of younger rocks. The Mississinewa shale in northern Indiana, which possesses Rochester affinities, may have some bearing on this interpretation, but faunal evidence is lacking to substantiate the exact age of these shale beds. A change in the type of land waste and shallowing of the Niagaran sea certainly occurred in the region of southern Michigan.

The seas of Manistique time originated[5] in the Gulf of St. Lawrence and spread southwest as far as Iowa. The waters were relatively warm and undisturbed for coral beds are abundant in the lower strata of the formation, and conditions were generally favorable to the preservation of marine fauna. The Manistique seas transgressed from the north and formed an overlapping series of rocks similar to the Burnt Bluff formation. The deposition of the Engadine dolomite evidently marked a shallowing of comparatively restricted seas because the formation is locally arenaceous, and the life forms indicate approaching high salinity. An extensive system of coral and stromatoporoid reefs was built during this period and according to Cumings,[6] "after the time of the cherty coral beds (Manistique of Michigan), the teeming life of the Niagaran sea assumes complete mastery of the sedimentation and builds a formation, the Racine-Guelph, entirely derived from its own exuviae." The steepness of dip off many of these reef "mounds" is partial evidence for the intensity of wave action during the period. Dolomitization of the reefs was probably favored by the change in climatic conditions toward greater aridity. The increased salinity brought on by these climatic changes must have had a certain controlling effect upon the formation of the dolomites.

MONROE—SALINA TIME

Niagaran deposition culminated with a gradual emergence of continental areas resulting in the isolation[7] of the greater part of the interior Silurian sea into a vast, partially or entirely enclosed basin. In this manner, a period of dessication began and a favorable warm, dry climate probably assisted the evaporation. The brines were concentrated in great inland lakes or temporarily restricted embayments where thick deposits of anhydrite, gypsum, and salt precipitated as the solutions became super-saturated with respect to one or more of these substances. The Salina relict seas initiated the first important evaporite period which affected the rocks of the Michigan synclinal basin, and the resulting deposits of salt, anhydrite, and gypsum exercised a controlling influence on much of the ensuing geologic history of the region. Beds of gypsum and anhydrite were formed frequently in the periods that followed, and the products of weathering from shores composed of Salina rocks contributed high salinity to many of the subsequent seas. The shape and confines of the "basin" formed at this time were relatively permanent throughout the greater part of the Silurian and Devonian periods.

The approximate shape of the "basin" of deposition throughout Monroe and Salina times is shown in Figure 7 by means of an isopachous contour map. This type of map is designed to illustrate the thickening

[5] Ehlers, G. M., Unpublished manuscript.

[6] Cumings, E. R., Silurian Studies. Two Fort Wayne Wells in the Silurian and their bearing on the Niagaran of the Michigan Basin: Proc. Ind. Acad. Sci., Vol. 39, p. 195 (1929).

[7] Grabau, A. W., Geology and Paleontology of Niagara Falls and Vicinity: Bull., New York State Mus., No. 45, pp. 127-128 (1901).

of beds into the center of the deepest part of the "basin," and each contour line represents an equal thickness of Monroe-Salina rocks. The area of maximum thickness is indicated to emphasize the extent of the region of greatest sinking and probably in most instances, the largest amount of deposition. This relation of the amount of deposition to the present thickness of the rocks is obviously an important one. However, it does not take into consideration the quantity of beds subsequently removed by weathering and erosion, or the character of the rocks laid down. These factors must be further evaluated when the maps are interpreted. The relation does indicate, however, the approximate size and dimensions of the synclinal or sinking area, the location of the major depression, the relative amount of downwarping which has taken place, the factors influencing sedimentation and migration of the sea, and the possible causes of the warping movement.

The data used in constructing this map and other maps designed to show the results of subsequent periods of deposition were derived from the records of wells throughout the State. These data are subject, therefore, to errors of interpretation and correlation common to such determinations. Many anomalous figures have been disregarded, and in the dominant major features, the figures used should be essentially correct.

The rocks beneath the Salina have not been penetrated in the central part of the basin. This lack of information explains why thickness maps were not inserted earlier in the discussion of geological history. The Salina has not been reached by the drill in the deepest part of the synclinal area so that the map merely explains the rate of thickening of the beds and only gives a very general outline of the basin proper. Other maps which follow are compiled from a larger quantity of data and show more accurately the structural and depositional conditions.

The axis of the depositional area during Monroe-Salina time is shown to have a major northwest-southeast elongation, and the presence of a barrier in the southeastern part of the State is strongly evident. That there was a shore line with gentle offshore slope in proximity of southwestern Michigan is suggested by the decrease in the convergence rate in that direction. These features seem to point out the low nature of existing shores and the restriction of the basin from seaward connections to the south. The fine granular dolomites of the Salina and Monroe represent lime muds derived from the limestones and dolomites laid down in previous periods. Argillaceous clastics are not abundant in the Monroe-Salina rocks and this indicates that the "basin" was largely surrounded by limestone areas, and that climatic conditions were not favorable for complete disintegration into clay soils. The salinity of the sea prevented the existence of many forms of life, and the beds of the Salina are almost entirely non-fossiliferous. The marginal sediments were probably frequently reworked, and their salt content was added to the salt present in the marine water which might have been separated from the main part of the sea at the time of prior uplift.

Subsidence of the basin must have been gradual to permit additions of water without inundation, and sinking probably kept close pace with evaporation during the three successive periods when thick beds of salt were laid down so uniformly in the central area. The flooding of local basins and salt flats very likely added to the slowly increasing salinity

PUBLICATION 38 - FIGURE 7

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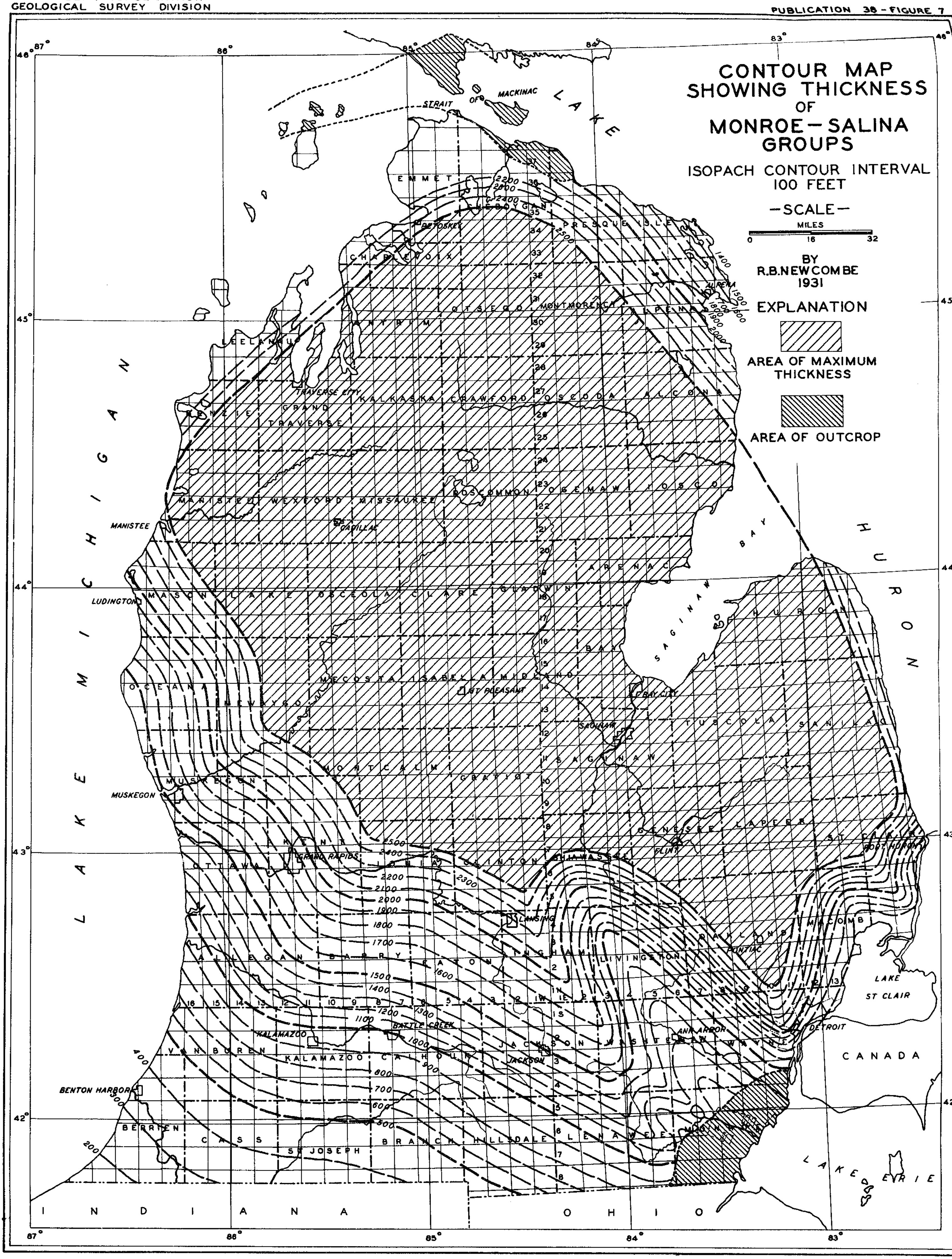
CONTOUR MAP
SHOWING THICKNESS
OF
MONROE—SALINA
GROUPS
ISOPACH CONTOUR INTERVAL
100 FEET
—SCALE—
MILES
0 16 32
BY
R.B.NEWCOMBE
1931
EXPLANATION
AREA OF MAXIMUM THICKNESS
AREA OF OUTCROP
LAKE MICHIGAN
LAKE HURON
SAGINAW BAY
STRAIT OF MACKINAC
LAKE ST CLAIR
LAKE ERIE
CANADA
INDIANA
OHIO
MANISTEE
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MUSKEGON
BENTON HARBOR
GRAND RAPIDS
LANSING
KALAMAZOO
BATTLE CREEK
JACKSON
ANN ARBOR
DETROIT
PONTIAC
FLINT
SAGINAW
BAY CITY
MT PLEASANT
CADILLAC
TRAVERSE CITY
PETOSKEY
ALPENA
PORT HURON

of the larger bodies of water. Desert cloudbursts may have been effective in causing these additions, as aridity probably existed at intervals throughout the period. Seasonal dry winds might have also caused concentration of salt in lagoonal flats.

The local occurrence of red shales has been advanced as evidence for arid conditions, but these are not prevalent in all parts of the Michigan Basin. In the western section of the State, red dolomites occur near the base of the Salina beds, indicating the possibility of thorough decay of a limestone land area or deltaic enrichment of iron from streams traversing an exposed portion of the iron bearing regions to the northwest.

BASS ISLAND TIME

At the opening of Bass Island time, conditions were about the same as in the preceding Salina period. Lime muds were being deposited and evaporation was still in progress, but the "basin" became connected with outside sources of water which freshened the sea sufficiently to permit the existence of more abundant life. Climatic changes toward high humidity were possibly effective in preventing precipitation of salt and the more soluble chlorides. Frequent incursions of the sea took place from the Atlantic, but the basin showed a gradual shrinkage. Local restriction furnished conditions of evaporation which caused calcium sulfate to precipitate and form thick beds of anhydrite. Apparently, the Michigan "basin" was not so extensively downwarped as in the preceding Salina time because the thickness of the Bass Island rocks shows considerable uniformity throughout the explored area of the State. The sea transgressed westward across the region, and a mixture of dolomite slime with some clay mud was washed into the "basin." The water was relatively shallow because beds with carbonaceous films indicate that vegetation was then present. Oolites of possible algal origin suggest deposition on tidal flats. Shallow water is also indicated by the ripple marks and sun cracks which are preserved on the surface of certain beds. Some of the dolomite represents secondary replacement after limestone, but the most of it is probably the reworked product of original magnesian rock. The waters of Bass Island time reached as far as Milwaukee, and there was an intermittent connection with the Indiana basin through the structural depression known as the Logansport "sag." The Kokomo limestone in Indiana was most likely formed at the times of this connection.

DEVONIAN PERIOD

SYLVANIA TIME

The emergence or retreat of the sea preceding Sylvania time took place in the Michigan Basin prior to the withdrawal of waters in the east. The St. Peter sandstone and various Cambrian sandstones were laid bare, resulting in disintegration and assorting by the winds. These drifting sands were piled into dunes and reworked by the advancing Sylvania sea. Deposition of colloidal silica took place locally, and the finer products from breaking down of clastic rocks were carried into deeper water and formed the white cherty to sandy dolomites of central Michigan. As at the present time, prevailing winds were probably from the west, and an uplift had advanced the shore line well into the southeastern part of the State. Local climatic conditions, and the probable presence of abundant vegetation covering the lime rocks in the southwestern part of the State caused weathering of the land mass to a clay which gave rise to deposits of green shale. This shale contains scattered typically rounded Sylvania sand grains. The green color was probably due to reduction of ferric iron to the ferrous condition. The shale may possibly represent a seaward deposit, but the presence of imbedded sand grains suggests that the water was shallow.

Local readvances of the sea near the end of Sylvania time caused offshore or littoral conditions which gave rise to a purer dolomite that contains marine fossils. Additional sand was furnished at the time of the final retreat, and this sand was reworked by the oncoming waves at the close of the period. As a result of the reworking process, siliceous dolomite beds were deposited.

The formation was probably laid down on an uneven land area of some relief and possibly overlaps a number of older formations in adjoining regions. The summation of its history, according to Sherzer and Grabau[8], includes the basal layers as sedimentary, the body eolian, the upper eolian deposits reworked by a transgressing sea, and the materials in the main derived from the St. Peter. Basally, it rests upon successively younger strata southeastward from Wisconsin and is younger than the youngest bed upon which it rests. The final cementing of incoherent sand grains was effected by percolating water introducing secondary silica with magnesium and calcium carbonates. The sulfates carried in the water were reduced to sulfides, and calcium was locally replaced by strontium to form cavity fillings of the mineral celestite ($Sr\ SO_4$). Further reduction, possibly aided by bacterial action, formed small amounts of free sulfur. Later oxidation of iron sulfides on exposure to the air resulted in abundant staining of the beds with the oxides of iron.

DETROIT RIVER TIME

During Detroit River time, the sea probably invaded from the north and occupied a shallow trough. At this time, much of the continent was out of water, and evolution of Devonian forms was going on in more remote areas. The character of the fauna found in the rocks of the series fixes its age as Devonian. The waters transgressed from the northwest, and the deposits overlap successively younger rocks to the southeast. This condition of overlap is also present in the case of the individual members of the Detroit River series.

The configuration of the "basin" at the time the Detroit River was deposited is shown in Figure 8. The shape of the synclinal area was in general asymmetrical with the gentle slope to the northeast. The major elongation was slightly north-northwest of directly north-south, and the restricted deep part of the "basin" was approximately circular in outline. The position of the shores to the southwest and northeast is indicated by the gradual thinning of the beds in these directions. Local gentle warping is indicated by the basinward bends of the contour lines.

Near the close of the period, a warm climate brought on the formation and growth of corals, giving rise to the Anderdon reefs. These condi-

[8] Grabau, A. W., and Sherzer, W. H., The Monroe Formation of Southern Michigan and Adjoining Regions: Michigan Geol. & Biol. Survey, Pub. 2, Geol. Ser. 1, p. 85 (1910).

PUBLICATION 38 - FIGURE 8

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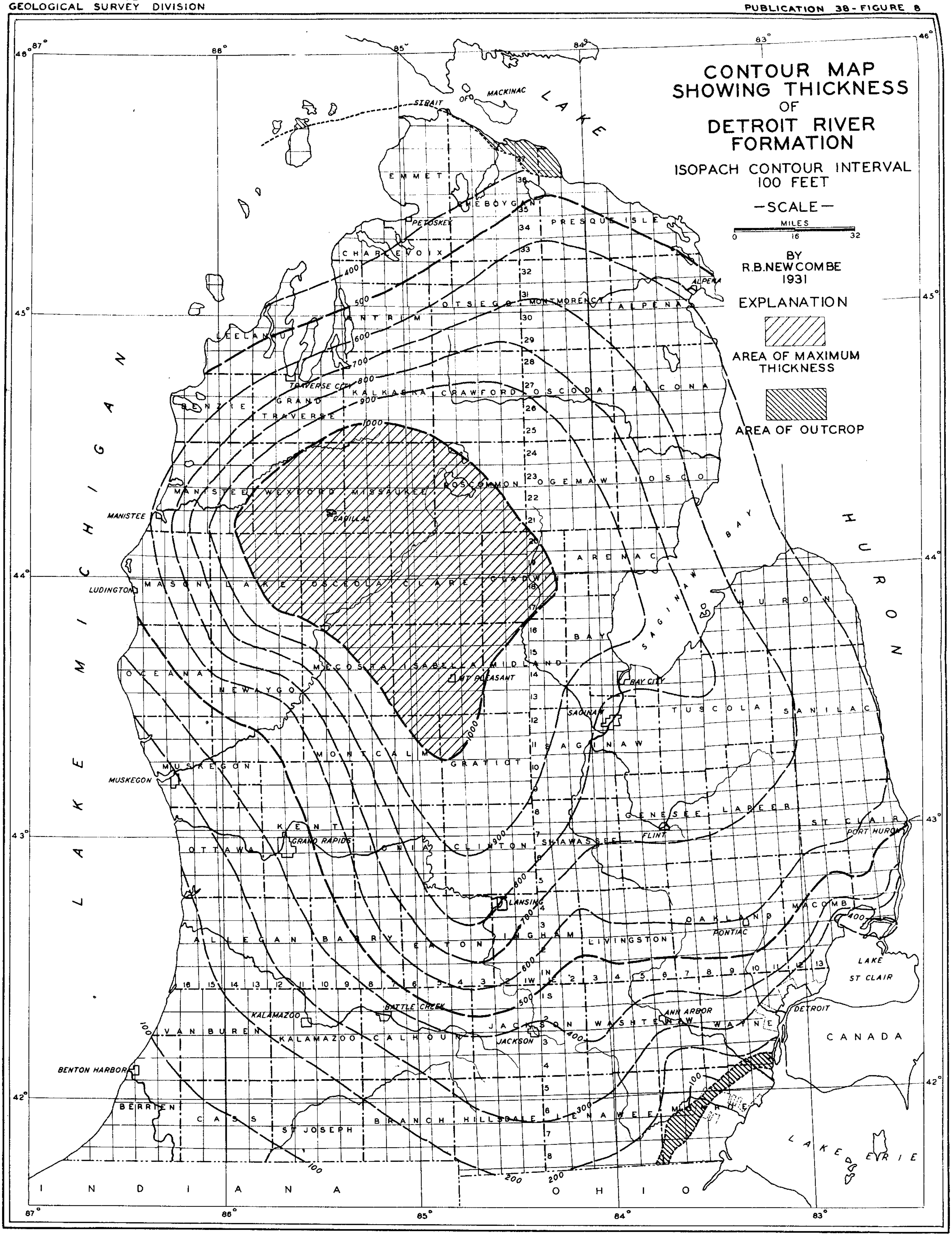
GEOLOGICAL SURVEY DIVISION


CONTOUR MAP
SHOWING THICKNESS
OF
DETROIT RIVER
FORMATION
ISOPACH CONTOUR INTERVAL
100 FEET
-SCALE-
MILES
0 16 32
BY
R.B.NEWCOMBE
1931
EXPLANATION
AREA OF MAXIMUM THICKNESS
AREA OF OUTCROP
LAKE MICHIGAN
LAKE HURON
SAGINAW BAY
LAKE ST CLAIR
LAKE ERIE
CANADA
INDIANA
OHIO
STRAIT OF MACKINAC
EMMET
CHEBOYGAN
PRESQUE ISLE
CHARLEVOIX
OTSEGO
MONTMORENCY
ALPENA
ANTRIM
LEELANAU
BENZIE
GRAND TRAVERSE
KALKASKA
CRAWFORD
OSCODA
ALCONA
MANISTEE
WEXFORD
MISSAUKEE
ROSCOMMON
OGEMAW
IOSCO
MASON
LAKE
OSCEOLA
CLARE
GLADWIN
ARENAC
HURON
BAY
OCEANA
NEWAYGO
MECOSTA
ISABELLA
MIDLAND
TUSCOLA
SANILAC
MUSKEGON
MONTCALM
GRATIOT
SAGINAW
GENESEE
LAPEER
ST CLAIR
KENT
OTTAWA
IONIA
CLINTON
SHIAWASSEE
ALLEGAN
BARRY
EATON
INGHAM
LIVINGSTON
OAKLAND
MACOMB
VAN BUREN
KALAMAZOO
CALHOUN
JACKSON
WASHTENAW
WAYNE
BERRIEN
CASS
ST JOSEPH
BRANCH
HILLSDALE
LENAWEE
MONROE
MACKINAC
PETOSKEY
ALPENA
TRAVERSE CITY
MANISTEE
CADILLAC
LUDINGTON
ST PLEASANT
BAY CITY
SAGINAW
MUSKEGON
FLINT
PORT HURON
GRAND RAPIDS
LANSING
PONTIAC
BATTLE CREEK
KALAMAZOO
ANN ARBOR
DETROIT
JACKSON
BENTON HARBOR
100
200
300
400
500
600
700
800
900
1000
87°
86°
85°
84°
83°
46°
45°
44°
43°
42°

tions of warmth and dryness and temporary restriction of the more interior portions of the "basin" caused the concentration of salt, and the deposition of saline residues. Restricted seas of evaporation did not remain so long as in Salina time, but several beds of rock salt were deposited in the central part of the "basin" during this period. There were possibly intermittent arid conditions with evaporation in excess of water additions. The Detroit River salt basin compares closely with the deepest downwarped part of central Michigan during Detroit River time. (See fig. 9). This relation supports the idea of salt forming from restricted or relict seas. The great salinity of the seas of this period possibly came about in part from stream erosion of earlier rocks containing salt beds. An explanation[9] for the Silurian aspects of the upper Detroit River fauna might be that "Devonian life probably did not migrate far into the center of the State; when the outlet to the trough was temporarily closed the remnants of the Silurian facies were brought back from the salt producing basin."

The distribution of the salt beds within the Michigan Basin is best illustrated by cross sections which demonstrate graphically the extent of the occurrence of salt. (See figs. 10 and 11). Other beds are disregarded in these sections and no stratigraphic sequence is given except the base of the Dundee formation, which may be used for comparing intervals within the Monroe-Salina groups. The general continuity of the thicker beds of rock salt in the deeper portion of the "basin" is shown. This feature is contrary to the generally accepted idea that salt beds in Michigan are irregular in their occurrence. The truth of this early conception probably maintains for the marginal deposits of thin beds where lagoonal districts and small individual basins were the controlling physiographic features in their formation. It seems conclusive, however, that over wide basins of sedimentation, salt concentration acts very much like any other chemical deposit in that the beds thicken more or less uniformly toward the region of major sinking.

DUNDEE TIME

A period of emergence and gentle folding followed the retreat of the last Detroit River sea, exposing the various Monroe beds to erosive agents. The general trend of the axes of this folding in southeastern Michigan is [10] N60°E. Erosion followed, and the absence of shales would indicate that the nearby land areas consisted of limestone. Solution and chemical wearing away were the dominant weathering processes, and plant life must have been almost absent.

As the sea advanced on the Michigan area from the east, the western part of the "basin" had been uplifted, and the eastern part depressed. The pre-Dundee folding was so slight that discordance in dip was not evident at the exposed contact of the Detroit River and Dundee beds. The first waters entering the basin carried some sand from the east where deposition of the Oriskany was going on in the Appalachian trough, but the invasion did not progress uniformly across the State. In the northern part of Michigan, the magnesian beds of the previous formation were reworked and breccias of doubtful and complex origin were formed

[9] Newcombe, R. B., Interpretation of Recent Discoveries in the Salt-Bearing Rocks of Michigan: Papers, Michigan Acad. Sci., Arts & Letters, Vol. 12, p. 248 (1929).
[10] Grabau, A. W., and Sherzer, W. H., Op. cit., p. 57.

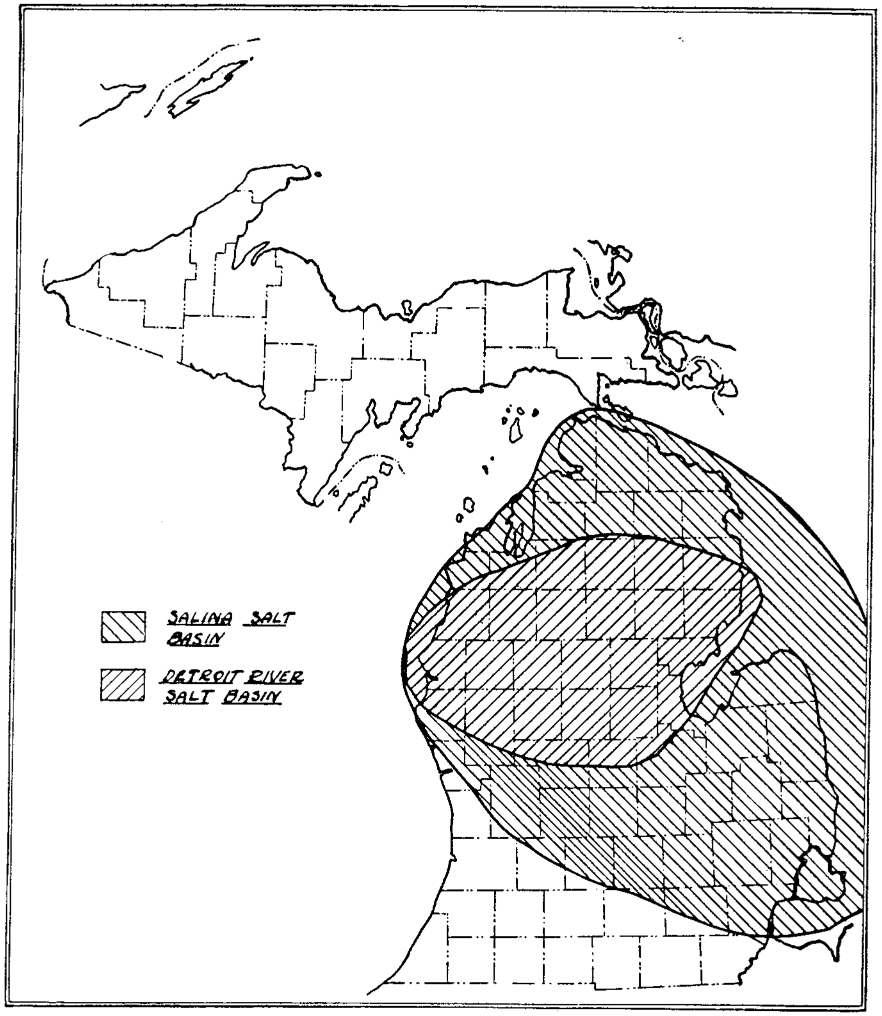


Figure 9. Map showing the approximate areas of the Detroit River and Salina salt basins.

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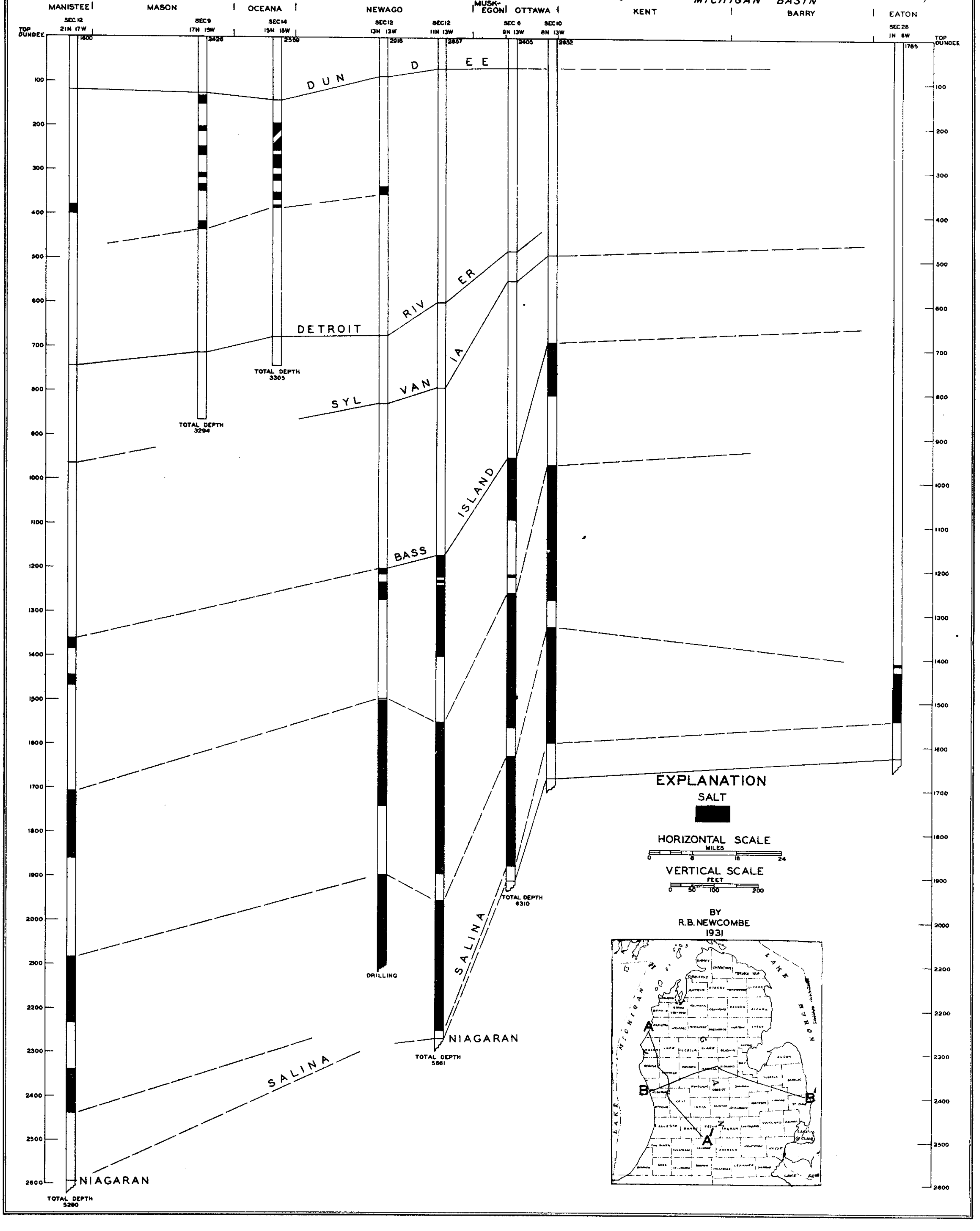
PUBLICATION 38 - FIGURE 10

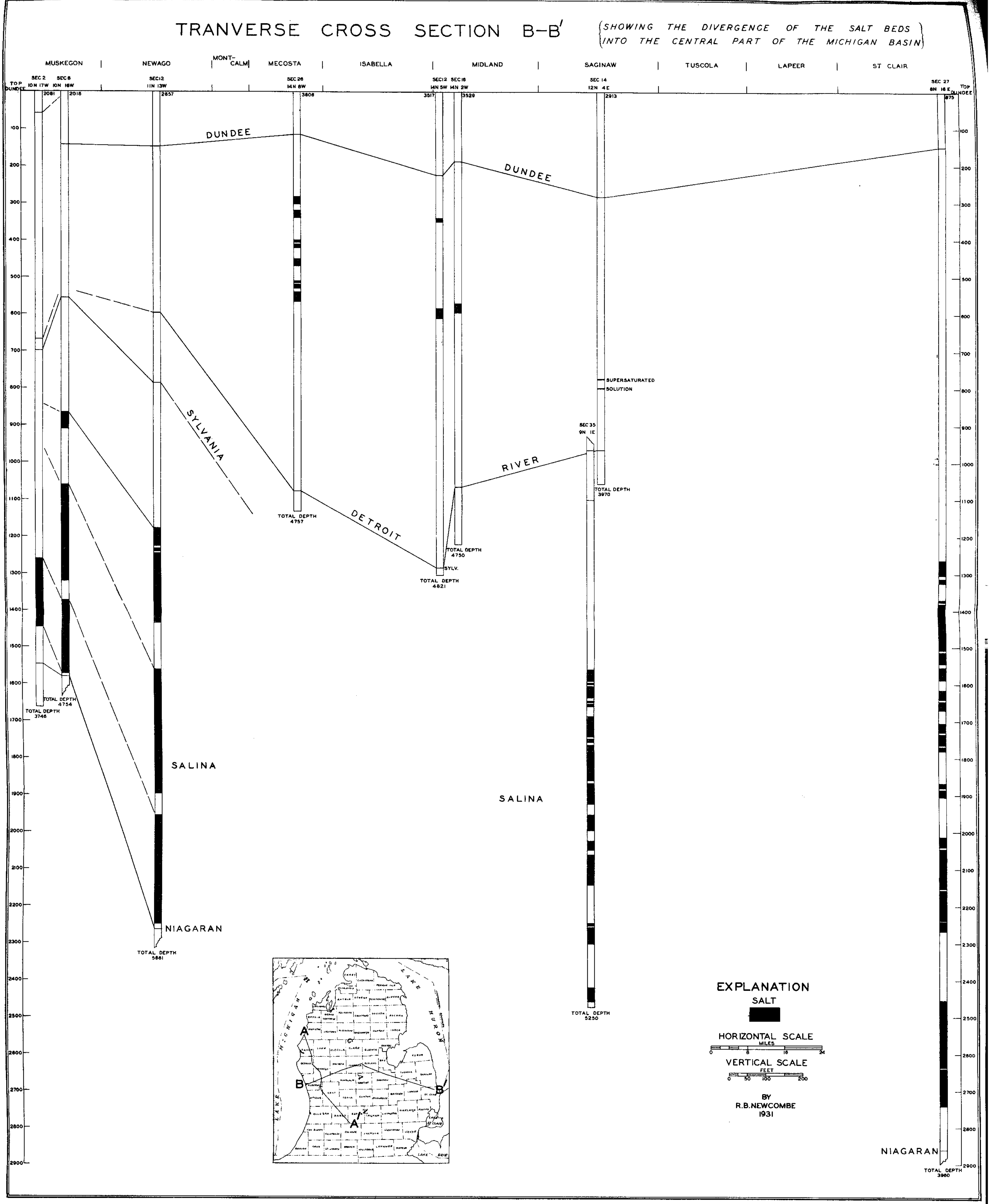
LONGITUDINAL CROSS SECTION A-A'

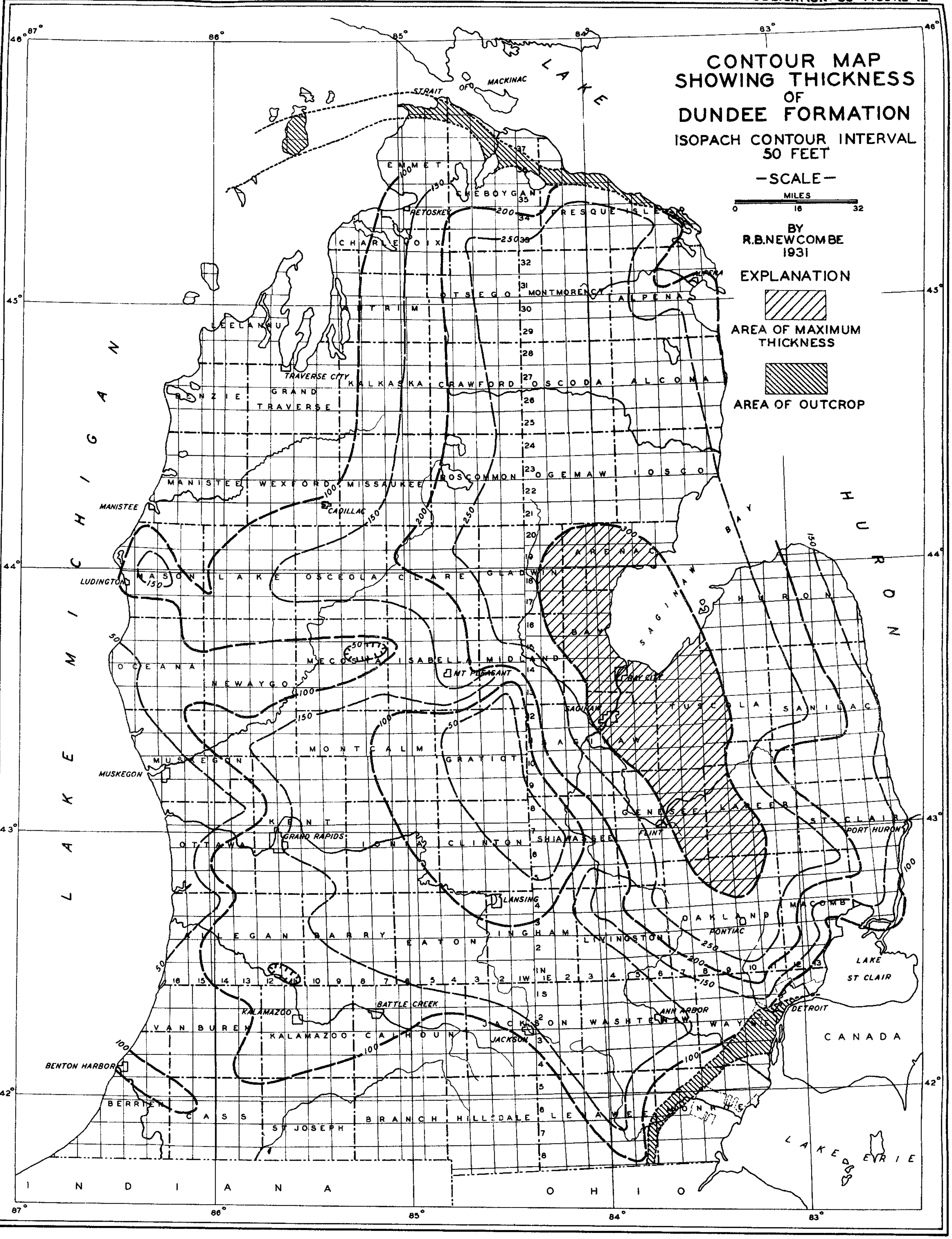
(SHOWING THE DIVERGENCE OF THE SALT-
BEDS INTO THE CENTRAL PART OF THE

LONGITUDINAL CROSS SECTION A-A'

(SHOWING THE DIVERGENCE OF THE SALT-BEDS INTO THE CENTRAL PART OF THE MICHIGAN BASIN)




TRANVERSE CROSS SECTION B-B'
(SHOWING THE DIVERGENCE OF THE SALT BEDS INTO THE CENTRAL PART OF THE MICHIGAN BASIN)
MUSKEGON
NEWAGO
MONT-CALM
MECOSTA
ISABELLA
MIDLAND
SAGINAW
TUSCOLA
LAPEER
ST CLAIR
TOP DUNDEE
SEC 2 10N 17W
SEC 8 10N 16W
SEC 12 11N 13W
SEC 26 14N 8W
SEC 12 14N 5W
SEC 16 14N 2W
SEC 14 12N 4E
SEC 35 9N 1E
SEC 27 8N 16E
2081
2018
2857
3808
3517
3529
2913
875
DUNDEE
SYLVANIA
DETROIT
RIVER
SALINA
NIAGARAN
SYLV.
SUPERSATURATED
SOLUTION
TOTAL DEPTH 3746
TOTAL DEPTH 4754
TOTAL DEPTH 5881
TOTAL DEPTH 4757
TOTAL DEPTH 4821
TOTAL DEPTH 4750
TOTAL DEPTH 3970
TOTAL DEPTH 5250
TOTAL DEPTH 3960
EXPLANATION
SALT
HORIZONTAL SCALE
MILES
0 8 16 24
VERTICAL SCALE
FEET
0 50 100 200
BY
R.B.NEWCOMBE
1931
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
A
A'
B
B'


CONTOUR MAP
SHOWING THICKNESS
OF
DUNDEE FORMATION
ISOPACH CONTOUR INTERVAL
50 FEET
-SCALE-
MILES
0
16
32
BY
R.B.NEWCOMBE
1931
EXPLANATION
AREA OF MAXIMUM THICKNESS
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LAKE MICHIGAN
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ALPENA
EMMET
CHEBOYGAN
PRESQUE ISLE
CHARLEVOIX
OTSEGO
MONTMORENCY
ANTRIM
LEELANAU
BENZIE
GRAND TRAVERSE
KALKASKA
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OSCODA
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WEXFORD
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ROSCOMMON
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ARENAC
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LAKE
OSCEOLA
CLARE
GLADWIN
BAY
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OCEANA
NEWAYGO
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MIDLAND
TUSCOLA
SANILAC
MUSKEGON
MONTCALM
GRATIOT
SAGINAW
KENT
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SHIAWASSEE
GENESEE
LAPEER
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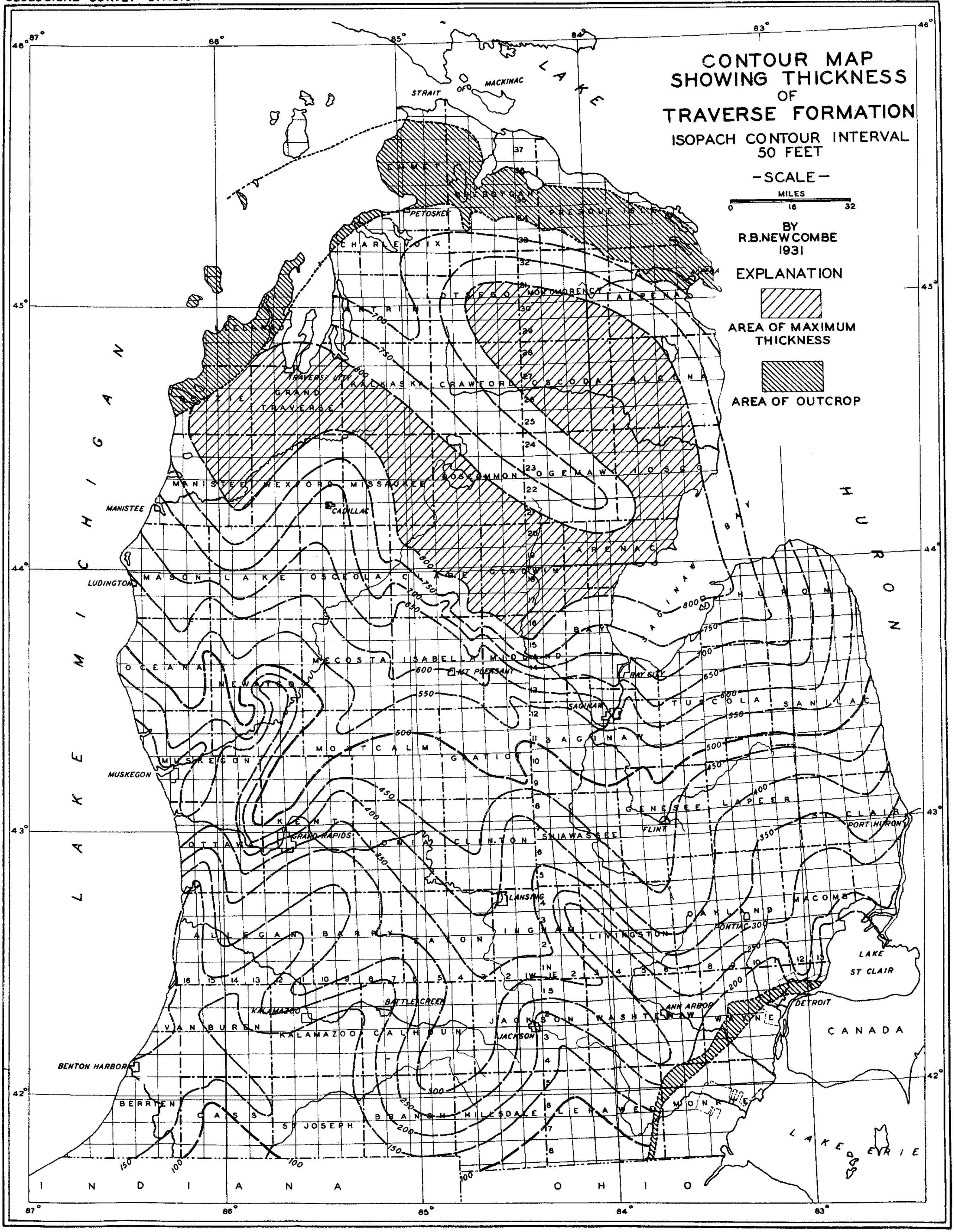
CONTOUR MAP
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TRAVERSE FORMATION
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50 FEET
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R.B.NEWCOMBE
1931
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near the base of the Dundee. Like the closing part of the Niagaran, the warm, dry climate, and clear water permitted corals and other life forms to flourish in abundance. Some forms were derived from the Atlantic and some probably came from southern connections, and the soft parts of certain organisms must have contributed to the bituminous products found in the rocks of this period. Various animals of the Dundee seas possessed siliceous hard parts and contributed silica. It also might have been deposited by direct precipitation (either from true solutions or colloidal solutions), or by replacement, thus forming beds and nodules of chert which are common to the strata.

The "basin" of deposition was greatly changed from Detroit River time, both in general uniformity and the position of the deepest trough. The thickest Dundee in the Michigan Basin is in a long narrow depression trending a little west of a north-south direction across the eastern side of the State. (See fig. 12). A ridge or upwarping apparently more or less parallel to the trough crosses Livingston County. This ridge widens out to a broad emergent region in the south central part of the State and joins with an east-west shallow area stretching across central Oceana, Newaygo, and Mecosta counties. The local basins almost parallel these shallow places. The greatest amount of sinking on the east side of the depositional basin is analagous to the Appalachian geosyncline where the sinking was also greatest on the east and seems to suggest a source of pressure from the eastward acting toward the west. This large basin is apparently asymmetrical in the central portion of the State and comparatively symmetrical to the northward. The presence of separate basins of deposition in the Michigan region during Dundee time is also indicated by the dissimilarity of faunas in the northern and southern districts of the State. The life forms from invasions of the sea originating in different quarters were prevented from completely intermingling because of this separation.

TRAVERSE TIME

The period between the laying down of the Traverse and Dundee sediments was featured by a marked change in climatic conditions. The fine argillaceous weathering product making up the Bell shale is evidence of increasing precipitation and plant growth, and the honeycombed, irregular Dundee land surface is evidence of organic, humous acids in the surface material. The sea invaded from the north and deposits progressively overlapped older strata in the southern part of the State. Traverse beds probably rest on those of the Detroit River series in parts of southwestern Michigan, but exact identification is difficult. The basal black shale and the fossiliferous gray shale of the Traverse group indicate that the shores were low with abundant vegetal growth, and the climate was favorable to the preservation of life forms. This carbonaceous Bell shale also overlaps older beds consecutively to the southwest and thins to a mere parting in that direction. The thinning of beds to the southwest has been attributed to[11] both extensive erosion of the Dundee limestone and non-deposition of the Bell shale. Limestones were deposited as the sea deepened to the north. Upward and downward oscillations of the sea bottom or periodic withdrawal of waters from other causes formed

[11] Newcombe, R. B., Middle Devonian Unconformity in Michigan: Bull., Geol. Soc. Am., Vol. 41, pp. 734, 735 (1930).

alternating beds of shale, calcareous shale, and thin limestone. The source of much of the shale must have been to the east, and the derivation was likely from limestone shores as indicated by the calcareous character of the mud.

Near the close of Traverse sedimentation, there was warm quiet water and the sea bottom subsided gradually. As a result, an extensive system of low coral and stromatoporoid reefs was built up over considerable areas. In northwestern Michigan, the reef formation was probably followed by somewhat violent wave action as shown[12] by broken up coral sands strewn in foreset beds which make up a "cross-bedded" limestone. The introduction of colloidal silica in the upper portion of the section brought about the formation of segregated and banded chert. This occurrence of chert seems to indicate strongly a return of conditions affected by shore influences, and waters from the land carrying silica in suspension mingled with the saline waters of the shallow inland sea.

The presence of anhydrite in the lower Traverse of western Michigan suggests that locally the sea was restricted, thus permitting drying up and evaporation. Slight emergence and erosion over most of the Traverse basin region probably took place near the close of the period. That the Traverse sea had northern connections[13] is proved by the fauna contained in the rocks.

During much of Traverse time the Michigan synclinal basin was divided in the northern part by an intermittent land barrier[14]. This fact is indicated by the difference in faunal life which occupied the separate regions and the evidence from the thickness map (see fig. 13), drawn to show the thinning and variation of the Traverse beds. An upwarping amounting to a thinning of over 200 feet of strata is shown to extend southeast from central Antrim County to central Ogemaw County. The two separate east and west basins trend parallel to this upwarped district, and the west basin seems to be asymmetrical with the steep dip into it from the west. The parallel warping in the central and southern parts of Michigan appears to have one pronounced direction in alinement with the deeper basins of sedimentation. The Livingston County ridge and the folds in the central part of the State evidently existed during Traverse time. The local basins associated with these structural highs are also shown. A prominent northeast-southwest structural element occurs in the southwestern section of the State and the flattening of slope in this region is present, as in previous periods of deposition. An important north-south structural element and an upwarping trending a few degrees east of north-south is characteristic of eastern Muskegon and Newaygo counties. This same shallow region of deposition seems to continue with somewhat less expression into Mecosta, Osceola, Wexford, and Missaukee counties. The importance of structural land barriers affecting deposition is well illustrated by the results of Traverse sedimentation.

Near the close of Traverse time, the land surface was worn down nearly to base level, and sluggish streams brought calcareous slime and argillaceous detritus into the sea. The upper Traverse beds are almost invariably shaly, but the color and general appearance does not suggest marked change in the other conditions that influence sedimentation. In some parts of the State, there may have been slight reelevation at the end of the deposition of the Traverse. Subsidence followed closely afterward and with this deepening of the sea came a changed climate, more moist and favorable to the growth of vegetation.

[12] Pohl, E. R., The Middle Devonian Traverse Group of Rocks in Michigan: A Summary of Existing Knowledge: Proc. U. S. Nat. Mus., No. 2811, Vol. 76, Art. 14, p. 20 (1930).
[13] Pohl, E. R., Op. cit., p. 33.
Ehlers, G. M., Personal communication.
[14] Pohl, E. R., Idem, p. 23.

ANTRIM TIME

Antrim time was the beginning of a complete sedimentary cycle. This cycle due to periodic uplift of the land areas furnishing sediments resulted in a succession of black shales, gray shales, and sandstones. A similar cycle beginning with the Sunbury black shale was repeated later in the Mississippian epoch. During the Antrim, the relief of the land areas was still low, affording complete rock disintegration, and the streams carried large amounts of macerated swamp waste and other vegetal matter out on tidal flats where the black mud was deposited. The muddy seas brought about toxic conditions and only the most hardy floating forms of life were able to live in this environment. The carbonaceous material from the biochemical breaking down of these entombed animals, the spore cases, and the other remains of vegetation probably are the source of the oil and gas which originated in this formation. Much of the calcareous material in the Antrim sea is in the large concretions which are thought to have been formed about the same time that the deposits were laid down. Fish remains are found in some of the smaller concretions and probably indirectly caused their formation.

After the Antrim sea had occupied the region for a period, a retreat must have taken place, because Mississippian fossils were found in the upper part of the formation. The beds laid down during the waning of Antrim time are much more irregular in color and other physical properties than the lower strata of the formation. Apparently, some oscillation of the sea took place, and possibly some of these beds represent the remotely distributed fine material from the delta deposits in the east.

The contour map (see fig. 14) showing the thickness of the beds deposited in Antrim time indicates that the deepest sinking and greatest sedimentation took place near the present geographical center of the southern peninsula. This basin, although irregular in shape, has a northwest-southeast elongation which is very narrow. The upwarped district in Saginaw and Midland counties divides it almost into two parts. A secondary deep basin, trending more nearly north-south, is located to the northeast. This relation suggests an avenue of sea migration from a northeasterly direction. The two basins are separated by an upwarp trending across a similar part of Crawford, Ogemaw, and Arenac counties that was crossed by the same type of structural feature in Traverse time. Two other shallower troughs extend to the southeast, and these may have been intermittent channels of sea invasion. The sharp Livingston County ridge separates these troughs. A gentle basinward slope indicates a land mass on the southwest side of the basin area, and the contours suggest several deep local basins in that region.

The western side of the southern peninsula was evidently an area of shallow waters during much of Antrim time. A northeast trending shallow trough seems to extend more or less continuously from the vicinity of Grand Rapids, across Kent, western Montcalm, and Mecosta counties. Minor east-west troughs occur throughout the western counties and evidently sedimentation took place in this part of the State in a very irregular manner. The apparently featureless area in Lake and northern Newaygo counties may possibly be explained by the scarcity of reliable data in that particular section.

MISSISSIPPIAN PERIOD

ELLSWORTH-BEDFORD-BEREA TIME

An increase in the relief of the land and quickening of the streams took place at the beginning of Berea time. This may have been accomplished either by uplift of the land or by a general drop in sea level from other causes. The former seems most plausible.

Conditions favorable to sandstone deposition were initiated with the depositing of the Bedford gray muds, differing markedly from the Antrim carbonaceous sediments. There is no evidence of great climatic change between the Bedford sandy shales and the Berea sandstone. The shoreline probably shifted from the east, possibly by a general westward progression of the Appalachian delta phase of Devonian times. Slow subsidence permitted the local deposition of a considerable thickness of sandstone, and the Berea is widespread from the Appalachian trough to the Michigan synclinal basin.

Students[15] of the Berea suggest that a rather important movement at the northern end of the Cincinnati anticline took place subsequent to early Mississippian, and this structural feature was not so pronounced as at present, or if so, it maintained an attitude quite different from that of the present time.

That the source of these sediments was to the east and north is indicated by the thick sandstone deposits in northwestern Ohio and eastern Michigan, the thinning of the Berea to the northwest, north, and south, and the low-lying character of the western limb of the Cincinnati anticline, which did not furnish any sediments with sandy phases farther to the westward in Indiana. The delta-like cross section of the deposits has been mentioned by Robinson[16], who points out the great thickening in eastern Michigan. The uniformity of ripple marks with northwest direction discovered by Hyde[17] may indicate sufficiently the direction of the shoreline to be an argument for the northwest elongation of the depositional basin. The local presence of shoal water caused by the immense thickness of sediments dumped in northwestern Ohio would explain the abundance of ripple marked sandstone.

The extent of Berea sedimentation is shown in Figure 5. The outlines on the map emphasize the fan shaped plan of the area over which the deposits were laid down. This fan-like spread of the deposit makes the delta conception seem even more logical.

In western Michigan, another set of depositional conditions prevailed during Berea-Bedford times. The isopachous map (see fig. 15) indicating the variations in thickness of the two formations together shows an entirely different picture. The deepest part of the basin is in the northwestern part of the State, instead of the southeast where the Berea sandstone attains its greatest thickness. A possible explanation would be

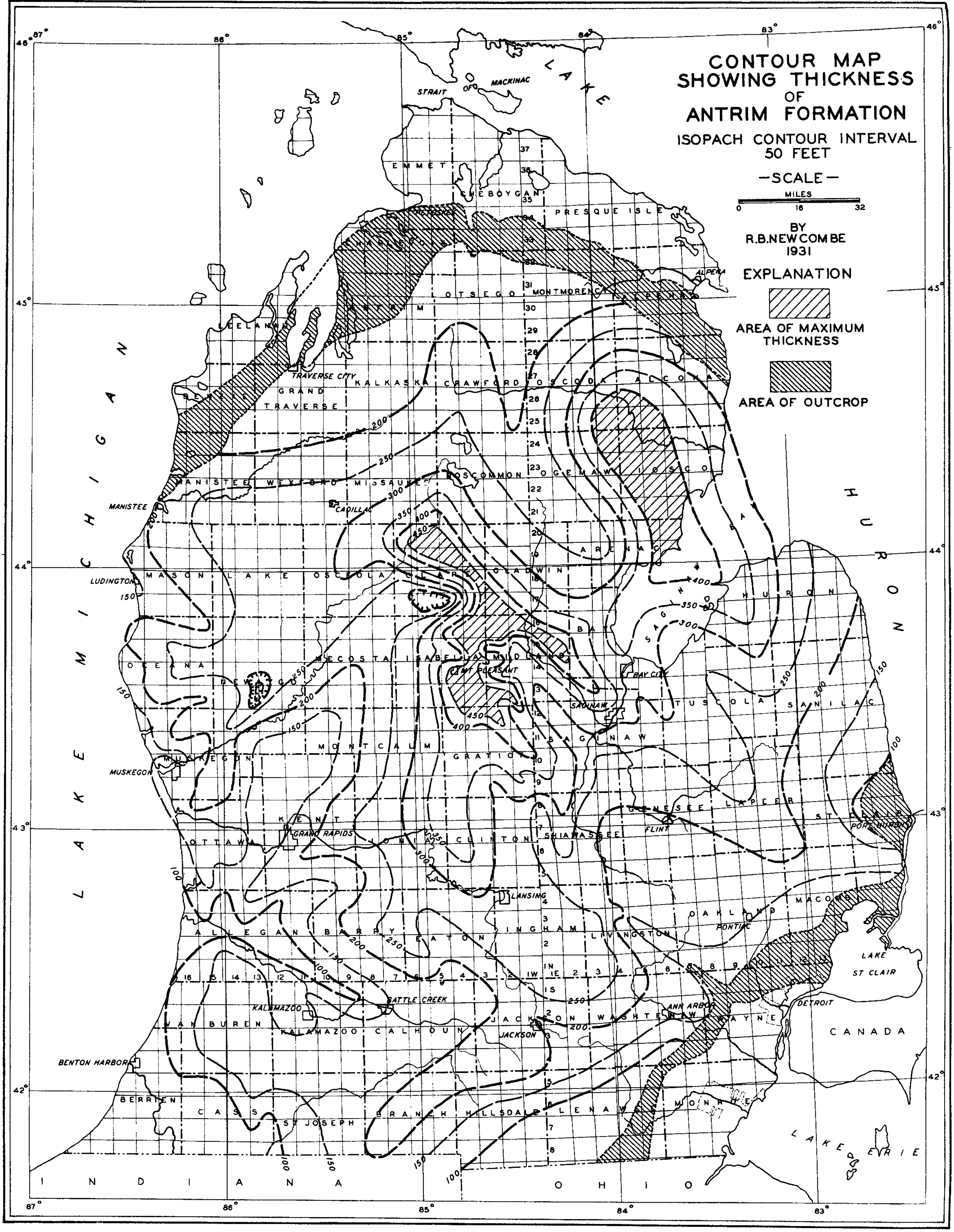
[15] Hyde, Jesse E., The Ripples of the Bedford and Berea formations of Central and Southern Ohio, with notes on Paleontology of that epoch: Jour. Geol., Vol. 19, p. 269 (1911). Robinson, W. I., Unpublished manuscript.

[16] Robinson, W. I., Unpublished manuscript.

[17] Op. cit., pp. 260, 261.

PUBLICATION 38 - FIGURE 14

MICH. DEP'T. CONSERVATION
GEOLOGICAL SURVEY DIVISION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INDIANA
OHIO
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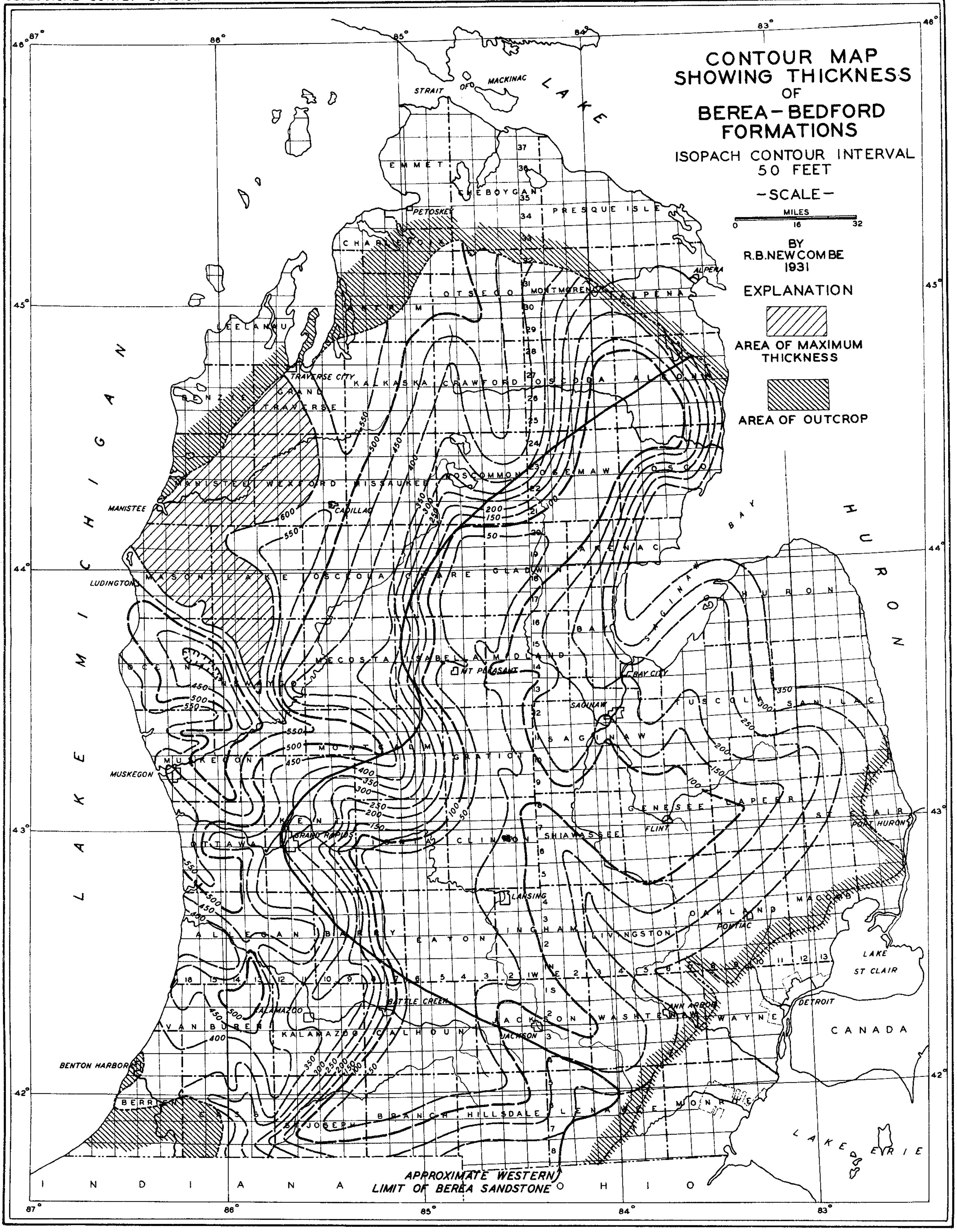
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CANADA
INDIANA
OHIO
APPROXIMATE WESTERN LIMIT OF BEREA SANDSTONE

that these fine sediments are the bottom-set beds of the delta originating to the southeast. This would seem logical if it were not for the fact that the texture, color, and composition of the thick shales of northwestern Michigan do not resemble either the Bedford shales or the shale partings in the Berea of the southeastern area.

It would seem, therefore, that the thick greenish gray shale in northwestern Michigan, approximately equivalent in stratigraphic succession to the Berea-Bedford of southeastern Michigan, is older and has a different depositional history. This shale series has been given the name Ellsworth formation. The history of Ellsworth time might be conceived as follows:

The shallow area extending northeast-southwest across Michigan was an axis of tilting throughout early Mississippian. At the close of Antrim time, an uplift took place along this axis, and the basin area was downtilted to the northwest. A sea invaded the area and brought in clastic sediments of variable nature, chiefly clay but including limy and sandy muds. The products of weathering of the "Wisconsin island" were added to this material and the resulting deposits must have been originally somewhat red in color. However, climatic conditions might have been such that nearly all of the red ferric iron was reduced to the green ferrous state. Whether this took place before or after deposition has not been determined, but a thick series of green colored sediments was laid down.

The minor structural irregularities in this downwarped area probably resulted from slight folding along pre-existing lines of weakness. In the main, they all have either an east-west or northwest-southeast trend. The north-south ridge in the northern part of the State is suggestive of the shallow basin which had existed in this general area since Traverse time.

At the beginning of Bedford time, tilting occurred in a reverse direction along approximately the same axis and the sea came in from the southeast. This sea deposited the Berea and Bedford sediments which correlate with those of Ohio. A red shale, which probably resulted by alteration of local ferruginous weathered clastic material, was laid down locally and is possibly equivalent to the Ohio red Bedford. Minor depressions in which thicker sediments were deposited trend northwest-southeast on the southwest side of Livingston County and south of Jackson, Jackson County. Shallow areas extend across Genesee and Lapeer counties and also northeastward across the "Thumb" region. A small trough parallels the upwarping in the "Thumb" on the northwest.

The complexity of sedimentation during the period may be partly explained by evident changes in the direction of the forces causing earth movements in the "basin." Instead of a warping with dominant northwest-southeast trend, the direction was almost at right angles to the former prominent direction. This condition may have exercised some control over the unusual movements along the axis of the Cincinnati anticline which are so difficult to interpret.

COLDWATER TIME

Coldwater time evidently began by a general downwarping of the central basin region where shallow water probably prevailed in the preceding period. A progessive tilting took place to the westward in which the waters gradually deepened in that direction. Various changes in the land relief and the depth of the sea resulted, but in the main, disintegration of the rocks furnishing waste material must have been rather complete. Climate favorable to the growth of vegetation, together with lowland conditions set in again at the beginning of Coldwater time, and black shale was laid down. This deposit was for the most part thin and widespread, but occasional sections of thick Sunbury shale suggest possible stream distributary channels depositing mud under broad, low, delta-like conditions. The location of the principal area of uplift to the east of the basin is shown by the coarser sandy phase of the beds in the "Thumb" part of the State. The proximity of the land is suggested by the quantity of undecomposed mica in some of the beds. Near the beginning and the close of the period, there were local conditions of sedimentation favorable to the preservation of red color. The source of this color was probably the ferruginous weathered product of basic igneous rocks which made up a part of the adjoining land mass. Likely, a humid climate with alternating long dry periods furnished the active agents for complete weathering to soils which were predominantly red in color. Throughout the greater part of the Coldwater time, there were low shore lines and the luxuriant vegetation decomposed to give products which helped reduce the reds and pinks to gray, blue, and light green colors. The climate was probably colder when the lighter colored shales were being deposited.

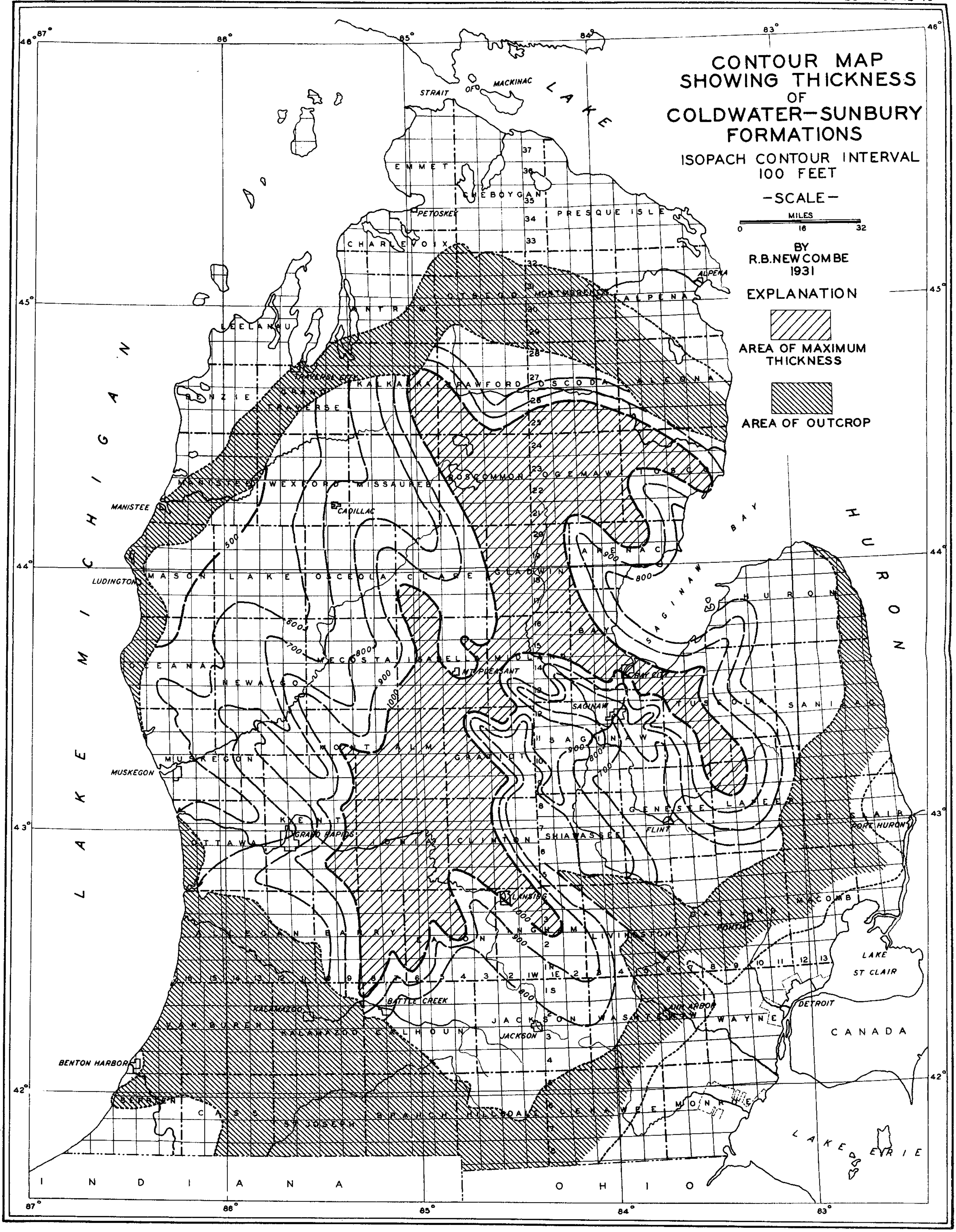
At the time of the deposition of the Coldwater, western Michigan was affected by conditions of sedimentation differing from those in other parts of the State. Deeper waters and less wave action caused intermittent limestone deposition. Early in the period, the conditions which brought about red sandy shale in the eastern part of the State probably gave rise to a red shaly limestone on the western side of the State. The macerated fossiliferous material in this red member indicates that the limestone was produced from the disintegration of older limestone shores. That the red limestone is more or less equivalent to the red shales to the east has been found by tracing in wells the lateral gradation across the State.

In western Michigan, another series of calcareous sediments is found about 250 to 300 feet below the top of the Coldwater formation. These beds are somewhat fossiliferous but not typical of a limestone sea. They are locally sandy, and the granular, oolitic texture suggests that they were laid down on shallow flats which were receiving calcareous sediments from the weathering of a limestone land area.

The character of the Coldwater is, therefore, the result of conditions shifting from those of the shore to those of the open sea, and the period ended with a general shallowing. The outline of the depositional basin is shown in Figure 16. The major elongation in a northeast-southwest direction continued over from Berea time, but the area of greatest downwarping was transferred into the central region of the State. Crosswarping in the opposite direction gained additional importance and almost divided the basin into two separate troughs. Minor wrinkling along this northwest-southeast direction governed sedimentation to a marked degree, and there was evidently uneven compaction of the muds over the topographic ridges resulting from older structural features. The larger of these features is in southwestern Ingham, northeastern Eaton,

PUBLICATION 38 - FIGURE 16

MICH. DEPT. CONSERVATION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Ionia, northeastern Kent, and Newaygo counties; Livingston, southwestern Shiawassee, Clinton, Montcalm, Mecosta, and southeastern Lake counties; Genesee, Saginaw, eastern Gratiot, southern Midland, northeastern Isabella, Clare, Missaukee, and Wexford counties; southwestern Arenac, southeastern Ogemaw, and southwestern Iosco counties. The deposits of Coldwater time very strongly reflect the control of minor structures on sedimentation.

MARSHALL TIME

A widespread uplift of the land took place at the beginning of Marshall time, and streams were quickened, giving greater erosive power. The western part of the basin probably remained out of water longer than the eastern, although there was probably greater topographic relief on the east. The Lower Marshall began in the "Thumb" area with a thin bed of fine-grained, so-called "peanut" conglomerate. These basal deposits, typical of rugged shores, were laid down westward across the State with the sea invading in that direction. The conglomerate and other basal beds of the Lower Marshall grade to the west into a pink, medium grained sandstone. As the shoreward phase moved westward, the eastern part of the basin gradually deepened and micaceous shaly sandstones were deposited. This type of deposit is a probable result of rather rapid disintegration of the large areas of basic greenstones, hornblende schists, and other ferruginous metamorphic rocks in regions furnishing the sediments. Local red beds indicate complete oxidation at times when rock disintegration was more complete, and although vegetation was probably locally abundant, the climate must have been for the most part temperate. The prevalence of red color scattered through the whole formation is evidence that there was a large quantity of iron in the waters of the Lower Marshall sea throughout the period. The absence of the red color in areas where it is usually present is ascribed to later reduction due to leaching along structural "highs." Since these generally represent regions of shallow water, the wave action would probably rework the sand and remove much of the red colored cementing material.

With the close of Lower Marshall time, an uplift again occurred that may have been simply a general tilting to the east. The waters were at least temporarily withdrawn, permitting considerable weathering and erosion. The relief of the irregular surface at the top of the Lower Marshall is just beginning to be appreciated from a study[18] of the many core test wells which penetrate this formation in the "Thumb" part of the State.

The deposits of the Napoleon sea are practically free from mud, and the coarse clastic sediments suggest the approach of drier climate. The Napoleon sandstone beds also indicate more pronounced wave action for the exposures are often extensively cross-bedded. The greenish gray color which prevails is probably due to waste products derived from greensands and chloritic rocks. Fragments of coaly material in the Napoleon sandstone are proof that some vegetation grew during Marshall time. They are probably carbonized chunks of driftwood entombed in the beds.

The Napoleon sea transgressed westward resulting in overlap and thinning of beds in that direction (See fig. 17). An uplift at the close

[18] Kirkham, Virgil R. D., Verbal communication.

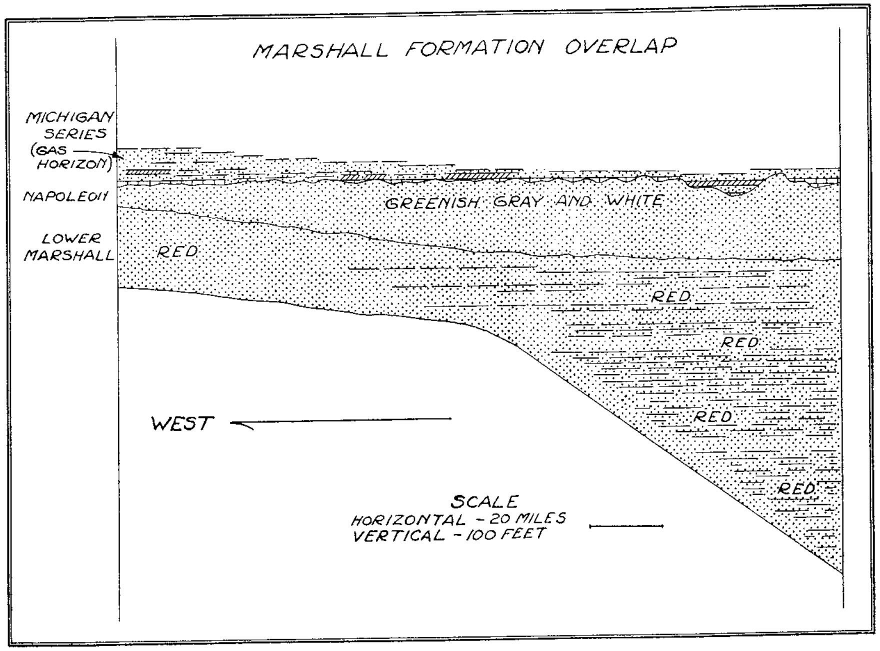


Figure 17. Diagrammatic sketch of the westward Marshall overlap.

of the period also may have contributed to the westerly thinning of this sandstone member and general widespread withdrawal of the waters culminated Marshall time. The top of the Napoleon was eroded giving rise to considerable surface relief and locally the entire formation may have been removed in the western portion of the basin. Several products of this erosion period are found at the Upper Marshall contact. These products of weathering include gibbsite ($Al\ OH_3$), glauconite, chlorite, and other unidentified aluminous minerals.

The deep part of the basin in Marshall time again shifted to the eastern side of the State (see fig. 18) and a small local deep area was formed in the south central portion. A shallower region trending northeast-southwest through the center of the synclinal area corresponds closely to a similar shallow area of Berea time. This feature of the basin may have exercised some control upon the origin of coarse clastic sediments. Excepting the uplifted region in Livingston County, the warping in the southeastern part of the State has a trend almost north-south and more or less parallel to the deep sinking areas. Folding or warping in the southwestern part of the State has a general northeast-southwest direction, but the predominant direction in the central and northwestern portions of the synclinal basin is northwest-southeast as in previous periods. Many local troughs indicate that minor structures guided sedimentation to a large degree.

GRAND RAPIDS TIME

The uplift which preceded Grand Rapids time finally restricted the "basin" to the extent necessary for the temporary preservation of relict

seas. For this reason, intermittent gypsum and anhydrite beds are characteristic of the Lower Grand Rapids or Michigan formation. The enclosure of the basin was affected by upward movement along both Cincinnati and Wabash arches, which temporarily cut off connections with the seas occupying the Appalachian trough and the Indiana-Illinois basin. This movement was probably related to the general emergence which brought about the formation of the thick Catskill beds in the East.

Apparently, at the time of the first isolation, lime was present in the waters in sufficient concentration to be thrown down soon after evaporation set in. The streams entering the basin were flowing over Marshall rocks and a slight reelevation enabled them to cut down fast enough to bring considerable quantities of reworked Marshall sand into the sinking area. Local monadnock-like hills of sandstone also probably projected above the waters of the Michigan "series" sea for some length of time after the new period commenced. These conditions brought about the deposition of fine-grained sandstones near the base of the Lower Grand Rapids group with lithologic characteristics similar to the Upper Marshall. A gentle westward tilt seems to have taken place, for to the west and northwest (see fig. 17), these basal sandstone members occur successively higher in the series as if they were deposited by a sea retreating in that direction.

About the middle of the period, the sea was completely cut off and evaporation and concentration took place sufficiently to precipitate anhydrite, which later altered to gypsum. The influence of the chemical composition of streams which flowed southeastward over iron-bearing formations probably affected the color of the evaporite beds of Grand Rapids age formed in the area. That this exercised a coloring effect is suggested by the fact that gypsum of western Michigan is pink and red, while that of the eastern part of the State is white, gray, and cream colored. The gypsum deposits of Michigan are not distributed uniformly in all parts of the old sea basin, but are concentrated in comparatively small sized areas. Grimsley[19] attributed the cause of this concentration to "salt pan" conditions in lagoons similar to the Karaboghaz (Black Gulf) of the Caspian Sea. On the basis of present evidence, a structural explanation for the occurrence of anhydrite and gypsum is more likely than one strictly physiographic. As the basin area was downwarped, local troughs probably formed roughly parallel to preexisting structural irregularities. Folding took place contemporaneously with the precipitation of anhydrite, and the thick gypsum beds that were formed largely by later hydration correspond to the minor downwarped regions. The gypsum beds thicken progressively into these smaller basins and are thin or even missing along the structural "highs." This relation has been found to hold for every extensively prospected area in the State and is, therefore, very significant.

The absence of salt beds might have been due to insufficient evaporation of the sea water, but this does not seem so likely as secondary removal of the salt by solution after burial. It is logical to assume that salt was formed locally somewhere within the basin because these dry periods probably were not interrupted for long duration and salines were probably constantly added from the erosion of exposed Salina beds sur-

[19] Grimsley, G. P., Origin of Gypsum with special reference to the origin of Michigan Deposits: Trans. Kansas Acad. Sci., Vol. 19, p. 114. (1905).

rounding the Michigan region. Much of the gypsum shows the effect of solution and both secondary crystalline gypsum and salt veins occur throughout the series. If salt beds were once present, they were probably not thick and the cover of superimposed sediments did not protect them from weathering agents and percolating ground water.

Conditions of sedimentation varied throughout Michigan "series" time. The muds washed into the basin were often from fine dust carried to the shores by the warm winds, and the mode of deposition was controlled by the flocculating effects of saline waters which were strongly concentrated and high in specific gravity. The resulting shales were fine grained, gray to black rocks with no particular structure or bedding. The toxic effect of high salinity on all forms of life brought about the concentration of carbonaceous material and many of the beds are thus black in color. The rocks derived from lime muds also show little or no structure and most of the limestones were precipitated from solution rather than through the agency of lime secreting life forms. The dolomitic character of the lime rocks is typical of saline basins. Red and green colors are more numerous in the thicker Michigan series section of the northwestern part of the State. These colors may be due to desert conditions, but more probably the streams from the proximate area of the crystalline rocks in the northern peninsula added iron in quantities sufficient for coloration. The streams bringing in sediments were not flowing over limestone beds to the same extent as in Salina time, and the dark colored mud rocks of the Michigan series indicate that much of the land waste was formed by extensive decomposition and disintegration. The dry climate probably did not prevail throughout the entire period.

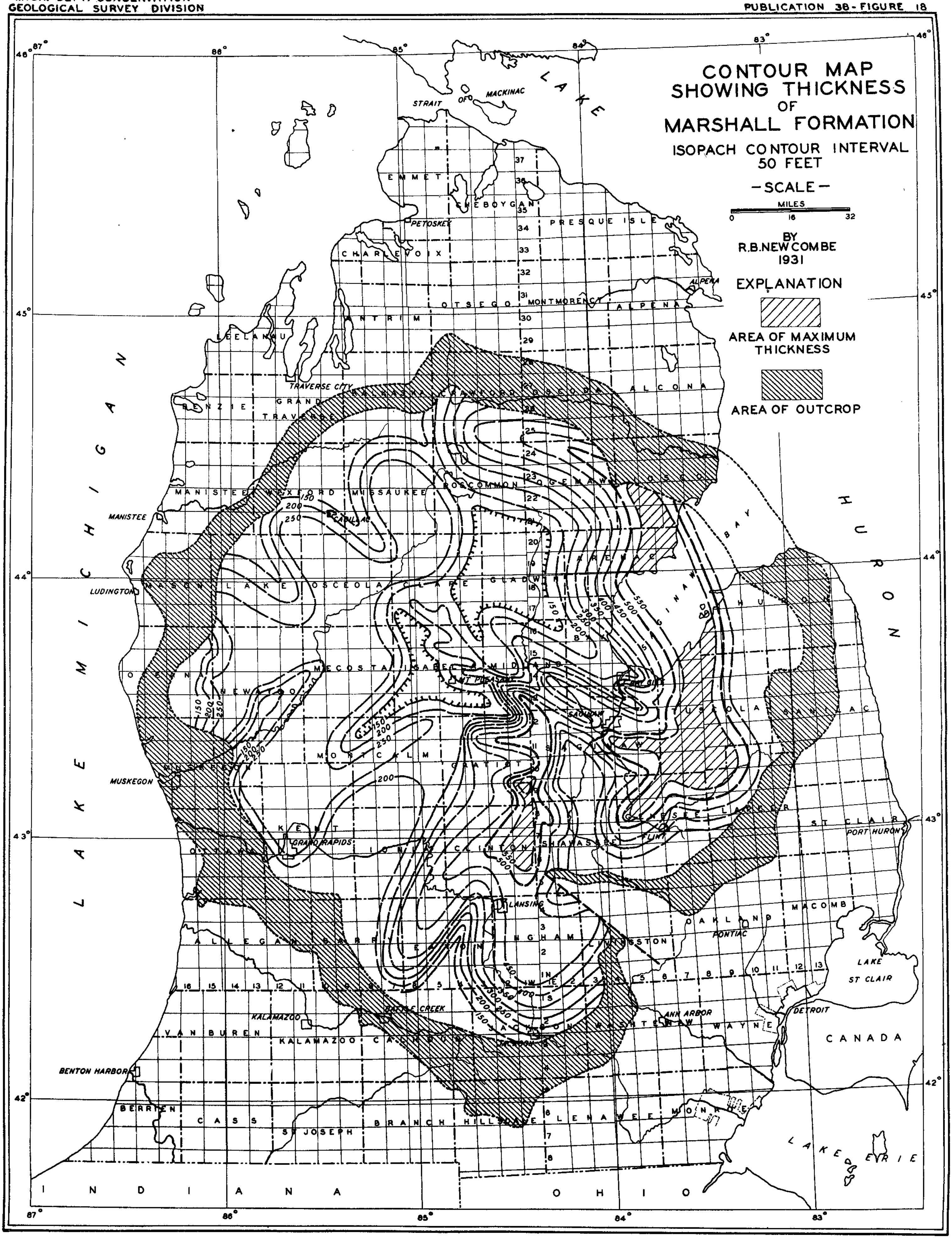
The shape and configuration of the "basin" in Grand Rapids time is shown in Figure 19. This map demonstrates the shifting of the most rapidly sinking region to the approximate central area. The deep portion is divided into two small secondary basins which are not greatly elongated, although there is a northwest-southeast major axis in the northern one. A possible north-south connection between these basins would emphasize the meridional direction.

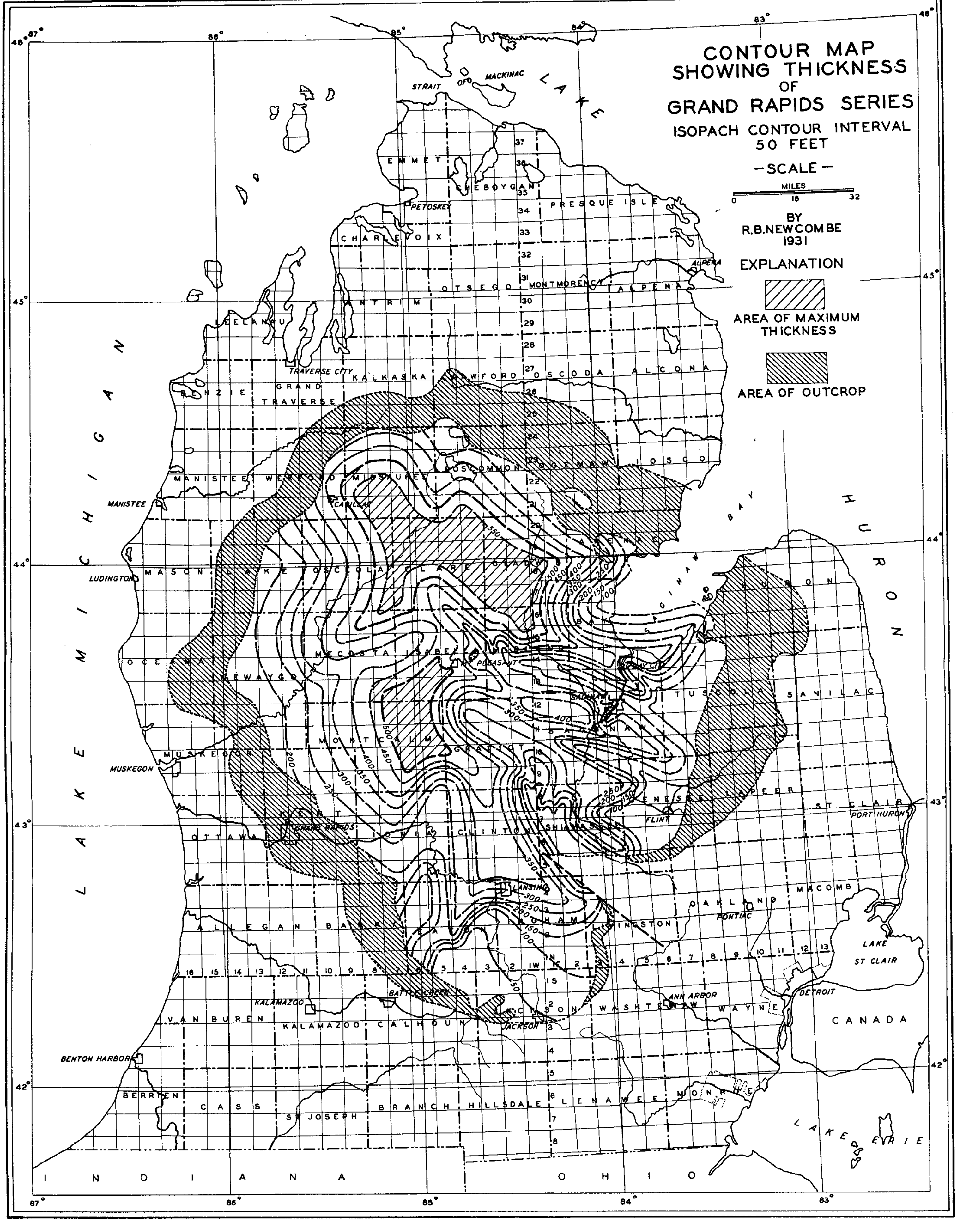
The contours indicate very sharp northwest-southeast minor basins and ridges. Some north-south features are present in southern and central Michigan in Clinton, Eaton, and Ionia counties. The sharpness of the troughs is probably partly due to contrasts in thickness that result from extensive post-Mississippian erosion which removed sediments from the upwarped areas. The outstanding characteristic feature of the map is the recurrence of a basin with the deep part approaching circular outline in about the same position as during Detroit River time when salt was deposited (Compare fig. 9). This comparison supports the conclusion that the reason for the frequent repetition of conditions of evaporation in Michigan was the structural position of the region, where recurrent upward earth movements of the surrounding positive structural areas caused periodic isolation of the basin. Future studies may show that similar structural conditions brought about the formation of many major saline basins.

New sea connections with the Illinois-Indiana basin opened in Bayport time, but rather warm dry conditions probably continued in Michi-

PUBLICATION 38 - FIGURE 18

MICH. DEPT. CONSERVATION


CONTOUR MAP
SHOWING THICKNESS
OF
MARSHALL FORMATION
ISOPACH CONTOUR INTERVAL
50 FEET
-SCALE-
MILES
0 16 32
BY
R.B.NEWCOMBE
1931
EXPLANATION
AREA OF MAXIMUM THICKNESS
AREA OF OUTCROP
LAKE MICHIGAN
LAKE HURON
SAGINAW BAY
LAKE ST CLAIR
LAKE ERIE
CANADA
INDIANA
OHIO
STRAIT OF MACKINAC
TRAVERSE CITY
MANISTEE
LUDINGTON
MUSKEGON
GRAND RAPIDS
LANSING
KALAMAZOO
BATTLE CREEK
BENTON HARBOR
ANN ARBOR
DETROIT
PONTIAC
PORT HURON
FLINT
SAGINAW
BAY CITY
CADILLAC
PETOSKEY
ALPENA
MT PLEASANT
JACKSON
EMMET
CHEBOYGAN
PRESQUE ISLE
CHARLEVOIX
OTSEGO
MONTMORENCY
ALPENA
ANTRIM
LEELANAU
BENZIE
GRAND TRAVERSE
KALKASKA
CRAWFORD
OSCODA
ALCONA
MANISTEE
WEXFORD
MISSAUKEE
ROSCOMMON
OGEMAW
IOSCO
MASON
LAKE
OSCEOLA
CLARE
GLADWIN
ARENAC
HURON
OCEANA
NEWAYGO
MECOSTA
ISABELLA
MIDLAND
BAY
TUSCOLA
SANILAC
MUSKEGON
MONTCALM
GRATIOT
SAGINAW
OTTAWA
KENT
IONIA
CLINTON
SHIAWASSEE
GENESEE
LAPEER
ST CLAIR
ALLEGAN
BARRY
EATON
INGHAM
LIVINGSTON
OAKLAND
MACOMB
VAN BUREN
KALAMAZOO
CALHOUN
JACKSON
WASHTENAW
WAYNE
BERRIEN
CASS
ST JOSEPH
BRANCH
HILLSDALE
LENAWEE
MONROE
87° 86° 85° 84° 83°
46° 45° 44° 43° 42°


CONTOUR MAP
SHOWING THICKNESS
OF
GRAND RAPIDS SERIES
ISOPACH CONTOUR INTERVAL
50 FEET
-SCALE-
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ANN ARBOR
DETROIT
BATTLE CREEK
KALAMAZOO
JACKSON
BENTON HARBOR

gan for some period thereafter. Lane[20] suggested that the deposition of gypsum might have terminated in two ways,—either by an increase in the precipitation and supply of fresh water, or a downwarped connection with adjoining basins, permitting entrance of the sea. The Bayport deposits include alternating limestones and dolomites, limestones, sandy limestones, and white sandstones. The limerocks are crowded with life and comparatively free from shale. These sedimentary characteristics indicate that the climate was probably rather dry and gypsum deposition ceased because the waters of adjoining seas were added to those of the Michigan "basin." The water must have been relatively quiet to permit coral life in the sea, but the chert in the Bayport signifies that the streams were probably carrying silica in considerable quantities. The thickness of Bayport would indicate a short lived transgression, but the intense subsequent erosion may have removed large amounts of the soluble limestone beds. At the close of Bayport time, the entire basin area was raised above water and active streams eroded deeply into the rocks of the Grand Rapids group. At some places, as in Jackson and Shiawassee counties, they cut down through the Michigan series into the Napoleon sandstone. The flow of these streams was largely directed by preexisting structures, and in many places the absence of Bayport limestone is evidence that there has been some type of deformation in the district.

PENNSYLVANIAN PERIOD

PARMA TIME

The uplift continued in the old positive land areas, but the Pennsylvanian age opened in Michigan with a shallow sea which formed rather continuous sandy shore deposits. The land must have been relatively close by and the parent rocks consisted of comparatively pure white quartz. Occasionally at the Parma-Bayport contact, later mineralization formed green and blue colors and chalcopyrite has been observed. Apparently, the colored rock contains hydrated carbonates of copper, but this has not been definitely proved. The basal beds are usually conglomeratic and have pebbles about the size and shape of a split pea. The sand was strewn widely and filled the hollows in the old pre-Pennsylvanian topography. Subsequently some of the Bayport limestone must have been periodically reworked because layers of limestone are often intercolated with typical Parma sandstone. Bayport intraformational breccias within the Parma indicate that wave action must have been decidedly violent on the shores of some of the limestone islands which remained above sea level during the early stages of Parma time.

SAGINAW TIME

Climatic conditions in Saginaw time showed only a few changes. The basin became a great shallow area supporting luxuriant vegetation in the swamps which occupied local basins. These swamps were seldom continuous with each other, and the resulting coal beds thin out laterally. The trend of the coal basins may parallel the predominant structural axes, but the relation between structure in the coal beds and deeper folding does not seem to be direct.

[20] Lane, A. C., Geological Report on Huron County, Michigan: Geol. Survey of Michigan, Vol. VII, Pt. II, pp. 103, 104 (1900).

The environmental control of deposition was featured by temperate climate and abundant rainfall. Torrential streams evidently brought in quantities of coarse clastic materials, and the land areas must have been rather completely disintegrated. The alternating character of the color and kind of sediments proves the oscillating nature of the surface on which they were laid down. The reducing properties of carbonaceous clay and silt probably played an important part in producing the drab colors which characterize the deposits. Occasional seas inundated the basin, depositing limestone beds which contain marine fossils. The principal connection seems to have been to the southwest with the Indiana-Illinois basin because the life forms in the Michigan beds are closely related to those of the Eastern Interior region.

"PERMO-CARBONIFEROUS" (?) PERIOD

"RED BEDS" TIME

At the close of Saginaw time, Michigan was again raised above water, and an unconformable unnamed series of deposits followed. The thickness of this series indicates that tilting must have taken place to deepen the basin to the north and west. The basal pink or russet colored sandstone has been called Woodville (Ionia) and may possibly be equivalent in age to the beds above which commonly have a red color. For the time being, the entire series is called "Red Beds" because it is similar in color, composition, and perhaps age to the "Red Beds" of the southwestern United States.

The origin and age of these beds is not known. Lane[21] has suggested that the coloring is caused by weathering or secondary oxidation, and that the beds may be Conemaugh, later Carboniferous, or early Permian. The general outline of the area of thick "Red Beds" has been determined, and the widespread presence of gypsum in the series indicates the manner of their origin.

An uplift to the south shut off additions of the sea and quickening stream activity brought in coarse sand. The approach of desert-like conditions caused sufficient oxidation to slightly color this basal sandstone. After the deposition of the basal Woodville, a warm alternating moist and dry climate set in. The exposed rocks on the land were rather completely disintegrated and red ferric oxides of iron were formed in the soils. Conditions of evaporation followed and, as a result, gypsum and gypsum residues were laid down in thin beds, alternating with red plastic shales, gray shales, and red shaly sandstones. The "Red Beds" are the latest consolidated rocks recorded in the sedimentary history of Michigan.

MESOZOIC AND CENOZOIC ERAS

TERTIARY PERIOD

The clues of erosional history of the Mesozoic and Cenozoic eras are masked by glacial drift, but recent erosion has not greatly affected the physiography of the pre-Pleistocene rock surface. Near the close of the Mesozoic, the region was considerably uplifted after the upturned edges of the strata had been leveled and the land surface had been reduced to a

[21] Lane, A. C., and Seaman, A. E., Notes on the Geological Section of Michigan: 10th Ann. Rept., State Geologist, Michigan Geol. Survey, p. 89 (1909).

peneplain. The Tertiary period began with a slight uplift and a variety of residual weathering products resulted. Before the beginning of Pleistocene glaciation, a thick mantle of soil and fragmental rock had formed. Toward the close of the Cenozoic era, a second important uplift probably took place and the streams eroded deeply into the rocks. The present topographic features of the rock surface in Michigan were incised largely at this time, and the bedrock topography reflects the Cenozoic physiographic history. Several drainage patterns postulated by Spencer[22] and Grabau[23] have partly explained the nature of the major streams which flowed across the region previous to the Great Ice Age. These writers postulate that the principal drainage was across Michigan in a northeast-southwest direction with the stream channel occupying a wide valley which is now filled in part by the waters of Saginaw Bay. Spencer believed that the direction of flow was northeast and called the stream the Huronian River, a tributary of his great ancient Laurentian River system. On the other hand, Grabau contended that the Ancient Saginaw River flowed southwestward in this same valley. Present data would favor Grabau's conceptions with certain minor modifications.

The origin of the deep basins now occupied by the lower Great Lakes is still a mooted question. Probably, all of the important weathering agents aided in the bringing about of these great troughs, but the respective roles of water, wind, and ice are still disputed subjects.

The fracturing of the Devonian limestones and the formation of large sinks along their strike in Alpena County, the unusual breccias in the St. Ignace region, and the major features of the Salina salt basin of Michigan revealed by a large number of recent wells records throw some new light on this problem of the origin of the Great Lakes basins. It is significant that there is a close correspondence between the outcrop of Salina rocks and several of these lake basins. The only known exposures of rocks in Michigan that might be Salina in age are near St. Ignace and Mackinac Island and these consist of a jumbled, brecciated mass, the origin of which has never been satisfactorily determined. Erosion remnants of this type are similar to talus slopes along bluffs formed of beds containing or directly overlying salt bearing rocks. These breccias are almost positive proof of slumping, no matter what may have been the cause of the undermining action that brought it about. Following around the strike of the Salina rocks into the lake basins, the depths of Lake Michigan and Lake Huron seem to be closely related to the variations in the thickness of the salt deposits in the central part of Michigan. Furthermore, the total known maximum thickness of salt in the Salina does not differ* greatly from the maximum lake depths. The deepest part of Lake Michigan compares very closely with the strike of the maximum downwarped area of the synclinal basin during Salina time. That is, the major axis of the Michigan Basin trends toward the deepest part of Lake Michigan. Since the Salina comes up under the lake, this would naturally be the locality of thickest salt beds along its outcrop. These relationships, though not conclusive, are strong arguments that the solution of salt brought about the initiation of the deep lake basins. The controlling effect of hard and soft rocks in the cutting of deep erosion

[22] Spencer, J. W., Origin of the Basins of the Great Lakes of America: Am. Geologist, Vol. VII, p. 7 (1891).
[23] Grabau, A. W., Guide to the Geology and Paleontology of Niagara Falls and Vicinity: New York State Mus., Bull. 45, p. 44 (1901).
*This relation was first pointed out to the writer by Evan Just.

channels now occupied by the four lower Great Lakes has been previously cited in several papers[24], but the close relation of the thickness of Salina salt to the depth of the lake basins suggests a plausible explanation of this important physiographic problem.

PHYSIOGRAPHIC HISTORY OF LOWER MICHIGAN

The physiographic history of lower Michigan can be traced best from a contour map showing the configuration of the base of the Pleistocene. (See pl. I). The bedrock surface beneath the glacial drift has considerable relief. The original pre-Pleistocene topography has been somewhat modified by ice action which removed old soils and much loose rock and probably gouged and deepened some of the valleys. In spite of these changes, the major pre-glacial physiographic features seem to be largely preserved.

The deep channel reaching below sea level apparently parallels the Lake Michigan shore as far south as Muskegon, and the direction of this channel is indicated by the elongated lakes and bays of the Grand Traverse region. The depths of the Lake Michigan basin seem to show that pre-glacial drainage took place northward along the depression which the lake now occupies.

A shallower channel can be traced across the State from Saginaw Bay to central Ottawa County, between Grand Haven and Holland. (See pl. I). Topographic ridges resulting from structural irregularities caused changes in the course of this channel, but the main valley is well defined. The river forming this valley was probably a consequent stream which resulted from a westward tilt of the land in Mesozoic or Cenozoic time or both. The channel does not appear to have sufficient fall northeastward to permit the stream to flow in that direction, although there may be a small sharp valley not revealed in the borings around Saginaw and Bay City. The fall to the southwestward is more definite.

A significant feature is the depression along this channel in the central part of the State. Possible errors may have crept into calculation of the depths to rock because the soft "Red Beds" might have been correlated in some wells as drift. The size of the topographic basin would seem to discount this source of error.

The depression must have been caused by differential erosion of the various hard and soft rocks. The pre-Pleistocene drainage basin in the approximate center of the area underlain by the "Red Beds" and their ease of erosion may possibly explain the origin of this topographic depression. The large stream flowing across central Michigan probably spread out like a braided river over these flats which were possibly saline, and the moving water eroded widely because of the soft and soluble character of the gypsum and of the weakness of other associated rocks.

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[24] Hall, James, In Foster, J. W., and Whitney, J. D., Report on the Geology of the Lake Superior Land District: U. S. Sen. Doc., Spec. sess. March 1851, Exec. No. 4, pp. 176-177 (1851).

———————, Organic Remains of the Lower Helderberg Group and the Oriskany Sandstone: Nat. Hist. Survey of New York, Pt. IV, Vol. 3, p. 31 (1859).

Leverett, Frank, The Illinois Glacial Lobe: U. S. Geol. Survey, Mon. 38, pp. 13, 14 (1899).

Grabau, A. W., Guide to Geology and Paleontology of Niagara Falls and Vicinity: Bull. New York State Mus., Vol. 45, p. 54 (1901).

Spencer, J. W., Relationship of the Great Lake Basins to the Niagara Limestone: Bull. Geol. Soc. Am., Vol. 24, pp. 229-232 (1913).

Ruedemann, Rudolf, Fundamental Lines of North American Geologic Structure: Bull. New York State Mus., Vol. 260, pp. 79, 80 (1924).

Subsequent streams formed tributaries to the main river and the valleys of these streams closely follow the general structural "grain" of the region. One of these streams headed in southeastern Calhoun County and flowed northwestward to the larger valley on the west side of Kent County near Grand Rapids. Another headed in central Jackson County and flowed into the main stream at about the same place in northwestern Kent County. Numerous other valleys formed by subsidiary streams of this type can be observed on the map. (See pl. I).

The principal divides of this drainage system are in the south central and the northeastern parts of the State. The main ridges forming these divides trend northeast-southwest and more or less parallel to the drainage course of the largest river. The ridges are dissected by the valleys of the smaller subsequent streams. The highest known preserved pre-glacial topography is over 1,100 feet above sea level and is located on the southern divide. The region in Northern Michigan which is mapped as a broad plateau stands at above 800 feet, but the maximum relief of the rock surface is unknown because of the lack of exploration. The surface topography would permit elevations of the rock of more than 1,100 feet, but no drilling has penetrated deep enough to reveal the depth to rock throughout the area.

An unusually high district rising above 700 feet and extending nearly north and south across western Kent County is difficult to explain. The rocks of this region are mapped as the Grand Rapids group and should respond readily to erosion. The most plausible explanation for this prominent bedrock physiographic feature seems to be a structural disturbance in the region, and the thickness and regional structure maps seem to support this conclusion.

QUATERNARY ERA

PLEISTOCENE PERIOD

The Pleistocene Ice Age which practically completed the geological history of Michigan rocks is complex in detail. The temperature gradually decreased until the accumulation of winter snows in northern ice centers was in excess of summer thaws, and a great mantle of snow and ice covered the State. The dispersion of these glacial masses was from northern centers in Labrador, the Keewatin center west of Hudson Bay, and possibly from an area between these two near Patricia, Ontario. The ice moved southward and occupied the larger depressions left by Tertiary erosion.

Two stages of glaciation have been recognized in Michigan, but there were also probably two preceding ones. After the Illinoian drift was deposited, the return of warmer climate caused a retreat or removal of ice from the region, and a period of weathering followed. With another general lowering of temperature, the ice again formed over the State, and the Wisconsin drift was laid down. Due to minor changes in climate there were retreats and readvances of the ice front, and as the weather gradually became more temperate these gave rise to a series of ice dammed glacial lakes.

The glacier front receded from the State in great ice lobes which were principally confined to the major topographic depressions. These lobes usually presented a convexly curved front which governed the form and alinement of resulting deposits. The glacial lobes, known as the Lake Michigan, Saginaw and Huron-Erie lobes, occupied the basins now filled by the Great Lakes. The directions of movement taken by the various lobes were largely controlled by climate, by distribution of ice load, and by the shape of the depressions which held and confined the ice. These directions are locally shown by the orientation of scratches and grooves which have been preserved on the surface of the bedrock. At the end of the Ice Age, the temperature finally moderated enough so that the ice sheet disappeared and the features of the glacial deposits were left much the same as they are now.

Chapter V

STRUCTURAL GEOLOGY

DISTRIBUTION OF SURFACE ROCKS

The distribution of surface rocks in Michigan is very difficult to map because of the scarcity of exposures. Except in the northern and southeastern parts of the southern peninsula, outcrops are very rare, and the only clues to formation boundaries over wide areas are those in well records. The local effects of topography on formation boundaries cannot be determined because the hills and valleys of the present earth surface may differ greatly in local districts from those of the bedrock surface. Oftentimes, the data from well logs are somewhat unreliable where the bed rock is encountered. The rock directly beneath the glacial drift is soft when weathered, and the driller often drives his pipe several feet into the bedrock before commencing to save samples of the material penetrated. The result of this oversight is that the boundaries of rock formations are incorrectly mapped, and the thickness of the glacial drift as determined is locally in error. The latter error may greatly distort the picture of pre-glacial topography which is partly shown by the present bedrock surface. Another source of error difficult to avoid is the possible misinterpretation of the age of formations in shallow wells which do not penetrate easily identifiable beds.

The map of the areal geology of the hard rock in Lower Michigan is shown in Plate II, and the tentative nature of this map is indicated by the dashed and dotted lines used for contacts. The regions which are mapped in greatest detail because of rock exposures are in Monroe, Jackson, Huron, Alpena, Presque Isle, Cheboygan, Emmet, and Charlevoix counties. Recent test well drilling in Huron, Tuscola, Sanilac, Livingston, Oakland, Wayne, Allegan, Ottawa, Kent, Roscommon, Kalkaska, and Presque Isle counties has aided in more accurately mapping many of the contacts in these counties. The extensive deep well exploration for oil and gas in western and central Michigan has necessitated many radical changes in the formational boundaries, especially in Lake and Wexford counties. Previous test borings for coal in Saginaw, Bay, Midland, Tuscola, Genesee, Shiawassee, Ingham and Jackson counties have greatly aided in the determinations of the formations from new wells. The results of test well projects completed and under way in Arenac, Ogemaw, Iosco, and several other counties have not been released, and the corrections which will necessarily follow any discoveries that may take place because of these operations must be omitted from the prsent map.

The following are some of the more important changes made on this map: The concentric arrangement of the outcropping rocks is still preserved, but the width of the outcrop and the sinuosity of the contact lines in many cases are very different than on previous maps. The changes in the areal geology which were described in a paper by Thomas[1] have been largely adopted. Other contacts that are radically different from pre-

[1] Thomas, W. A., A Study of the Marshall Formation in Michigan: Papers, Michigan Acad. Sci., Arts and Letters, Vol. XIV, pp. 487-498 (1930).

vious maps are those in the vicinity of the Howell structure in Livingston and bordering counties; the new boundaries of the Saginaw formation in the northwestern part of the State in Wexford and Lake counties; and those of the Traverse-Dundee, Dundee-Monroe boundaries in Cheboygan and Presque Isle counties. Minor alterations have been made to the Bedford-Antrim contacts in north central Michigan, in Leelanau and Cheboygan counties, and in southeastern Michigan in St. Clair, Wayne, Washtenaw, and Oakland counties. Changes have also been made in the Saginaw formation, Grand Rapids series, Marshall formation, and Coldwater-Sunbury-Berea contacts in the western counties of the State. The Saginaw-Grand Rapids contact has been altered in Arenac County, and the Grand Rapids-Marshall contact has been revised in Huron, Tuscola, Ogemaw, Arenac, and Sanilac counties. The Coldwater formation also appears at the surface beneath the drift on the West Branch structure, Ogemaw County.

The "Red Beds" have been added to the formation units, and the region underlain by these beds is mapped in the central part of the State. The complete continuity of these deposits is only postulated, but the characteristic red strata have been found so regularly throughout the region that the area mapped as "Red Beds" seems approximately correct. As new information is gained from drilling operations the outer boundaries now drawn will be found to have irregularities and there will also be separate erosion remnants beyond. Accurate mapping will always be difficult because the soft clay-like layers are easily mistaken for drift material. Close observations in all new wells for the first appearance of red colors should aid in further corrections of the boundaries of the Michigan "Red Beds."

The occurrence of outliers is illustrated by the remnant of the Grand Rapids group in northeastern Allegan County (see pl. II) and this suggests that numerous other unmapped remnants probably exist. The outliers of Marshall formation in Calhoun and Kalamazoo counties and in Hillsdale County seem to represent erosional remnants of sandstone, which may be partly due to structural control of pre-glacial drainage. The inliers or "windows" of the Grand Rapids group in Jackson County result from the uneven erosion surface at the top of the Mississippian and similar Bayport hills should protrude through the Saginaw formation in other localities. The inlier in southern Ogemaw County is indicated by the outcrop of Marshall sandstone in the valley of the Rifle River. This exposure is due to a large anticlinal structure in the region (West Branch anticline), and the size and shape of the mapped district is determined by a comparison with other better known anticlinal structures in the State. The outlines of the formation contacts in this area will probably be greatly modified when more exact data become available. The peculiar shaped outcrop of the Saginaw formation in central Arenac County may be evidence of the southwest parallel syncline in the same structural trend as the Ogemaw County anticline. (West Branch anticline).

The information from wells which outline the large Howell structure in Livingston County necessitates several radical changes in formation boundaries in this region, but the interpretation of both the boundaries and the structure is by no means final. It is quite certain, however, that all of the wells in the portions of northern Livingston County and

PUBLICATION 38 -FIGURE 20

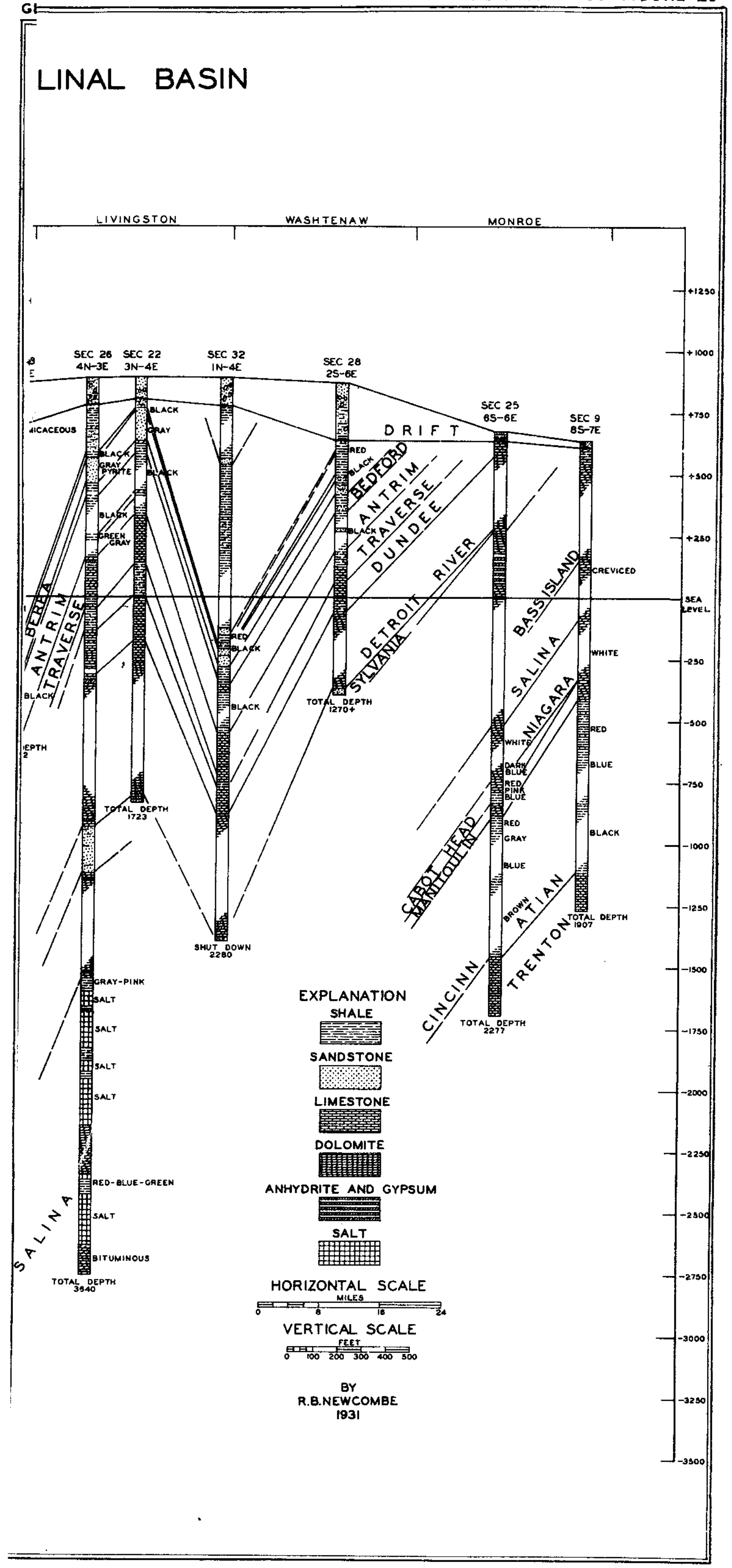
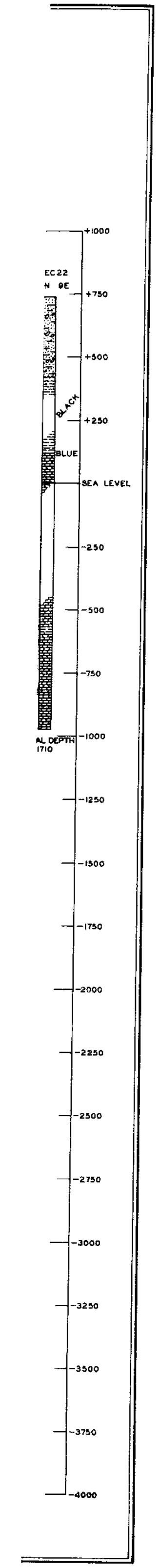
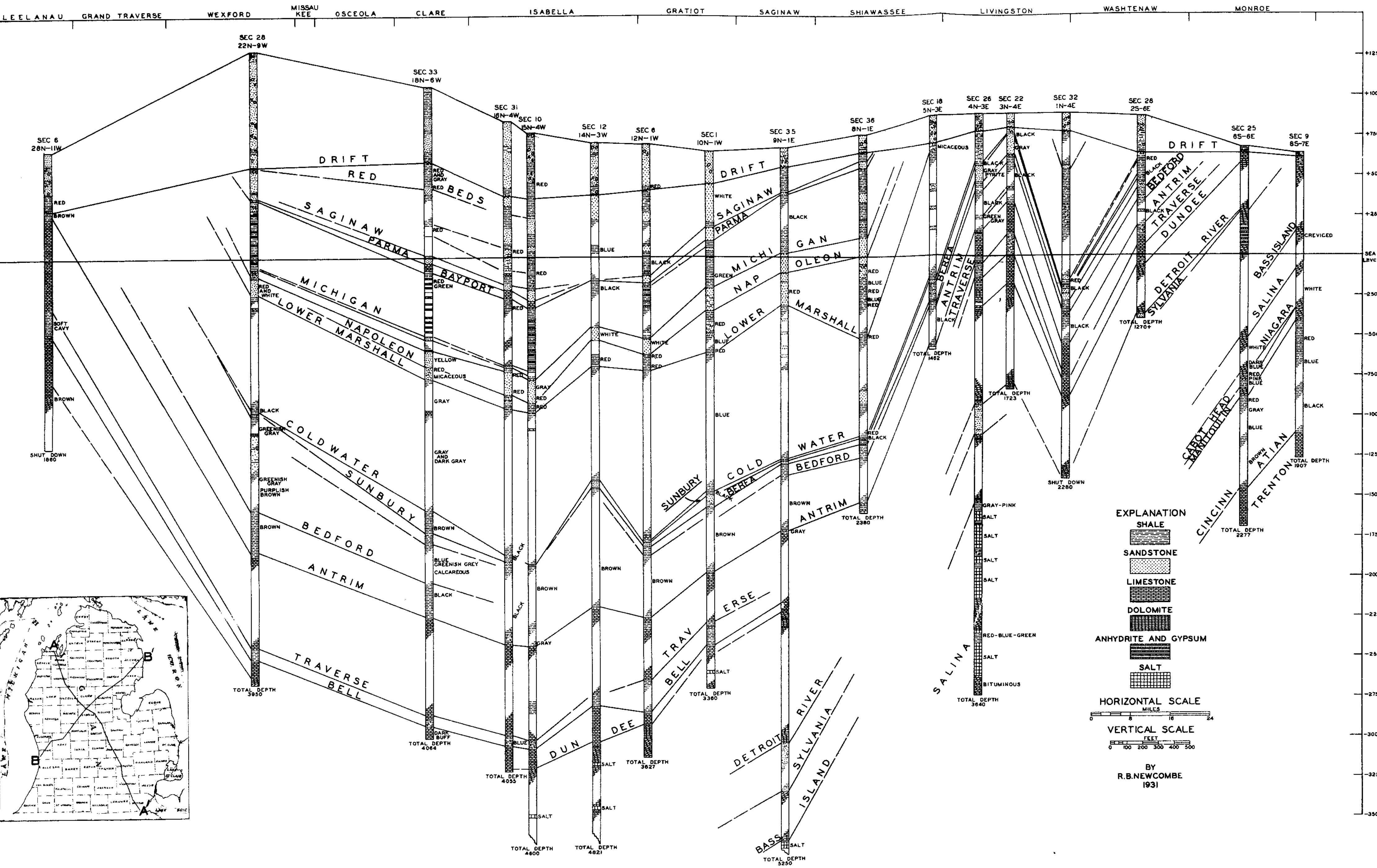


FIGURE 21



GENERALIZED LONGITUDINAL SECTION A–A' OF MICHIGAN SYNCLINAL BASIN
BY
COMPARISON OF WELL RECORDS



GENERALIZED TRANSVERSE SECTION B-B′ OF MICHIGAN SYNCLINAL BASIN

BY

COMPARISON OF WELL RECORDS