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AN ANALYSIS OF THE PERMO-CARBONIFEROUS "RED BEDS" OF MICHIGAN

By

John Egan Sander

AN ABSTRACT

Submitted to the College of Science and Arts of Michigan State University of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Department of Geology

1959

Approved ______________________________

ABSTRACT

Due to the general absence of outcrops, the studies undertaken in this thesis utilized chiefly subsurface geological methods.

This analysis of the "Red Beds" consisted of several lines of approach. An isopach map of the "Red Beds was constructed from the data obtained from sample studies and drillers logs. This map showed the bulk of the "Red Beds" to form an elliptical shaped body in the center of the Lower Peninsula within the limits of Lake, Kent, Gratiot, and Roscommon counties. Numerous erosional outliers were found to surround this body. The average determined thickness for the "Red Bed" body is approximately 87 feet with the greatest thicknesses tending to be located in its center. A map indicating the approximate distribution of gypsum in the "Red Beds" was also constructed which showed no significant trends in gypsum distribution. The clay fraction of eight samples was X-rayed. Illite was the most common constituent. A total potassium analysis was therefore run to determine the percentage of illite in each sample. A sphericity study was conducted on the fine sand constituent of the above samples to help determine a possible source for the "Red Beds." The coloring agent of the "Red Beds" was isolated and analyzed as iron.

An extensive search for fossils revealed unusual markings in a sample from Mecosta county which may be an indication of life that existed during the deposition of the "Red Beds."

On the basis of the data collected, it is postulated that the "Red Beds" were deposited under marine conditions. The time of deposition appears to have been Pennsylvanian. The results of sphericity studies as well as paleogeographic considerations suggest that a possible major source for the "Red Beds" was located to the southeast.

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PURPOSE

Lying in the center of the Lower Peninsula of Michigan and stratigraphically subjacent to the glacial drift is a group of reddish siltstones and associated gypsum beds which has been designated as the Permo-Carboniferous "Red-Beds." Relatively little data is known concerning these beds, and it was felt that any new information obtained from them would be of value. This value would be not only of an academic nature, but further, since these beds lie within the water saturated zone of the area that they encompass, any additional information on the "Red Beds" might well contribute to the knowledge of the water resources of the state.

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INTRODUCTION

Location of the "Red Beds"

The "Red Beds," situated in the center of the Lower Peninsula of Michigan, comprise an area of about 3,500 square miles. They are located or inferred to be located within the counties of Roscommon, Ogemaw, Lake, Osceola, Clare, Newaygo, Mecosta, Isabella, Midland, Montcalm, Gratiot, Saginaw, Clinton, and Kent.

Previous Work on the "Red Beds"

Before 1932, the "Red Beds" had been mentioned occasionally in the geologic literature. In 1932, Newcombe described them as "a series including red shale, red to greenish sandy shale, sandstone, and gypsum. . . . (which) occur above a thick basal sandstone and are widespread in the central part of the State." Kelly in 1936 again briefly mentioned the "Red Beds" in his discussion of the Pennsylvanian system of Michigan. In 1951, a study of some "Red Bed" samples from the subsurface laboratory at the University of Michigan was undertaken by D. H. Swartz in conjunction with a Masters thesis at that university. From this study a map was made defining the limits of the "Red Beds" and showing the elevations of the contact between the "Red Beds" and the underlying strata at various points.

GENERAL STRATIGRAPHY

The Michigan Basin

The Michigan Basin, which is considered to be a classic example of a structural basin, is centered in the approximate center of the Lower Peninsula of Michigan. The Basin includes within its bounds Lake Huron and Lake Michigan and its margins extend into the Upper Peninsula of Michigan, into Ohio, Indiana, Illinois, Wisconsin, and Ontario. This basin is not a true circular basin but rather somewhat elliptical in shape with its major axis trending approximately north-south. The extensive deposits of Silurian salt beds within the basin indicate that it was present as a structural unit as far back as Silurian time, and it can be indeed postulated that the basin was in existence even earlier.

The Michigan Basin has a base of Precambrian rocks. Above this Precambrian base is a sequence of sediments representing every system from Cambrian through Pennsylvanian.

Stratigraphic Position of the "Red Beds"

The "Red Beds" lie stratigraphically directly beneath the Quaternary glacial drift and are separated from the overlying drift by a definite unconformity. Thus, post "Red Bed"-preglacial erosion has removed the upper part of the "Red Beds" as well as any possible post "Red Bed" sediments.

Definite Pennsylvanian sediments lie just below the "Red Beds." In some places the "Red Beds" overly a basal sandstone, whereas in other places they overly black shales or limestones. This strongly suggests that at least a local unconformity separates the "Red Beds" from the underlying sediments.

SAMPLE STUDIES

Scope of the Sample Studies

In this study of the "Red Beds," no outcrops of the beds were found. Thus, the study was limited to subsurface geologic methods. As no drill cores were found, this study was restricted to crushed rock samples taken during the drilling of oil wells in the area of the state covered by the "Red Beds." The samples were taken from the sample collections of the Geology Department of Michigan State University and the Michigan Geological Survey. Samples from approximately 1150 wells were investigated. Of these, 133 wells definitely showed the "Red Beds," or gave indirect evidence that the "Red Beds" were likely present, and 493 wells showed the "Red Beds" to be absent. The remaining wells, approximately 524 in number, yielded no information on the "Red Beds" because samples were not available stratigraphically high enough in these wells to include the area of the "Red Beds." The samples from these wells were contained in vials with the contents of each vial representing a small interval (5 to 10 feet) of drilled stratum.

Description of a Representative "Red Bed" Sample

A description of the "Red Beds" from a well in Mecosta County from the sample collection of the Geology Department at Michigan State University is given below. The sample in each vial represented 5 feet of drilled stratum. A series of adjacent vials with similar lithology is recorded here as a stratigraphic unit. The thickness of the unit is the sum of the footages included by samples.

SAMPLE STUDY

Michigan State University Sample Collection
Mecosta County T. 16N. -R. 8W. -Sec. 1
M. S. U. Catalogue #4046 Permit #11154

Lithology	Thickness (in feet)	Depth (in feet)
Glacial Drift	605	605
Red Beds:		
Aggregates of reddish brown fine grained siltstone with occasional streaks of greyish clay within the siltstone. This siltstone appears to have a high clay content. Some aggregates of siltstone have apparent glacial material in them, suggesting that these aggregates were cemented together from pulverized material during the drilling.	20	625
Red siltstone with a few small aggregates of white chalky gypsum.	05	630
An approximately equal mixture of reddish siltstone and chalky gypsum.	20	650
Predominantly gypsum mixed with some reddish brown siltstone and glacial drift. The gypsum has a chalky appearance. Some of it is granular and some of it shows a platelike basal cleavage. Occasional patches of clear selenite are seen within the platy gypsum.	65	715
A mixture of dark red shale and grey shale containing mica. One aggregate of dark red shale appears to grade into grey-black shale. A small amount of black shale is present.	10	725
Definite Pennsylvanian:		
Predominantly a grey micaceous siltstone with occasional plant remains. Some gypsum, red siltstone, and an increasing amount of black shale are present.	5	730

The "Red Beds" are interpreted here as comprising the reddish-brown siltstone and chalky gypsum which directly underly the glacial drift at a depth of 605 feet. This siltstone and gypsum continue down to a depth of about 727 feet where dark purplish-red siltstone, grey siltstone, and some dark grey shales are encountered. These sediments are not considered as part of the "Red Beds" because their color is not the typical "hematite brown" of the "Red Bed" siltstones. The depth of 727 feet was chosen as the base of the "Red Beds" because in the sample vial marked 715-720 (feet depth), the underlying sediments are found mixed with definite Red Bed sediments. Thus, the base of the "Red Beds" is assumed to be at a depth of 715 feet to 720 feet, and the value of 717 feet was chosen on the basis of the approximate ratio of "Red Bed" sediments to underlying sediments in this vial.

ANALYSIS OF THE SILT AND CLAY FRACTIONS OF THE "RED BEDS"

Selection of Wells for Sampling

In addition to the gypsum, siltstone and clay were found to be the major constituents of the "Red Beds." It was therefore thought that an investigation of these silts and clays would yield pertinent information.

As many of the samples were considerably contaminated with cavings from the overlying drift, some difficulty was encountered in obtaining pure samples while still giving a uniform coverage of the "Red Beds." Eight wells were chosen for study following an examination of the available wells. These are listed below:

Samples obtained from the Geology Department at Michigan State University.

Well No. 1, No. 4479 Ogemaw Co., 11N-1E-Sec.8, Cities Service, Hickey No. 1, Permit No. 12267.

Well No. 2, No. 4355 Clare Co., 18N-5W-Sec. 13, Burton, Thompson No. 1, Permit No. 10380.

Well No. 4, No. 3825 Mecosta Co., 15N-10W-1, Gulf, Colfax Project No. 2, No permit number given.

Well No. 5, No. 3516, Mecosta Co., 15N-7W-Sec. 21, Gulf, Warner No. 1, Permit No. 9841.

Well No. 6, No. 4223, Montcalm Co., 12N-8W-Sec.6, Gordon, No. 1, Paris, Permit No. 10922.

Samples obtained from the Michigan Geological Survey.

Well No. 3, Isabella Co., 16N-5W-Sec. 23, J. V. Wickland, Gamble No. 1, Permit No. 12635.

Well No. 7, Newaygo Co., 12N-11W-Sec. 20, Sun Oil Co., Woodard Brown No. 1, Permit No. 17132.

Well No. 8, Montcalm Co., 11N-7W-Sec. 35, Howard D. Atha, C. Dancer No. 1, Permit No. 17262.

These wells will be referred to here by the number assigned to them from 1 through 8. These numbers run consecutively from north to south with well No. 1 being the furthest north and No. 8 being the well furthest south (see Figure 1).

Sampling Procedure

As much sample as possible was removed from each vial without "robbing" the vial. This amounted to about one-fourth of the contents of each vial. The total sample from the vials in a given well was mixed to give a composite sample for that well.

After obtaining a composite sample for a well, the siltstone, and clay aggregates were separated from the gypsum and glacial drift by hand and the siltstone fraction then weighed. The weight of the siltstone-clay fraction from each well is given in Table I.

TABLE I

INITIAL SILT-CLAY SAMPLE WEIGHTS

Well Number	Weight of Siltstone-Clay Fraction (grams)
1	5.49
2	3.89
3	7.88
4	1.67
5	3.59
6	1.80
7	7.12
8	3.67

The yields, as can be seen, are very unequal with wells 4 and 6 giving relatively little sample; however, this was sufficient for the subsequent analysis of the samples.

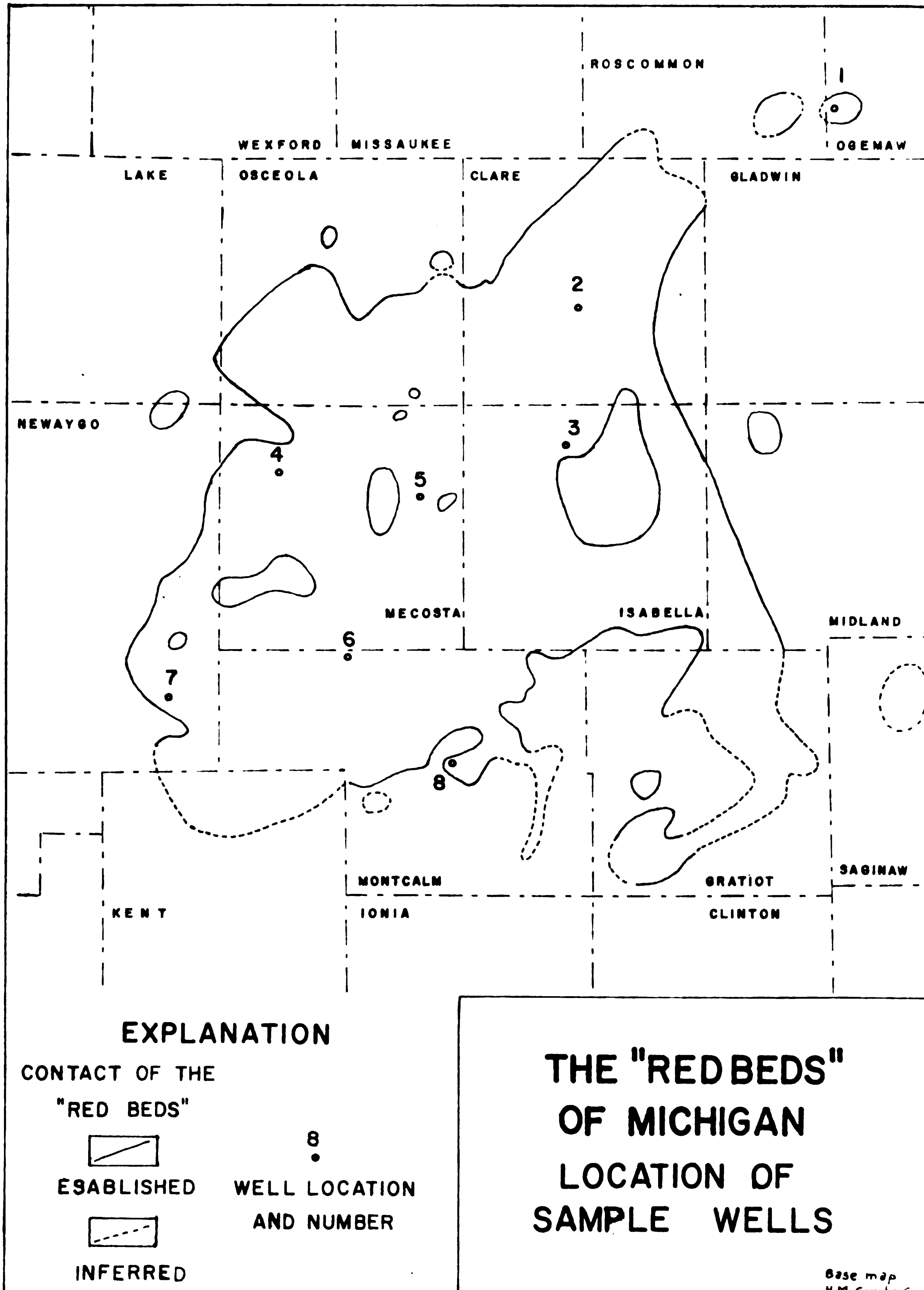

ROSCOMMON
1
WEXFORD
MISSAUKEE
OGEMAW
LAKE
OSCEOLA
CLARE
GLADWIN
2
NEWAYGO
3
4
5
MECOSTA
ISABELLA
MIDLAND
6
7
8
MONTCALM
GRATIOT
SAGINAW
KENT
IONIA
CLINTON
EXPLANATION
CONTACT OF THE "RED BEDS"
ESABLISHED
INFERRED
8
WELL LOCATION AND NUMBER
THE "RED BEDS" OF MICHIGAN
LOCATION OF SAMPLE WELLS
Base map
H.M. Gousha Co.

Figure 1

Separation and Purification of the Silt and Clay Fractions

The silt and clay in these samples were not present as discrete aggregates, but rather the clay was largely present interstitially within impure siltstone aggregates, making it necessary to separate and purify the silt and clay fractions. This was done according to the following method based on recommendations of the Soil Science Department of Michigan State University.

Removal of Water Soluble and Acid Soluble Salts

The samples appeared to have little or no organic matter; so it was not considered necessary to subject them to the hydrogen peroxide-acetic acid method for the removal of organic matter. Instead, the samples were placed in a beaker and treated with a weak solution of hydrochloric acid and then heated. This treatment was repeated until all bubbling ceased which indicated that all carbonates had been dissolved. Each sample was then placed in fine filter paper, washed with about 200 ml of 1 N hydrochloric acid, and then washed repeatedly with distilled water until no precipitate was obtained when a 1.5M Na_2CO_3 solution or a crystal of $AgNO_3$ was added to the filtrate. This then indicated that no Ca^{++}, Mg^{++}, Cl^-, or similar ions were present, and that the sample was likely free of carbonates, gypsum, and any water soluble halogen salts (if present).

Removal of Iron

In the above acid treatment, sample No. 3 was treated with hydrochloric acid of sufficient concentration to remove the red iron stain from this sample. It was feared that removing the iron in this manner might further dissolve or damage some clays such as the sepiolite-attapulgite-palygorskite minerals (Grim 1953) if they were present. The method chosen for iron removal (Jackson 1956) with some modifications is as follows: Each sample was placed in a beaker and 40 ml. of 0.3M sodium citrate solution and 5 ml of 1M sodium bicarbonate solution were added. The temperature was then brought to approximately 80° centigrade with the aid of a water bath, and 1 gram of solid $Na_2S_2O_4$ (sodium hydrosulfite) was slowly added. The mixture was stirred constantly for one minute, and then occasionally for fifteen minutes. Heating above 80° centigrade is avoided as much as possible because FeS is formed at these higher temperatures. The mixture then stood for a fifteen minute digestion period. In order to promote flocculation, 10 ml of saturated sodium chloride solution was afterward added. The samples were then placed in No. 50 filter paper with a portion of the filtrate of each being saved for iron determination; then the samples were washed several times with distilled water. Since the clays at this stage were so well dispersed that the finer particles passed through the filter paper, it was necessary to add calcium chloride to the residue to flocculate the clays and retard this loss.

Dispersion of Clays and Separation of the Silts from Clays

The iron free samples were next placed in small bottles, titrated with sodium hydroxide past the phenolphthalein endpoint, and placed in a reciprocating shaker for 17 hours to affect complete dispersion. At the end of this period, the samples were still alkaline beyond the phenolphthalein endpoint. Following dispersion, the samples were placed in 1 liter graduated sedimentation cylinders, shaken thoroughly, and allowed to settle. The clay minerals were separated from the samples at this point in accordance with the principle that clay minerals are generally smaller than 1 microns, whereas nonclay-minerals are commonly larger than 1 to 2 microns (Grim 1953). Stokes' law shows that particles 2 microns in diameter and with a density of 2.63 (density of clay) will settle in water 21.76 centimeters in 17 hours. A yield of almost pure clays (particles 2 microns or less) was thus obtained by siphoning off the top 21 centimeters of suspension in the sedimentation cylinders 17 hours after the initial shaking.

Qualitative X-Ray Clay Analysis

It was apparent that a determination of the types of clay minerals in the "Red Beds" would not only lead to a better understanding of the "Red Bed" clays themselves, but that it would also give possible clues to the mode of origin of these beds. One of the best methods available for a qualitative determination of clay minerals is X-ray diffraction analysis. The X-ray diffraction apparatus of the Soil Science Department of Michigan State University was available, and, using this apparatus, an X-ray analysis of the clays of the eight samples was made.

Theory of X-Ray Diffraction Analysis

A crystalline clay mineral, on a molecular scale, is composed of a three dimensional framework or lattice of atoms having a characteristic arrangement and spacing for each mineral. By the use of X-rays, this lattice spacing (called "d" spacing) can be determined and the mineral thus identified. This is due to the fact that a lattice acts as a plane surface to an X-ray beam striking it, and reflects the beam back at the same angle at which it strikes the lattice. That is to say, the X-ray's angle of incidence is equal to its angle of reflection. As the lattice is three dimensional, the X-ray will encounter different planes when striking a given mineral at different angles.

At a given series of angles, depending on the average length of the X-ray and the crystal's inter-lattice of "d" spacing, the reflected X-ray beams from thousands of parallel lattice planes will interfere constructively resulting in an intensified reflected beam. Any slight variation from this angle will cause virtually complete destructive interference and consequently no reflection. This relationship is expressed in Bragg's equation which states:

$$n\lambda = 2d \sin \theta$$

where λ is the wave-length of the X-ray beam, θ is the angle that the X-ray beam makes with the lattice plane, n is the number of wave-lengths of path difference of the reflected X-ray beams (1λ, 2λ, 3λ, etc.), and d is the distance between successive lattice planes. As can be seen from the above equation, n increases as θ increases, and constructive interference will result only when n is equal to 1, 2, 3, etc. Since n, λ, and θ can be readily determined, it is possible to calculate the "d" spacing and thus identify the mineral.

Clay minerals commonly display good basal cleavage, and a very advantageous procedure in clay X-ray analysis (Kinter and Diamond 1955) consists of orientating the mineral aggregates parallel to this basal cleavage and measuring the "d" spacing of their "basal" lattices. This method was employed here.

Preparation and X-Ray Diffraction Analysis of the "Red Bed" Clays

The eight samples were prepared and X-rayed as oriented aggregates according to the procedure given below which was based primarily on recommendations of the Soil Science Department of Michigan State University.

About 10 cc. of the clay suspension was poured on a porous plate contained in a porous plate holder that rested on a vacuum flask. The suction from the flask drew the water through the plate, while the clay aggregates were retained on the surface of the plate as a thin film of particles lying parallel to one another on their vasal cleavage planes. This film was then leached with three increments of 0.1<u>N</u> $CaCl_2$ which contained 3 percent glycerol by volume and washed several times. The calcium replaced all replaceable ions in the lattice structures of the clay minerals, while the glycerol spread the "d" spacing of montmorillonite (if present). In this manner, the clay minerals were "standardized" to give consistent results in X-raying.

Each porous plate with its film of oriented aggregates was placed in a holder on the X-ray diffraction apparatus and the sample bombarded with X-rays from a copper source. A revolving goniometer measured the angle and the intensity of the reflected beam which was recorded on a chart (see Figure 2). A rotation of the goniometer through an angle of from 2° to 30° 2θ (1°-15° θ) was sufficient to record the presence of any clay minerals.

The sample was then removed from the machine, placed in a porous plate holder, and suction applied. Following this, calcium saturated clays were leached with 0.1<u>N</u> KCl, washed thoroughly with distilled water, then heated to approximately 110° centigrade for about 12 hours, and X-rayed again. This process collapsed the structure and "d" spacing of any vermiculite or montmorillonite present resulting in consequent destructive interference for them (Brown 1951). This was easily noted on the graph of the second X-ray experiment and served as a further indication of the presence or absence of these minerals.

To collapse the structure of any kaolinite, the sample was removed and heated to about 550° centigrade for approximately one hour (Grim 1953). The third X-ray experiment recorded this change.

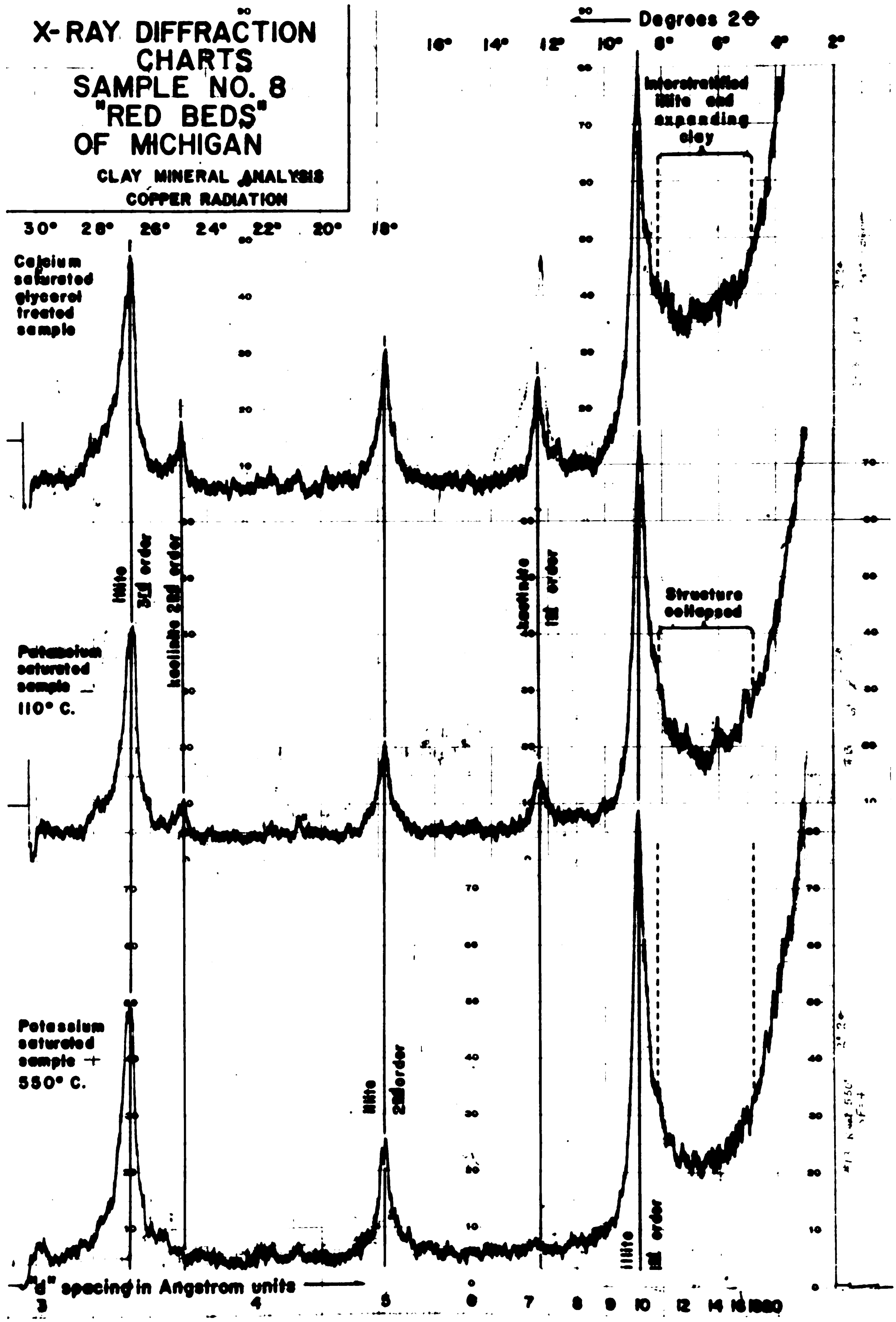

X-RAY DIFFRACTION CHARTS
SAMPLE NO. 8
"RED BEDS"
OF MICHIGAN
CLAY MINERAL ANALYSIS
COPPER RADIATION
Degrees 2θ
Interstratified illite and expanding clay
Calcium saturated glycerol treated sample
Illite 3rd order
Kaolinite 2nd order
Kaolinite 1st order
Structure collapsed
Potassium saturated sample — 110° C.
Potassium saturated sample + 550° C.
Illite 2nd order
Illite 1st order
"d" spacing in Angstrom units

Figure 2

Results of the X-Ray Diffraction Analysis

The charts of the three experiments for each sample gave a qualitative recording of the clay minerals present in that sample. These results are listed for each of the eight samples in Table II.

TABLE II

RESULTS OF THE QUALITATIVE CLAY MINERAL ANALYSIS

Sample Number	Clay-Minerals Found
1	kaolinite illite interstratified with an expanding type clay mineral(s) (vermiculite and/or montmorillonite).
2	some kaolinite illite randomly interstratified with an expanding type clay mineral(s) (vermiculite and/or montmorillonite).
3	kaolinite illite interstratified with an expanding type clay mineral(s) (vermiculite and/or montmorillonite).
4	illite randomly interstratified with an expanding type clay mineral(s) (vermiculite and/or montmorillonite).
5	possibly some kalonite illite randomly interstratified with an expanding type clay mineral(s) (vermiculite and/or montmorillonite).
6	illite randomly interstratified with an expanding type clay mineral(s) (vermiculite and/or montmorillonite).
7	kaolinite illite randomly interstratified with an expanding type clay mineral(s) (vermiculite and/or montmorillonite).
8	kaolinite illite randomly interstratified with an expanding type clay mineral(s) (vermiculite and/or montmorillonite).

The dominant mineral found is illite which is interstratified with an expanding type clay that could be either vermiculite or montmorillonite or both. In samples 1, 4, 5, 6, 7, and 8, the general diffusion of the X-ray diffraction pattern of the interstratified clays suggests that this interstratification is random (no particular sequence in the interstratified layers). On the other hand, samples 1 and 3 show a few small peaks in the diffraction intensities of their interstratified clays suggesting possibly some order in the sequence of their interstratified layers.

Quantitative Determination of Illite by Total Potassium Analysis

As illite was found to be the most significant clay mineral in the X-ray diffraction analysis, it was considered important that a quantitative determination of this mineral be made in each of the eight samples.

Illite, generally speaking, may be considered the only clay-mineral that contains potassium to a significant degree (Grim 1953). Assuming a relationship exists between the amount of illite and the amount of potassium in a given clay sample containing illite, a quantitative determination of this illite can be made from the total amount of potassium found. It is possible to determine fairly accurately the amount of potassium in a sample by the strength of its potassium emission spectrum. In this manner, the total potassium content was determined in each of the eight samples using the Beckman flame spectrophotometer of the Soil Science Department of Michigan State University.

Procedure

The procedure (Webber and Shivas 1953) described below was recommended by the Soil Science Department of Michigan State University. Certain modifications have been added.

Samples weighing between 0.25 and 0.5 grams were dried at 110° C., cooled in a desiccator, and weighed to four decimal places in platinum crucibles. One ml of a solution of H_2SO_4 (1:5) was added to each sample. The samples were placed on a hot plate, approximately 5 ml of concentrated hydrofluoric acid (HF) added to each sample, and the samples evaporated to dryness. This removed the silica in the samples as volatile silicon tetrafluoride (SiF_4) (Kolthoff and Sandell 1952). Five ml of the concentrated HF was again added to each of the samples and the process repeated. The residue was then taken up with distilled water, filtered, and the remaining residue washed with 0.1N HCl and distilled water. The volume of the filtrate of each sample was next adjusted to 200 ml. The Beckman flame Spectrophotometer was then calibrated to the samples, a portion of each solution poured through the spectrophotometer and its value recorded. From these values, the total potassium and illite concentration was calculated for the eight samples.

Results of the Total Potassium Analysis

The values obtained from the spectrophotometer were converted into milligrams of potassium and then calculated as corresponding theoretical milligrams of K_2O. Knowing the weight of the original samples, the percentage of K_2O was calculated for each sample. The percent illite was then calculated on the assumption that pure illite would contain approximately 5.5 percent K_2O (Grim 1953). These results are listed in Table III.

These results cannot be taken as completely accurate, but they give a general indication that illite is the predominant clay mineral of the "Red Beds."

TABLE III

PERCENTAGE ILLITE CALCULATED FROM THE TOTAL POTASSIUM CONCENTRATION

Sample No.	Mgs. K	Mgs. K_2O	Total Sample Wt. Mgs	Percent K_2O	Percent Illite
1	5.1	6.15	311.6	$\frac{6.15}{311.6} = 1.98$	36.0
2	13.6	16.4	332.8	$\frac{16.4}{332.8} = 4.93$	89.7
3	18.9	22.8	484.0	$\frac{22.8}{484.0} = 4.71$	85.6
4	6.3	7.59	275.8	$\frac{7.59}{275.8} = 2.76$	50.3
5	11.4	13.73	356.5	$\frac{13.73}{356.5} = 3.85$	70.1
6	6.5	7.84	259.2	$\frac{7.84}{259.2} = 3.03$	55.1
7	16.0	19.3	448.3	$\frac{19.3}{448.3} = 4.30$	78.2
8	14.0	16.9	317.7	$\frac{16.9}{317.7} = 5.32$	96.6

Significance of the Clay Minerals Found

Studies have shown that the types of clay minerals found in a sediment reflect, in a general way, the age and conditions of deposition of that sediment. Investigations of sediments in eastern France and the adjacent sections of Germany and Switzerland which were known from paleontological and stratigraphic evidence to be marine sediments, contained illite as the dominant clay mineral (Grim 1953). Kaolinite was often present as a secondary mineral with chloritic mica and vermiculite often present as minor constituents. Sediments of lagoonal and lacustrine origin contained different mineral assemblages and proportions. The universal presence of illite in the "Red Bed" samples along with the frequent presence of kaolinite and possible presence of vermiculite suggest a possible marine type environment for the deposition of the "Red Beds." Attapulgite and sepiolite often indicate an evaporite type environment. The fact that they were not found here, however, does not preclude the possibility that the "Red Bed" gypsum was formed under "salt lake" conditions because attapulgite and sepiolite are apparently found only in recent sediments.

Montmorillonite has been found to be almost exclusively absent in sediments older than Mesozoic age. Since the presence of montmorillonite as a constituent of the expanding clays could not be definitely established or refuted, no determination of a pre-Mesozoic or a Mesozoic-post Mesozoic age for the "Red Beds" could be determined. The presence of kaolinite shows that the "Red Beds" are likely post-Devonian, but this is readily established from their stratigraphic position.

The clay minerals found indicate then that the "Red Beds" were possibly formed under marine conditions; however, insufficient information was available to give any new clues as to the age of the "Red Beds."

Sphericity Analysis of the "Red Bed" Clastics

The "Red Bed" siltstones were composed predominantly of quartz particles and contained practically no heavy minerals. Consequently, a sphericity study was made on the quartz with the intension of determining the possible direction of its source.

Preparation of the Samples

The clastics in each of the samples were separated from the dispersed clays, washed several times with tap water, and then dried. Following this, the silts and fine sands were sieved and separated, in accordance with Wentworth's classification, into one size covering medium sands and larger (particles greater than 0.25 mm), four sizes of fine sand between 0.25 mm and 0.065 mm, and one size covering the silt size particles--0.065 mm to 0.0039 mm--(Krumbein and Pettijohn 1938). The quantitative size of the fractions decreased with increasing grain size, and the silt fraction was in each case the largest. The fractions of medium sand or larger were generally insignificantly small and were probably contaminated to a considerable degree by the overlying glacial drift.

It was desirable to obtain for study a fraction from each of the samples that would be as large as possible in sieve size and still not have contamination from the fine sands of the overlying drift. After an examination of the samples, the sand between 0.112 mm and 0.125 mm (very fine sand) was chosen from each of the eight samples for study.

Separation of the Light and Heavy Minerals

The fractions chosen for study were next placed in funnels filled with bromoform ($CHBr_3$) to separate the "light" minerals from the "heavy" minerals. Bromoform has a specific gravity of approximately 2.89, and minerals with a higher specific gravity than this (rutile, magnetite, etc.) will sink in bromoform; whereas minerals with a lesser specific gravity (quartz, feldspar, etc.) will float. After all the heavy minerals had settled, enough of the bromoform was released from the bottom of the funnel to wash these heavy minerals onto filter papers placed below the funnels. The light minerals remained floating in the bromoform left in the funnels, and the separations were thus completed.

Mounting and Optical Examination

The light and heavy fractions of each sample were mounted of glass slides in a medium of araclor (index of refraction 1.66). An examination of the heavy minerals with a petrographic microscope showed only a few grains on each slide indicating that the "Red Bed" clastics likely contained little or no heavy minerals. The few heavy minerals found could easily have been contamination from the overlying drift. The examination of the light minerals showed quartz to be the predominant mineral with occasional fragments of feldspar. These quartz grains were very angular.

Measurement of Sphericity

The sphericity of the light minerals was measured in each of the samples according to the following formula (Riley 1941):

$$S = \sqrt{\frac{i}{I}}$$

where S is the sphericity of a given grain, i is the diameter of the largest circle that can be inscribed within the projection of the grain on a plane surface, and I is the diameter of the smallest circle that can be circumscribed around that same projection. From this formula, a perfect sphere has a sphericity of one, whereas values decreasing from one to zero indicate a corresponding decrease in sphericity.

In selecting individual grains for measurement, an attempt was made to choose grains such as quartz which display no distinct cleavage. The sphericity of at least fifty grains was measured for each sample, and these measurements averaged to give a composite value for the sphericity of that sample. The results for each of the eight samples is listed in Table IV.

TABLE IV

SPHERICITY OF RED BED CLASTICS
VERY FINE SAND FRACTION

Sample No.	Sphericity
1	0.799
2	0.774
3	0.803
4	0.808
5	0.785
6	0.785
7	0.794
8	0.786

Significance of the Sphericity Analysis

Figure 3 shows that there is a slight tendency toward an increase in sphericity in the "Red Bed" samples toward the northwest. Proceeding on the assumption that sphericity in detrital sediments increases with distance from source, then a source for the "Red Beds" might be postulated to have existed somewhere toward the southeast--perhaps in the old Appalachian landmass. This proposal must be made with reservations, however, first because of the small number of samples, and secondly because the assumption that sphericity in detrital sediments increases with distance from source has not been definitely proved (O'Hara 1954).

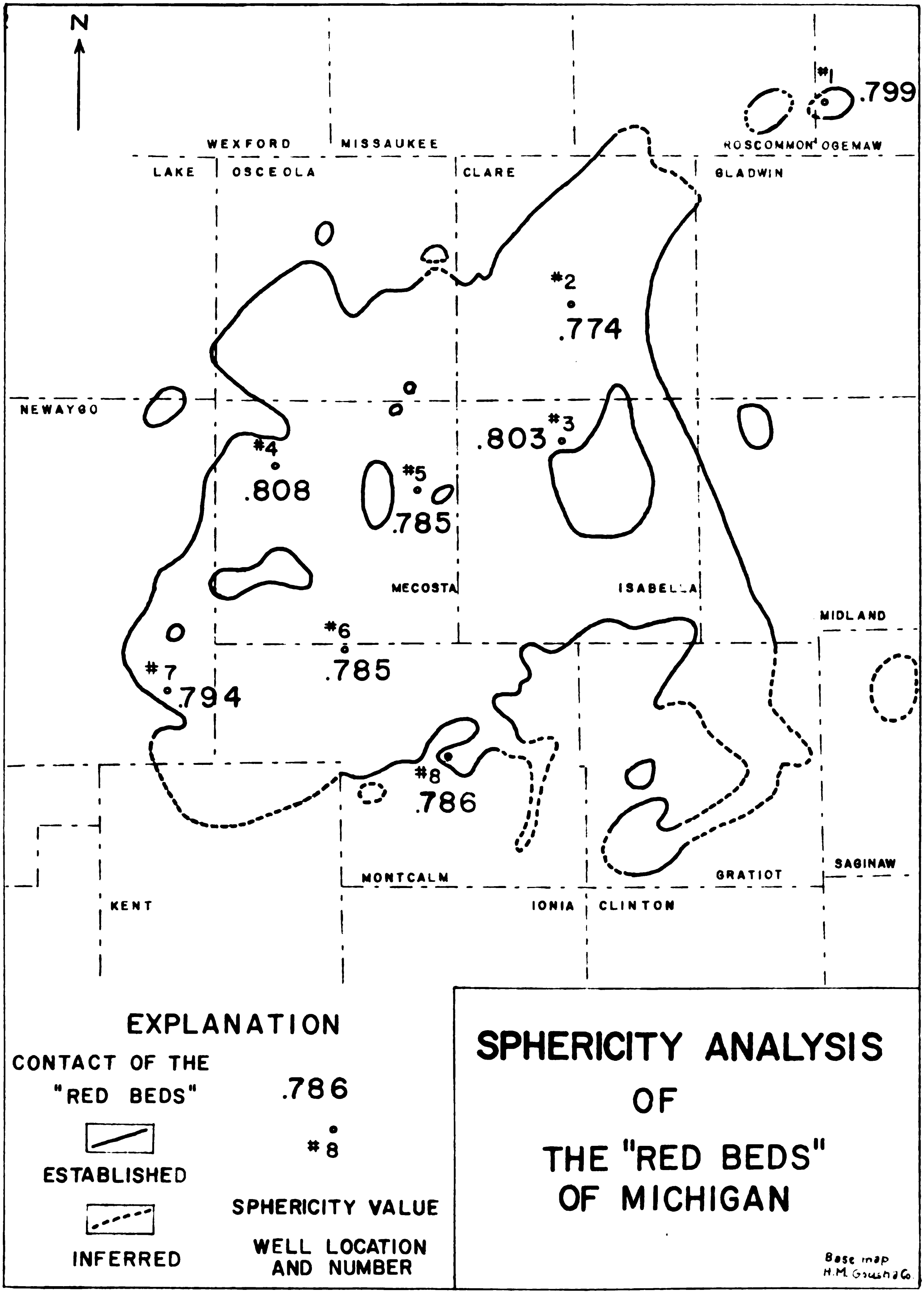

N
WEXFORD
MISSAUKEE
ROSCOMMON
OGEMAW
LAKE
OSCEOLA
CLARE
GLADWIN
#1
.799
#2
.774
NEWAYGO
#3
.803
#4
.808
#5
.785
MECOSTA
ISABELLA
MIDLAND
#6
.785
#7
.794
#8
.786
MONTCALM
GRATIOT
SAGINAW
KENT
IONIA
CLINTON
EXPLANATION
CONTACT OF THE "RED BEDS"
ESTABLISHED
INFERRED
.786
#8
SPHERICITY VALUE
WELL LOCATION AND NUMBER
SPHERICITY ANALYSIS OF THE "RED BEDS" OF MICHIGAN
Base map H.M. Gousha Co.

Figure 3

THE "RED BED" GYPSUM

Manner of Occurrence

The sample studies indicate that gypsum comprises approximately one-half of the "Red Beds." Accordingly gypsum may be considered to be a major, if not the major, constituent of the "Red Beds." This gypsum generally occurs in chalky masses displaying a selenite like cleavage. Patches of clear selenite are often found within the chalky gypsum suggesting that this chalky gypsum is possibly selenite that has lost some of its water of hydration (Kraus, Hunt, and Ramsdell 1951), however, no detailed qualitative study was made of the "Red Bed" gypsum.

This gypsum is likely of primary rather than of secondary origin due to the fact that it is found in many wells in thicknesses of tens of feet indicating that it was deposited in fairly homogeneous thick beds. In addition, small laminae of gypsum about one millimeter in thickness are often found within siltstone aggregates. It is unlikely that gypsum of secondary origin would occur in this manner.

Quantitative Distribution of Gypsum in the "Red Beds"

To obtain an idea of the quantitative distribution of the "Red Bed" gypsum, a study was made of the relative amount of gypsum in all possible wells, and, from this data, a generalized map of the quantitative distribution of gypsum in the "Red Beds" was made (see Figure 4).

Procedure

Due to the large number of wells studied and the questionable accuracy of the quantitative representation of the gypsum in the samples,

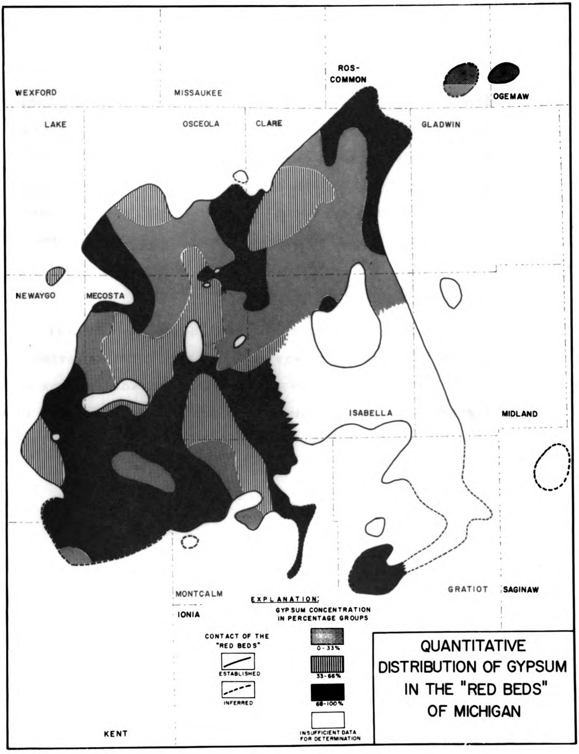

ROS-
COMMON
WEXFORD
MISSAUKEE
OGEMAW
LAKE
OSCEOLA
CLARE
GLADWIN
NEWAYGO
MECOSTA
ISABELLA
MIDLAND
MONTCALM
GRATIOT
SAGINAW
IONIA
KENT
EXPLANATION:
GYPSUM CONCENTRATION
IN PERCENTAGE GROUPS
CONTACT OF THE
"RED BEDS"
ESTABLISHED
INFERRED
0-33%
33-66%
66-100%
INSUFFICIENT DATA
FOR DETERMINATION
QUANTITATIVE
DISTRIBUTION OF GYPSUM
IN THE "RED BEDS"
OF MICHIGAN

Figure 4

the amount of gypsum in each sample was visually estimated to the nearest third. These values were then plotted on a map, and all adjacent wells of equal gypsum concentration (to within the nearest third) were grouped together. In this manner, the "Red Beds" were divided into generalized areas of 0-33%, 33-66%, or 66-100% gypsum concentration. It was felt that the lack of precise information from the individual wells and the small number of wells gave insufficient control for a contour map and that a map of this type would be, therefore, more representative. A complete list of the wells used in this determination is listed in the Appendix.

Significance of the Gypsum Analysis

The map shows that there is no uniform trend in the gypsum concentration but rather that the gypsum is randomly distributed. This suggests that gypsum was concentrated in certain areas more than in others instead of being uniformly precipitated throughout the extent of the "Red Beds."

POSSIBLE FOSSIL REMAINS IN THE "RED BEDS"

What appear to be possible fossil remains were found in samples from Mecosta County, Well No. 3516, Permit No. 9841 of the Michigan State University Collection of Well Samples (see Figure 5). These remains appear in the form of small regularly spaced furrows and ridges on the surface of some siltstone aggregates. This suggests that they may be fragments of steinkerns or external molds of the shells of some type of invertebrate such as Pelecypoda, or from the appearance of the furrows and ridges, perhaps Conularida (Shrock and Twenhofel 1935). It has also been demonstrated that they show rather marked similarity to early garnoid-type fish scales or plates of Astracoderm like vertebrates. No definite statement, however, can be made as to their identification or even that they are of organic origin. It is possible that they were formed in some bizarre manner from pulverized particles recemented during the drilling operations at this well. From their appearance, however, they are more easily explained as some type of organic remains.

These remains suggest that the "Red Beds" are possibly more fossiliferous than was previously assumed and that perhaps future investigations will uncover more definite fossil evidence.

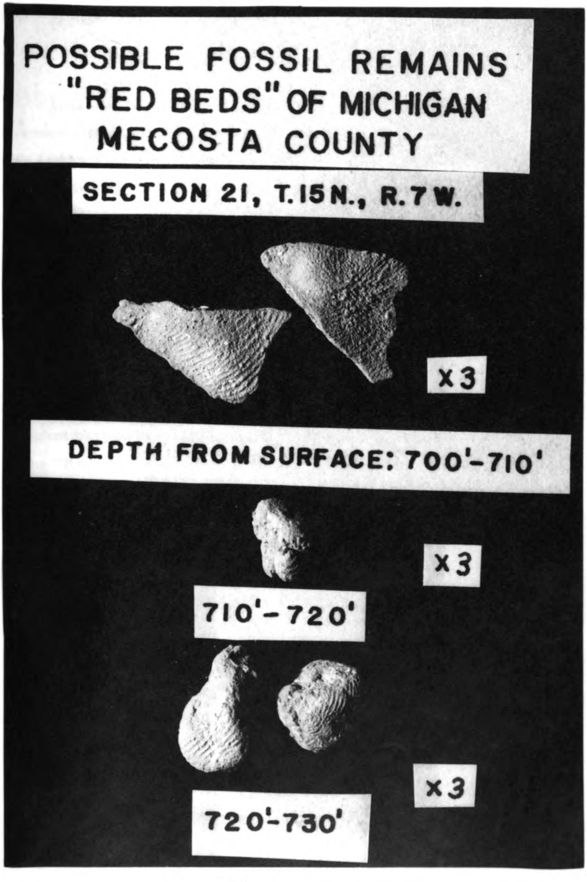

POSSIBLE FOSSIL REMAINS
"RED BEDS" OF MICHIGAN
MECOSTA COUNTY
SECTION 21, T. 15 N., R. 7 W.
X 3
DEPTH FROM SURFACE: 700'-710'
X 3
710'-720'
X 3
720'-730'

Figure 5

THE "RED BED" IRON

Iron has generally been considered to be the cause of the characteristic reddish color of the "Red Beds," and this assumption was further confirmed here by testing qualitatively for the presence of iron in the "Red Bed" samples. This test was accomplished by treating the samples with a weak solution of hydrochloric acid, removing a portion of this solution, and adding to it a weak solution of potassium thiocyanate. In each case an intense purple solution of $Fe(CNS)^{++}$ formed indicating the presence of considerable iron in the solution.

The fact that this iron could be completely removed from the samples leaving them grey in color strongly suggests that this iron was present as a coating and possibly as a fine matrix between the surfaces of the individual particles of the "Red Bed" sediments but not as an inherent part of their chemical composition. The brownish red color of the "Red Bed" sediments is very similar to the color of hematite. This further suggests that this iron occurs in the "Red Beds" as ferric oxide.

It is difficult to deduce definite climatic conditions which caused this precipitation of iron in the "Red Beds." The presence of iron in "Red Beds" has often been assumed to indicate oxidizing conditions of an arid climate; although conditions favoring the deposition of iron oxide may be found in many areas today having tropical climates.

THICKNESS AND DISTRIBUTION OF THE "RED BEDS"

Procedure of Analysis

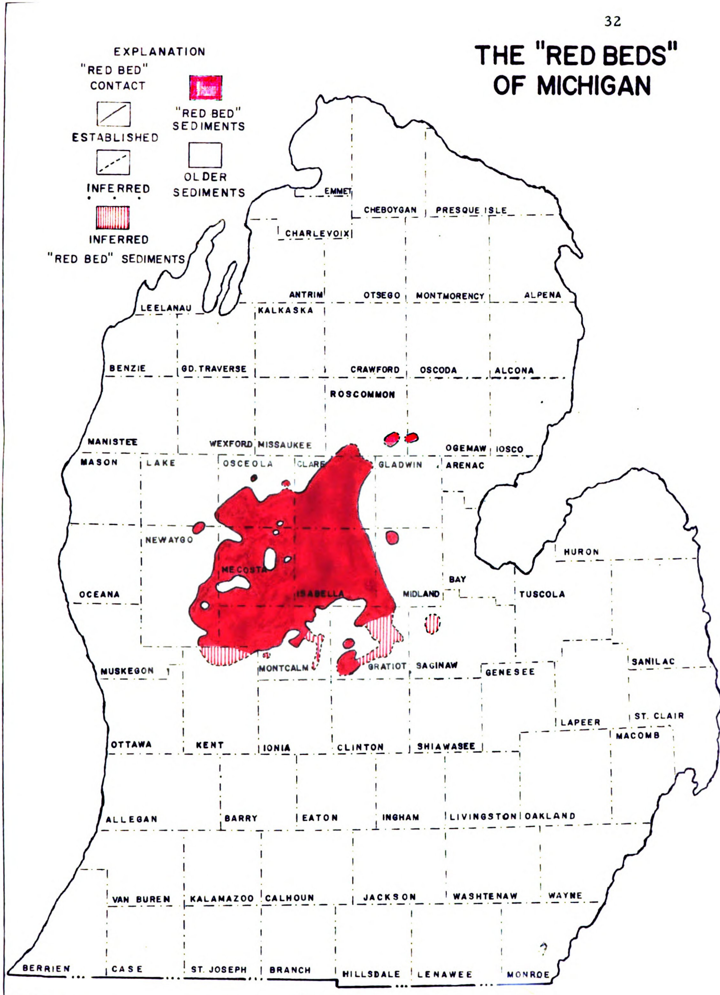
An isopach map of the "Red Beds" was constructed using the thicknesses and distribution of the wells from the sample study as control points. Often the upper contact between the "Red Beds" and the overlying drift was not present in the samples due to sampling being started at a lower point. In this case the data was taken from information on the drillers logs. The drillers logs were used in other instances where it was felt that they would be helpful in clearing up ambiguities but, due to possible inaccuracies contained in them, they were used very sparingly.

Thickness and Distribution

The average thickness of the "Red Beds," calculated from the thicknesses found at the various well sites, was found to be approximately 87.1 feet. The greatest thickness found is 220 feet and was found in a well located in central Mecosta County.

The "Red Beds" appear roughly in the form of an elliptical shaped body whose major axis trends north-northeast (see Figure 6). This is approximately coincident with the axis of the Grand River Group. The major axis is, however, inclined to the major axis of the Michigan Basin proper as the axis of the basin trends approximately north-south.

The thickest part of the "Red Beds" follows the trend of this major axis of the "Red Beds" very closely with the strata becoming generally thinner on the flanks of the body at increasingly greater distances from the major axis.



Base map
Mich. Geological Survey

Figure 6

Due to a lack of definite information, the presence of the "Red Beds" can only be inferred in certain areas. This is especially true of the arm of the "Red Beds" that is found in Gratiot County. Although actual evidence is lacking here, the extensive presence of Grand River Sediments suggests that the stratigraphically overlying "Red Beds" may, at least to some degree, be present. In northwest Saginaw County, red gypsiferous sandstones were found. Although these sandstones are probably correlatable with the Grand River Group, they suggest that overlying "Red Beds" may occur here as scattered remnants. In Kent County, reddish shales and gypsum extend approximately as far south as Grand Rapids; while definite "Red Bed" sediments occur in the northern extremities of this county. These reddish shales and gypsum are likely part of the Saginaw Formation because of the fact that their color is a much deeper red than is found in the usual "Red Bed" siltstones and also that they frequently overlie Mississippian sediments.

Several definite erosional outliers were found to border the "Red Beds" suggesting that the beds were originally much more extensive than they are at present and that erosion has reduced the "Red Beds" considerably in size and thickness.

PALEOGEOGRAPHIC CONSIDERATIONS

Using the concept of paleogeographic probability--that is, the probability of what the physiographic picture of an area was at certain times in the earth's history--it is possible to obtain some idea of the general manner and approximate time of formation of the "Red Beds." Some aspects of the paleogeographic picture of the Michigan Basin and inferences drawn from them are presented below.

As no definitely marine deposits are known in the Appalachian trough after Pennsylvanian time, and indeed after the Conemaugh series of the Upper Pennsylvanian, it would appear that the epeiric seas withdrew from the trough after Conemaugh time due either to lowering of the sea level or rise of the land in the eastern part of the country. The sediments of the Monongahela series (late Pennsylvanian) and Permian system of the east were presumably received in fresh water bodies near the center of the West Virginia Basin. The general paleogeographic picture of the Pennsylvanian would indicate any epeiric sea in the Michigan Basin to have occurred in an arm of a larger continental sea located to the south. Thus, the sea withdrawal after Conemaugh (late Pennsylvanian) time must have been to the south, and it is paleogeographically unlikely that marine waters should have occurred further north in the Michigan Basin after Conemaugh time.

If the "Red Beds" of the Michigan Basin area are truly marine, as herein concluded, their age then, on this basis, could be reasoned as no younger than Conemaugh of Upper Pennsylvanian.

CONCLUSIONS

In this work, the "Red Beds" were studied in sufficient detail to give a more precise concept of their thickness and distribution. In addition, some of the various characteristics of the "Red Beds" were studied. It is perhaps possible, with the data obtained from these investigations, to state a few tentative postulations concerning the time and manner of origin of the "Red Beds."

It seems probable, on the basis of paleogeographic considerations and the type of clay minerals found in the "Red Beds," that these "Red Beds" were deposited in a northward encroaching arm of a shallow continental sea that covered an extensive area south of the Michigan Basin. This arm was perhaps separated from the main body of the sea from time to time along the Basins relatively shallow rim forming, in the Michigan Basin, a dead sea. This isolation of the Michigan Basin sea resulted in increased salinity of its water due to evaporation. After continued evaporation of this sea, supplemented by replenishments of sea water by several temporary marine invasions into the basin, considerable deposits of gypsum were precipitated. Other more soluble evaporites such as halite may have been deposited, but, if so, they have long since been leached away. During the evaporation of this sea and the deposition of the gypsum, the thoroughly oxidizing conditions of the shallow water environment brought about precipitation of the red iron oxides. These highly saline conditions would have generally been unfavorable for abundant life, and, as a result the "Red Beds" would be expected to contain relatively few fossils.

The "Red Bed" sediments were generally fine grained clastics consisting chiefly of silt and clay size particles. These sediments perhaps came chiefly from a source to the southeast--possibly the old Appalachian landmass.

Due to the fact that the northeastern part of the United States is generally considered to have been an elevated landmass after Pennsylvanian time, it is unlikely that any subsequent post Pennsylvanian marine invasions of any magnitude occurred here. Thus, due to their apparent marine origin, it does not seem likely that the "Red Beds" were formed after Pennsylvanian time.

It is still possible that the "Red Beds" are perhaps Permian or later in age or even that they are transitional between the Pennsylvanian and Permian periods. However, the findings of this work, together with paleogeographic probability, suggest to the author a Pennsylvanian age for the "Red Beds." More specifically, the age would appear no younger than the Conemaugh series of the Pennsylvanian since non-marine sedimentation began in Monongahela (uppermost Pennsylvanian) and carried through the Permian in the Appalachian Basin. Additional support for a Conemaugh age of the "Red Beds" is found in the fact that the Conemaugh series of the Appalachian Basin is comprised of a high percentage of red beds, much of which occurs in the marine phase of the sedimentary cycle. The underlying Grand River group (Conemaugh age) in Michigan also contains considerable red beds which are largely sandstone.

No definite fossils were observed upon which the age relationships of the "Red Beds" could be established. However, a few questionable forms that were found might well make additional future search worth-while.

SUGGESTIONS FOR FURTHER STUDY

The chief deterrent to a more comprehensive knowledge of the "Red Beds" has been a lack of material available for study, and the total knowledge thus far accumulated has come from a limited number of well samples and drillers logs. The study of any additional samples would, therefore, contribute new information on the "Red Beds." In addition, it is recommended that a search be made for drill cores and outcrops since these would be of greatest value in future studies.

In certain areas, the presence of the "Red Beds" has been presumed from indirect evidence but not definitely established, and further investigation here is advisable. This is especially true in the northern part of Kent County and in a large part of Gratiot County.

Further investigations of the clastic components of the "Red Beds" may well prove of value. These might include a more extensive sphericity analysis as well as a study of roundness and a more detailed quantitative and qualitative mineral analysis of the "Red Beds" clastics.

A lithologic comparison between the "Red Beds" of Michigan and late Paleozoic and Permian red beds located in other areas of the continent could also be helpful in further defining the age of the "Red Beds."

The fossil-like markings found in this investigation demonstrate that further search for fossils in the "Red Beds" would be of value. A palentological study that might well be the most valuable single study to undertake in the immediate future would be palynological investigation of any plant spores, pollen, or other similar microfossils found in the "Red Beds." Palynology could very possibly give exact information concerning the age and formation of the "Red Beds" of Michigan.

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APPENDIX

LIST OF WELLS FOUND TO CONTAIN THE "RED BEDS"

PART I

MICHIGAN STATE UNIVERSITY GEOLOGY DEPARTMENT SAMPLE COLLECTION

Location	Operator	Farm	Permit Number	M. S. U. Geology Department Catalogue No.	Thickness of "Red Beds" in Feet	Percent Gypsum
			Clare County			
17N-5W-23	Mich. Cons.	No. 1 Frizzell	11435	4345	10+	0-33
17N-6W-7	Bauer	No. 1 Loker	16914	5739	54	0-33
17N-6W-7	Sohio	No. 1 Loker	10687	3945	105	33-36
17N-6W-18	Pure	A-1 Marble	12698	3975	90	?
18N-4W-7	Pure	No. 1 Powell	11323	4159	?	66-100
18N-5W-12	Pure	A-1 Holbrook	10795	3978	82	33-66
18N-5W-13	Burton	No. 1 Thompson	10380	4355	46	0
18N-6W-1	Pure	No. 1 State-Freeman "A"	8298	2890	54	33-66
*20N-4W-19	Union	No. 1 Newland	8775	3296	?	66-100
			Gratiot County			
9N-4W-2	Chartiers	No. 1 Wagner	8167	2837	?	Present
			Isabella County			
13N-4W-16	Union Dev.	No. 1 Cole	13472	4869	?	Present
*14N-6W-33	Carter Oil Co.	No. 5 Hill	12836	4577	?	Present
15N-6W-2	Sun	No. 1 Eddy	11747	4366	42	Present
15N-6W-5	Mongul	A-1 Dent	13018	4797	90+	0-33
16N-5W-23	Wicklund-Mongul	No. 1 Gamble	12635	4613	95+	0-33
16N-5W-25	Sohio	No. 1 Gilmore	11849	4496	100±	66-100
16N-5W-25	Sohio	No. 4 Gilmore Unit	11766	4495	?	Present

*Insufficient data for positive identification of the "Red Beds."

PART I -- Michigan State University Geology Department Sample Collection -- Continued

Location	Operator	Farm	Permit Number	M.S.U. Geology Department Catalogue No.	Thickness of "Red Beds" in Feet	Percent Gypsum
			Kent County			
7N-9W-6	Thourlby	No. 1 Doyle	6768	2243	?	Present
8N-10W-5	J. McGarey	No. 1 Pass	13104	4896	?	Present
8N-10W-20	Huffman	No. 1 Barker	6591	2221	?	66-100
9N-11W-10	Wicklund	No. 1 Davis	6115	2045	?	0-33
9N-11W-28	Roach	No. 1 Holden	8534	3042	?	33-66
9N-12W-28	Crauford	No. 1 Anderson	17657	5856	?	0
10N-10W-3	Mich. Cons.	No. 1 Phillips	11288	4218	?	66-100
10N-11W-30	Wagenner	No. 1 Lawrence	10826	3971	?	Present
10N-11W-34	Rex Oil	No. 1 Beals	12688	4640	?	0
10N-12W-27	MacCallum	No. 1 Landheer	12876	4754	?	Present
			Mecosta County			
13N-9W-2	Mich. Cons.	No. 1 Crane	12157	4435	?	Present
13N-9W-8	Maguire	No. 1 Blair	10385	3929	170+	Present
14N-7W-9	Carter Oil	No. 1 Flachs	10678	4007	?	Present
14N-8W-4	Gulf	No. 1 Mecosta Project	--	3781	?	66-100
14N-8W-19	Ohio	No. 1 Thurkow	13176	4908	177	Present
15N-7W-21	Gulf	No. 1 Warner	9841	3516	85	0-33
15N-7W-35	Michigan Consol	No. 1 Carpenter	13654	4918	87	33-66
15N-8W-29	Gulf	No. 2 Mecosta Project	--	3779	145	33-66
15N-8W-33	Rowmor, Rand, and Meyer	No. 1 Baker	12915	4723	85	Present
15N-9W-5	Mich. Cons.	No. 1 Bush	11488	4207	?	Present
15N-9W-5	Mich. Cons.	No. 1 L. Tetz-loff	11489	4197	?	Present
15N-9W-9	Gulf	No. 1 Colfax Project	--	3819	109+	66-100
15N-10W-1	Gulf	No. 2 Colfax Project	--	3825	115	33-66

PART I -- Michigan State University Geology Department Sample Collection -- Continued

PART I -- Michigan State University Geology Department Sample Collection -- Continued

Location	Operator	Farm	Permit Number	M.S.U. Geology Department Catalogue No.	Thickness of "Red Beds" in Feet	Percent Gypsum
			Mecosta County (Cont'd)			
15N-10W-11	Taggart	No. 1 Taggart	10923	4058	91	?
15N-10W-27	Rand and Meyer	No. 1 Curtis	12687	4632	30+	Present
16N-7W-6	Gulf	No. 2 Compson	10630	3890	135	Present
16N-7W-6	Gulf	No. 3 Compson	11459	4204	132	66-100
16N-7W-7	Gulf	No. 1 Meier	10437	3801	125	33-66
16N-7W-8	Gulf	No. 2 Hamill	10014	3627	135	0-33
16N-7W-18	Gulf	No. 1 VanSyckle	10452	3799	111	Present
16N-7W-18	Gulf	No. 2 VanSyckle	10558	3862	53	33-66
16N-7W-27	Maguire	No. 1 Wood	8806	3155	?	Present
16N-8W-1	Gulf	No. 1 Bottorff	11017	4044	116	0-33
16N-8W-1	Gulf	No. 2 Bottorff	11155	4048	111	Present
16N-8W-1	Gulf	No. 3 Bottorff	11260	4075	130	Present
16N-8W-1	Gulf	No. 4 Bottorff	11877	4364	104	66-100
16N-8W-1	Gulf	No. 2 Daggy	11154	4046	122±	66-100
16N-8W-12	Gulf	No. 1 Dickinson	11629	4257	53	Present
16N-10W-1	Taggart, Bors	No. 1 Rauch	11724	4320	88±	?
			Montcalm County			
10N-8W-5	Golden Oil	No. 1 Steffenson	--	59	52±	33-66
10N-8W-15	Daily Crude	No. 1 Peterson	11485	4256	?	Present
11N-7W-1	Sohio	No. 1 LeBeck	12170	4546	?	Present
11N-7W-28	Whitney	No. 1 Bentley and Black	12343	4558	70	66-100
11N-8W-36	Sun	No. 1 Martens	11099	4121	90	66-100
12N-8W-3	Union Drlg.	No. 1 Douglas	11919	4424	143	33-66
12N-8W-4	Sohio Pet.	No. 1 Switzer	12954	4840	50	Present
12N-8W-6	Gordon	No. 1 Paris	10922	4223	130	66-100
12N-8W-27	Weller	No. 1 Fallig	11188	4417	23+	Present
12N-8W-28	Weller	No. 1 Keyt	11504	4288	?	Present

... State University Geology Department Sample Collection -- Continued

PART I -- Michigan State University Geology Department Sample Collection -- Continued

Location	Operator	Farm	Permit Number	M.S.U. Geology Department Catalogue No.	Thickness of "Red Beds" in Feet	Percent Gypsum
			Newaygo County			
*12N-11W-29	Busk	No. 1 Hatchew	16558	5805	?	Present
12N-12W-10	Melvin	No. 1 Calvert	17295	5782	?	Present
11N-11W-20	Pure	No. 1 Butler Cons	10778	3943	23	66-100
13N-11W-14	Sun	No. 1 Consumers Power	10680	4084	?	66-100
13N-11W-16	Sun	No. 2 Consumers Power	10707	4013	64	66-100
13N-11W-21	Sun	No. 3 Consumers Power	10829	4109	?	Present
13N-11W-22	Taggert	No. 2 Consumers Power	10979	4289	?	Present
			Ogemaw County			
21N-1E-8	Cities Serv.	No. Hickey	12267	4479	48	0-33
			Osceola County			
17N-7W-33	Chapman	No. 1 McNeilly	7862	2691	?	66-100
17N-9W-1	Maguire	No. 1 State Watson	8632	3111	?	Present
17N-10W-5	Gulf	Bregg Salt Water Disposal Well	--	3701	?	?
17N-10W-5	Gulf	No. 1 Fulmerhouser	--	3724	16	66-100
17N-10W-25	Pure	A-1 Haist	11282	4108	105	66-100
19N-7W-24	Pure	A-1 Jones	10009	3640	43	0-33
19N-9W-1	Rowmor Corp.	No. 1 Ranch	10159	3735	77	Present
			Saginaw County			
*11N-2E-4	Teater	No. 1 Halzke	13677	4967	?	Present
*11N-2E-11	Darke Bors	No. 1 Butler	6535	2148	?	Present

* Insufficient data for positive identification of the "Red Beds"

PART II

MICHIGAN GEOLOGICAL SURVEY SAMPLE COLLECTION

Location	Operator	Farm	Permit Number	Thickness of "Red Beds" in Feet	Percent Gypsum
		Clare County			
17N-3W-6	Sun Oil	R. Armentrout No. 1	14675	?	66-100
18N-4W-7	Pure Oil	Root No. 1	12236	190	33-66
18N-4W-33	Sohio	J. McKay No. 1	13364	123	0-33
18N-5W-5	Sohio	L. Nichols No. 1	14463	90	33-66
16N-5W-8	Turner Pet.	J. Silover No. 1	13376	58	33-66
18N-6W-3	Socony-Vac.	A. VanHorn No. 3	5387	65	33-66
19N-4W-5	Gordon Oil	E. Case No. 1	12345	110	0-33
19N-4W-7	Lakeland Oil	Skinner and Schaaf No. 1	16258	170	66-100
19N-4W-11	Union Drlg.	Asberry Rigs et al. No. 1	7306	108?	?
19N-5W-11	Lud Segerland	Kuehl No. 1	17938	?	0-33
20N-3W-25	Sun	Yeager No. 2	19588	20	0
20N-4W-22	H. E. Bell	Carpenter No. 1	17181	?	Present
		Gratiot County			
9N-3W-9	Weller	Baker No. 1	2331	30±	Present
10N-4W-25	Harper and Turner Oil Co. - Sohio	Rudd-McLaren et al. No. 1	13862	15	66-100
		Isabella County			
15N-6W-13	C. Galvin	Drallette No. 1	18330	30+	0-33
15N-6W-5	Mongul Oil	P Dent A-1	13018	90+	0-33
15N-6W-21	Brazos Oil	State Sherman "QN" No. 1	19842	90	0-33
15N-6W-32	Pure Oil	W. Chaffee No. 1	12733	50	Present
15N-6W-33	Pure Oil	Buetler No. 2	4741	15	66-100
15N-6W-33	Pure Oil	Baker No. 1	3784	60	33-66
16N-3W-7	Mich. G & O	Parker No. 1	1149	75	0
16N-3W-28	Turner Pet.	White No. 1	5090	22±	?
16N-5W-23	J. Wicklund	Gamble No. 1	12635	110+	0?33
16N-5W-25	Sohio	Gilmore Gas Unit No. 1	11849	145	66-100

PART II -- Michigan Geological Survey Sample Collection -- Continued

Location	Operator	Farm	Permit Number	Thickness of "Red Beds" in Feet	Percent Gypsum
			Isabella County (Cont'd)		
16N-6W-28	Sohio	Gas Unit No. 10	12183	140±	66-100
16N-6W-30	Sohio	E. Chapman No. 1	12182	130+	66-100
16N-6W-30	Sohio	Gas Unit No. 11	12286	?	Present
			Kent County		
*7N-10W-13	Leonard Oil	J. Ward No. 1	18013	?	Present
*8N-10W-5	McGerry, Tr.	Paas No. 1	13104	?	0-33
*9N-10W-29	Assoc. Pet.	Plank No. 1	3144	?	0-33
*9N-10W-33	Sun Oil	Geerlings et al. No. 1	18208	?	66-100
*9N-11W-7	J. McGerry	L. Rathburn No. 1	15150	?	0-33
*9N-11W-10	J. Wickland	Davis No. 1	6115	?	0-33
*9N-11W-14	J. McGerry	VanderHyde No. 1	12966	?	66-100
*9N-11W-32	M. B. Keeler	Bristol No. 1	7994	?	66-100
*9N-12W-27	C. Crawford	Zwyghuizen No. 1	16964	?	0
*9N-12W-28	Crawford	Anderson	17657	?	0-33
*10N-9W-1	Ford Oil Co.	Rasmussen No. 1	19837	?	?
*10N-12W-28	B. MacCallum	Landbeer No. 1	12876	?	Present
*10N-12W-28	B. MacCallum	English No. 1	13341	?	0
			Mecosta County		
13N-8W-11	C. W. Teater	Keilholz No. 1	13005	?	Present
13N-8W-21	Chapman Oil	O. Nienhius	14233	?	Present
13N-9W-2	Mich. Cons. Gas	Rogers-Crane No. 1	12157	110	66-100
13N-9-W-17	O'Niell Oil Co.	A. Larsen No. 1	19879	70	33-66
13N-10W-12	Merrill Drlg.	Stephenson No. 1	12475	110±	66-100
*14N-7W-7	Smith Pet.	Ortwein No. 1	11305	25±	Present
*14N-7W-9	Carter Oil	Flachs No. 1	10678	127	0-33

*Insufficient data for positive identification of the "Red Beds."

PART II -- Michigan Geological Survey Sample Collection -- Continued

PART II -- Michigan Geological Survey Sample Collection -- Continued

Location	Operator	Farm	Permit Number	Thickness of "Red Beds" in Feet	Percent Gypsum
			Mecosta County (Cont'd)		
14N-7W-9	Carter	J. Snyder G-1	13615	75±	0-33
*14N-7W-17	Goll, Graves and Mechlung Inc.	Reutz No. 1	2811	55±	Present
14N-8W-18	W. Mich. Cons.	State-Minkel No. 1	11867	90±	33-66
14N-8W-22	Mich. Cons. Gas	Bary-Smith-McLeod	13029	220±	66-100
14N-8W-24	Leonard Oil	Minkel No. 1	18828	70	33-66
15N-7W-21	Gulf Oil	Warner No. 1	9841	80+	33-66
15N-9W-14	Big Rapids O and G	Anderson No. 1	483	187±	0-33
15N-9W-29	Russell Fletcher	W.C. Taggart No. 1	19965	105	33-66
15N-10W-11	Hanchett Manuf.	Hanchett No. 1	18832	25	0-33
15N-10W-18	Scott Drlg.	Bower No. 1	14478	122	0-33
15N-10W-27	Rand and Meyer	Dr. Curtis et al. No. 1	12687	50	33-66
16N-7W-8	Gulf Ref. Co.	Ralph Unit No. 1	19283	138	33-66
16N-7W-24	J. Bauer	Williams et al.	15437	140	0-33
16N-7W-31	Sun Oil	L Harper No. 1	12725	81	66-100
16N-8W-4	Sun Oil	Jennie Freer No. 1	10747	56±	0-33
16N-8W-35	Sohio Pet.	Brewer-Smith et al.	15606	?	Present
16N-10W-28	J. Thompson	F. Box No. 1	14661	78	66-100
			Midland County		
*14N-2W-8	F. Schrot	Scott No. 4	13044	?	Present
16N-2W-13	J. Wicklund	Neal No. 1	2292	28±	0
			Montcalm County		
9N-6W-12	Jetter Dev.	Middleton No. 1	3435	34±	66-100
11N-7W-1	Sun	West No. 1	11901	140+	66-100
11N-7W-1	Sohio	Lebeck No. 1	12170	40+	33-66
11N-7W-1	Sohio	H. Lebeck No. 2	12391	115	33-66
11N-7W-3	E. Brehm	Jordan No. 1	19474	76	0-33

*Insufficient data for positive identification of the "Red Beds."

Survey Sample Collection -- Continued

PART II -- Michigan Geological Survey Sample Collection -- Continued

Location	Operator	Farm	Permit Number	Thickness of "Red Beds" in Feet	Percent Gypsum
		Montcalm County (Cont'd)			
11N-7W-28	P. Whitney	Bentley No. 1	12343	65	66-100
11N-7W-35	H. Atha	Dancer No. 1	17262	103	0-33
11N-8W-4	Mich. Cons. Gas	Clark No. 1	17168	50+	33-66
11N-8W-4	Mich. Cons. Gas	Anderson et al. No. 1	17236	139±	?
11N-8W-6	Granville and Berlin	H. N. Wright No. 1	20122	180	0-33
11N-8W-15	D. Jones	Towle No. 1	3214	110	Present
12N-6W-19	L. Barber	Jensen No. 1	3463	48±	33-66
12N-6W-24	Stewart Oil	S. and B White No. 1	12425	195±	66-100
12N-7W-9	Mich. Cons.	S-176	18146	44+	0-33
12N-8W-3	Hilliard	Welch No. 1	12320	10+	33-66
12N-8W-5	McClanahan	Frost No. 1	12365	120±	?
12N-8W-10	Sohio	D. Wendal No. 1	12439	122	0-33
12N-8W-20	Dale, Hickey, and Snyder	Snyder No. 1	400	?	66-100
12N-8W-27	C. Weller	Faling-Beherenwald No. 1	11888	192±	66-100
12N-9W-8	McClure-SK-Basin Ackerman	Lint Heirs No. 1	20004	98+	66-100
12N-9W-19	Mich. Cons. Gas Co.	Petersen et al. No. 1	20546	120+	0-33
		Newaygo County			
11N-11W-10	Carne and Glendenning	Charles Hawkins	20102	6?	Present
12N-11W-20	A. Busk	Shutts et al. No. 1	15360	?	Present
12N-11W-29	Busk and Ormiston	Moser et al. No. 1	17052	?	Present
12N-11W-29	Sun Oil	Woodard-Brown	17132	120	33-66
13N-11W-2	Carter Oil	P Thumster No. 1	12421	?	Present

PART II - - Michigan Geological Survey Sample Collection - - Continued

PART II -- Michigan Geological Survey Sample Collection -- Continued

Location	Operator	Farm	Permit Number	Thickness of "Red Beds" in Feet	Percent Gypsum
		Newaygo County (Cont'd)			
13N-11W-28	Sun Oil	Consumers Power No. 5	14886	50	66-100
13N-11W-31	E. Cordell	S. Gorman No. 1	16361	41	33-66
14N-11W-23	Pure	Miller A-1	15127	56	66-100
14N-11W-31	Mich. Cons.	State Ward	12191	25	33-66
14N-11W-33	Penn O and G	Miller No. 1	654	20±	Present
16N-11W-5	H. Bell	Adams No. 1	15300	31	66-100
		Ogemaw County			
21N-1E-8	Cities Service	Hickey No. 1	12267	50	0-33
		Osceola County			
*17N-7W-11	Sohio Pet.	Orient Gas Unit No. 5	13159	?	66-100
17N-7-W-12	Pure Oil	Zimmerman A-1	12375	101	60-100
17N-7W-16	Mogul Oil	Lloyd No. 1	17842	?	0-33
17N-7W-22	D Slusser	C Wood No. 1	16192	53	0-33
17N-7W-29	Blunt Pet. and Leonard Oil	Davy and Umphrey No. 1	20397	128	0-33
17N-8W-5	Hartman and Kunning	Fleming Heirs *et al.* No. 1	19822	?	0-33
17N-8W-8	Grayling Dev.	State 16	1130	90	0-33
17N-8W-22	Columbia O. and G.	Custer No. 1	18602	140	33-66
17N-9W-1	Maguire	State-Watson No. 1	8632	?	Present
17N-9W-2	Grayling Dev.	State No. 3	1168	60	0-33
17N-9W-2	Grayling Dev.	State No. 15	1099	35	33-66
17N-9W-2	C. Jetter	State-Hersey No. 1	18170	45	Present
18N-8W-12	Turner Pet.	Gas Unit No. 4	9197	5	Present
18N-9W-10	Sun	Richardson No. 6	13134	197	33-66
18N-9W-27	Sun and Ohio	Zimmerman No. 1	10002	40+	33-66

*Insufficient data for positive identification of the "Red Beds."

PART II -- Michigan Geological Survey Sample Collection -- Continued

Location	Operator	Farm	Permit Number	Thickness of "Red Beds" in Feet	Percent Gypsum
		Roscommon County			
21N-1W-9	Grale Oil	Halestro Reserve Inc. No. 1	9094	?	0-33
21N-1W-17	Ohio Oil	Roseville Nester Gun Club No. 1	13623	90±	0-33
21N-3W-30	Farmers Pet. Coop.	State Roscommon No. D-2	12511	?	66-100
		Saginaw County			
*12N-2E-23	Dow Chemical Co.	Dow Monroe No. 75	Brine 75	?	0-33

*Insufficient data for positive identification of the "Red Beds."

Pocket has: 1 Maps

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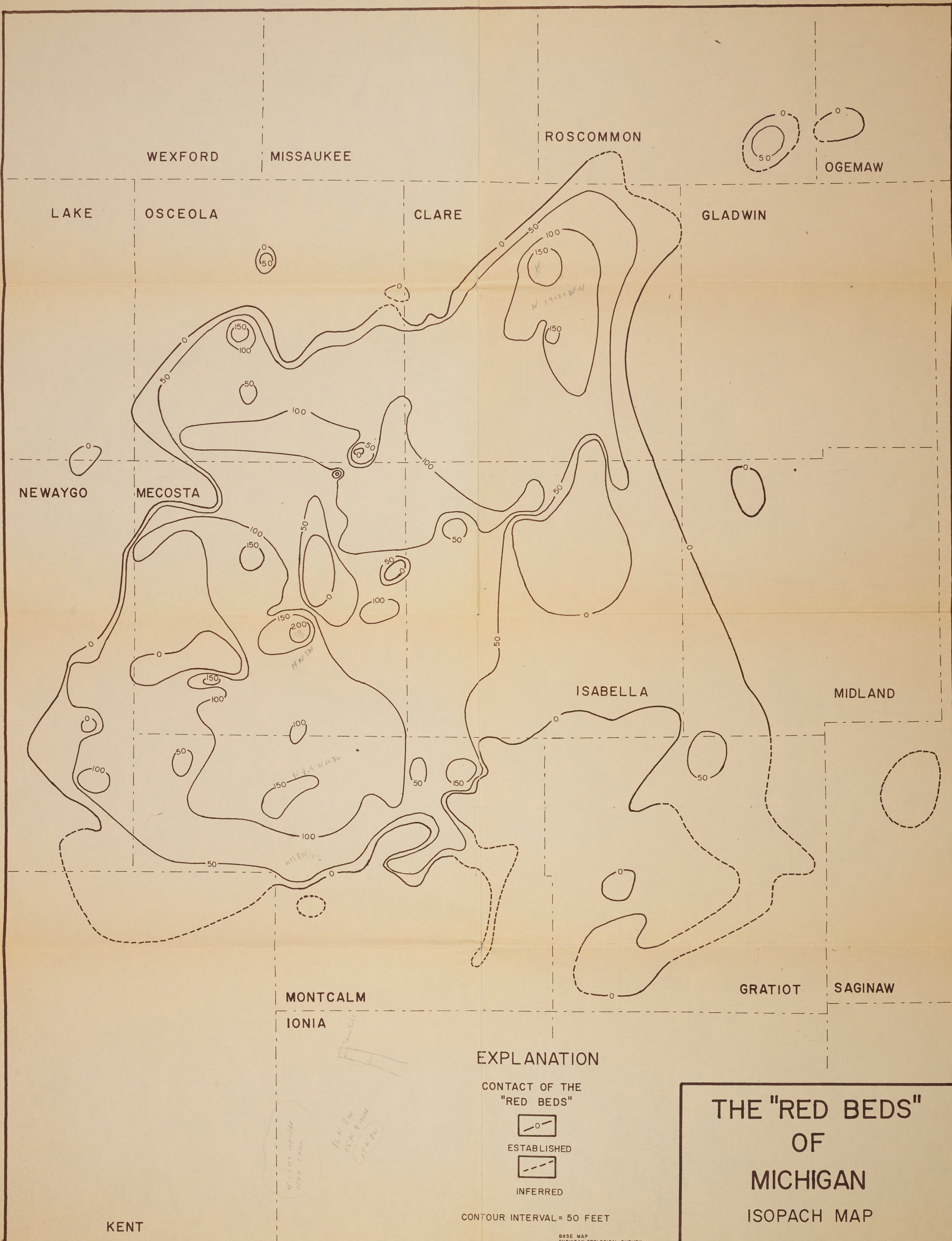
WEXFORD
MISSAUKEE
ROSCOMMON
OGEMAW
LAKE
OSCEOLA
CLARE
GLADWIN
NEWAYGO
MECOSTA
ISABELLA
MIDLAND
MONTCALM
GRATIOT
SAGINAW
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KENT
EXPLANATION
CONTACT OF THE "RED BEDS"
ESTABLISHED
INFERRED
CONTOUR INTERVAL = 50 FEET
BASE MAP MICHIGAN GEOLOGICAL SURVEY
THE "RED BEDS" OF MICHIGAN
ISOPACH MAP

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