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THE MICHIGAN FORMATION  
A Study In The Use Of  
A Computer Oriented System  
In Stratigraphic Analysis

by  
Frank Moser

A dissertation submitted in partial fulfillment  
of the requirements for the degree of  
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1963

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## INTRODUCTION

The last few years have seen the introduction of the electronic computer into all phases of the geological sciences. Three important developments have emphasized the need for those functions provided by the computer and its ancillary equipment, such as card sorters, tabulators and automatic plotting devices. These are the geological information explosion, the acceptance of statistics as a tool in geological research, and the concept of the mathematical model in geology.

The main impetus was due to the increasing amount of data that was daily becoming available for analysis. At the same time the petroleum industry entered a period when more detailed and careful work was needed for each barrel of oil found. Over a million wells have been drilled in the U.S.A., and studies have shown (Wilson, 1962) that many geologists are hampered in the interpretation of these data both by the labor necessary in searching for and recording the information and the inability to digest all the information that is available on any subject.

A second important development has been the increased application of statistical analysis to many geological problems. Not only has statistics become a commonly used tool (Miller and Kahn, 1962) but the type of analysis done has reached the point of sophistication that necessitates the use of high speed computers. The geological literature now contains numerous references to techniques such as factor analysis, random walk processes, and discriminant functions.

Within the last decade strides have been made in the theoretical-mathematical approach to certain geological problems. The main interest is currently centered in the mathematical model as a method of

analysis in sedimentation, tectonics and geomorphology. Geomathematics will undoubtedly become another in the long list of accepted geological specialities.

Since a great part of stratigraphy involves the synthesis of data from few sample points in a large and often truncated population, stratigraphic analysis can be regarded as a problem in both data processing and statistics. The pioneers in the application of computers to geology are found in several universities (Krumbein and Sloss, 1958) and in the petroleum research laboratories (Bonham, 1963). However, the emphasis in stratigraphy was in solving specific problems rather than in an integrated approach.

The purpose of this study was to develop and test a computer oriented system for the recording, storing, analysing and retrieving of stratigraphic data. The system would reduce to a minimum the manual labor involved in proceeding from data collecting to the final interpretations. Although designed specifically for subsurface data, the methods can easily be adapted to surface studies. This type of system could and should be useful to the average geologist who has at his disposal equipment normally available in a computer center. Therefore specialized and expensive tools such as automatic plotting and contouring machines were not integrated into the plan.

In testing the system the following questions were examined:

- 1) Could it be simple and yet powerful enough to facilitate its use in normal day to day problems?
- 2) Would it be economically feasible? That is, would it not only solve problems and do work faster but also cheaper

on a cost per item basis?

3) How would it improve the final interpreted result?

The procedure used in answering the above questions was to apply the system to a subsurface geological problem whose scope would encompass enough different aspects to be a valid test. The test would thus be more than just a pilot project. Since this is one of the first such systems developed and tested under actual working conditions, it is not intended to be the final word on the subject.

The problem chosen was a lithostratigraphic study of the Michigan formation of Middle Mississippian age. This formation constitutes the last major evaporite cycle in the Michigan Basin and the study therefore complemented research work on the foundations of evaporite deposition being carried out at the Subsurface Laboratory of the University of Michigan. There was an economic interest as well for not only is the Michigan formation the source of gypsum which has been mined since 1841, but is also the reservoir rock (Michigan Stray unit) from which 616,710 MCF of gas were produced in 1961. From 1934-1955 the Michigan Stray was the major producer of gas in Michigan. Because it is a gas reservoir, this formation has very extensive electric log and drill cuttings coverage. In addition to evaporite sedimentation, other geological problems investigated were the stratigraphic relationships between the Michigan and the formations underlying and overlying it, especially the old but unsolved problem of the correlative position of Michigan Stray.

## THE COMPUTER ORIENTED STRATIGRAPHIC ANALYSIS SYSTEM

The author is responsible for the design of the system and the computer programs used therein. The programs were written in MAD (Michigan Algorithm Decoder), a computer language developed by B. Arden, B. Galler and R. Graham of the University of Michigan Computing Center. The computer used was an IBM 7090 and the costs which are given for using the system are relative to the execution time on this computer.

### DATA INPUT

The form of input data is of primary concern in a machine oriented system. There is a natural division in a subsurface lithostratigraphic study into identification information, lithologic descriptions and stratigraphic data. Consequently a separate punched card (IBM card) was designed to record the data for each of the above three groups. The information from a well would then be contained in a deck of punched cards (referred to as a decklet) consisting of one identification card and as many lithologic and stratigraphic description cards as are necessary.

#### Identification Card

The information recorded on the identification card and an example of such a card is given in Figure 1. Columns 1-47 include all the basic identification and location data. A discussion of the individual items on the card follows.

Company and farm names are not suitable for use in machine identification inasmuch as they usually change a number of times during the

|       |                               |
|-------|-------------------------------|
| 1-15  | Company, Farm and Well Number |
| 16-19 | State                         |
| 20-24 | County                        |
| 25-26 | Section                       |
| 27-28 | Township Number               |
| 29    | North or South                |
| 30-31 | Range Number                  |
| 32    | East or West                  |
| 33-34 | 1/4-1/4-1/4 Section           |
| 35-36 | 1/4-1/4 Section               |
| 37-38 | 1/4 Section                   |
| 39-43 | Permit Number                 |
| 44-47 | Elevation                     |
| 48-51 | X-Coord                       |
| 52-55 | Y-Coord                       |
| 74-75 | 01 (Code For I.D. Card)       |
| 76-80 | Permit Number                 |

[illegible]

Figure 1  
Identification Card

life of a well. Fifteen spaces are allotted for the names, which in most cases still allows for readability.

Wells should be located by coordinates rather than by political subdivision to enable the machine to plot maps and cross sections as well as for the application of trend surface analysis and other multiple regression techniques. Although there is progress in the development of a unified geological coordinate system for the whole of the U.S.A., this is not yet available. Accordingly, an arbitrary coordinate grid was established to accommodate all of the Michigan Basin. By using the computer our coordinates can be transformed with little difficulty to those of another grid system.

Coordinates of every well can be read directly from a base map, but this would be both inefficient and inaccurate because of paper distortion, the time it would take, and the scale of map necessary for accurate reading of closely spaced points. The simple layout of the townships in Michigan allows for easy and accurate machine computation of the coordinates of a well from its section, township, range,  $1/4$   $1/4$   $1/4$  section and the coordinates of the township to which it belongs.

The land surveys of the U.S. General Land Office make their corrections on the western and northern boundaries of the township. Therefore all the sections except those along these two tiers are considered to be the standard one square mile, and their coordinates relative to the southeast corner of the township can be computed. From the corners of two adjacent townships it is possible to know the exact amount of the adjustment made and the appropriate correction can be made to the wells situated in these off-size sections. The coordinates of the southeast corner of each township were read off the base map.

The two main sources of error in reading locations off a map are paper distortion caused by humidity changes and operator bias. In order to reduce these errors to a minimum the coordinates were recorded over a short period of time by one operator. A computer program was written which accepts as input the identification card of the well. Using the information available on this card and the coordinates of the particular township, the X-Y coordinates of the well are computed and punched out on a new identification card. The program is given in Appendix A.

The computations involved assume that the township lines are parallel to the coordinate grid lines. This is only true for the central part of the State because of the relationship between the grid system and the polyconic projection used on the base map. Where the township and coordinate lines are not parallel, it is possible to make a correction by rotating the well location through the angle between the actual and theoretical township lines. The coordinates have been checked against actual locations and have been found to be completely adequate in their accuracy for projects on a regional scale and only slightly distorted in very detailed field studies.

Columns 55-73 on the I.D. card are left blank to allow for flexibility if more details are desired.

The different types of information are given a numeric code and the code number for each card type is put in columns 74-75 of the card. This is done for both input information such as the I.D. card and output data such as thicknesses or lithologic percentages. This coding allows quick and easy access to specific kinds of information.

Since the total information from a well will consist of many cards of different types some method of identifying the well on each card is

necessary. Numeric coding is more convenient for the machine to handle and takes less space than alphabetic identifiers. Michigan is fortunate in that there is such a coding already available in the permit number of the well. These permits have been issued since 1927 by the State Conservation Department for all oil and gas wells. Wells drilled before 1927 or specialized wells such as for brine disposal, gas storage or water which don't have permits are assigned numbers. The permit number is found in Columns 76-80 of every card type used in the system.

### Lithologic Description Card

Figure 2 is an example of the form upon which the lithologic characteristics of the sample are recorded. The basic unit of description is the interval which is defined as any lithologic sequence the geologist wants to describe as one unit, or must describe as one unit due to the inability to subdivide it. Therefore, the size of an interval is variable, and depends on the nature of the particular study as well as on the kinds of data available for the study. Each lithologic card contains the description of one interval. An interval can contain three distinct lithologic rock types and each type can consist of three end members. The data are key punched on the cards in numeric code according to the code given for each characteristic on the description form. However due to the nature of this form the geologist recording the data does not have to concern himself with the numeric coding. An illustration of a punched lithologic card is given in Figure 3. The interval described on this card consists of calcareous, glauconitic sand interbedded with a foraminiferal black fissile shale.

A minimax concept was the guiding principle behind the decisions on

## LITHOLOGIC DESCRIPTION CARD

| TOP OF INTERVAL |   |   |   |   | BOTTOM OF INTERVAL |   |   |   |    | NO. OF LITHOLOGIES<br>IN SEQUENCE 11, 2, or 3 | PERCENTAGE OF<br>EACH LITHOLOGY |            |             |
|-----------------|---|---|---|---|--------------------|---|---|---|----|-----------------------------------------------|---------------------------------|------------|-------------|
| 1               | 2 | 3 | 4 | 5 | 6                  | 7 | 8 | 9 | 10 |                                               | MAIN<br>12                      | SEC.<br>13 | THIRD<br>14 |
|                 |   |   |   |   |                    |   |   |   |    |                                               |                                 |            |             |

COLUMNS 15-33 — MAIN LITHOLOGY  
 COLUMNS 34-52 — SECOND LITHOLOGY (IF PRESENT)  
 COLUMNS 53-71 — THIRD LITHOLOGY (IF PRESENT)

| DOMINANT<br>COMPOSITION | CODE | 15 | 34 | 53 |
|-------------------------|------|----|----|----|
| CLAY                    | 1    |    |    |    |
| SILT                    | 2    |    |    |    |
| SAND                    | 3    |    |    |    |
| CONG-SED                | 4    |    |    |    |
| CONG-IG                 | 5    |    |    |    |
| DOLOMITE                | 6    |    |    |    |
| LIMESTONE               | 7    |    |    |    |
| CHERT                   | 8    |    |    |    |
| ANHYDRITE               | 9    |    |    |    |
| GYPSPUM                 | 10   |    |    |    |
| SALT                    | 11   |    |    |    |
| COAL                    | 12   |    |    |    |
| HEMATITE                | 13   |    |    |    |
| LIMONITE                | 14   |    |    |    |
| FELDSPAR                | 15   |    |    |    |
| VOLCANICS               | 16   |    |    |    |
| BENTONITE               | 17   |    |    |    |

| SUBORDINATE<br>COMPOSITION | CODE | 17 | 36 | 55 |
|----------------------------|------|----|----|----|
| CLAY                       | 1    |    |    |    |
| SILT                       | 2    |    |    |    |
| SAND                       | 3    |    |    |    |
| CONG-SED                   | 4    |    |    |    |
| CONG-IG                    | 5    |    |    |    |
| DOLOMITE                   | 6    |    |    |    |
| LIMESTONE                  | 7    |    |    |    |
| CHERT                      | 8    |    |    |    |
| ANHYDRITE                  | 9    |    |    |    |
| GYPSPUM                    | 10   |    |    |    |
| SALT                       | 11   |    |    |    |
| COAL                       | 12   |    |    |    |
| HEMATITE                   | 13   |    |    |    |
| LIMONITE                   | 14   |    |    |    |
| FELDSPAR                   | 15   |    |    |    |
| VOLCANICS                  | 16   |    |    |    |
| BENTONITE                  | 17   |    |    |    |
| MICA                       | 18   |    |    |    |
| GLAUCONITE                 | 19   |    |    |    |
| PYRITE                     | 20   |    |    |    |
| SIDERITE                   | 21   |    |    |    |
| DARK MIN.                  | 22   |    |    |    |
| CHALK                      | 23   |    |    |    |
| PHOSPHATE                  | 24   |    |    |    |

| CEMENT<br>OR MINOR<br>COMPOSITION | CODE | 19 | 38 | 57 |
|-----------------------------------|------|----|----|----|
| CLAY                              | 1    |    |    |    |
| SILT                              | 2    |    |    |    |
| SAND                              | 3    |    |    |    |
| CONG-SED                          | 4    |    |    |    |
| CONG-IG                           | 5    |    |    |    |
| DOLOMITE                          | 6    |    |    |    |
| LIMESTONE                         | 7    |    |    |    |
| CHERT                             | 8    |    |    |    |
| ANHYDRITE                         | 9    |    |    |    |
| GYPSPUM                           | 10   |    |    |    |
| SALT                              | 11   |    |    |    |
| COAL                              | 12   |    |    |    |
| HEMATITE                          | 13   |    |    |    |
| LIMONITE                          | 14   |    |    |    |
| FELDSPAR                          | 15   |    |    |    |
| VOLCANICS                         | 16   |    |    |    |
| BENTONITE                         | 17   |    |    |    |
| MICA                              | 18   |    |    |    |
| GLAUCONITE                        | 19   |    |    |    |
| PYRITE                            | 20   |    |    |    |
| SIDERITE                          | 21   |    |    |    |
| DARK MIN.                         | 22   |    |    |    |
| CHALK                             | 23   |    |    |    |
| PHOSPHATE                         | 24   |    |    |    |
| CHLORITE                          | 25   |    |    |    |
| SILICA                            | 26   |    |    |    |

| HUE OR<br>COLOR | CODE | 21 | 40 | 59 |
|-----------------|------|----|----|----|
| LIGHT           | 1    |    |    |    |
| DARK            | 2    |    |    |    |
| WHITE           | 3    |    |    |    |
| BLACK           | 4    |    |    |    |

| COLOR      | CODE | 22 | 41 | 60 |
|------------|------|----|----|----|
| GREY       | 1    |    |    |    |
| GREEN      | 2    |    |    |    |
| RED        | 3    |    |    |    |
| BROWN      | 4    |    |    |    |
| YELLOW     | 5    |    |    |    |
| BLUE       | 6    |    |    |    |
| VARIEGATED | 7    |    |    |    |
| SPECKLED   | 8    |    |    |    |
| MOTTLED    | 9    |    |    |    |

## TEXTURES

| DOMINANT<br>COMPOSITION | CODE | 23 | 42 | 61 |
|-------------------------|------|----|----|----|
| CLASTIC                 | 1    |    |    |    |
| BIOCLASTIC              | 2    |    |    |    |
| ORGANIC                 | 3    |    |    |    |
| XLYNE                   | 4    |    |    |    |
| LITHOGR                 | 5    |    |    |    |
| REALYZED                | 6    |    |    |    |
| S.S. OR<br>SILT         |      |    |    |    |
| ROUND                   | 1    |    |    |    |
| ANG.                    | 2    |    |    |    |
| FISSILE                 | 1    |    |    |    |
| SOFT                    | 2    |    |    |    |
| HARD                    | 3    |    |    |    |
| MASSIVE                 | 1    |    |    |    |
| FIBROUS                 | 2    |    |    |    |
| SELENITE                | 3    |    |    |    |

| GRAIN<br>TYPE | CODE | 25 | 45 | 64 |
|---------------|------|----|----|----|
| OLITIC        | 1    |    |    |    |
| PSEUDO-OLITIC | 2    |    |    |    |
| PISOLITE      | 3    |    |    |    |
| PSEUDO-PIS.   | 4    |    |    |    |
| PELLETS       | 5    |    |    |    |
| SUCROSIC      | 6    |    |    |    |

| POROSITY   | CODE | 27 | 46 | 63 |
|------------|------|----|----|----|
| GOOD > 17% | 1    |    |    |    |
| POOR < 7%  | 2    |    |    |    |

| FOSSIL<br>CONTENT | CODE | 29 | 48 | 67 |
|-------------------|------|----|----|----|
| ALGAE             | 2    |    |    |    |
| CORALS            | 3    |    |    |    |
| FORAMS            | 4    |    |    |    |
| OSTRACOIDS        | 5    |    |    |    |
| GRINIDS           | 6    |    |    |    |
| BRYOZOA           | 7    |    |    |    |
| PELECYPOD         | 8    |    |    |    |
| GASTROPOD         | 9    |    |    |    |

| HYDROCARB.<br>CONTENT | CODE | 28 | 47 | 66 |
|-----------------------|------|----|----|----|
| CARB. ACEOUS          | 1    |    |    |    |
| OIL & GAS ST.         | 2    |    |    |    |
| BITUMINOUS            | 3    |    |    |    |

A 1 IS PUT IN COLUMN 72 OF LITHOLOGIC CARD  
 WHEN NEXT CARD IN SEQUENCE WILL BE A  
 STRATIGRAPHIC CARD

|    |
|----|
| 72 |
|----|

| CARD<br>CODE | PERMIT NO.     |
|--------------|----------------|
| 74 75        | 76 77 78 79 80 |
| 0 2          |                |

## STRATIGRAPHIC DESCRIPTION CARD

| TOP OF<br>INTERVAL |   |   |   |   | CODE NO.<br>OF UNIT |   |   |    |    | STRATIGRAPHIC UNIT |    |    |    |    |    |    |    |    |    |    |  |  |  |  |  |  |  |
|--------------------|---|---|---|---|---------------------|---|---|----|----|--------------------|----|----|----|----|----|----|----|----|----|----|--|--|--|--|--|--|--|
| 1                  | 2 | 3 | 4 | 5 | 7                   | 8 | 9 | 10 | 11 | 12                 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |  |  |  |  |  |  |  |
|                    |   |   |   |   |                     |   |   |    |    |                    |    |    |    |    |    |    |    |    |    |    |  |  |  |  |  |  |  |

| CARD<br>CODE | PERMIT NO.     |
|--------------|----------------|
| 74 75        | 76 77 78 79 80 |
| 0 3          |                |

University of Michigan  
 Department of Geology  
 Subsurface Laboratory

FIGURE 2

## LITHOLOGIC AND STRATIGRAPHIC DESCRIPTION FORM

**Figure 3**  
**Lithologic Description Card**

which properties to include on the card. Simply stated, this was an attempt to maximize the information that can be retrieved from the card but at the same time to minimize the amount of superfluous data that is recorded. Geological descriptions contain a great deal of ambiguity, and therefore it is often difficult to interpret the details of another's work. If one of the products of a geological information retrieval system is to be the ability to store and distribute information gathered by many people with varied backgrounds, it is necessary to inculcate the concept of standardization into the descriptions. This can be done mainly by eliminating those subjective terms which tend to fluctuate greatly in their meaning among users. Thus, terms such as "some," "slightly," "a little" or "occasionally" have no place on the card and are in most cases replaced by more quantitative categories. Color is another property which has caused a great deal of confusion. Compound descriptions such as greyish blue or slightly buff gray are not only biased by the operator's color perception, but by such factors as lighting and whether the sample is examined wet or dry. On the form in Figure 2 there is only a choice of the main color, with the added ability to tell whether it is light or dark.

The subdivisions within the clastic textural descriptions are particularly prone to inconsistencies. What appears as subrounded to one investigator is often subangular to another. It is felt that the extremes such as "well rounded" or "very angular" or "poorly sorted" versus "well sorted" are not only the most consistent but are also the most important in their interpretive value. If a texture is not recorded as an end member, it is understood to be in the intermediate range. Similarly the binocular determination of porosity is often recorded in

great detail but rarely useful due to the wide variance of the true porosity about the estimated one. Here, too, only the extreme end members of "very porous" or "tight" are acceptable.

The process of recording the data on the form is simple and faster than by written Description. In the top line go upper and lower limits of the designated interval, the number of lithologic types present and the percentage of each to the closest 10 percent. In the section for the actual descriptions the first column in each box is for the predominant lithology, and the second and third columns are for the other lithologies, if present. Column 72 is connected with the stratigraphic card which is described later.

A number of alternate methods were examined in order to eliminate the duplication in first recording and then punching of the data. In the first method a small portable punch was used to punch the card directly as the sample was being examined. Since these small punches do not print as well as punch the information, it is difficult to verify the punching for errors. The method is also much slower because of the manual rather than automatic feed of the punch card. A somewhat different form of portable punch is the port-a-punch. A pre-printed and perforated card is inserted into a frame. The desired number can be pushed out in the correct column by using a special stylus. This method was also too slow for office use but might have advantages for work under field conditions. The third alternative would be some form of automatic scanning device. Here the data are recorded in the normal fashion on a form, the form is optically scanned and the required card is automatically punched out. Optical scanners are still too expensive for occasional use, but should be considered in any large scale adaptation

of machine systems.

The lithologic card adequately covered all problems met in the study of the Michigan Formation. Spot checks on other parts of the section showed no obvious deficiencies. There will of course be specialized projects where the need will arise for more detail or different types of information, but this was anticipated by allowing for expansion of the card without disturbing the arrangement of the data.

#### Stratigraphic Description Card

The form of the stratigraphic card is given at the bottom of Figure 2. A stratigraphic card is inserted whenever the lithologic interval represents the top or all of a stratigraphic unit. The unit may be any subdivision of either the time or rock stratigraphic scale. Although the actual name of the unit is given for use in subsequent printed output, the code of the unit is the method by which efficient retrieval of the stratigraphic data is made.

The coding plan which was developed is in part hierarchal. Starting with the Quaternary and going down the stratigraphic column each system is consecutively assigned a block of numbers. The proposed coding scheme for the Michigan Basin is given below.

|               |           |
|---------------|-----------|
| Quaternary    | 0- 249    |
| Permian       | 250- 499  |
| Pennsylvanian | 500- 999  |
| Mississippian | 1000-2499 |
| Devonian      | 2500-3999 |
| Silurian      | 4000-6999 |
| Ordovician    | 7000-8999 |

|             |           |
|-------------|-----------|
| Cambrian    | 9000-9499 |
| Precambrian | 9500-9999 |

Any subunit is then assigned a block of numbers within the unit. For example the Michigan Formation of Mississippian age covers the interval from 1150-1299 while individual units within the Michigan are allotted the numbers 1200-1210, 1210-1220, etc. Since a number represents a hypothetical plane separating two units the unit itself is designated by two code numbers giving the top and bottom planes. The number therefore quickly gives both the level of stratigraphic nomenclature as well as the location of the unit within the stratigraphic column.

## RETRIEVAL AND ANALYSIS OF THE DATA

General Comments

The process of recording the data onto cards marks the completion of one important phase of the project. Each well then consists of a decklet of cards. It must be remembered that the lithostratigraphic data represents only a part of the total information available from the well. Drilling rates, production figures, chemical analyses and economic factors, among others, would already be stored. This would involve more punched cards than are manageable, and therefore the ultimate storage of the data would be on magnetic tapes or magnetic discs. Each of the above storage methods contains the equivalent of hundreds of thousands of cards per tape or disc. The same information would be stored on different tapes according to different classifications. Thus, one tape might be an individual well file containing everything known about the well while another tape might contain reference to all the occurrences of some specific stratigraphic system.

One must differentiate between the retrieval and the analysis of the data. In the former case the system is concerned mainly with the recall and display of the coded data. We might rearrange the order of the data but we get nothing back that we didn't originally put in. However in data analysis or processing we add new data by virtue of the computations that are done.

Retrieval

That part of the system which is concerned with information retrieval is called AUTOLOG. A copy of the program is given in Appendix

B and the different kinds of output are given in Figures 4 and 5. Figure 4 is the familiar subsurface columnar section. The scale of the log is at the discretion of the user and is limited only by the number of lines per inch that the particular printer can print.

The abbreviations and the symbols for the different lithologies were kept as close as possible to standard usage. Since there are 10 symbols per line, each one represents 10 percent of the total, and the whole column is therefore in the form of a quantitative percentage log. The log is, of course, a synthesis of the information available on the three different card types. Any number of cross-sections can be accurately and quickly prepared by the use of an option which is available in this program. For this purpose the lithologic descriptions are deleted from the percentage log while the title is moved to the left over the columnar section. The distances between the wells are computed from the coordinates according to the horizontal scale desired. Then, using these distances and the printed log, the section can be completed by hand in a matter of minutes.

The output in Figure 5 is a more compact description of the well data and is for use in the permanent log file.

### Data Analysis

The value of the machine system as applied to stratigraphic studies lies in the speed and ease with which any desired analysis can be carried out and then displayed. It is dependent completely on the thoroughness with which the data were originally recorded. For example, it is not possible to compute how many feet of oolitic limestone there is in a particular part of the section if textural characteristics were



BENEDUM-WONDE 1  
 STATE-MICH COUNTY-MISSA  
 NNNE 32-21N 6W ELV-1179  
 PERMIT NO. 22206

| UNIT     | SUBSEA | DEPTH TO TOP | LITHOLOGY              |                        |                             |
|----------|--------|--------------|------------------------|------------------------|-----------------------------|
| MICHIGAN | 119    | 1060         | ANHY- GREY,            | SH.- GREEN,FISSL       | DOL.- LIGHT BROWN,FGRN      |
| K        | 92     | 1087         | ANHY- WHITE            | SH.- GREEN,FISSL       | DOL.- LIGHT BROWN,FGRN      |
| L        | 54     | 1125         | SH.- VARIE,FISSL       | DOL.- BROWN,CALCR FGRN | ANHY- LIGHT RED,            |
| M        | 4      | 1175         | ANHY- WHITE DLMTG      | SH.- GREY,             |                             |
| N        | -37    | 1216         | SH.- GREY,             | DOL.- LIGHT BROWN,FGRN |                             |
| O        | -66    | 1245         | LMST- GREY, DLMTG FGRN | SH.- GREY,             | ANHY- WHITE                 |
| P        | -106   | 1285         | LMST- GREY, SANDY FGRN | SH.- GREY,             | DOL.- LIGHT BROWN,FGRN      |
| Q        | -141   | 1320         | ANHY- WHITE            | SH.- GREY,             | LMST- DARK GREY, SHALY FGRN |
| R        | -192   | 1371         | ANHY- WHITE            | LMST- GREY, SHALY FGRN |                             |
| S        | -281   | 1400         | S.S.- SHALY            | SH.- BLACK GREY, FISSL |                             |
| T        | -304   | 1460         | DOL.- DARK BROWN,FGRN  | SUCRS                  |                             |
|          | -316   | 1483         | DOL.- DARK BROWN,FGRN  | SUCRS                  | SH.- DARK GREY, FISSL       |
| MARSHALL |        | 1495         |                        |                        |                             |

Figure 5  
 One Form of Output from AUTOLOG

not included in the original format. Since the handling of the raw material is often very time consuming, there is therefore great value in making a complete description to begin with so that it will be possible to make computations in the future that were not considered for the original project.

There are two main programs, each with a number of subsections or subroutines, which are included in this portion of the system. One of these, called VTSTAT, (Appendix C) does the actual data analysis according to the instructions of the user, while the other named MAP (Appendix D) will, as its name implies, prepare a map ready for contouring.

VTSTAT. The operational unit in this program is the stratigraphic interval, such as system, group, formation or member. It can also include any other unit that the study encompasses, as for example the interval between two electric log markers or two bentonite beds. The convenience with which an interval can be defined is based on the concept of the hierarchal numeric coding of the units.

One well decklet at a time is read in and any number of different or overlapping intervals can then be studied in every well. The only information that the program needs from the user is the number of intervals and the code numbers for the planes defining each interval. If for any reason an interval is not present in the well a comment to that effect is printed out and the next interval is examined. When the study of all the requested intervals has been completed for a well, the next well is read in and the procedure is repeated.

If the interval being studied is found in a well, control in the program is passed to a subroutine (DETAIL) with the location of this

interval within the total well data. The subroutine then computes the required information and automatically punches out a card which contains the results, the permit number and X-Y coordinates of the well, the interval being studied and a code for the type of information on the card. A sample output card used in the Michigan Formation study is shown in Figure 6. The output from VTSTAT is used as the input for programs like MAP, whose purpose is data display.

Inasmuch as it is impossible to anticipate all the different types of computations that might be requested, the subroutine contains a standard package which includes the thickness, sub-sea elevation and all the common lithologic ratios. If some other computation is desired, such as the ratio of black to red shale or clastic to non-clastic carbonates, it is necessary for a programmer to write a few simple instructions and insert them into DETAIL. A more elegant procedure would be for DETAIL to have a program writing section that would write the necessary instructions when given the requested information in simple English as input to the program. The tools for writing this kind of program are available at the University of Michigan Computing Center.

When DETAIL has finished its task, it passes control back to the main program either to search for the next interval or to read in the next well.

A very positive aspect of the scheme is that it is extremely inexpensive. In the Michigan Formation study the cost was around 20 cents per well when 8 intervals were examined in one pass or 2 1/2 cents per interval per well. The unit cost is inversely proportional to the number of intervals examined in one pass, since the cost of reading in the data remains constant.

| GENERAL PURPOSE-20 FIELD                                                      |   |   |   |   |   |   |   |   |   |
|-------------------------------------------------------------------------------|---|---|---|---|---|---|---|---|---|
| 1150130041676042 500 106 98 32 23100 17 94 41 39 19 16 1 23196 % 831161017813 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| CODE FOR INTERVAL TOP                                                         | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| CODE FOR INTERVAL BOTTOM                                                      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| X-COORDINATES                                                                 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Y-COORDINATES                                                                 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| THICKNESS                                                                     | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| SUB-SEA ELEV                                                                  | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| % CLASTIC                                                                     | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| SAND/CLASTIC                                                                  | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| % EVAPORITE                                                                   | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| ANHYDRITE/EVAPORITE                                                           | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| % CARBONATE                                                                   | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DOLomite/CARBONATE                                                            | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| DOL/DOL + EVAP                                                                | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| % SHALE                                                                       | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| % SAND                                                                        | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| % DOLOMITE                                                                    | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| % LIMESTONE                                                                   | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| % ANHYDRITE                                                                   | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| FT. SHALE                                                                     | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| FT. SAND                                                                      | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| FT. DOLOMITE                                                                  | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| FT. ANHYDRITE                                                                 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| CODE TYPE                                                                     | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| PERMIT NO.                                                                    | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

Figure 6  
Interval Analysis Card-Output From VTSTAT

MAP. The contoured map is a valuable aid in the interpretation and display of data. It is the most concise method of showing the relationships among the various properties of a stratigraphic unit. Increased effort in quantitative facies analysis in the last ten years has spawned a multitude of new map types (Forgotson, 1960, Krumbein and Imbrie, 1963), but often the efforts to put even more information on one map has been more concealing than revealing. It is difficult to decide in advance which of these mappable variables best answers the needs of a specific problem while the prohibitive costs of hand plotted maps in large scale projects limits the number of maps that can be examined. The development of computer programs and contouring plotting machines, which can automatically produce maps with no error and with greatly reduced cost and effort, will therefore have a pronounced effect on the methods of stratigraphic analysis.

The mapping program (MAP) developed for the system will prepare a map with location and variables plotted, but it will leave contouring to the interpretation of the geologist. There are contouring programs available, but they are operated in conjunction with automatic plotting machines. MAP, on the other hand, needs only a computer and the auxiliary printing device. Since the map is printed directly on computer output paper, the narrow width of this paper necessitates the division of the map into vertical strips. These strips, each ten inches wide, are then joined together to make the complete map (Fig. 7).

The requested map can be of any scale, while the size is limited solely by the internal storage of the particular computer available. The user need give only the maximum and minimum X and Y coordinates of the map and the desired scale. The remainder of the calculations such

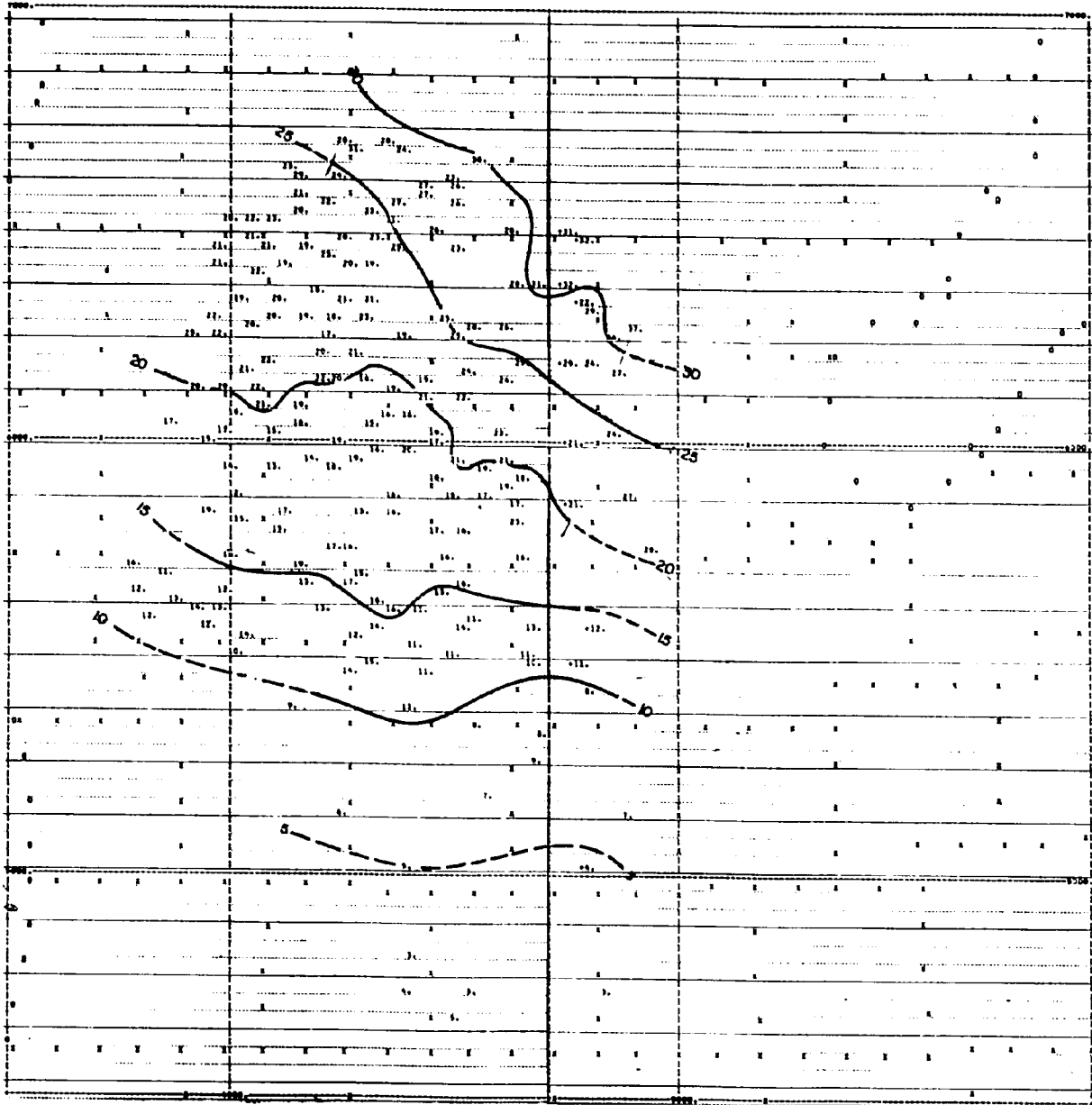


FIGURE 7

PERCENTAGE EVAPORITES IN MICHIGAN FORMATION  
Working Map-Output From MAP

as the size of the map and number of vertical strips necessary are done by the program. The plotting program ignores those control points which are not within the limits of the area to be mapped. This alleviates the need to pre-sort the data.

There are only a few restrictions on the form of the input data. Each card can contain the information from only one control point. The X-Y coordinates of the well must be present, but there may be any number of mappable variables. A separate map can be produced for each variable, but only those variables requested will be mapped. The user also has the option of printing the Michigan state and county outlines and the grid system on the map.

The cost of preparing a map is determined by the number of control points. In the present study over 250 wells were plotted on each map and the cost ran about 80 cents per map. It is therefore very feasible to make a quick visual examination of the data to see where further work is necessary. The maps prepared by the computer are used directly for contouring and then traced onto the final copy.

## SUMMARY

The feasibility of computer systems in stratigraphic analysis has been shown by designing a system and testing it on a study of the Michigan Formation. The results indicate that besides the saving in manpower, time and money, it is possible to achieve a much better understanding of the data.

The following points were noted:

- 1) It is practical to design systems to handle complicated geological problems which can be employed with a minimum of computer knowledge required of the casual user. However the geologist for whom the computer is an important tool should have a working knowledge of both the art of programming and how a computer functions. This is analogous to the understanding a mineralogist has of x-rays and the x-ray machine when this is an important tool to him.
- 2) The costs of preparing maps, cross-sections and logs is far less than by manual methods. The cost of computations is incomparably smaller than by hand. This reduced cost permits the researcher to greatly increase his sample size and thereby improve his interpretations.
- 3) The speed with which the work is done allows the geologist to apply the concept of multiple working hypothesis on a day to day basis. It is truly possible to fit many hypothesis and check them quickly with the appropriate computations.

## THE MICHIGAN FORMATION

### PREVIOUS INVESTIGATIONS

Interest in the Michigan Formation began with the discovery around 1830 that the unit contained gypsum. The first finds were made in the Grand Rapids area, followed by the discovery of near surface exposures at Alabaster in Iosco county.

Reference to the strata are found in Houghton (1838) and Hubbard (1841). The section was first described systematically by Alexander Winchell in a series of papers on the Mississippian of Michigan published between 1860 and 1870 (Martin and Straight, 1956). Rominger (1876) describes the outcrops at Grand Rapids and in the Saginaw Bay area. Monnett (1948) gives a good summary of the early work.

Although a mill was opened in Grand Rapids in 1841, with quarrying beginning at Alabaster somewhat later, intensive growth in the Michigan gypsum industry awaited the coming of the railway in the later 1800's. The rapid development in the industry provided the impetus for increased research on the Michigan Formation. Grimsley (1904b) reviews all that was known on the Michigan to that date. His work also contains a comprehensive history of the early progress in the gypsum industry. Other work published during this period include Grimsley (1904a, 1905) and Smith (1912, 1920). The recognition of large gypsum reserves resulted in a decrease in the attention given to the Michigan and there is nearly a total hiatus in publication till the early 1930's.

In 1929 gas was discovered in the Michigan Stray, a sand unit in the lower part of the Michigan Formation. During the next ten years the Stray was the target in many of the wells drilled in Michigan. With

the increased data available there was renewed interest in studies on the Michigan Formation. The relationship of the Stray to the Upper Marshall is discussed by Thomas (1931), Kirkham (1932), Hard (1939), Hake (1938) and Monnett (1948). Rawlins and Schellhardt (1936), in a study made for the Bureau of Mines, were concerned mainly with the estimated gas reserves. Descriptions of the sands and hypotheses as to their origins are found in Ball et al (1941), Bergquist (1938), and McGregor (1954).

The complete section in the Michigan Formation has not been the subject of a complete study since Grimsley (1904b).

#### METHODS OF STUDY AND ANALYSIS

The majority of the data for the study was obtained from electric and nuclear log correlations and sample descriptions. The only exceptions were the sections examined in two mines at Grand Rapids and the quarry at National City. All the correlations and descriptions were done by the author.

A total of 665 mechanical logs were used in the correlations of which 250 were included in the control grid that was established for the purpose of mapping the information. Samples were not available for many of the control points and even where present, the quality was often too poor for detailed work. To achieve a high level of reliability in the sample descriptions, the cuttings from two or three neighboring wells were examined for each control point. Over 700 sets of samples were examined for the 250 control points.

In most of the area studied control was good and the spacing averaged 2 wells per township. However in the south and southeast there

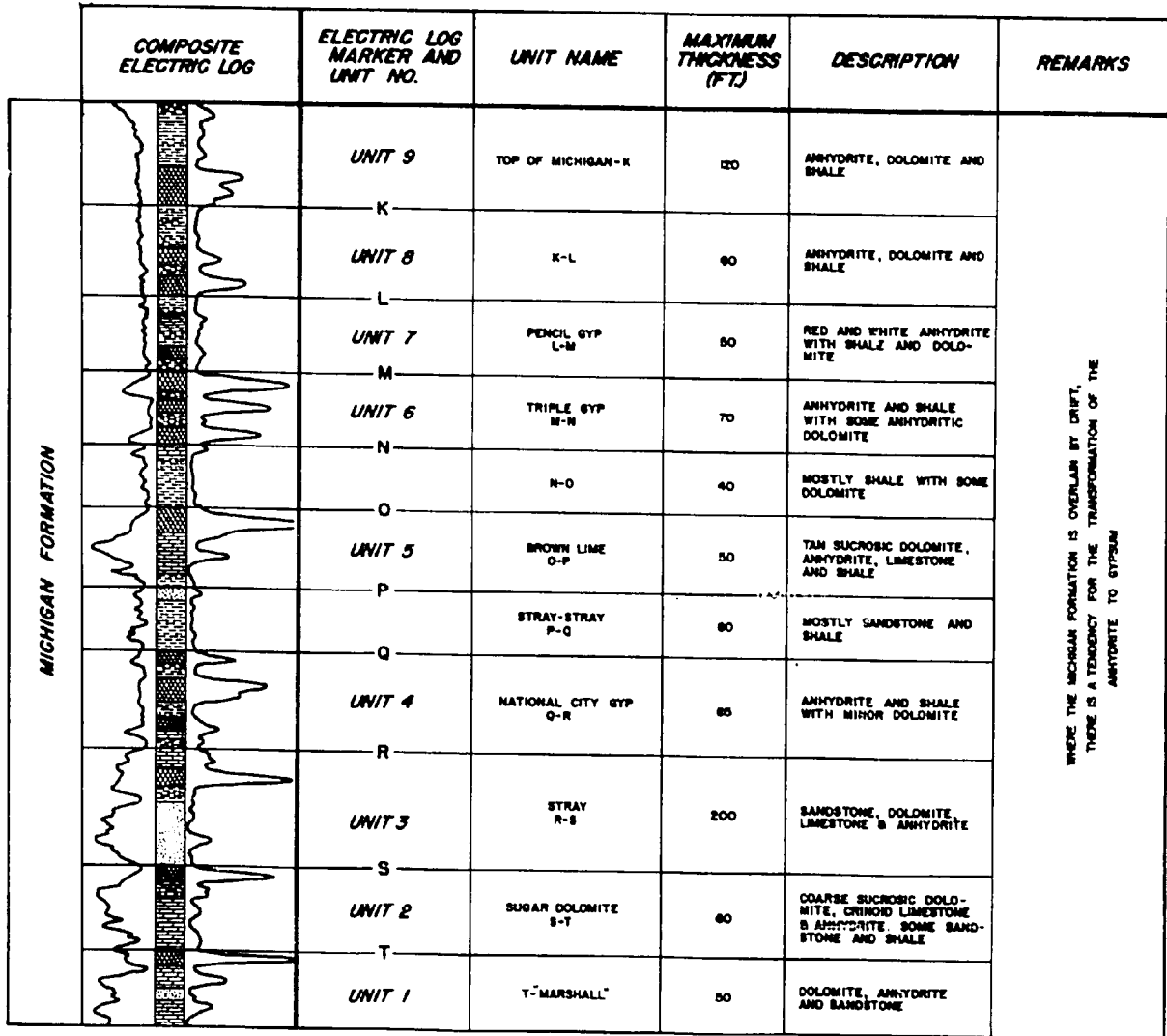
are few wells drilled and even fewer mechanical logs available. The control is therefore sparse and in a few instances wells which had no mechanical logs were used as control points.

The total interval of the Michigan Formation was subdivided into units for mapping purposes (fig. 8). The breakdown into smaller units reveals a more complex picture of basin history than that suggested by the patterns shown by the total interval. The units were both lithologically meaningful and characterized by distinctive mechanical log markers. Since the lithological changes are gradual and the control good, the units were traced across lithologic facies changes. Isopach and lithofacies maps of the individual units and cross sections were used in interpreting the geological history of the Michigan basin during the deposition of the Michigan Formation.

#### TECTONIC SETTING

The Michigan Basin, which is an elliptically shaped autogeosyncline, has had a comparatively simple structural history. The positive elements which played an important part in the development of the basin include the Laurentian Shield to the north, the Wisconsin Arch to the west and the Kankakee and Findlay Arches to the south and southeast. It is generally agreed that these features had a Precambrian or early Cambrian origin, (Pirtle, 1932, Newcombe, 1938) and were fairly consistent throughout the history of the basin. They were also the major source of sediment into the sinking basin. The northeast boundary, however, fluctuated between positive and negative elements and often represented the main connection of the basin with the open seas.

Within the basin the gentle dips toward the center are interrupted



DIVISION OF MICHIGAN FORMATION IN SUBSURFACE BY ELECTRIC LOG MARKERS

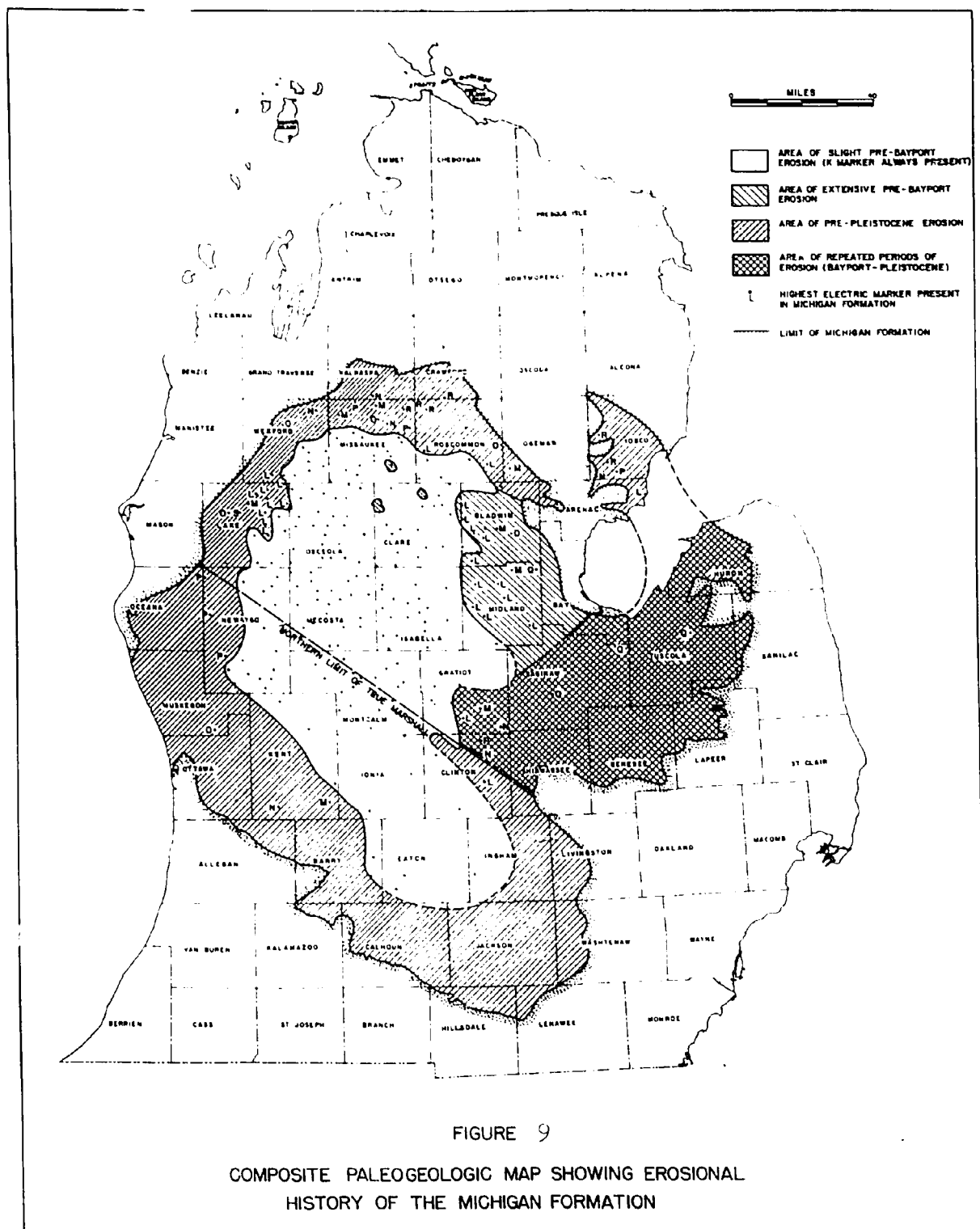
FIGURE 8

by relatively small scale folding and faulting. The deepest part of the basin is today found near the area where Midland, Gladwin, Isabella and Clare counties meet. The maximum depth to the basement is over 14,000 ft. Isopach maps of the individual systems show that the center of the subsiding basin varied considerably. The principal SE-NW trend exhibited by the majority of the structural features in the basin was noted by Pirtle (1932) and Newcombe (1933). This strong trend is interpreted by most authors as evidence of strong basement control on the tectonic activity that took place in the basin throughout geological time.

#### AREAL EXTENT

The Michigan Formation is today confined to a circular area approximately 170 miles in diameter, whose perimeter represents an erosional edge. Within this circular area the formation has been completely removed from the top of two large structures, the Howell anticline in the south and a series of en echelon folds in Ogemaw, Arenac and Bay counties (fig. 9). The extent of the Michigan Formation in the eastern part of the state (to the south of Saginaw Bay) is poorly known due to the paucity of data. This area has apparently had a complex history of erosion which began with a pre-Bayport uplift, and continued at least through the Pennsylvanian. Numerous channels and valleys were cut into and through the Michigan with the subsequent deposition of younger sediments. This has caused a great deal of stratigraphic miscorrelation and is the basis for many seemingly anomalous depositional sequences.

The erosional edge is generally overlain by drift but there are a



number of widely separated small surface exposures along the western, southern and eastern parts of the perimeter (Martin and Straight, 1956). The best known exposures are exploited for gypsum in the vicinity of Grand Rapids and in Iosco county. From the outcrop edge the beds dip toward the center of the basin in eastern Isabella county where the top of the Michigan is found at its maximum depth of 1000 feet (fig. 10).

#### STRATIGRAPHIC FRAMEWORK

Winchell (1861) defined the Michigan Formation in the Grand Rapids area. He included in the Michigan a sequence of limestones, shales and gypsum overlying a thick series of sandstones. He placed the sands in the Marshall. As originally defined the Michigan included strata which were later separated out as the overlying Bayport Formation. The boundary between the Michigan and the Marshall was thus simply placed at the first appearance of sandstone beneath the evaporites. This concept held until drillings in the central part of the basin indicated that there was a sandstone present above the lowermost anhydrite. This sand, which produced large quantities of gas, was given the name Michigan Stray. The boundary problem between the Michigan and the Marshall was alleviated by including in the Michigan all strata down to the lowermost carbonate rock. As drilling progressed and more data became available on the section between the center of the basin and the Grand Rapids area, it became evident that there was a close relationship between the Stray and Marshall sandstones in the southwest area of their distribution. This relationship has been the center of a controversy for the last 30 years. There evolved two schools of thought. Some believed that the Stray was younger than any of the Marshall and in fact represented

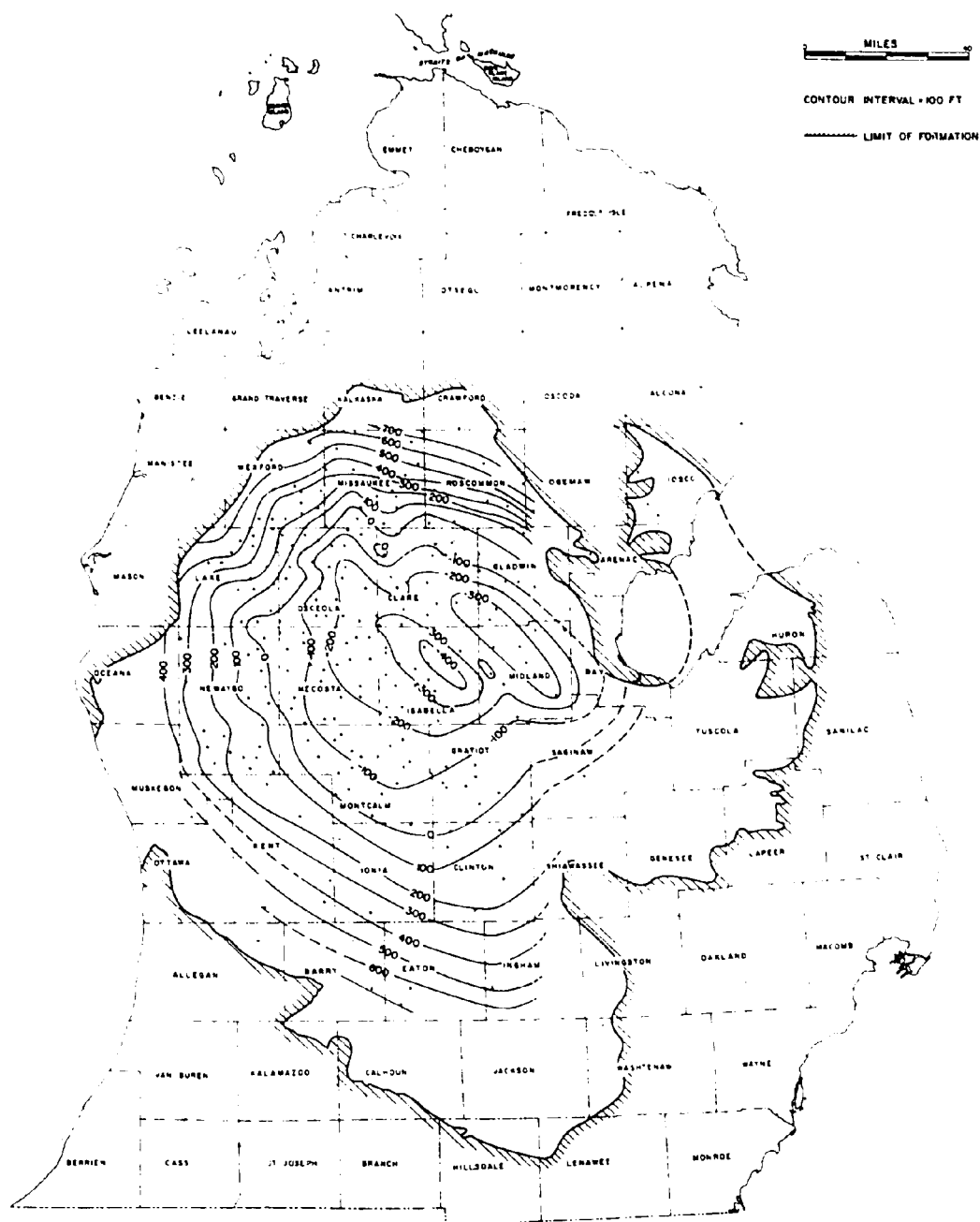


FIGURE 10  
STRUCTURE CONTOUR MAP ON THE TOP OF THE TRIPLE GYP

the redeposited Marshall in the Michigan Seas (Newcombe, 1933), while others contended that at least the upper part of the Marshall or Napoleon was time equivalent to the Stray (Hard 1938, Hake 1938).

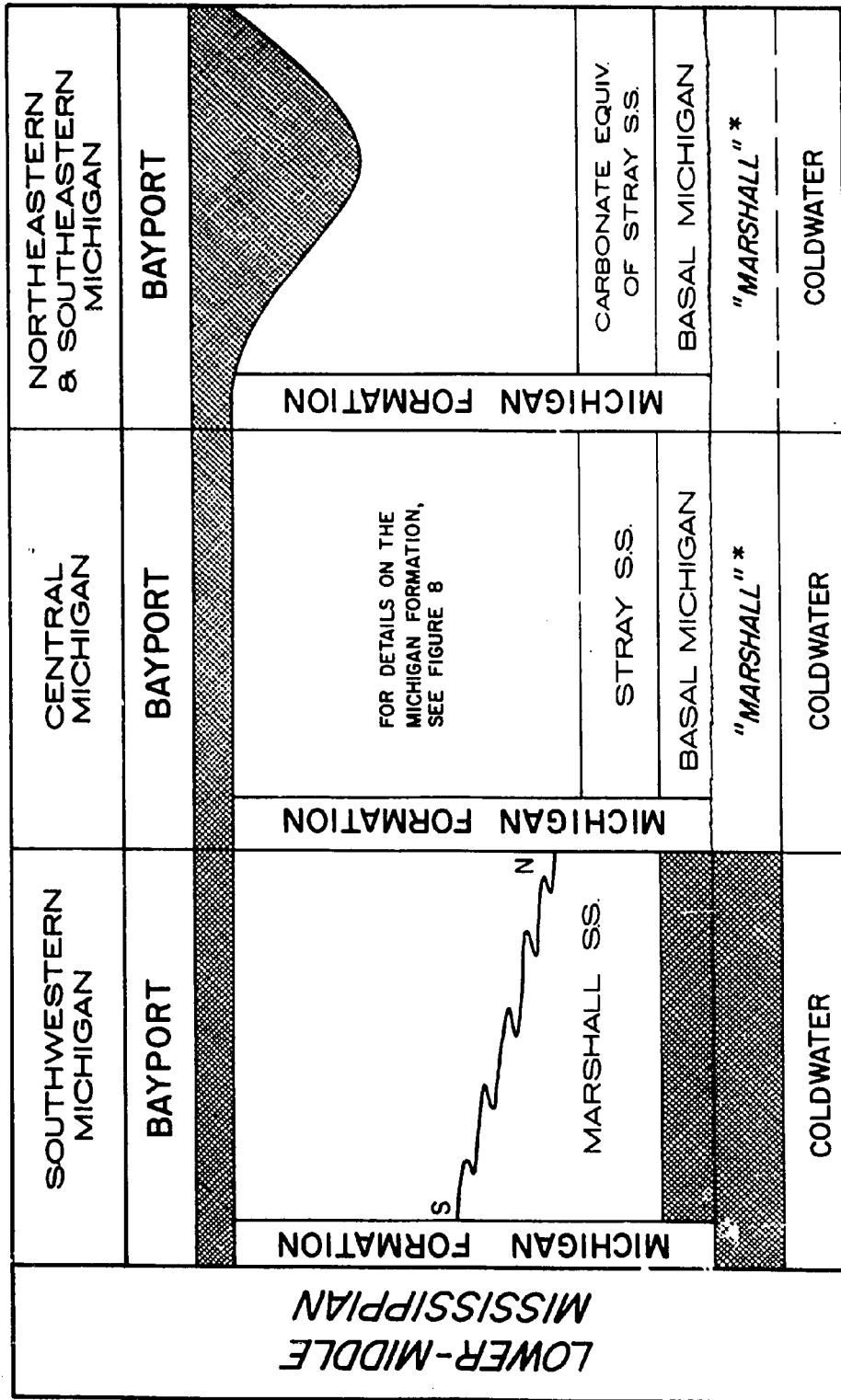
The key to unraveling these problems of stratigraphic correlations lay in detailing the transgressive character of the Michigan seas. This was accomplished by subdividing the Michigan into units (fig. 8) and carefully tracing these units and the changes that take place within them. The distribution of the evaporites within the individual units of the Michigan Formation (fig. 11) clearly shows the succeeding transgressive phases of the sea. As used in this paper the Michigan Formation defines a sequence of rocks and their equivalents that were deposited during a period when evaporitic conditions prevailed in the basin.

The concept of evaporite facies was the basis for understanding the type of deposition that took place. This concept was developed by Briggs (1957, 1958) in his study of the Silurian evaporites in the Michigan Basin and surrounding area. As a result of the evaporation of the water as it flows from the restricted opening of a basin, salts are concentrated in the brine. When the solubility product of a mineral is reached, it precipitates. The sequence of precipitation is from carbonates to sulfates to halides. These then are the evaporite facies and appear in the strata both horizontally and vertically. During the deposition of the Michigan Formation the concentration reached only the sulphate phase, for none of the halite minerals are present. The ideal sequence is often interrupted by increased inflow of water, climatic changes or the mixing of the concentrated brines with fresh water draining off the land in the near shore environment. The result may be a reversal in the sequence of precipitation.



The stratigraphic relationships of the Michigan Formation with the underlying and overlying Mississippian rocks as developed in this study are shown in figure 12. The background for the changes will be given in the discussion on the individual units in the Michigan. It is interesting that according to this correlation chart there were elements of truth in both schools of thought concerning the Michigan-Marshall boundary. All of the Marshall in the southwest part of the state is the time equivalent to the lower part of the Michigan Formation. As indicated there is a hiatus between the Michigan and the Coldwater formations in this region. The dashed line across the middle of the map in figure 9, is the approximate northern limit of the Marshall which is equivalent to the Michigan. What has been called "Marshall" northeast of this line is older than the Michigan and is separated from the Stray by other units. Since the type section for the Marshall and the Napoleon are located in the southwest, the use of these stratigraphic names should be restricted to the Michigan equivalent sandstones and the sequence of sands between the Michigan and the Coldwater should be redefined and renamed. In this paper these older sediments will be referred to as "Marshall" to differentiate them from the true Marshall. There are a number of possible outcrops in the Saginaw Bay area which could serve as type sections.

The upper boundary of the Michigan Formation marks the end of evaporite sediments and the return to normal marine conditions. There is a disconformity between the Bayport and the Michigan, as a result of a period of erosion and/or non-deposition. The eastern part of the state was most effected and on some of the anticlinal structures almost all of the Michigan was removed before the deposition of the Bayport.



\* THE "MARSHALL" IN THE CENTRAL AND EASTERN PARTS OF THE STATE IS OLDER AND NOT EQUIVALENT TO THE TRUE MARSHALL IN THE S.W. AND SHOULD BE RENAMED.

FIGURE 12  
LOWER-MIDDLE MISSISSIPPIAN CORRELATION CHART-MICHIGAN

## STRATIGRAPHY AND DEPOSITIONAL HISTORY

Definition of Units

Electric and nuclear logs measure a physical quantity which is the sum effect of many different parameters of the rock and the bore hole within which the recording sonde is placed. Among the more important of these parameters are the composition, porosity, permeability and fluid content of the rock. The importance of a particular parameter will vary with the different logs.

Under the above assumptions, the mechanical log in its entirety can be considered a unique property of a well. Because of this uniqueness the logs can be used to define time equivalent units. The writer believes that when a whole sequence of closely spaced electric or nuclear log markers can be traced over a large area, the individual marker will represent time horizons. It is the concept of using sequences of markers, rather than individual ones, that is crucial in this application of mechanical logs. When single "kicks" are traced it is very possible that they describe nothing more than time transgressive or regressive lithologic units. The method is especially suited to sections containing two or more thinly interbedded lithologies since their mechanical logs will contain many distinct markers.

The geologists in the Michigan petroleum industry have long known the existence of individual markers in the Michigan Formation and used them as key beds for contouring in their studies on the Stray sand (Wolcott, 1948). A preliminary review of the 650 mechanical logs available revealed that the markers of the complete Michigan section could be traced over large areas and was therefore appropriate for division into time equivalent units.

Figure 8 gives the proposed subdivision of the Michigan Formation with the main lithologic features and a composite electric log showing the electric markers used. The clastic sediments and chemical sediments were placed into separate units because of the different conditions under which each is deposited. It was thus possible to examine the interaction of the two forms of deposition which are dominant in the Michigan.

The prevailing terminology was used wherever possible even though most of the names were not formally defined in the literature. The mechanical log markers are designated by single letters. For reference purposes the units which contained evaporites were numbered.

#### Paleogeographic Framework

The Upper "Marshall" sediments are exclusively sandstones and were deposited in a regressing sea (Newcombe, 1933; Lane and Seaman, 1909). Positive tectonic elements enclosed the basin on all sides except northeast where the "Marshall" seas joined the open ocean. As the "Marshall" seas retreated from the land in a generally northeastwardly direction, the sediments they had deposited were exposed, subjected to erosion, and incorporated back into the "Marshall." The paucity of heavy mineral types found in these sediments by Stearns (1933) and Stearns and Cook (1932), is indicative of the extensive reworking that took place.

The return of the sea marked the beginning of the Michigan Formation. Conditions of sedimentation which favored the deposition of evaporites developed contemporaneously with the reappearance of the sea. Circulation of the salt water between the basin and the open sea was probably restricted by a sub-aqueous sill (Sloss, 1953) which had the familiar northwest trend. There were probably changes in the climatic regime as

well. Isopach and facies maps indicate that the present areal extent of the Michigan Formation represents only the southern half of a much larger depositional basin, and the the northeast perimeter of the outcrop area is the approximate position on the central axis of deposition. Each of the units in the Michigan had a mirror image to the northeast which has since been eroded away.

Total Interval (K - Bottom of Formation)

A series of maps showing the relative percentages of the main lithologic types for the interval from the K marker (fig. 8) to the bottom of the Michigan Formation is shown in figure 13. This is approximately the total interval. The top was taken at marker K to eliminate the obvious error introduced by the period of erosion at the end of Michigan deposition (fig. 9). By lumping together the individual units there is an averaging effect on the total picture with the resulting loss in the details of the geologic history of the basin. However the long-period average of the geologic events become more apparent.

The strong northwest trend of all the percentage lines is a reflection of the dominant direction in the strand lines that persisted during most of the Michigan deposition. The source of the clastics was mainly from the southwest while the direction to the open sea was northeast. The zone of highest anhydrite deposition was the approximate center of the subsiding basin.

The interval is of nearly uniform thickness but as will be shown in the detailed descriptions that follow, this is the result of the adding together units which are thickening in opposite directions. The slight thickening to the north again shows that the center of the basin was in that direction.

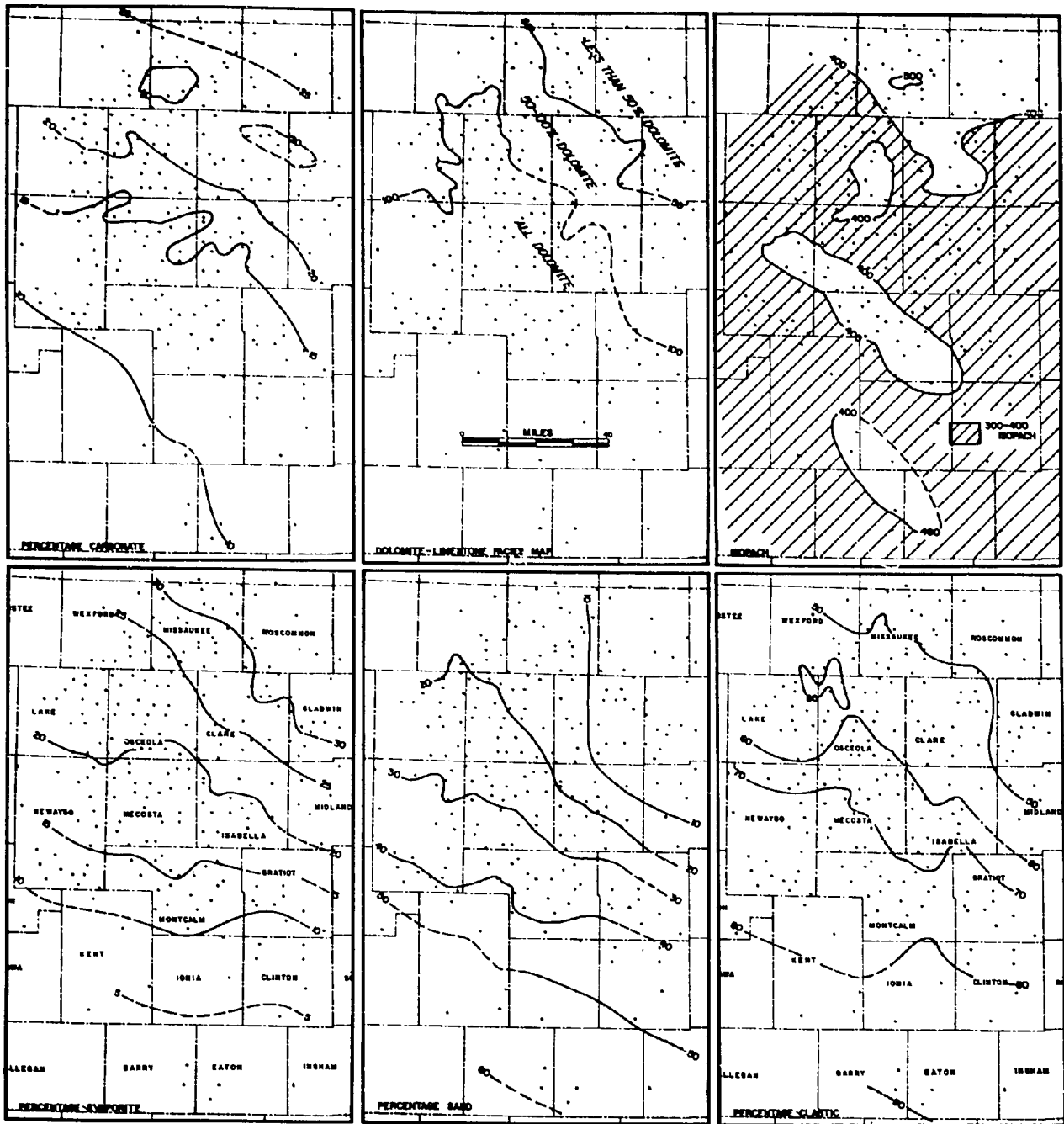


FIGURE 13

ISOPACH AND LITHOFACIES MAP OF TOTAL MICHIGAN INTERVAL

A stratigraphic cross-section in which the individual well logs were prepared by the computer is shown in figure 14. The cross-section is perpendicular to the dominant northwest trend and therefore exhibits the maximum variations in lithology and thickness within the units. The transgressive nature of the Michigan sea is clearly indicated by the progressive facies changes in the units.

#### I-"Marshall" (Unit 1)

The lowermost unit in the Michigan Formation was deposited during the initial advance of the Michigan sea over an eroded "Marshall" landscape. The unit is limited to a small area in the northcentral part of the state.

The first sediments consisted mainly of reworked "Marshall" sands, but as the water balance in the basin favored evaporation there was a concentration of salts by ocean water inflow and dolomites and anhydrites were precipitated.

The clastics of Unit 1 are fine grained, shaly sandstones and gray shales. The presence of a carbonate cement make the sands fairly tight. The cement is mostly calcite but some dolomite cement is also found. Minor cross-bedding features as well as scouring and evidence of worm action were observed in a core. The sands of Unit 1 are distinguished from the "Marshall" sediments which underly them by their texture and lithology. The "Marshall" sandstones are coarse, porous and contain abundant green clay-like minerals. Very likely they are in part of continental origin. The above differences between the two sands is reflected in the electric log, where the "Marshall" has a higher spontaneous potential curve. Because of the nature of the eroded surface the clastic member of Unit 1 is unevenly distributed.

PERMIT NO. 22672  
 STATE-DEPT. COUNTY-DEPT.  
 SECTION 21-14 TO 21-15  
 PERMIT NO. 22672

DEPT-ALBANY  
 STATE-DEPT. COUNTY-DEPT.  
 SECTION 21-14 TO 21-15  
 PERMIT NO. 22672

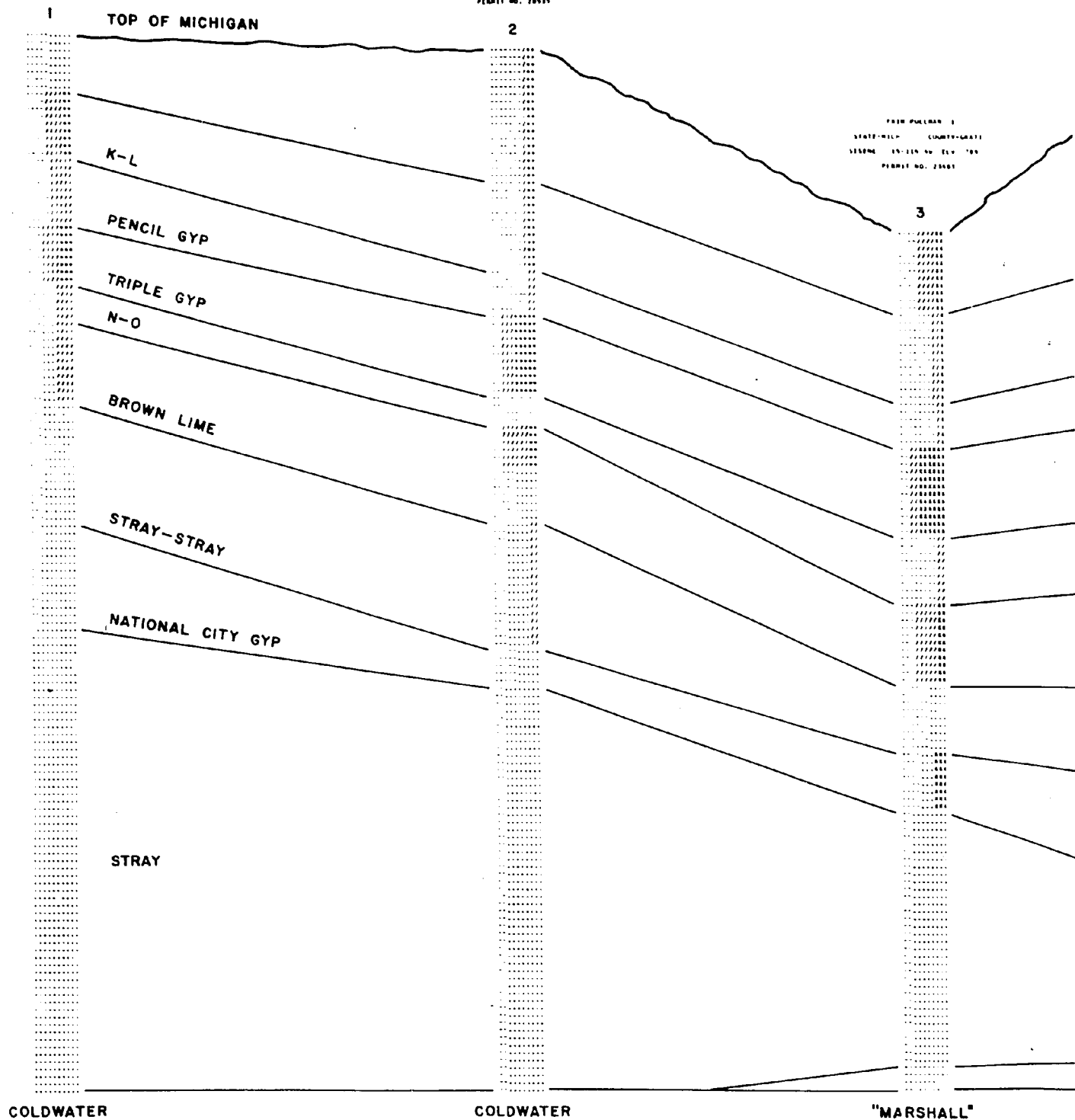
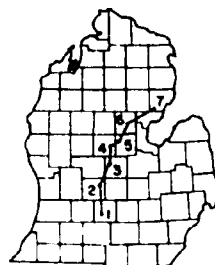


FIG  
 NE-SW STRATIGRAF  
 DATUM BAS

SECTION 4  
STATE-HIGH COUNTY-ROAD  
SECTION 17-18-19-20-21-22  
PERMIT NO. 11000



MAP

LEGEND

- XXX ANHYDRITE
- LLL LIMESTONE
- /// DOLOMITE
- SHALE
- ..... SAND
- ■ GYPSUM

SUMMIT HARBOR 21  
STATE-HIGH COUNTY-ROAD  
SECTION 17-18-19-20-21-22  
PERMIT NO. 11000

VERTICAL SCALE (FEET)



HORIZONTAL SCALE (MILES)



SECTION 6  
STATE-HIGH COUNTY-ROAD  
SECTION 17-18-19-20-21-22  
PERMIT NO. 11000

SECTION 7  
STATE-HIGH COUNTY-ROAD  
SECTION 17-18-19-20-21-22  
PERMIT NO. 11000

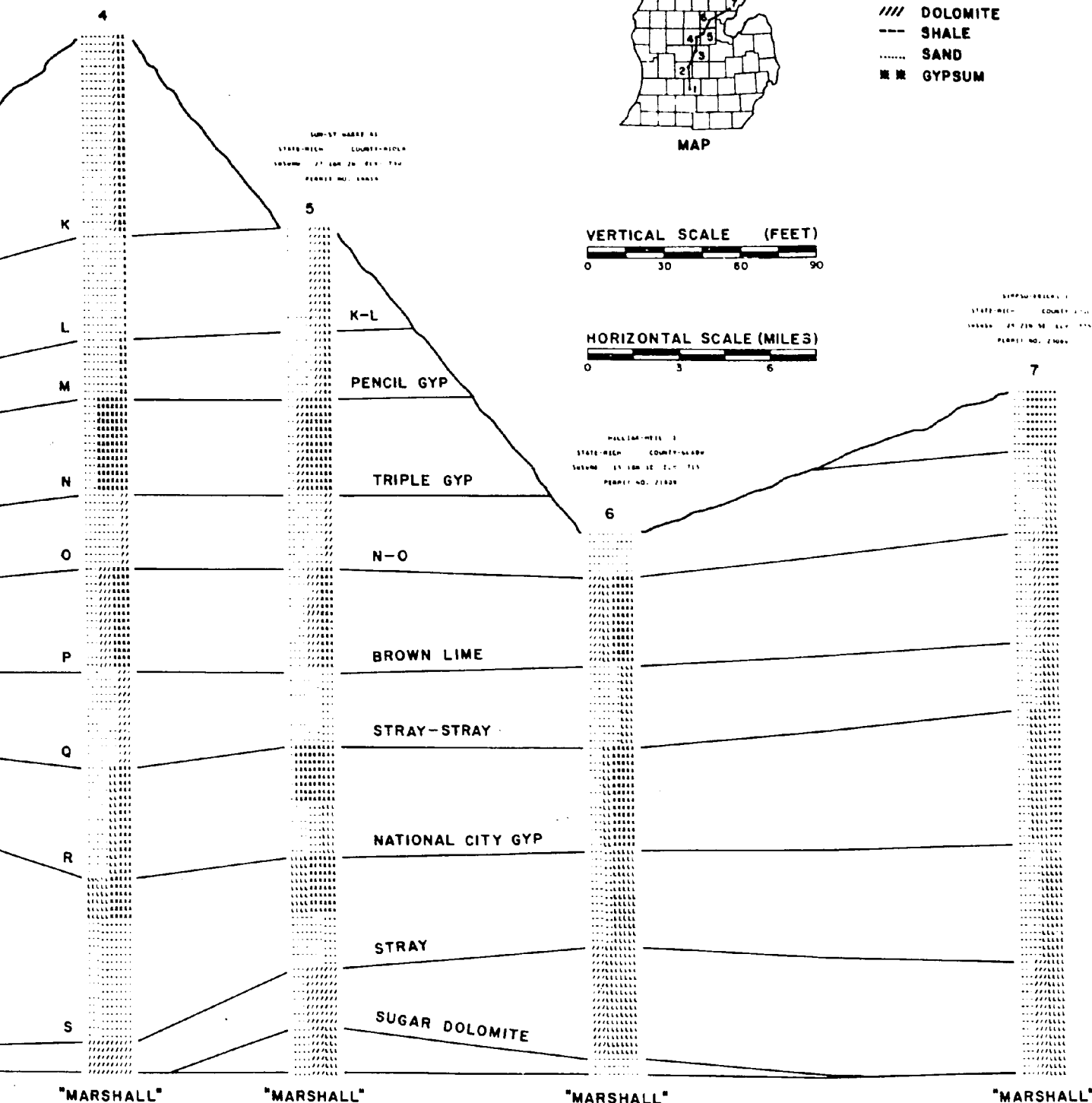


FIGURE 14  
GEOLOGIC CROSS SECTION  
OF MICHIGAN

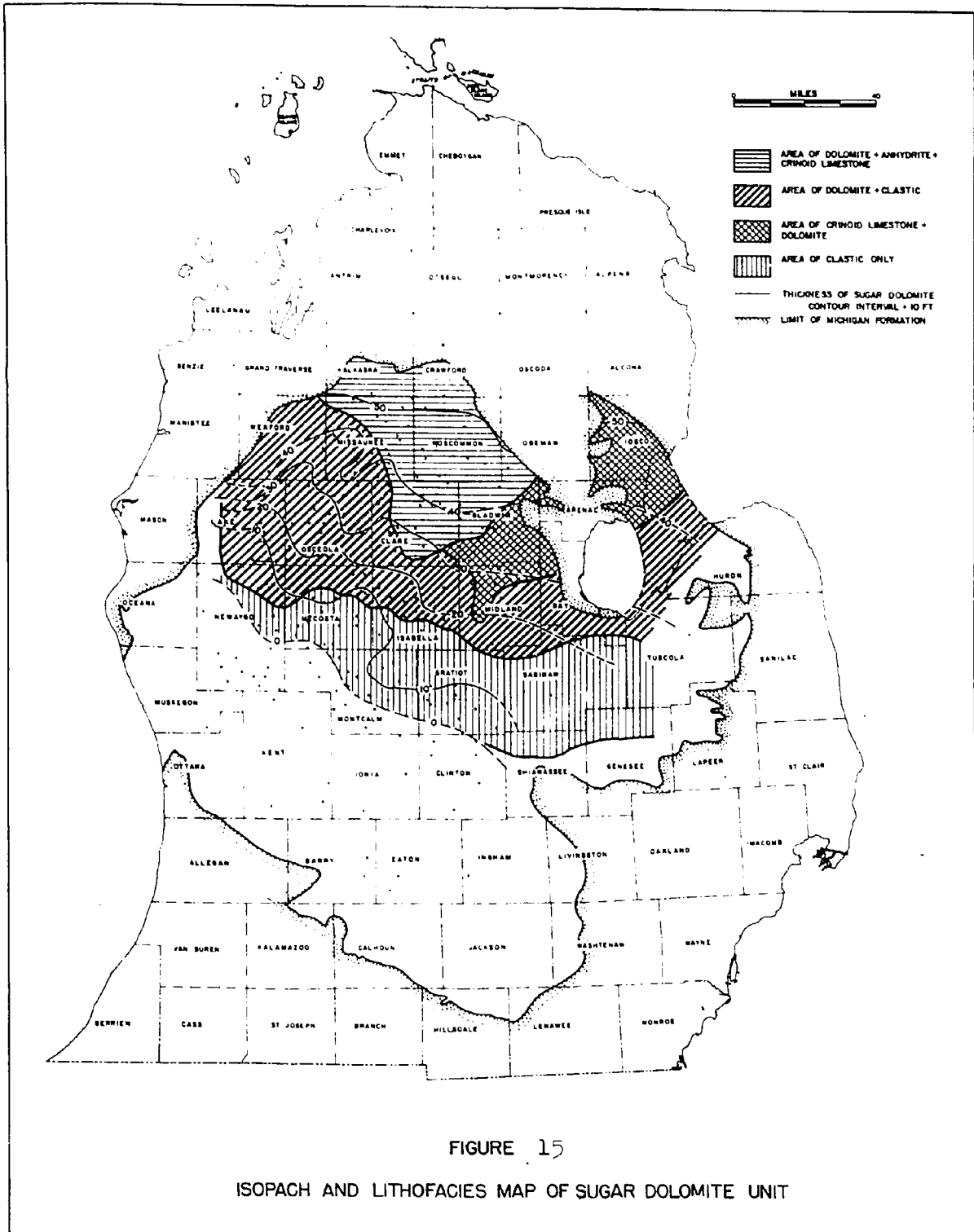
Overlaying the clastic sediment is a bed of dark brown, coarse grained dolomite. No structure was seen in the cuttings and it is therefore difficult to determine from the lithology alone to what extent the dolomite is primary or secondary. There is, however, an anhydrite bed on top of the dolomite, and the juxtaposition of the dolomite and the anhydrite indicates that at least part of the dolomite is a primary precipitate. The top of this anhydrite is the marker T, which is the upper boundary of Unit 1. The anhydrite grades shoreward through an anhydritic dolomite and dolomite into a carbonate sand. The distinctive electric marker can be traced through the lithologic change.

#### Sugar Dolomite (Unit 2)

The Sugar Dolomite derives its name from the characteristic dolomite which is dominant in this unit. Figure 15 is an isopach and lithofacies map of the unit. From a maximum of 58 feet in the north the Sugar Dolomite thins out to its depositional edge. The steeper rate of thinning in the northwest is suggestive of a much steeper depositional slope on this side of the basin.

The areal extent of the Sugar Dolomite is much greater than that of the previous unit because of the continuing transgression of the Michigan sea. Consequently, there is a crescent-shaped belt in which the Sugar Dolomite sits unconformably on the "Marshall," while in the remaining area it is underlain by Unit 1.

The lower part of the unit is composed of light and dark brown sucrosic dolomite and black fissile dolomitic shale. The upper section consists of a thin, continuous bed of fossiliferous limestone overlain by a bed of anhydrite. The limestone has a slightly larger areal extent than the anhydrite but they both grade laterally into dolomite.



The sucrosic dolomite has all the characteristics usually ascribed to a primary dolomite. It is fine grained, very thinly laminated and is closely associated with evaporites. The laminae are caused by vertical changes in the grain size and are between 2 and 5 millimeters thick. The structures are most clearly seen in cores but can be discerned in the cuttings when the chips are large. The fossiliferous limestone has an average thickness of only 7 feet but can be traced over a large area. Rominger (1876) describes outcrops of this limestone in Tuscola and Iosca counties. In Tuscola county the limestone contains numerous nodular concretions of sphalerite. However, because of its relative thinness it was described in only a handful of drillers logs. The principal fossil components are thin-shelled brachiopods and crinoids but only the crinoids can be distinguished in the cuttings. The two fossils are nearly mutually exclusive with the brachiopods concentrated toward the bottom of the bed. There is a small transition zone between the limestone and the anhydrite consisting of a black calcareous shale containing pockets of crinoids. In these pockets the crinoids appear to have died suddenly and been buried in situ. The component plates of individual stems are found close together like a pile of fallen poker chips.

The upper boundary of the Sugar Dolomite is put at the end of another cycle of evaporite deposition and the beginning of a new regressive phase in which the Stray sandstone was deposited.

The depositional history of the Sugar Dolomite can be interpreted as follows. The sea in the Michigan Basin was apparently never very deep. As a result, minor fluctuations in sea-level moved the shore line great distances and increased the inflow of normal marine water into the basin

over the submerged sill. One of these recurrent transgressive phases upset the delicate balance of anhydrite deposition which had been reached at the end of Unit 1. At first this resulted only in a reversal in the trend of evaporite deposition with the precipitation of dolomite but then the water sweetened sufficiently to sustain an animal population with the subsequent deposition of a bioclastic limestone. When the transgressive phase came to an end, the tectonic and climatic conditions again reached a steady state. The salinity changed rapidly causing the sudden death of the fossil community, followed by the deposition of anhydrite.

### Stray (Unit 3)

The name originated as a drillers term in the early 1930's and is first mentioned in the literature by Newcombe (1933). The name was applied to the gas producing sand in the Lower Michigan and the use of the expression "stray" was based on the belief that the sand was not a continuous body. This idea was later incorporated by Ball et al (1941) into the hypothesis that the Stray sands were offshore bars which developed against underwater shoals in a transgressing sea. Actually the concept of a discontinuous sand arose mainly from the drillers' practice of using the name Stray only when the sand contained gas. The continuity of the sand is today an accepted fact but the term Stray Sand is still confined to that area of Michigan bounded by the producing gas fields. As defined in this paper the Stray Unit contains the Stray sand of common usage and all the equivalent rocks as demarcated by markers R to S (fig. 8).

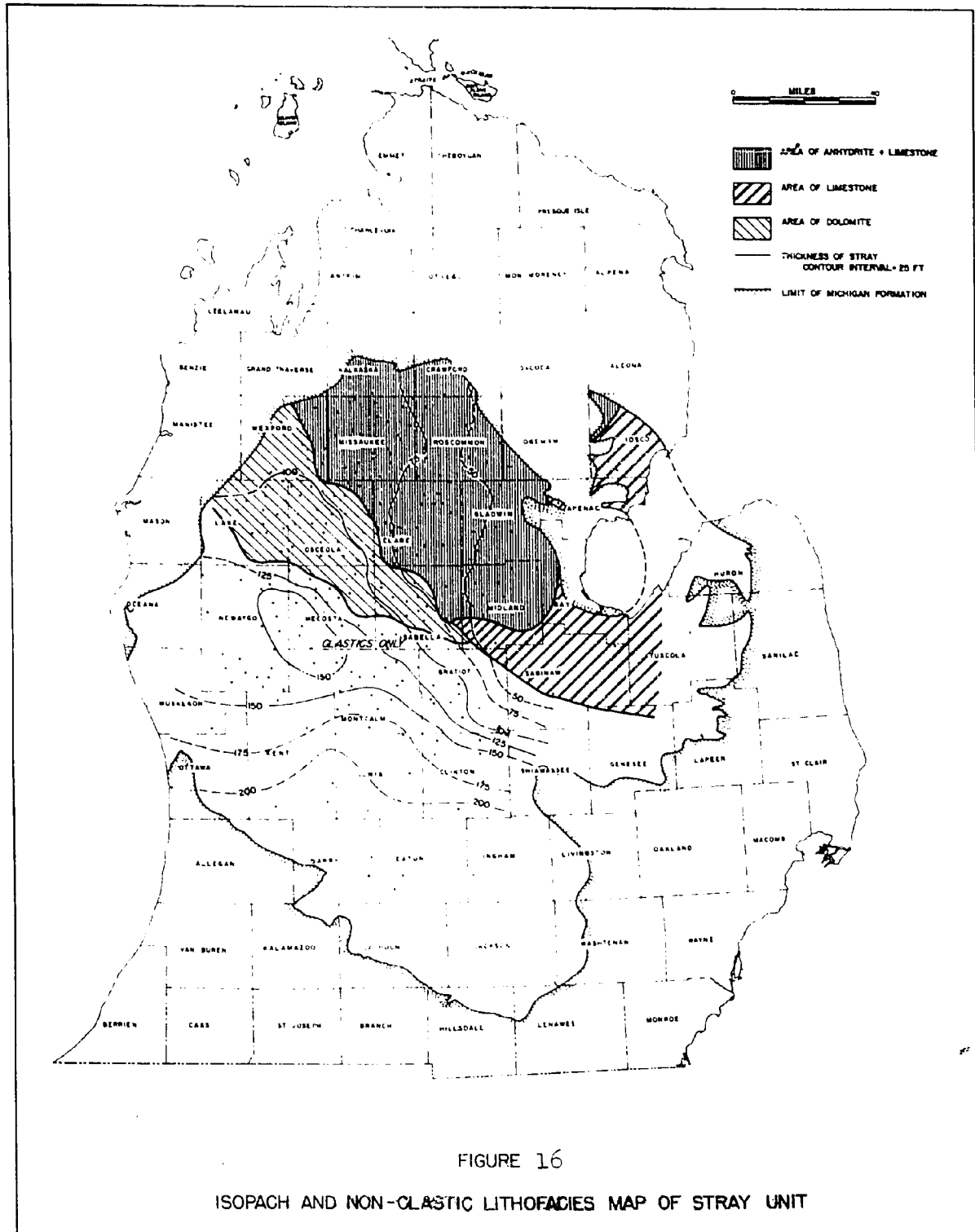
The problem of the stratigraphic relationships between the Stray and the surrounding rocks has been referred to previously. The difficulty

lay in the fact that to the northeast the sands grade into marine precipitates while to the southwest the thinning of the Sugar Dolomite unit below the Stray caused the early workers to jump the top of the "Marshall," i.e., the unit older than the Michigan, to the top of the Stray sand. In the present study it has been possible to throw some light on a previously confused picture.

The excellent control by mechanical logs made it possible to carefully trace the Stray Sand and its equivalents throughout the basin. In following the unit as it thickened to the southwest it soon became apparent that it gradually included more and more of what was called Marshall until finally it engulfed everything down to the Coldwater shale. Thus, the "Marshall" was missing in part of the basin. This is not unexpected when one considers that during the deposition of most of the Upper "Marshall" and Lower Michigan the southwest part of the state was undergoing erosion. The rate of thickening in the Stray Unit (fig. 16) is fairly even.

Figure 17 is a combination clastic percentage and sand isolith map. Clastic sediments predominate in the Stray. They are everywhere more than half the section and over a large area they are the only component. By far the largest clastic component is sand. To the northeast there is a gradual facies change and the sand slowly gives way to various types of limestones, shale and anhydrite. There is a small area of dolomite.

In the central part of the basin the sands are fine to medium grained, with minor amounts of shale and dark minerals. To the southwest these sands coarsen slightly and a fine grained, silty, hematitic sand appears. Although the hematitic sand usually underlies the gray



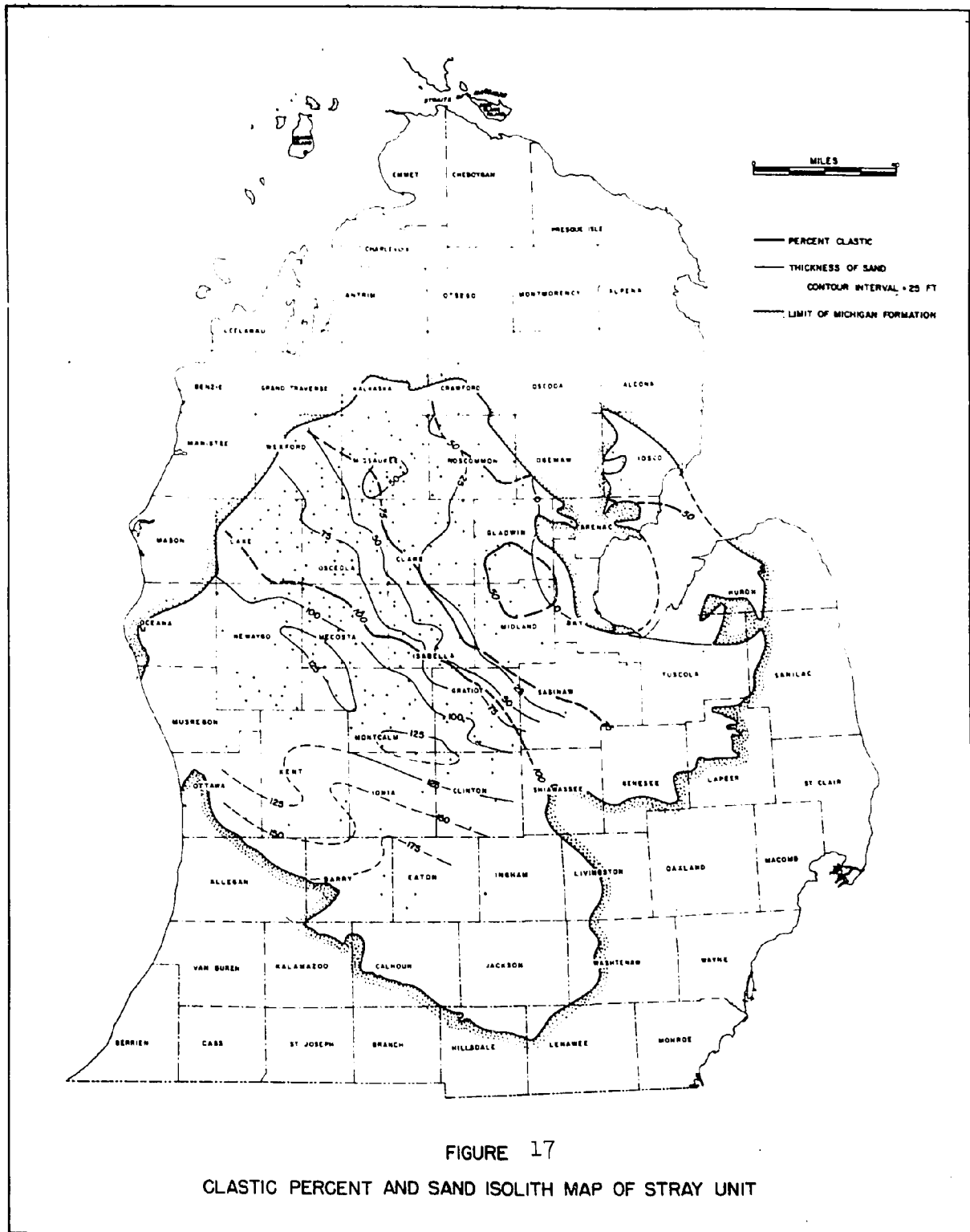


FIGURE 17

CLASTIC PERCENT AND SAND ISOLITH MAP OF STRAY UNIT

sand this is not always the case and often the position of the two sands is interchanged. Since the Stray sand is derived from the "Marshall" with very little additional transport or weathering, the two are similar in both appearance and content. It is possible to distinguish one from the other only by its relative position in the well.

The red color caused by the hematite (or limonite) coating on the grains was once considered an important stratigraphic marker. The variable vertical distribution of the color in the section is now recognized and its value as a marker discredited. The rapid change in the horizontal as well as vertical distribution of the red color suggest that it is due to variations in the oxidation potentials of the environment during deposition. Lateral differences in potentials are a feature of deltaic, estuarine and tidal environments. In addition, redeposition of the red sediments would tend to distribute the color further.

The non-clastic equivalents of the Stray in the northeast consist of dark, shaly, fine-grained limestones, white massive anhydrite and light brown, somewhat sandy dolomite. There is a complex relationship between these three lithologic types (fig. 16). There are two similar looking primary dolomites which were deposited in different phases of the evaporite cycle. The lower one is equivalent to the limestone. As the limestone precipitated the concentration of magnesium rose and when the critical calcium/magnesium ratio was reached, dolomite precipitated as a shore-ward facies of the limestone. The upper dolomite is equivalent to the anhydrite and was deposited as a result of the mixing of the brine with the water coming from the land.

The gas is produced from the upper part of the Stray sand, in small anticlinal traps. The area of gas production is confined to the north-

east by the zero isolith line of the sand, to the southeast by the zone of extensive erosion, to the northwest by the eroded edge of the Michigan, and to the southwest by the wedge edge of the "Marshall." This would indicate that the gas originated in the "Marshall" and moved up into the Stray as a result of the tectonic activity that was responsible for the structural traps.

#### Summary of Stray Deposition

The elevation of the land mass and the reopening of the basin was the product of a northeasterly epeirogenic tilt. As a result of increased erosion, the anhydrite at the top of the Sugar Dolomite gave way to a clastic phase. Initially the sands were deposited in a beach and near-shore environment but the creation of a deltaic front changed the character of the sand deposited. Upward movement of the sill restricted the water inflow anew, and contemporaneously with the deposition of clastics near shore, evaporitic rocks were precipitated towards the center of the basin.

#### National City Gyp (Unit 4)

The unit is exposed in quarries of the National Gypsum Company at National City in Iosco county, and is correlated to the subsurface by a number of wells in the vicinity. The gypsum at Alabaster is also quarried from the same unit. Gypsum is present in those areas where the anhydrite has been altered as a result of coming in contact with the ground water.

The conditions of sedimentation during the deposition of National City Gyp were similar to those that existed during the upper part of the Stray. The contact is placed at marker R (fig. 8) as a convenient break

between the predominant sand sequence below and the shale-anhydrite beds in the National City Gyp. Figure 18 shows the facies relationship in this unit. To the north the sediments are composed of massive anhydrite (or gypsum) interbedded with shale. This area was the central portion of the depositional basin. As is indicated on the composite electric log, there are three anhydrite beds of which the middle one is not only the thickest but has the greatest areal extent. In a shoreward direction there is a gradation from the sulfate to a carbonate facies. To the southwest a dolomite facies appears followed by a clastic facies while to the southeast the carbonate equivalent is limestone. Both carbonates are sandy as they approach the clastic facies. The limestones are dark gray, shaly and are very different from the light brown, medium grained dolomites. The lack of data to the southeast makes it difficult to ascertain the reasons for the differences in carbonate types in the two directions. The proximity of land could have been a factor. As indicated in figure 11 the transgressive Michigan sea moved very little to the southeast between the deposition of the Stray and the National City Gyp (Units 3 and 4).

This unit marks the first appearance of large quantities of shale, in association with non-shaly anhydrites in the Michigan Formation. Two important questions are: 1) What is the source for this shale? 2) What could cause the sudden cessation of anhydrite precipitation, followed by the deposition of shale, and then just as suddenly replace the shale with pure anhydrite again? The source of the shale is postulated to be the Coldwater Formation. During the deposition of the National City Gyp the Michigan sea continued its transgression onto the land. Much of the "Marshall" had been eroded previously and the underlying Coldwater shale

ISOPACH AND LITHOFACIES MAP OF NATIONAL CITY GYP UNIT

became a prime source of supply. It is of interest to note that there is little sand, but a great deal of shale in the units above the Stray. Climatic changes alone are sufficient to explain the shale-anhydrite sequence. During a humid phase the increased rainfall would bring a fresh influx of clastic debris into the basin and would serve as well to arrest the anhydrite deposition. When arid conditions returned, the carrying capacity of the streams would decrease rapidly and if the salt balance in the basin had not been drastically upset there would be a renewal of anhydrite precipitation. The importance of climate in this type of deposition has been cited by Hollingsworth (1962) and Anderson and Kirkland (1960).

The isopach map (fig. 18) shows a steady basinward thickening. This is a reflection of the slow sinking that the center of basin was undergoing. The slight reversal in the extreme southwest corner represents a zone of thick sand deposition, along the margins of the basin.

#### Summary of National City Gypsum Deposition

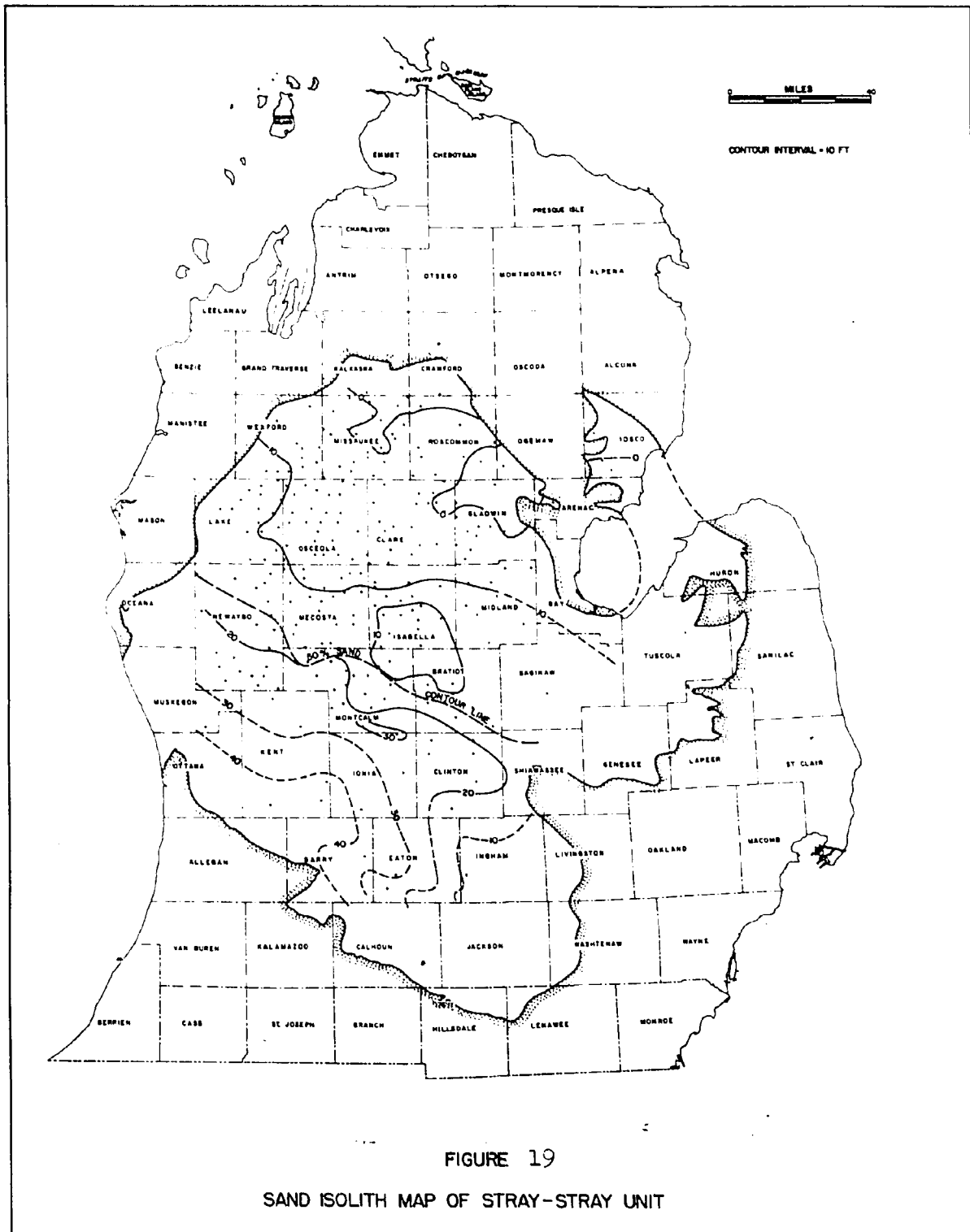
The size of the basin continued to grow, and during the deposition of this unit the strand line was in the vicinity of the present day outcrop in the southwest. Sand was deposited along the margins of the sea while anhydrite, dolomite and limestone were being precipitated basinward. There were periodic climatic changes on a scale similar to that of the Pleistocene. Successions of arid and humid periods gave rise to interbedded anhydrites and shales. The shale came mostly from the Coldwater Formation which had just been exposed to erosion.

### Stray-Stray

The Stray-Stray unit consists almost exclusively of gray to dark gray shales topped by a sandstone bed. This sandstone was mistakenly identified as the Stray sand in the early drillings for the Lower Michigan gas. When the error was recognized the term Stray-Stray was applied to the sand higher in the section. There is a small area of anhydrite deposition and isolated pockets of light brown, fine grained dolomite. The unit has fairly uniform thickness which ranges between 25 and 40 feet with only a slight thickening to over 50 feet in the southwest. As in the previous unit the thickening is caused by the increased sand deposition along the margins of the basin.

Figure 19 is a sand isolith map with the 50 percent sand contour line shown. The sands in the north are very fine grained, calcareous and contain large quantities of a green mineral closely resembling glauconite. The sand grades to the northeast into a sandy limestone which contains glauconite. To the southwest the sand is coarser, shaly and is void of glauconite. Although there are reports of gas from this unit there is as yet no commercial production.

The deposition of the shale was due to a long interlude of humid weather, similar to that which caused the deposition of clastic sediments in the National City Gyp. With the change in climate came decreased evaporation and more rainfall. This increased the erosive power and carrying capacity of the streams. The waters in the basin were apparently both shallow and quiet for the main body of coarse to medium sand was concentrated along the littoral zone and only the shales were carried into the basin. For a short period of time there was enough energy available to carry the very fine grained sand towards the center



of the basin. The top of this sand is taken as the upper boundary of the Stray-Stray. The environment was essentially open marine as witnessed by the glauconite but the areas of anhydrite deposition (fig. 11) indicate there were isolated spots where the salts reached a higher concentration. These were well into the center of the basin away from the influx of fresh water from the land.

#### Brown Lime (Unit 5)

The Brown Lime unit is an excellent example of the vertical and horizontal development of an evaporite facies. The vertical sequence is shale to carbonate to sulfate. Each of these beds can be traced horizontally over a large area, indicating very stable conditions of sedimentation. In the near shore environment they all grade gradually into a sandstone. The conditions of sedimentation during the deposition of the lower part of the unit were similar to those that prevailed during Stray-Stray deposition. The result was a consistent bed of gray shales throughout the basin. Since the shales are everywhere present they are not shown on the isopach and lithofacies map (fig. 20) of the Brown Lime.

The length of the humid stage in the climate which prevailed during the deposition of the shales, upset the equilibrium conditions, and the salts in the water were at nearly normal concentration. When the climate changed and evaporitic conditions returned, the first sediment to precipitate was a carbonate. The carbonate grades from a gray and brown lithographic limestone in the north to a brown, fine grained, sucrosic dolomite in the south. It is easily recognized on the mechanical logs and has long been used as a structural marker when drilling for the Stray sand. The common use of the carbonate bed as a marker gave the unit its name.

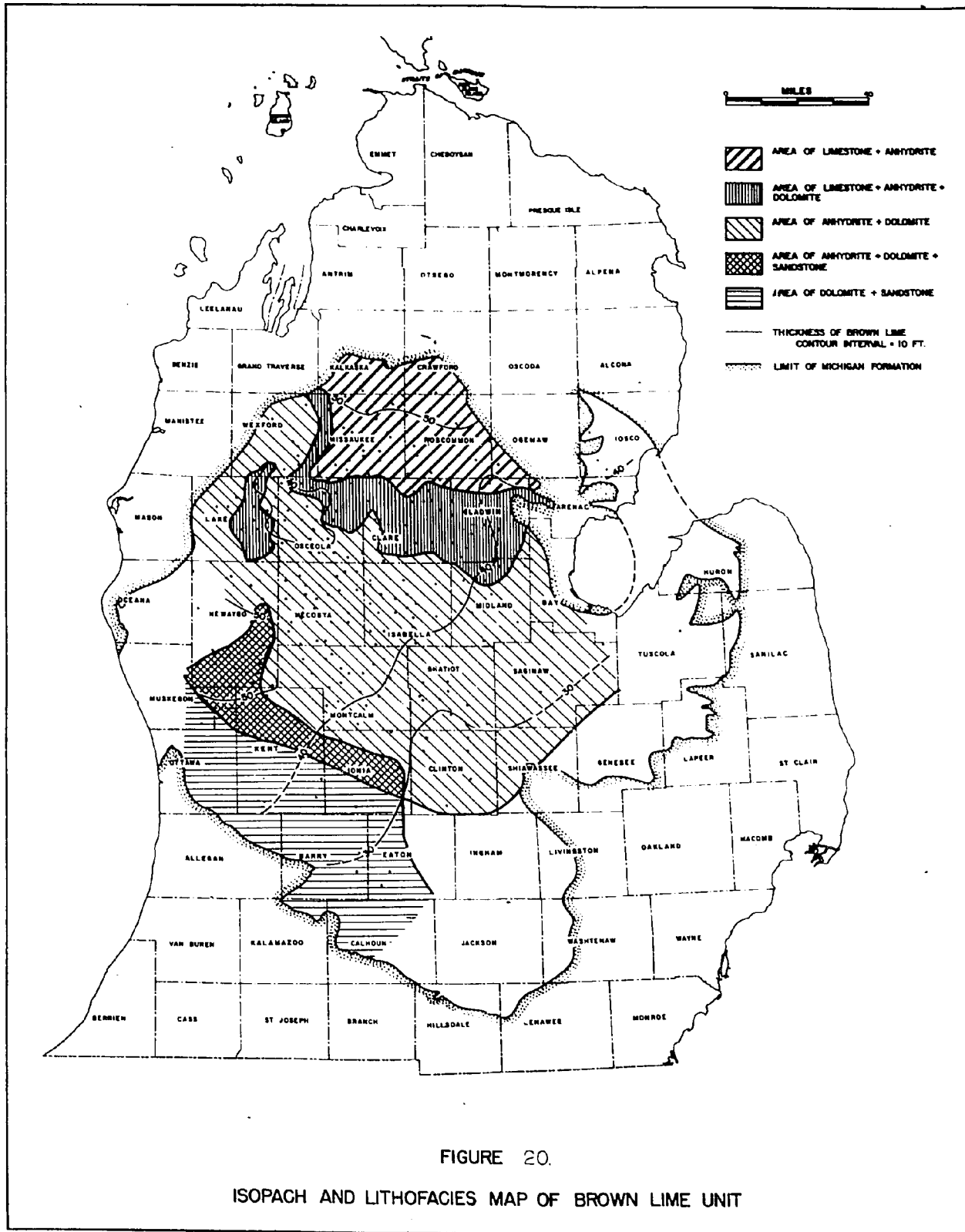


FIGURE 20.

ISOPACH AND LITHOFACIES MAP OF BROWN LIME UNIT

The top of the unit is a bed of massive anhydrite which is thickest in the north where it reaches a maximum of 15 feet. Over most of the central part of the basin it is less than 10 feet thick. To the southwest the anhydrite grades laterally through an anhydritic dolomite into sandy dolomite.

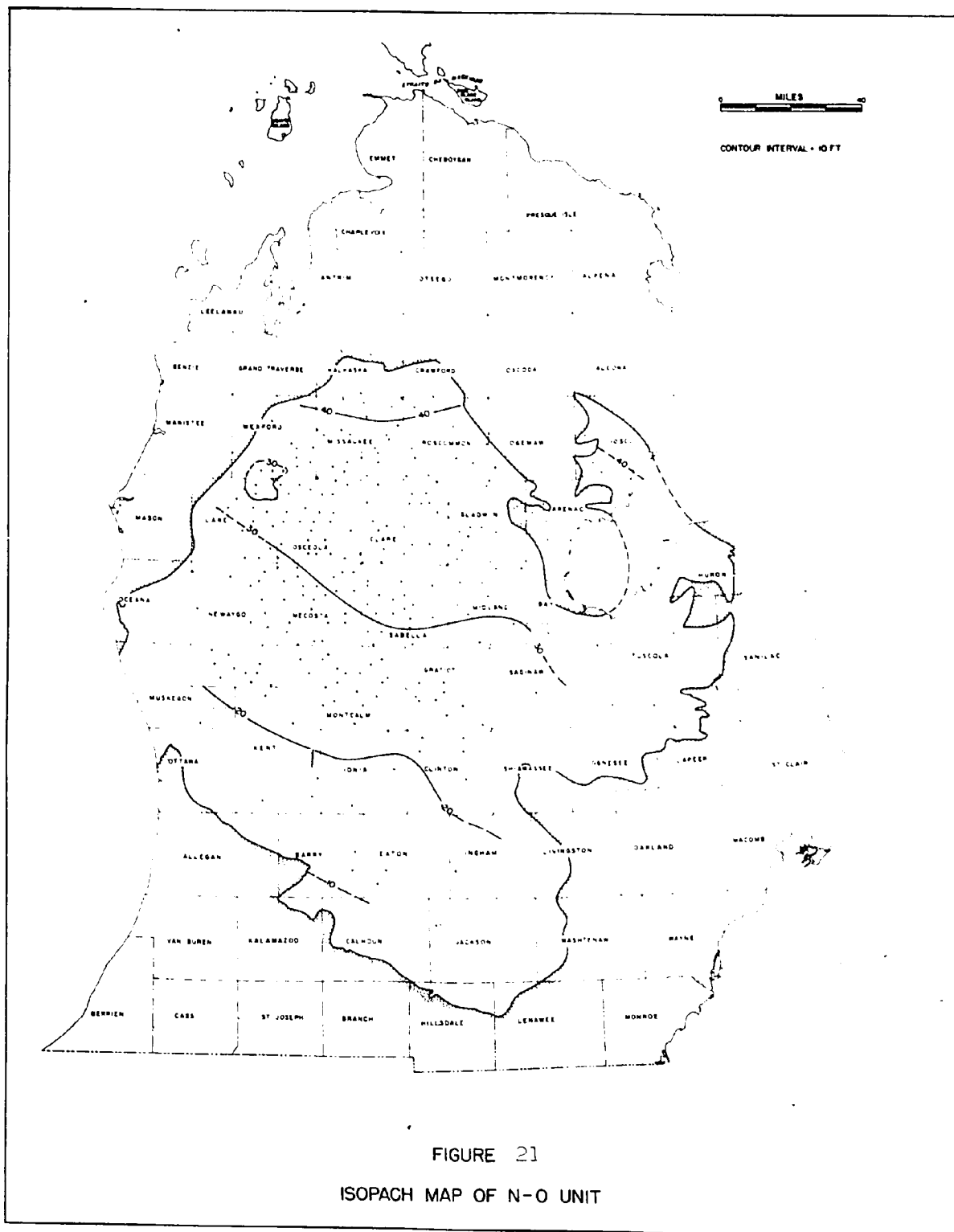
The isopach map (fig. 20) indicates that the central part of the basin received the most sediments. There is a regional thinning both to the southeast and southwest. The thickening along the western margin represents a zone of greater sand accumulation.

The deposition of the Brown Lime ends with yet another climatic change and a new influx of clay sized particles.

#### N - O

The predominant lithology in this unit is a massive gray shale. The shale percentage averages 85 and is never less than 70. The lower boundary is taken at the top of the anhydrite in the Brown Lime. In most places there is a transition zone between the anhydrite and the shale which consists of a fine grained, anhydritic, brown dolomite. The presence of the dolomite implies that the climatic change which brought about the new shale phase was gradual and that the relief of the land was low. Thus, the water was freshened sufficiently to bring about a reversal in the sequence of precipitation before the big influx of shale. There is a small range of concentrations where the carbonate and sulfate will coprecipitate.

There is no sand present in this unit or any of the higher units in the Michigan Formation. The isopach map (fig. 21) indicates a consistent thinning to the southwest. From the location of the 10 foot isopach it is apparent that the shoreline was not far from the present



outcrop and the lack of sand was caused by the absence of a source of supply. The "Marshall" which had been the main source for the sand in the lower Michigan, was either eroded or under the transgressing Michigan sea, during the deposition of this unit.

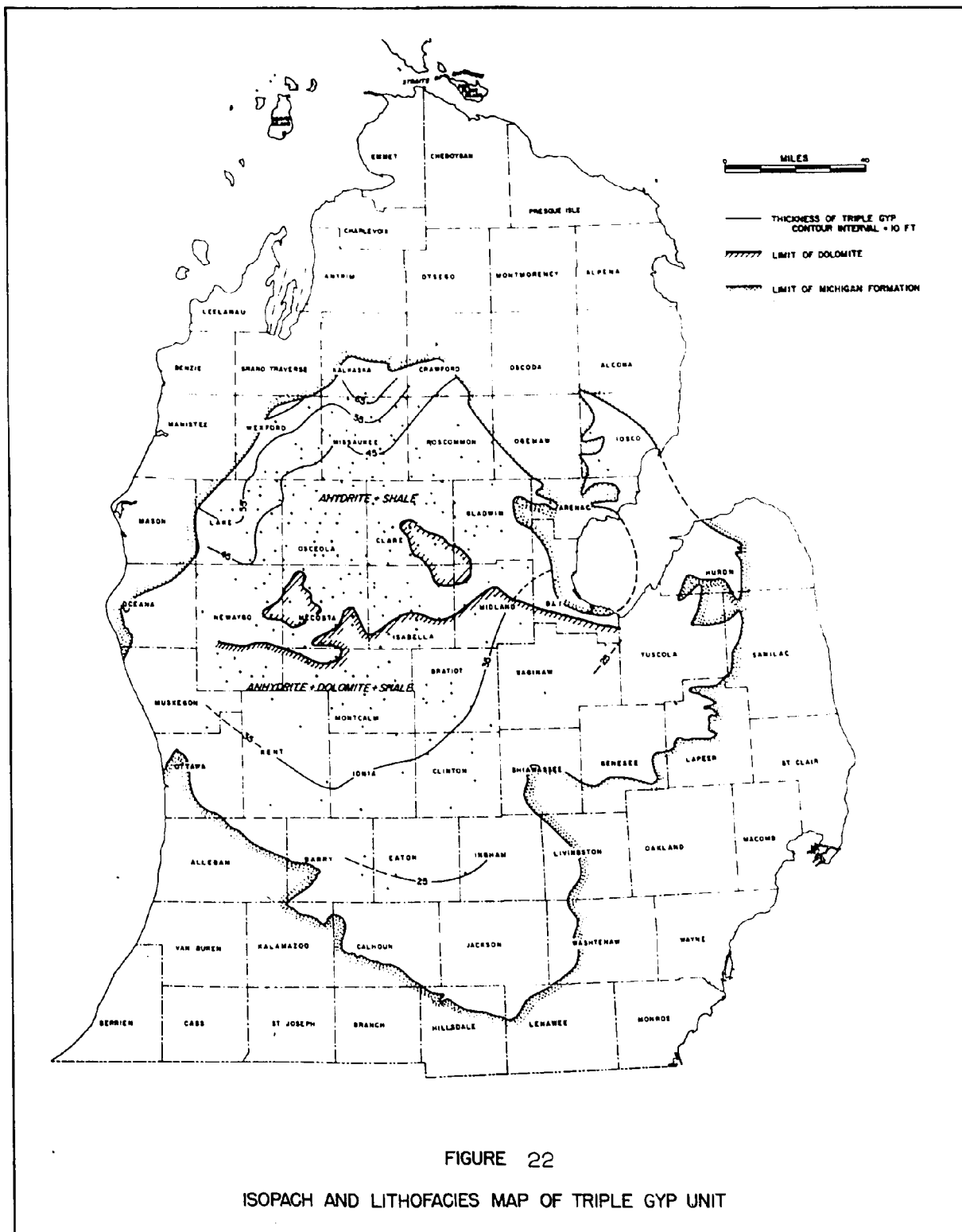
At the upper boundary (marker N) there is another small transition zone to the overlying anhydrite in the Triple Gyp. This zone, too, consists of a bed of fine grained, brown dolomite. In the middle of the basin there is a small area where anhydrite was deposited before the deposition of the Triple Gyp (fig. 11).

#### Triple Gyp (Unit 6)

The ingress of the Michigan sea onto the land culminated with the deposition of the Triple Gyp. The unit was named by the petroleum industry geologists for the three distinct electric log "kicks" (fig. 8) exhibited by the three massive anhydrite beds interbedded with two shale members. There are, in fact, thin shale separations within the individual anhydrites which do not show up on the electric log.

The anhydrite beds in the Triple Gyp have the greatest areal extent of any precipitate member in the Michigan Formation (fig. 11). They can be traced to the erosional edge of the formation, where the anhydrite alters to gypsum owing to the action of ground water. The Triple Gyp contains the gypsum which is mined at Grand Rapids. In the direction of the paleoshoreline some of the anhydrite grades into a brown, anhydritic dolomite (fig. 22).

The fortuitous find of a fossil shark spine in the Triple Gyp provided additional evidence for the hypothesis that the climate was the main cause for the interbedded shale and anhydrite (Dorr and Moser, 1963). The spine was found in an eight inch sandy shale layer within the main



gypsum bed at the mine of the Bestwall Gypsum Company in Grand Rapids. The specimen was embedded in a small pocket of medium, well rounded sand in association with an abundance of objects which have all the appearances of coprolites. An x-ray analysis showed that the coprolites were composed entirely of carbonapatite, which is usually of organic origin, while the shale was mainly illite with minor amounts of chlorite and traces of anhydrite. The shark belonged to a family which inhabited waters of normal marine salinity.

The locality of the mine was probably not far from the distal edge of the sea during the deposition of the Triple Gyp. During the precipitation of the anhydrite the salt-saturated waters would have been intolerable for the sharks. However, during the time represented by the shale partings, when climatic changes brought an increased influx of fresh water, the animals could enter the basin and live along the margins.

The isopach map of the unit (fig. 22) shows a thickening to the north where the center of the subsiding basin was situated. The shale is consistently between 20 and 30 percent of the total, the dolomite increases from its zero isolith line southward to a maximum of 30 percent, and the sulfate decreases from a maximum of 80 percent in the north to 50 in the south.

#### Pencil Gyp (Unit 7)

The use of the name Pencil Gyp for this unit has a history which goes back to the beginnings of the gypsum industry in Grand Rapids. Grimsley (1904b) recounts that the quarrymen in the area referred to a 4 inch red gypsum layer as the pencil rock. Much later the subsurface geologists applied the term "pencil gyp" to any red colored anhydrite or gypsum in the Michigan Formation, irrespective of the stratigraphic

position. The present study has shown that although there is a spotty distribution of red anhydrite in most of the upper part of the Michigan Formation, 90 percent is concentrated in a continuous bed above the Triple Gyp. Therefore, the name Pencil Gyp is considered to be appropriate for the unit overlying the Triple Gyp.

The unit consists mainly of gray shales intercalated with anhydrite and brown dolomite. To the northeast the dolomite grades into white anhydrite. The isopach map (fig. 23) shows the prevalent northward thickening. The percentage of carbonate plus sulfate decreases while the shale percentage increases in the direction of the clastic source. In parts of Gladwin and Midland counties the Pencil Gyp was removed prior to the deposition of the Bayport Formation (fig. 9). A period of pre-Bayport erosion was noted and described by Addison (1940), Landes (1944) and Cohee et al (1951).

The anhydrite in this unit is not as widely distributed as that in the Triple Gyp (fig. 11). This most likely reflects a less pronounced climatic change than took place before the deposition of the Triple Gyp evaporites. The red color of the anhydrite grades to white in a southerly direction (fig. 23). The origin of the red color remains an unsolved problem. Newcombe (1933) suggested that it was caused by disseminated iron, which was brought by streams that were flowing into the basin from the northwest over the iron formations. Grimsley (1904b) noted that chemical analyses failed to disclose more iron in the red than in the white anhydrite. The possibility that the color is due to crystal defects is discounted by the fact that the red anhydrite in the subsurface can be traced to gypsum at the surface, which has the identical tone of red. The two minerals belong to different crystal systems and it is



unlikely that a crystal defect could be passed on in the transformation process. It is suggested that a detailed x-ray fluorescence study would provide the data to answer the question.

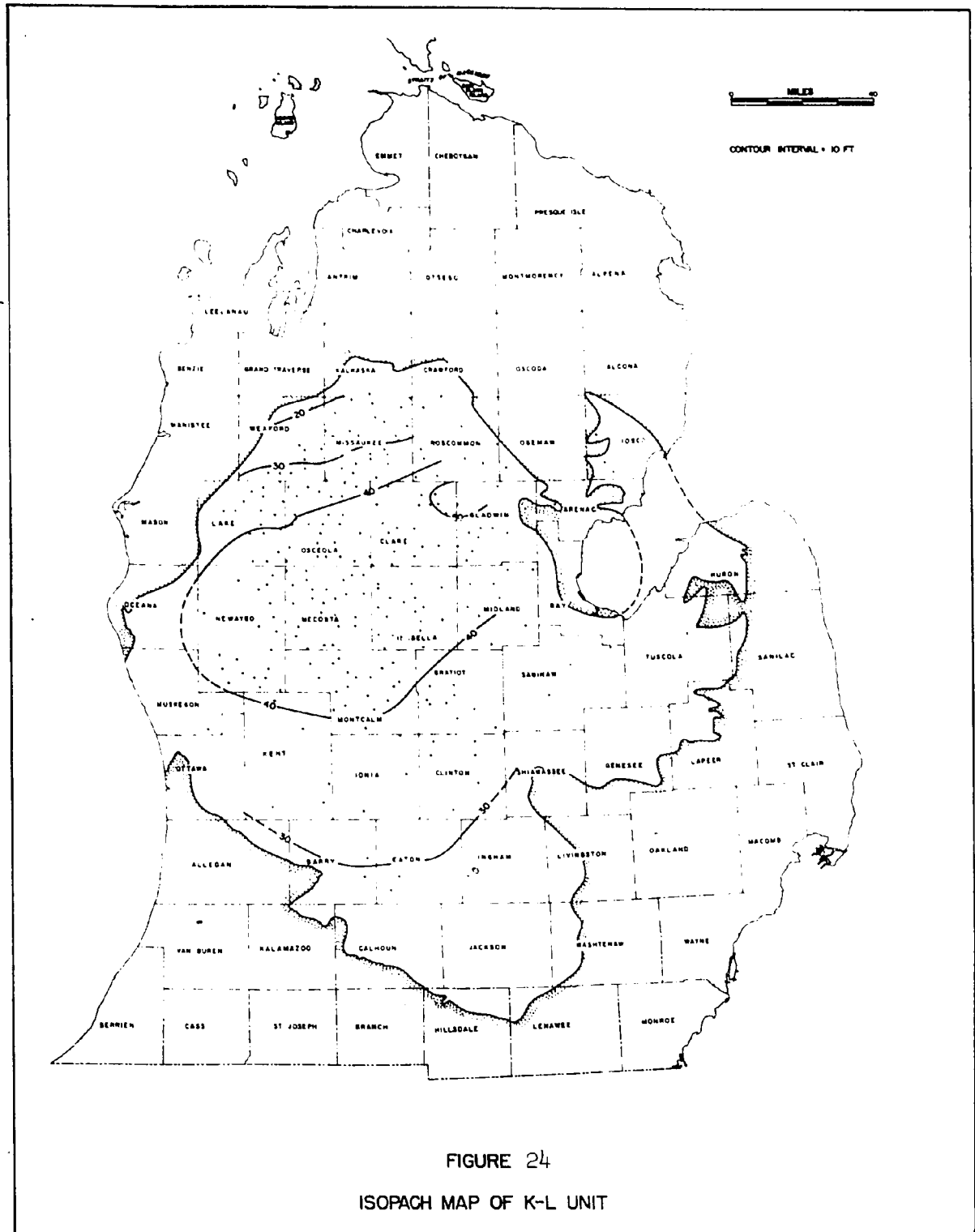
#### K - L (Unit 8)

The basic shale-anhydrite-dolomite alterations, typical of the upper part of the Michigan Formation, continue during the deposition of Unit 8. There are, however, important signs both in lithology and in isopach patterns, of the impending termination of those environmental conditions which gave rise to the clastic-precipitate cyclicity.

The intervals of evaporite deposition were becoming much shorter. The percentage of shale in this unit increases rapidly from 40 percent in the north to over 70 percent in the southern areas. The only consistent anhydrite bed is the one at the bottom of the unit at marker L. There are a number of small, discontinuous occurrences of anhydrite higher in the unit. These can usually be traced over a few townships only and grade laterally into dolomite. In the eastern part of the state, part or all of the unit is missing due to pre-Bayport erosion (fig. 9), and just along the margin of the missing area the anhydrites of Unit 8 have a high shale content. The isopach map (fig. 24) indicates that the size of the basin was decreasing. The northern edge was not far from the present day outcrop area and the center had shifted southward.

#### Top of Michigan - K (Unit 9)

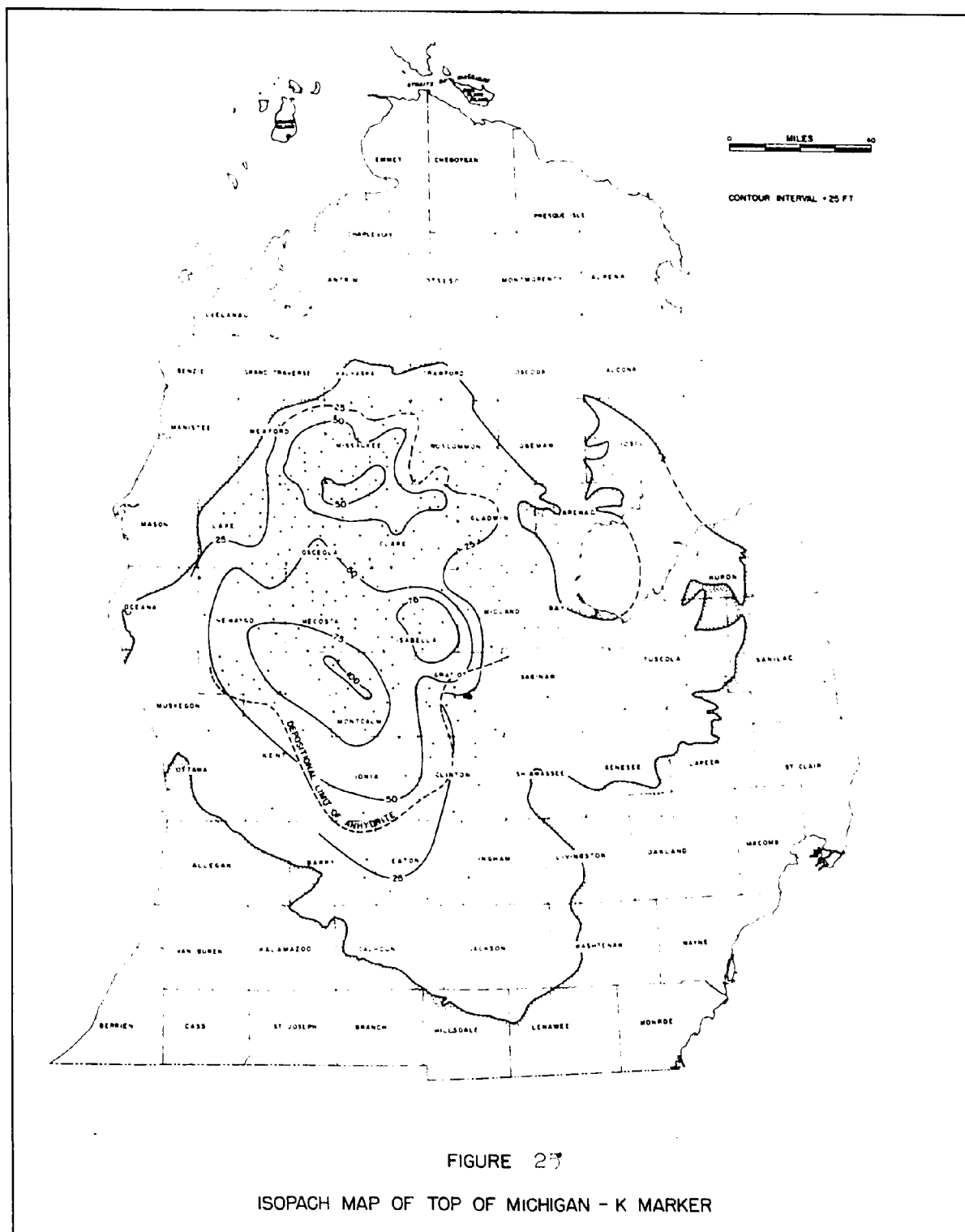
The top of the Michigan Formation is represented by a disconformity surface. An abrupt change in depositional environment marks the contact between the Michigan and the overlying rocks. The stratigraphy of the overlying strata is not well known. They have generally been assigned



to the Bayport Formation but the multiplicity of lithologic types and their irregular distribution makes it apparent that the relationships are more complex. McGregor (1954) and Newcombe (1933) describe the Bayport as consisting of limestone, sandy limestone, dolomite, sandstone, shale and chert. Notwithstanding the stratigraphic problem it is fairly simple to pick the top of the Michigan both in the samples and on the mechanical logs.

The top unit of the Michigan Formation can be subdivided into two members. The lower precipitate member is composed of red and white anhydrite which grades into a light brown dolomite. The distribution of the red color shows no pattern as it did in the Pencil Gyp. Because this unit is below an unconformity, the anhydrite has been hydrated to gypsum in many wells. The upper member is predominantly gray and green shale with localized development of anhydrite and dolomite. Owing to erosion the thickness of the upper member varies greatly and this is reflected in the isopach map of the total unit (fig. 25).

The isopach map also shows the depositional limit of the anhydrites in this unit. A comparison of this map with the paleogeologic map (fig. 9) reveals much on the tectonic activity that was responsible for the re-opening of the basin to the open oceans. A series of northwest trending en echelon folds began to form in Ogemaw, Gladwin, Midland and Gratiot counties at the end of the deposition of the K-L unit. These anticlines continued to grow during the deposition of the uppermost unit in the Michigan Formation and by their presence controlled the distribution of anhydrite precipitation. Towards the end of the Michigan the anticlinal areas were well out of water and the upper part of the formation was being eroded off. The greatest erosion took place across the tops of



the anticlines and their extensions into Clare and Missaukee counties, while the area in southwest Michigan was least effected. The temporary retreat of the sea from the whole basin marked the end of Michigan Formation deposition for when the water returned normal marine conditions prevailed.

## CONCLUSIONS

By dividing the total interval of the Michigan Formation into a number of smaller units it was possible to obtain a clearer picture of the geologic history of the Michigan Basin during the deposition of this formation.

The period of deposition which preceded the Michigan Formation had its climax in a widespread regression of the seas from the basin and produced a profound unconformity between the Michigan and the Coldwater everywhere in the basin and a complete hiatus between these two units in southwest Michigan.

During the deposition of the Michigan Formation the basin was enclosed by land on all sides except to the northeast. In this direction lay the connection with the open ocean. A tectonic sill in the vicinity of the connection was the cause of restricted water exchange between the basin and the ocean. The sill combined with climatic changes resulted in clastic-precipitate cycles of deposition. During the arid phase evaporites were precipitated while during the humid phases sands and shales were deposited. The source of the clastic sediments lay mainly in the land margins of the basin.

The evaporite deposits of the Michigan Formation consist predominantly of dolomite-anhydrite sequences with some limestone-anhydrite and dolomite-limestone cycles. No salt was found and the available evidence indicates that the waters did not reach the salt precipitating stage.

The Michigan sea transgressed gradually into the basin from the northeast with only minor regressive movements during the deposition of the Stray and Stray-Stray units. The transgression reached its apex during the deposition of the Triple Gyp unit. This slow shelfward

expansion caused the sand-evaporite margin to lie progressively southward. The center of the depositional basin during Michigan times was in the area of the present northern edge of the formation and only the southern half of the deposited sediments remain.

The deposition of the Michigan Formation terminated as a result of epeirogenic activity which was strongest in the eastern parts of the state. This eventually resulted in a complete withdrawal of the seas from the Michigan Basin for a short period. Along a series of an echelon folds in eastern Michigan much or all of the Michigan Formation was removed prior to the return of the sea and the deposition of the overlying Bayport Formation.

# APPENDIX A

COMPUTER PROGRAM TO COMPUTE THE RECTANGULAR  
COORDINATES OF A WELL FROM THE GEOGRAPHIC  
LOCATION

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R
R
R  PROGRAM--- COORD
R
R  COORDINATE CONVERSION PROGRAM
R  PROGRAMMER--- FRANK MOSER / UNIV. OF MICHIGAN / GEOLOGY
R
R  THE PROGRAM COMPUTES THE RECTANGULAR COORDINATES
R  OF A WELL FROM THE SEC.-TWP-RANGE AND THE COORDINATES
R  OF THE SOUTH-EAST CORNER OF THE TOWNSHIP
R
R  DIMENSION XMAT(1846,D),YMAT(1846,D),QRT(6),FQRT(6)
R  INTEGER XSEC,YSEC,SEC,TWPN,RNGN,PERM,X1,Y1,L,U,W,A,B,D
R  INTEGER TWP,RNG,QRT,COMA,COMB,FARM,STATE,COUNTY,ELV
R  VECTOR VALUES D=2,1,38
R  VECTOR VALUES XSEC(1)=0,1,2,3,4,5,5,4,3,2,1,0,0,1,2,3,4,5,5,4
R  1,3,2,1,0,0,1,2,3,4,5,5,4,3,2,1,0
R  VECTOR VALUES YSEC(1)=5,5,5,5,5,5,4,4,4,4,4,4,3,3,3,3,3,2,2
R  1,2,2,2,2,1,1,1,1,1,1,0,0,0,0,0,0
R  READ FORMAT DATA,XMAT(1)...XMAT(1824)
R  READ FORMAT DATA,YMAT(1)...YMAT(1824)
R  VECTOR VALUES DATA=$18F4.0  *$
R  M=94./12.
R  H=M*2.
START READ FORMAT INFO,COMA,COMB,FARM,STATE,COUNTY,SEC,TWPN,TWP,
1RNGN,RNG,QRT(1)...QRT(6),PERM,ELV
R  VECTOR VALUES INFO=$2C6,C3,C4,C5,2I2,C1,I2,7C1,I5,I4  *$
R  WHENEVER SEC.E. 0, TRANSFER TO ERR
R  WHENEVER TWP.E.$N$
R  A=40-TWPN
R  OR WHENEVER TWP.E.$S$
R  A=39+TWPN
R  OTHERWISE
R  TRANSFER TO ERR
R  END OF CONDITIONAL
R  WHENEVER RNG.E.$W$
R  B=22-RNGN
R  OR WHENEVER RNG.E. $E$
R  B=21+RNGN
R  OTHERWISE
R  TRANSFER TO ERR
R  END OF CONDITIONAL
R  THROUGH S, FOR L=1,2,L.G.5
R  WHENEVER QRT(L).E.$N$
R  FQRT(L)=1.
R  OR WHENEVER QRT(L).E.$S$
R  FQRT(L)=-1.
R  OTHERWISE
R  FQRT(L)=0.
R  END OF CONDITIONAL

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WHENEVER QRT(L+1).F.30$
  FQRT(L+1)=1.
OR WHENEVER QRT(L+1).F.31$
  FQRT(L+1)=-1.
OTHERWISE
  FQRT(L+1)=0.
S  END OF CONDITIONAL
  WHENEVER XSEC(SEC).E.5.AND.XMAT(A,B)-XMAT(A,B-1).G.94.
  N=XMAT(A,B)-XMAT(A,B-1)-(10.*M)
  X=XMAT(A,B)-(M*10.)-(1.5*N)+((N/4.)*FQRT(6))+((N/8.)*FQRT(4))
  1+((N/16.)*FQRT(2))
  OTHERWISE
  X=XMAT(A,B)-M-(H*XSEC(SEC))+((M/2.)*FQRT(6))+((M/4.)*FQRT(4))
  1+((M/8.)*FQRT(2))
  END OF CONDITIONAL
  WHENEVER SEC.L.7.AND.YMAT(A-1,B)-YMAT(A,B).G.94.
  N=YMAT(A-1,B)-YMAT(A,B)-(10.*M)
  Y=YMAT(A,B)+(M*10.)+(1.5*N)+((N/4.)*FQRT(5))+((N/8.)*FQRT(3))+
  1+((N/16.)*FQRT(1))
  OTHERWISE
  Y=YMAT(A,B)+M+(H*YSEC(SEC))+((M/2.)*FQRT(5))+((M/4.)*FQRT(3))
  1+((M/8.)*FQRT(1))
  END OF CONDITIONAL
  WHENEVER ((A.G.19.AND.A.L.39).AND.(B.E.22.OR.B.E.30)).OR.
  1((A.G.41.AND.A.L.45).AND.(B.E.25.OR.B.E.30))
  EXECUTE ROTATE.(B,B+1)
  OTHERWISE
  EXECUTE ROTATE.(B-1,B)
  END OF CONDITIONAL
  X1=X
  Y1=Y
  PRINT FORMAT RESULT,PERM,X1,Y1
  VECTOR VALUES RESULT=$1H0,S38,318      *$
  PUNCH FORMAT RESUL, COMA,COMB,FARM,STATE,COUNTY,SEC,TWPN,TWP,
  1RNGN,RNG,QRT(1)...QRT(6),PERM,ELV,X1,Y1,PERM
  VECTOR VALUES RESUL=$2C6,C3,C4,C5,212,C1,12,7C1,15,314,S16,
  12H01,15      *$
  TRANSFER TO START
ERR PRINT FORMAT MISTAK,COMA,COMB,FARM,STATE,COUNTY,PERM
  VECTOR VALUES MISTAK=$1H0,5C6,S3,18, /50H ILLEGAL OR MISSING
  1SPECIFICATIONS IN SEC-RWP-RNG      *$
  TRANSFER TO START
R
R  INTERNAL FUNCTION---ROTATE
  INTERNAL FUNCTION(W,U)
  ENTRY TO ROTATE.
  WHENEVER .ABS.(YMAT(A,U)-YMAT(A,W)).L.1.,TRANSFER TO NOROT
  ALPHA=ATAN.(.ABS.((YMAT(A,U)-YMAT(A,W))/(XMAT(A,U)-XMAT(A,W))
  1))
  BETA=ATAN.((Y-YMAT(A,B))/(XMAT(A,B)-X))
  WHENEVER YMAT(A,U).L.YMAT(A,W),ALPHA=-ALPHA
  R=SQRT.(((Y-YMAT(A,B)).P.2)+(XMAT(A,B)-X).P.2)
  Y=YMAT(A,B)+(SIN.(BETA-ALPHA)*R)
  X=XMAT(A,B)-(COS.(BETA-ALPHA)*R)
NOROT FUNCTION RETURN
  END OF FUNCTION
  END OF PROGRAM

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## APPENDIX B

COMPUTER PROGRAM TO PREPARE WELL LOGS FROM  
CODED WELL DATA

E1

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E5      READ FORMAT TITLE,COMA,COMB,FARM,STATE,COUNTY,SEC,TWP,NS,
1RNGE,EW, QRT, PERM,ELV,XCORD,YCORD
VECTOR VALUES TITLE=$2C6,C3,C4,C5,2I2,C1,I2,C1,C6 ,I5,I4,2I5
1*$
PRINT FORMAT T'
VECTOR VALUES TP=$///// *$
WHENEVER COL.L.O
PRINT FORMATHEAD1,COMA,COMB,FARM,STATE,COUNTY,QRT,SEC,TWP,NS,
1RNGE,EW,ELV,PERM ,6* LOG, LOG
VECTOR VALUESHEAD1=$1H1,S10,2C6,C3, //S 4,6HSTATE-,C4,S6,7HCOU
INTY-,C5, //S 3,C6,S3,I2,1H-,I2,C1,I2,C1,S2,4HELV-,I4, //S10,11H
1PERMIT NO. I5, //, S16,5HSCALE/,S12,9H 1 INCH= 12,5H FEE
1T/,S12,9H 1 LINE= 12,5H FEET // *$
TRANSFER TO BEGIN
END OF CONDITIONAL
PRINT FORMAT HEAD,COMA,COMB,FARM,STATE,COUNTY,QRT,SEC,TWP,NS,
1RNGE,EW,ELV,PERM
VECTOR VALUES HEAD=$1H1,S52,2C6,C3, //S46,6HSTATE-,C4,S6,7HCOU
INTY-,C5, //S45,C6,S3,I2,1H-,I2,C1,I2,C1,S2,4HELV-,I4, //S52,11H
1PERMIT NO. I5 *$
WHENEVER LOG .E.O
PRINT FORMAT PAGE
VECTOR VALUES PAGE=$1H4,S7,4HUNIT,S9,6HSUBSEA,S4,12HDEPTH TO
1TOP, S15, 9HLITHOLOGY // *$
OTHERWISE
PRINT FORMAT SCAL,6*LOG,LOG
VECTOR VALUES SCAL=$1H0,S58,5HSCALE/,S54,9H 1 INCH= 12,5H FEE
1T/,S54,9H 1 LINE= 12,5H FEET // *$
END OF CONDITIONAL
BEGIN   ZZ=0
        XX=0
        BT=0B
        THROUGH LOOP, FOR I=1,1,BT
            READ FORMAT INFO, MATRIX(I,1)...MATRIX(I,55)
            BT=MATRIX(I,1 ).L.O
            WHENEVER MATRIX(I,55).NE.O
                READ FORMAT INFO2,MATRIX(I,56)...MATRIX(I,58)
                XX=XX+1
            END OF CONDITIONAL
LOOP    VECTOR VALUES INFO=$2I5,4I1,3(3I2,13I1),I1*$
        VECTOR VALUES INFO2=$S6,I4,2C6 *$
        QQ=I-2
        THROUGH REPT, FOR J=1,1,J.G.QQ
            WHENEVER MATRIX(J,2).NE.O
            WHENEVER(MATRIX(J,2).NE.MATRIX(J+1,1).AND.J.NE.QQ).OR.MATRIX(
1J,2).LE.MATRIX(J,1)
            PRINT FORMAT CMNT
            TRANSFER TO GOON
            END OF CONDITIONAL
            OTHERWISE
            WHENEVER LOG.NE.O
            PRINT FORMAT BOTTOM,MATRIX(J,57),MATRIX(J,58),MATRIX(J,1)
            VECTOR VALUES BOTTOM=$1H9,S3,2C6,S14,1H-,I5 *$
            OTHERWISE
            PRINT FORMAT BOTTM2,MATRIX(J,57),MATRIX(J,58),ELV-MATRIX(J,1)
1,MATRIX(J,1)
            VECTOR VALUES BOTTM2=$1H0,S5,2C6,S4,I6,S5,I5 *$
            END OF CONDITIONAL
            TRANSFER TO GOON

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END OF CONDITIONAL
WHENEVER LOG.E.0, TRANSFER TO NOLOG
TEN=MATRIX(J,4)+MATRIX(J,5)+MATRIX(J,6)
WHENEVER MATRIX(J,3).E.1.AND.TEN.NE.C.OR.(MATRIX(J,3).C.E.1.AN
10.TEN.NE.10 )
PRINT FORMAT CMNT
VECTORVALUES CMNT=$44H      TCH, TCH, TCH, ---PARTLY PUNCHED C
1ARD      *$
TRANSFER TO GOON
END OF CONDITIONAL
N=1
WHENEVER MATRIX(J,3).E. 0
THROUGH C, FOR Z=1,1,2.G.10
C FORM(Z)=$ $
DESC(N)=$ $
N=N+1
TRANSFER TO NEXT
END OF CONDITIONAL
WHENEVER MATRIX(J,3).E.1.OR.(MATRIX(J,3).E.0.AND.MATRIX(J,23)
1.E.MATRIX(J,7))
THROUGH C1, FOR Z=1,1,2.G. 10
C1 FORM(Z)=SYMBOL(MATRIX(J,7))
OR WHENEVER MATRIX(J,3).E.2
WHENEVER MATRIX(J,7).LE.MATRIX(J,23)
THROUGH C2, FOR Z=1,1, 2.G. MATRIX(J,4)
C2 FORM(Z)=SYMBOL(MATRIX(J,7))
FORM(Z+MATRIX(J,4))=SYMBOL(MATRIX(J,23))
OTHERWISE
THROUGH C3, FOR Z=10,-1, 2.E.MATRIX(J,5)
C3 FORM(Z)=SYMBOL(MATRIX(J,7))
FORM(Z-MATRIX(J,5))=SYMBOL(MATRIX(J,23))
END OF CONDITIONAL
OTHERWISE
WHENEVER MATRIX(J,7).LE.MATRIX(J,23).AND.MATRIX(J,7).LE.MATRI
1X(J,39)
AZ=4
WHENEVER MATRIX(J,23).LE.MATRIX(J,39)
BZ=5
CZ=6
OTHERWISE
BZ=6
CZ=5
END OF CONDITIONAL
OR WHENEVER MATRIX(J,23).LE.MATRIX(J,7).AND.MATRIX(J,23).LE.
1MATRIX(J,39)
AZ=5
WHENEVER MATRIX(J,7).LE.MATRIX(J,39)
BZ=4
CZ=6
OTHERWISE
BZ=6
CZ=4
END OF CONDITIONAL
OTHERWISE
AZ=6
WHENEVER MATRIX(J,7).LE.MATRIX(J,23)
BZ=4
CZ=5
OTHERWISE

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BZ=5
CZ=4
END OF CONDITIONAL
END OF CONDITIONAL
C5=MATRIX(J,7+((AZ-4)*16))
THROUGH C4, FOR Z=1,1,Z.G.MATRIX(J,AZ)
C4 FORM(Z)=SYMBOL(C5)
C6=MATRIX(J,7+((BZ-4)*16))
THROUGH C7, FOR Z=2,1,Z.G.MATRIX(J,AZ)+MATRIX(J,BZ)
C7 FORM(Z)=SYMBOL(C6)
C8=MATRIX(J,7+((CZ-4)*16))
THROUGH C9, FOR Z=3,1,Z.G.10
C9 FORM(Z)=SYMBOL(C8)
END OF CONDITIONAL
WHENEVER C9L.2.1
T=1
    WHENEVER MATRIX(J,55).E.1
    PRINT FORMAT LOGA, MATRIX(J,57), MATRIX(J,58), FORM(1)...FORM(10
1), MATRIX(J,1)
    VECTOR VALUES LOGA=$ 1H9, S3, 2C6, 10C1, S4, 1H-, I5 *5
    OTHERWISE
    PRINT FORMAT LOGA, FORM(1)...FORM(10), MATRIX(J,1)
    VECTOR VALUES LOGA=$ 1H9, S15, 10C1, S4, 1H-, I5 *5
END OF CONDITIONAL
TRANSFER TO NEXT
END OF CONDITIONAL
NOLOG
N=1
EXECUTE BRKDON.(10)
WHENEVER MATRIX(J,3).E.1, TRANSFER TO NEXT
DESC(N)=$ 1
N=N+1
EXECUTE BRKDON.(16)
WHENEVER MATRIX(J,3).E.2, TRANSFER TO NEXT
DESC(N)=$ 1
N=N+1
EXECUTE BRKDON.(32)
NEXT
WHENEVER LOG.E.0
EXECUTE ONPG.(DESC,N,MATRIX,J,ELV)
TRANSFER TO REPT
END OF CONDITIONAL
WHENEVER N.G. 14
T=2
    WHENEVER MATRIX(J,55).E.1
    PRINT FORMAT LOGA, MATRIX(J,57), MATRIX(J,58), FORM(1)...
1 FORM(10), MATRIX(J,1), DESC(1)...DESC(13), FORM(1)...FORM(
1 10), DESC(14)...DESC(N-1)
1 VECTOR VALUES LOGA=$ 1H9, S3, 2C6, 10C1, S4, 1H-, I5, S5, 13C6,
1 /S16, 10C1, S20, (13C6) *5
    OTHERWISE
    PRINT FORMAT LOGB, FORM(1)...FORM(10), MATRIX(J,1), DESC(1
1 ...DESC(13), FORM(1)...FORM(10), DESC(14)...DESC(N-1)
1 VECTOR VALUES LOGB=$ 1H9, S15, 10C1, S4, 1H-, I5, S5, 13C6, /S16
1 , 10C1, S20, (13C6) *5
    END OF CONDITIONAL
    OTHERWISE
    T=1
    WHENEVER MATRIX(J,55).E.1
    PRINT FORMAT LOGC, MATRIX(J,57), MATRIX(J,58), FORM(1)...FORM(10
1), MATRIX(J,1), DESC(1)...DESC(N-1)

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      VECTOR VALUES LOGC=$1H9,S3,2C6,10C1,S4,1H-,15,S5,(13C6)*$
      OTHERWISE
      PRINT FORMAT LOGC,FORM(1)...FORM(10),MATRIX(J,1),DESC(1)
1    ...DESC(N-1)
      VECTOR VALUES LOGE=$1H9,S15,10C1,S4,1H-,15,S5,(13C6)*$
      END OF CONDITIONAL
      END OF CONDITIONAL
ONLCOL THIC= MATRIX(J,2)-MATRIX(J,1)
      THICA=THIC+ZZ
      LINE=THICA/LOG
      WHENEVER LINE.L.2
      ZZ=ZZ+THIC-(T*LOG )
      TRANSFER TO REPT
      END OF CONDITIONAL
      THROUGH D1 ,FOR Z=1,1,Z.G.LINE-T
D1    PRINT FORMAT LOGF,FORM(1)...FORM(10)
      VECTOR VALUES LOGF=$1H9,S15,10C1 *$
      ZZ=ZZ+THIC -(LOG*LINE)
      REPT CONTINUE
      PRINT FORMAT LAST,MATRIX(QG,2)
      VECTOR VALUES LAST=$1H9,S29,1H-,15*$
      GOON WHENEVERMATRIX(QG+1,1).E.-1,TRANSFER TO E5
      TRANSFER TO E1
      INTERNAL FUNCTION(L)
      ENTRY TO BRKDON.
      WHENEVER MATRIX(J,L+7).E. 0
      PRINT FORMAT COMNT
      VECTOR VALUES COMNT=$ 64H WHY IS YOUR LITHOLOGY PUNCHED IN WR
      LONG COLUMN FOR THIS UNIT *$
      TRANSFER TO GOON
      END OF CONDITIONAL
      DESC(N)=LITH(MATRIX(J,L+7))
      N=N+1
      WHENEVER MATRIX(J,10+L).E.0,TRANSFER TO A1
      DESC(N)=HUE(MATRIX(J,10+L))
      N=N+1
A1    WHENEVER MATRIX(J,11+L).E.0, TRANSFER TO AA1
      DESC(N)=COLOR(MATRIX(J,11+L))
      N=N+1
AA1   WHENEVER MATRIX(J,8+L).E.0,TRANSFER TO A2
      DESC(N)= ADJ(MATRIX(J,8+L))
      N=N+1
A2    WHENEVER MATRIX(J,9+L).E.0, TRANSFER TO A3
      DESC(N)= ADJ(MATRIX(J,9+L))
      N=N+1
A3    TRANSFER TOBA(MATRIX(J,L+7))
BA(1) WHENEVER MATRIX(J,12+L).E.0, TRANSFER TO LIT
      DESC(N)=SHTX(MATRIX(J,12+L))
      N=N+1
      TRANSFER TO LIT
BA(2) CONTINUE
      BA(3) WHENEVER MATRIX(J,12+L).E.0, TRANSFER TO A4
      DESC(N)=SSTX(MATRIX(J,12+L))
      N=N+1
A4    WHENEVER MATRIX(J,13+L).E.0, TRANSFER TO LIT
      DESC(N)=BSSTX(MATRIX(J,13+L))
      DESC(N+1)=BSSTX(3)
      N=N+2
      TRANSFER TO LIT

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BA(4)      TRANSFER TO LIT
BA(5)      TRANSFER TO LIT
BA(6)      CONTINUE
BA(7)      WHENEVER MATRIX(J,12+L).E.0,TRANSFER TO A0
           DESC(N)=LMTX(MATRIX(J,12+L))
           N=N+1
A0         WHENEVER MATRIX(J,13+L).E.0, TRANSFER TO LIT
           DESC(N)=XLTP(MATRIX(J,13+L))
           N=N+1
           TRANSFER TO LIT
BA(8)      TRANSFER TO LIT
BA(9)      TRANSFER TO LIT
BA(10)     WHENEVER MATRIX(J,12+L).E.0, TRANSFER TO LIT
           DESC(N)=GYPTX(MATRIX(J,12+L))
           N=N+1
           TRANSFER TO LIT
BA(11)     TRANSFER TO LIT
BA(12)     TRANSFER TO LIT
BA(13)     TRANSFER TO LIT
BA(14)     TRANSFER TO LIT
BA(15)     TRANSFER TO LIT
BA(16)     TRANSFER TO LIT
BA(17)     TRANSFER TO LIT
BA(18)     TRANSFER TO LIT
BA(19)     TRANSFER TO LIT
BA(20)     TRANSFER TO LIT
BA(21)     TRANSFER TO LIT
BA(22)     TRANSFER TO LIT
BA(23)     TRANSFER TO LIT
LIT        WHENEVER MATRIX(J,14+L).E.0, TRANSFER TO A5
           DESC(N)=SIZE(MATRIX(J,14+L))
           N=N+1
A5         WHENEVER MATRIX(J,15+L).E.0, TRANSFER TO A6
           DESC(N)=OOL(MATRIX(J,15+L))
           WHENEVER MATRIX(J,15+L).E.2.OR.MATRIX(J,15+L).E.4
           DESC(N+1)=OOL(MATRIX(J,15+L)-1)
           N=N+1
           END OF CONDITIONAL
           N=N+1
A6         WHENEVER MATRIX(J,17+L).E.0, TRANSFER TO A7
           DESC(N)=ORGN(MATRIX(J,17+L))
           N=N+1
A7         WHENEVER MATRIX(J,18+L).E.0, TRANSFER TO A8
           DESC(N)=FOSS(MATRIX(J,18+L))
           N=N+1
A8         WHENEVER MATRIX(J,16+L).E.0, TRANSFER TO A9
           DESC(N)=POR(MATRIX(J,16+L))
           N=N+1
A9         FUNCTION RETURN
           END OF FUNCTION
           END OF PROGRAM

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R
R
R
R   EXTERNAL FUNCTION ONPG--- USED WHEN ONLY A PRINTED
R   LOG IS DESIRED BUT NO COLUMNAR SECTION
R
R   EXTERNAL FUNCTION(DESC,N,MATRIX,J,ELV)
R   ENTRY TO ONPG.
R   NORMAL MODE IS INTEGER
R   SUBSEA=ELV-MATRIX(J,1)
R   WHENEVER N.G.14
R   WHENEVER MATRIX(J,55).E.1
R   PRINT FORMAT LOG1,MATRIX(J,57),MATRIX(J,58),SUBSEA,MATRIX(J,1
1),DESC(1)...DESC(13),DESC(14)...DESC(N-1)
R   VECTOR VALUES LOG1=$1H0,S5,2C6,S4,I6,S5,I5,S5,13C6,/S48,
1(13C6) *$
R   OTHERWISE
R   PRINT FORMAT LOG2,MATRIX(J,1),DESC(1)...DESC(13),DESC(14)...D
1ESC(N-1)
R   VECTORVALUES LOG2=$1H0,S32,I5,S5,13C6,/ S48,(13C6) *$
R   END OF CONDITIONAL
R   OTHERWISE
R   WHENEVER MATRIX(J,55).E.1
R   PRINT FORMAT LOG3,MATRIX(J,57),MATRIX(J,58),SUBSEA,MATRIX(J,1
1),DESC(1)...DESC(N-1)
R   VECTOR VALUES LOG3=$1H0,S5,2C6,S4,I6,S5,I5,S5,13C6 *$
R   OTHERWISE
R   PRINT FORMAT LOG4,MATRIX(J,1),DESC(1)...DESC(N-1)
R   VECTOR VALUESLOG4=$1H0,S32,I5,S5,13C6 *$
R   END OF CONDITIONAL
R   END OF CONDITIONAL
R   FUNCTION RETURN
R   END OF FUNCTION

```

# APPENDIX C

## COMPUTER PROGRAM TO COMPUTE AND PUNCH THE PARAMETERS USED IN STRATIGRAPHIC ANALYSIS

```

R
R
R   PROGRAM---VTSTAT
R
R   PROGRAMMER---FRANK MOSER/UNIVERSITY OF MICHIGAN/ GEOLOGY
R   THE PROGRAM WILL COMPUTE AND PUNCH THE STANDARD
R   LITHOLOGIC RATIOS AND PERCENTAGES FOR ANY GIVEN
R   STRATIGRAPHIC INTERVAL
R
R   THE DATA ARE READ INTO A MATRIX IN WHICH THE ROWS
R   ARE INTERVALS AND THE COLUMNS ARE CHARACTERISTICS
R   THE MATRIX IS SEARCHED TO SEE WHICH ROWS REPRESENT
R   THE REQUESTED INTERVAL AND CONTROL IS PASSED TO
R   THE SUBROUTINE DETAIL WHICH DOES THE ACTUAL COMPUTATIONS
R   IF OTHER THAN THE STANDARD LITHOLOGIC COMPUTATIONS
R   ARE DESIRED THE PERTINENT INSTRUCTIONS MUST BE
R   MUST BE INSERTED INTO DETAIL
R
R
R   TWO EXTERNAL FUNCTIONS ARE USED --DETAIL AND RD
R
R
R   BOOLEAN BT
R   NORMAL MODE IS INTEGER
R   PROGRAM COMMON STAT,NMB,ISOINT,COMA,COMB,FARM,STATE,COUNTY,
R   1SEC,TWP,NS,RNGE,EW,PERM,ELV,XCORD,YCORD,ZZ,XX,QQ,STRAT
R   2,MATRIX,PER,TOTAL,T,B,SUBSEA,ISOP,RESERV,THIC,DIM,DIM2
R   DIMENSION TOTAL (30),PER(30),MATRIX(15000,DIM),
R   1ISOINT(90),RESERV(30),STRAT(400,DIM2)
R   VECTOR VALUES DIM2=2,1,2
R   VECTOR VALUES DIM=2,1,58
E1  READ FORMAT CONTRO ,STAT,NMB
R   VECTOR VALUES CONTRO =$2I5 *$
R   READ FORMAT CONTR2,ISOINT(1)...ISOINT(NMB*3)
R   VECTOR VALUES CONTR2=$18I4*$
R   PRINT FORMAT TITLE1
R   VECTOR VALUES TITLE1=$97H1          INTERVAL          ELV      THI
R   1C CLASTIC SAND/CLS EVAPORITE ANH/EVAP CARBONAT DOL/CARB
R   2 *$
E5  READ FORMAT TITLE,COMA,COMB,FARM,STATE,COUNTY,SEC,TWP,NS,
R   1RNGE,EW, PERM,ELV,XCORD,YCORD
R   VECTOR VALUES TITLE=$2C6,C3,C4,C5,2I2,C1,I2,C1,S6,I5,I4,2I4*$
R   PRINT FORMAT TITLE3,COUNTY,COMA,COMB,FARM,SEC,TWP,NS,RNGE,EW,
R   1PERM
R   VECTOR VALUES TITLE3=$1H6,S20,C5,S2,2C6,C3,S4,2I2,C1,I2,C1,S3
R   1,I5 *$
R   ZZ=0
R   XX=0
R   BT=0B
R   WHENEVER STAT .L.2
R   THROUGH LAAP,FOR I=1,1,BT
R   READ FORMAT INFO1, MATRIX(I,1),MATRIX(I,2),MATRIX(I,55)

```

```

      VECTOR VALUES INFO1=$215,S61,1) *$
WHENEVER MATRIX(I,1).NE.MATRIX(I-1,2)
WHENEVER MATRIX(I,1).L.0.OR.1.E.1
CONTINUE
OTHERWISE
ZZ=ZZ+1
ERR=I
END OF CONDITIONAL
END OF CONDITIONAL
      BT=MATRIX(I,1).L.0
      WHENEVER MATRIX(I,55).NE.0
READ FORMAT INFO2,CHECK,MATRIX(I,56)...MATRIX(I,58)
VECTOR VALUES INFO2=$15,S1,14,236 *$
WHENEVER MATRIX(I,1).NE.CHECK
ZZ=ZZ+1
ERR=I
END OF CONDITIONAL
      XX=XX+1
      STRAT(XX,1)=MATRIX(I,56)
      STRAT(XX,2)=1
LAAP  END OF CONDITIONAL
      OTHERWISE
EXECUTE RD.
END OF CONDITIONAL
THROUGH TEST, FOR Z=1,1,Z.E.XX
WHENEVER STRAT(Z+1,1).LE.STRAT(Z,1)
PRINT FORMAT REMIND, MATRIX(STRAT(Z,2),57)
TRANSFER TO F5
END OF CONDITIONAL
TEST  CONTINUE
      VECTOR VALUES REMIND=$1H0,S20,40HTHERE IS AN ERROR IN THE COD
1E OF UNIT /S25, C6 *$
      QQ=I-1
      WHENEVER ZZ.E.0,TRANSFER TO F0
      PRINT FORMAT OUT,ZZ,MATRIX(ERR,1),MATRIX(ERR,2)
      VECTOR VALUES OUT=$55,11HTHERE ARE 13,S3,15HMISPLACED CARDS
1 / ,S5, 39H THE LAST ONE IS THE FOLLOWING INTERVAL /,S5,15,
21H-,15 *$
      TRANSFER TO F5
FO    THROUGH F1, FOR Z=1,3,Z.G.3*NMB
      TAG=0
      FLAG=0
      THROUGH F2,FORI=1,1,I.G.XX.OR. FLAG.E.1
      WHENEVER TAG.E.0
      WHENEVER ISOINT(Z).G.STRAT(I,1)
      CONTINUE
      OP WHENEVER ISOINT(Z).E.STRAT(I,1)
      TAG=1
      T=STRAT(I,2)
      OTHERWISE
      WHENEVER ISOINT(Z+1).G. STRAT(I,1).AND. ISOINT(Z+2).GE.3
      TAG=1
      T=STRAT(I,2)
      OTHERWISE
      MISSIN(4)=$UPPER $
      TRANSFER TO MINOR4
      END OF CONDITIONAL
      END OF CONDITIONAL
      OTHERWISE

```

```

WHENEVER ISOINT(Z+1).G. STRAT(I,1)
CONTINUE
OR WHENEVER ISOINT(Z+1).E.STRAT(I,1)
FLAG=1
B= STRAT(I,2)
OTHERWISE
WHENEVER ISOINT(Z+2).E.1 .OR. ISOINT(Z+2).E.4
FLAG=1
B=STRAT(I,2)
OTHERWISE
MISSIN(4)=$BOTTOM$
TRANSFER TO MINOR4
END OF CONDITIONAL
END OF CONDITIONAL
END OF CONDITIONAL
F2 CONTINUE
WHENEVER TAG.E.0
MISSIN(4)=$UPPER $
TRANSFER TO MINOR4
OR WHENEVER FLAG.E.0
MISSIN(4)=$BOTTOM$
TRANSFER TO MINOR4
END OF CONDITIONAL
MINOR3 SUBSEA=ELV-MATRIX(T,1)
WHENEVER STAT.E. 0, TRANSFER TO MINOR1
ISOP=MATRIX(B,1)-MATRIX(T,1)
WHENEVER STAT.E.1,TRANSFER TO MINOR2
EXECUTE DETAIL.
TRANSFER TO F1
MINOR1 PRINT FORMAT ONLYEL,MATRIX(T,57),MATRIX(T,58) ,SUBSEA
VECTOR VALUES ONLYEL=$1H ,2C6,S12,I5 *$
PUNCH FORMAT RESU ,MATRIX(T,56), PERM,XCORD,YCORD,
1SUBSEA,PERM
VECTOR VALUES RESU=$ 14,S4,I5,2I4,S4,I5,S43,2H10,I5 *$
TRANSFER TO F1
MINOR2 PRINT FORMAT ISOPEL,MATRIX(T,57),MATRIX(T,58),MATRIX(B,57),
1MATRIX(B,58),SUBSEA,ISOP
VECTOR VALUES ISOPEL=$1H ,2C6,1H-,2C6,I5,S2,I4 *$
PUNCH FORMAT RESUL,MATRIX(T,56),MATRIX(B,56),PERM,XCORD,YCORD
1,ISOP,SUBSEA,PERM
VECTOR VALUES RESUL=$ 2I4,I5,3I4,I5,S43,2H10,I5 *$
TRANSFER TO F1
MINOR4 PRINT FORMAT MISSIN,ISOINT(Z),ISOINT(Z+1)
VECTOR VALUES MISSIN=$1H ,I5,S4,1H-,I7, S3,38HUPPER MARKER
1NOT DESIGNATED IN WELL *$
F1 CONTINUE
F5 WHENEVER MATRIX(QQ,1).L.-1,TRANSFER TO E1
TRANSFER TO E5
END OF PROGRAM

```

```

R
R
R   EXTERNAL FUNCTION RD   TO READ IN A MATRIX
R
EXTERNAL FUNCTION
ENTRY TO RD.
BOOLEAN BT
NORMAL MODE IS INTEGER
PROGRAM COMMON STAT,NMB,ISOINT,COMA,COMB,FARM,STATE,COUNTY,
1SEC,TWP,NS,RNGE,EW,PERM,ELV,XCORD,YCORD,ZZ,XX,QQ,STRAT
2,MATRIX,PER,TOTAL,T,B,SUBSEA,ISOP,RESERV,THIC,DIM,DIM2
DIMENSION TOTAL (30),PER(30),MATRIX(15000,DIM),
1ISOINT(90),RESERV(30),STRAT(400,DIM2)
VECTOR VALUES,DIM2=2,1,2
VECTOR VALUES DIM=2,1,58
BT=0B
THROUGH LOOP,FOR I=1,1,BT
  READ FORMAT INFO, MATRIX(I,1)...MATRIX(I,55)
  VECTOR VALUES INFO=$2I5,4I1,3(3I2,13I1),I1 *$
  WHENEVER MATRIX(I,3).G.3
  PRINT FORMAT NOTE, MATRIX(I,1)
  VECTOR VALUES NOTE=$1H0,S15,I4,/S15,60HTHE NUMBER IN COLUMN 1
  11 AT THIS DEPTH IS GREATER THAN 3..,S15,68H IT HAS BEE
  2N REPLACED IN STORAGE BY A 3 EXECUTION WILL CONTINUE *$
  END OF CONDITIONAL
  WHENEVER MATRIX(I,1).NE.MATRIX(I-1,2)
  WHENEVER MATRIX(I,1).L.0.OR.I.E.1
  CONTINUE
  OTHERWISE
  ZZ=ZZ+1
  ERR=I
  END OF CONDITIONAL
  END OF CONDITIONAL
  BT=MATRIX(I,1).L.0
  WHENEVER MATRIX(I,55).E.1
  READ FORMAT INFO2,CHECK,MATRIX(I,56)...MATRIX(I,58)
  VECTOR VALUES INFO2=$15,S1,I4,2C6 *$
  WHENEVER MATRIX(I,1).NE.CHECK
  ZZ=ZZ+1
  ERR=I
  END OF CONDITIONAL
  XX=XX+1
  STRAT(XX,1)=MATRIX(I,56)
  STRAT(XX,2)=I
  END OF CONDITIONAL
  FUNCTION RETURN
  END OF FUNCTION

```

LOOP

```

R
R
R   DETAIL--EXTERNAL FUNCTION TO COMPUTE AND PUNCH
R
EXTERNAL FUNCTION
ENTRY TO DETAIL.
PROGRAM COMMON STAT,NMB,ISOINT,COMA,COMB,FARM,STATE,COUNTY,
1SEC,TWP,NS,RNGE,EW,PERM,ELV,XCORD,YCORD,ZZ,XX,QQ,STRAT
2,MATRIX,PER,TOTAL,T,B,SUBSEA,ILOP,RESERV,THIC,DIM,DIM2
DIMENSION TOTAL (30),PER(30),MATRIX(15000,DIM),
1ISOINT(90),RESERV(30),STRAT(400,DIM2)
VECTOR VALUES DIM=2,1,58
VECTOR VALUES DIM2=2,1,2
NORMAL MODE IS INTEGER
SNDCLS=0
CLSTIC=0
EVAP=0
ANHEVA=0
CARBON=0
DOLCRB=0
ANDOL=0
DOLEVA=0
EXECUTE ZERO.(PER(1)...PER(30))
EXECUTE ZERO.(TOTAL(1)...TOTAL(30))
MISS=0
THROUGH F3, FOR I=T,1,1.E.B
TRANSFER TO E(MATRIX(I,3))
TOTAL(MATRIX(I,39))=TOTAL(MATRIX(I,39))+((MATRIX(I,2)-MATRIX(
1,1))*MATRIX(I,6))
TOTAL(MATRIX(I,23))=TOTAL(MATRIX(I,23))+((MATRIX(I,2)-MATRIX(
1,1))*MATRIX(I,5))
TOTAL(MATRIX(I,7 ))=TOTAL(MATRIX(I,7 ))+((MATRIX(I,2)-MATRIX(
1,1))*MATRIX(I,4))
TRANSFER TO F3
TOTAL(MATRIX(I,7))=TOTAL(MATRIX(I,7))+((MATRIX(I,2)-MATRIX(I,
1))*10)
TRANSFER TO F3
MISS=MISS+MATRIX(I,2)-MATRIX(I,1)
CONTINUE
THIC=ISOP-MISS
THROUGH F4, FOR I=1,1, I.G. 20
PER(I)=(TOTAL(I)*10 )/THIC
TOTAL(I)=TOTAL(I)/10
R PERCENT CLASTIC AND SAND/CLASTIC RATIO
CLSTIC=PER(1)+PER(2)+PER(3)+PER(4)+PER(5)
WHENEVER CLSTIC.E.0
SNDCLS=1
OTHERWISE
SNDCLS=(PER(3)*100)/CLSTIC
END OF CONDITIONAL
R EVAPORITE PERCENTAGE AND ANH/FVAP RATIO
EVAP=PER(9)+PER(10)+PER(11)
WHENEVER EVAP.E.0
ANHEVA=1
OTHERWISE
ANHEVA=(PER(9)*100)/EVAP
END OF CONDITIONAL
R CARBONATE PERCENT AND DOL/CARB RATIO

```

```

CARBON=PER(6)+PER(7)
  WHENEVER CARBON .E. 0
    DOLCRB=1
  OTHERWISE
    DOLCRB=(PER(6)*100)/CARBON
END OF CONDITIONAL
R DOL/DOL+ANHY RATIO
ANDOL=PER(6)+PER(9)
  WHENEVER ANDOL.E. 0
    DOLEVA=1
  OTHERWISE
    DOLEVA=(PER(6)*100)/ANDOL
END OF CONDITIONAL
PRINT FORMAT FINAL,MATRIX(T,57),MATRIX(T,58),MATRIX(B,57),
1MATRIX(B,58),SUBSEA,ISOP,CLSTIC,SNDCLS,EVAP,ANHEVA,CARBON,
2DOLCRB
  VECTOR VALUES FINAL=$1H ,2C6,1H-,2C6,15,S2,I4,S5,I3,5I10 *$
  PUNCHFORMAT RESUL,MATRIX(T,56),MATRIX(B,56),      XCORD,YCORD,
1ISOP,SUBSEA,CLSTIC,SNDCLS,EVAP,ANHEVA,CARBON,DOLCRB,DOLEVA,
2PER(1),PER(3),PER(6),PER(7),PER(9),TOTAL(1),TOTAL(3),TOTAL(6)
3,TOTAL(9),PERM
  VECTOR VALUES RESUL=$ 214,   314,15,1613,   2H10, 15 *$
  FUNCTION RETURN
END OF FUNCTION

```

# APPENDIX D

## COMPUTER PROGRAM TO PREPARE ONLINE MAPS

```

R
R  PROGRAM--MAP
R
R  PROGRAMMER---FRANK MOSER/UNIVERSITY OF MICHIGAN/GEOLOGY
R  PROGRAMM   WILL PREPARE A MAP OF ANY SCALE OR SIZE
R  THE MAP WILL CONSIST OF LOCATIONS AND VARIABLES
R  AT EACH LOCATION
R  THE MAIN PROGRAM SETS UP THE DIMENSIONS OF THE MAP
R  PLOTS THE GRID, COUNTY AND STATE OUTLINE
R  A SUBROUTINE CALLED PLTN PLOTS THE ACTUAL VALUE
R
R  ONE EXTERNAL FUNCTION IS USED--PLTN
R
  VECTOR VALUESYCNT( 11)=8150.,8055.,8045.,7967.,7956.,7872.,
17864.,7777.,7770.,7683.,7682.,7681.,7677.,7595.,7593.,7586.,
27586.,7586.,7584.,7587.,7587.,7591.,7593.,7597.,7598.,7601.,
37604.,7500.,7498.,7496.,7495.,7493.,7492.,7497.,7405.,7400.,
47408.,7312.,7307.,7315.,7223.,7222.,7220.,7220.,7218.,7217.,
57215.,7213.,7211.,7213.,7215.,7217.,7220.,7221.,7225.,7227.,
67229.,7140.,7139.,7137.,7133.,7127.,7122.,7120.,7125.,7039.,
77030.,7030.,7022.,7031.,6949.,6942.,6939.,6934.,6940.,6865.,
86862.,6857.,6855.,6852.,6852.,6851.,6849.,6848.,6846.,6845.,
96845.,6845.,6844.,6843.,6843.,6842.,6844.,3845.,6846.,6850.
  VECTOR VALUESYCNT( 97)=6852.,6853.,6854.,6760.,6752.,6749.,
16746.,6753.,6663.,6660.,6653.,6653.,6657.,6570.,6566.,6562.,
26560.,6565.,6495.,6490.,6485.,6482.,6480.,6479.,6478.,6477.,
36475.,6473.,6471.,6471.,6470.,6468.,6467.,6467.,6467.,6467.,
46467.,6470.,6472.,6475.,6476.,6386.,6379.,6371.,6373.,6385.,
56294.,6286.,6280.,6279.,6290.,6290.,6198.,6193.,6185.,6185.,
66200.,6200.,6200.,6114.,6111.,6107.,6105.,6104.,6102.,6100.,
76099.,6098.,6096.,6095.,6094.,6092.,6091.,6091.,6091.,6091.,
86091.,6107.,6106.,6008.,6003.,5999.,5997.,6013.,5920.,5915.,
95910.,5907.,5922.,5944.,5948.,5953.,5957.,5961.,5966.,5971.
  VECTOR VALUESYCNT( 193)=5977.,5825.,5819.,5813.,5814.,5828.,
15827.,5782.,5828.,5865.,5745.,5739.,5737.,5731.,5727.,5726.,
25725.,5723.,5722.,5720.,5720.,5720.,5719.,5719.,5719.,5736.,
35737.,5782.,5782.,5737.,5737.,5767.,5638.,5632.,5625.,5625.,
45642.,5672.,5544.,5542.,5541.,5539.,5539.,5538.,5537.,5532.,
55530.,5547.,5570.,5574.,5577.,5450.,5448.,5445.,5442.,5441.,
65457.,5458.,5460.,5462.,5465.,5478.,5532.,5490.,5360.,5359.,
75358.,5356.,5354.,5350.,5350.,5350.,5350.,5350.,5348.,5348.,
85347.,5347.,5357.,5358.,5360.,5362.,5370.,5397.,5402.,5406.,
95413.,5419.,5258.,5252.,5252.,5251.,5267.,5274.,5304.,5165.
  VECTOR VALUESYCNT( 289)=5161.,5160.,5159.,5171.,5182.,5208.,
15073.,5066.,5065.,5063.,5076.,5081.,5084.,5087.,5098.,5103.,
25106.,5115.,5119.,5123.,4985.,4984.,4983.,4980.,4980.,4980.,
34979.,4978.,4977.,4977.,4976.,4976.,4975.,4973.,4972.,4973.,
44982.,4982.,4983.,4985.,4986.,4988.,5012.,5029.,4883.,4882.,
54880.,4882.,4897.,4923.,4938.,4788.,4787.,4785.,4790.,4800.,
64826.,4695.,4693.,4692.,4692.,4705.,4730.,4610.,4608.,4605.,
74604.,4604.,4603.,4602.,4600.,4599.,4598.,4598.,4597.,4597.,
84597.,4597.,4597.,4600.,4600.,4600.,4601.,4603.,4602.,4611.,
94616.,4620.,4626.,4632.,4637.,4642.,4506.,4502.,4500.,4503.

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VECTOR VALUESCNT( 385)=4524.,4423.,4420.,4417.,4412.,4410.,  
 14412.,4432.,4326.,4321.,4317.,4315.,4319.,4340.,4233.,4233.,  
 24230.,4227.,4225.,4225.,4223.,4223.,4223.,4223.,4223.,4223.,  
 34223.,4222.,4221.,4223.,4223.,4225.,4226.,4227.,4234.,4237.,  
 44241.,4244.,4245.,4256.,4140.,4133.,4127.,4126.,4130.,4143.,  
 54046.,4038.,4033.,4032.,4034.,4049.,3955.,3945.,3940.,3941.,  
 63940.,3953.,3849.,3862., -0., -0., -0., -0., -0., -0.  
 VECTOR VALUESCNT( 1)=4723.,4724.,5085.,4724.,5085.,4725.,  
 15090.,4725.,5090.,4538.,4630.,4723.,5090.,4262.,4353.,4724.,  
 24815.,4907.,5000.,5091.,5186.,5278.,5368.,5463.,5552.,5645.,  
 35730.,4353.,4447.,4538.,4631.,4724.,5000.,5372.,4628.,5000.,  
 45374.,4635.,5000.,5369.,4267.,4360.,4450.,4540.,4635.,4726.,  
 54820.,4912.,5000.,5090.,5185.,5276.,5370.,5463.,5552.,5645.,  
 65735.,3712.,3805.,3901.,3991.,4266.,4634.,5000.,5371.,3900.,  
 74265.,4632.,5000.,5373.,3899.,4264.,4632.,5000.,5374.,3613.,  
 83710.,3802.,3896.,3985.,4077.,4169.,4261.,4355.,4445.,4536.,  
 94631.,4722.,4815.,4908.,5000.,5090.,5188.,5281.,5375.,5465.  
 VECTOR VALUESCNT( 97)=5555.,5650.,5742.,3894.,4262.,4631.,  
 15000.,5376.,3892.,4260.,4631.,5000.,5377.,3890.,4259.,4630.,  
 25000.,5378.,3511.,3607.,3705.,3796.,3890.,3983.,4073.,4164.,  
 34260.,4353.,4444.,4536.,4631.,4724.,4819.,4909.,5000.,5093.,  
 45191.,5287.,5380.,5472.,5564.,3715.,4083.,4449.,4819.,5154.,  
 53714.,4080.,4446.,4817.,5154.,5250.,3710.,4079.,4446.,4816.,  
 65155.,5251.,5342.,3431.,3522.,3616.,3709.,3801.,3894.,3986.,  
 74077.,4167.,4260.,4353.,4445.,4535.,4629.,4721.,4815.,4909.,  
 85000.,5060.,5154.,3706.,4075.,4445.,4815.,5155.,3704.,4074.,  
 94445.,4814.,5154.,5701.,5791.,5884.,5974.,6065.,6157.,6252.  
 VECTOR VALUESCNT( 193)=6345.,3701.,4072.,4445.,4812.,5154.,  
 15251.,5431.,5525.,5979.,3423.,3515.,3608.,3700.,4070.,4164.,  
 24256.,4350.,4445.,4534.,4626.,4721.,4811.,4905.,4997.,5059.,  
 35154.,5251.,5340.,5431.,5522.,5984.,3698.,4067.,4625.,4998.,  
 45523.,5987.,3698.,3790.,3882.,3975.,4067.,4161.,4255.,4625.,  
 54998.,5525.,5804.,5898.,5990.,3797.,3890.,4262.,4632.,4998.,  
 65346.,5436.,5528.,5619.,5712.,5797.,5981.,6073.,3520.,3612.,  
 73705.,3796.,3890.,4262.,4355.,4448.,4539.,4632.,4725.,4818.,  
 84907.,4998.,5062.,5155.,5253.,5348.,5715.,6077.,6172.,6260.,  
 96355.,6447.,3892.,4262.,4631.,5000.,5349.,5717.,6081.,3891.  
 VECTOR VALUESCNT( 289)=4262.,4631.,5000.,5351.,5720.,6086.,  
 13891.,4262.,4630.,5000.,5352.,5537.,5630.,5725.,5815.,5904.,  
 25997.,6090.,6185.,6285.,3611.,3705.,3795.,3890.,3983.,4075.,  
 34166.,4262.,4350.,4445.,4536.,4630.,4723.,4816.,4908.,5001.,  
 45074.,5165.,5264.,5356.,5449.,5542.,6001.,6290.,4075.,4444.,  
 54816.,5170.,5546.,6005.,6295.,4074.,4442.,4815.,5174.,5549.,  
 66009.,4073.,4442.,4816.,5185.,5552.,6013.,3516.,3610.,3702.,  
 73795.,3886.,3978.,4072.,4163.,4251.,4350.,4441.,4534.,4629.,  
 84721.,4815.,4908.,5000.,5085.,5186.,5276.,5370.,5464.,5557.,  
 95650.,5742.,5837.,5925.,6016.,6111.,3895.,4265.,4722.,5190.  
 VECTOR VALUESCNT( 385)=5656.,3440.,3530.,3895.,4265.,4722.,  
 15190.,5661.,3530.,3895.,4266.,4725.,5191.,5661.,3530.,3621.,  
 23714.,3805.,3896.,3987.,4077.,4170.,4266.,4359.,4451.,4544.,  
 34635.,4728.,4821.,4911.,5000.,5091.,5191.,5290.,5384.,5475.,  
 45568.,5662.,5756.,5851.,3528.,3895.,4266.,4635.,5000.,5478.,  
 53526.,3895.,4265.,4635.,5002.,5481.,3520.,3889.,4262.,4631.,  
 65004.,5488.,5005.,5490., -0., -0., -0., -0., -0., -0.  
 VECTOR VALUESCNT( 1)=6200.,6255.,6283.,6330.,6362.,6370.,  
 16375.,6397.,6427.,6435.,6445.,6462.,6492.,6535.,6510.,6495.,  
 26495.,6475.,6410.,6368.,6350.,6370.,6385.,6332.,6295.,6232.,  
 36260.,6210.,6190.,6150.,6070.,6008.,5978.,5945.,5950.,5885.,  
 45835.,5810.,5715.,5740.,5795.,5835.,5750.,5695.,5705.,5800.,

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55820.,5833.,5807.,5805.,5800.,5798.,5715.,5690.,5625.,5603.,
65605.,5540.,5530.,5440.,5355.,5345.,5330.,5395.,5525.,5600.,
75658.,5675.,5713.,5760.,5837.,5855.,5913.,6000.,6030.,6085.,
83354.,3420.,3462.,3500.,3518.,3533.,3546.,3551.,3551.,3548.,
93535.,3512.,3478.,3432.,3398.,3374.,3341.,3318.,3370.,3405.
  VECTOR VALUESXOUT( 97)=3395.,3375.,3348.,3418.,3445.,3500.,
13545.,3559.,3572.,3575.,3560.,3650.,3704.,3705.,3725.,3765.,
23820.,3875.,3953.,4020.,4115.,4095.,4062.,4095.,4062.,4030.,
34050.,4106.,4160.,4140.,4110.,4188.,4225.,4235.,4245.,4232.,
44272.,4360.,4450.,4590.,4500.,4460.,4440.,4480.,4570.,4515.,
54630.,4723.,4825.,4935.,5075.,5180.,5225.,5350.,5460.,5625.,
65715.,5675.,5582.,5490.,5395.,5300.,5209.,5107.,5005.,4911.,
74820.,4726.,4665.,4665.,4630.,4537.,4448.,4355.,4261.,4169.,
84075.,3980.,3890.,3795.,3705.,3610.,3518.,3427.,3335.,3240.,
93149.,3025.,3096.,3187.,3237.,3292.,5735., -0., -0., -0.
  VECTOR VALUESYOUT( 1)=6328.,6300.,6246.,6157.,6070.,5980.,
15885.,5794.,5697.,5604.,5508.,5421.,5327.,5230.,5161.,5040.,
24951.,4858.,4754.,4754.,4807.,4843.,4881.,4902.,4863.,4825.,
34770.,4751.,4645.,4548.,4511.,4475.,4391.,4275.,4170.,4085.,
44062.,4010.,7690.,7600.,7508.,7405.,7462.,7415.,7320.,7250.,
57138.,7040.,6948.,6855.,6763.,6667.,6570.,6600.,6500.,6390.,
66351.,6343.,6285.,6283.,6200.,6104.,6007.,5922.,5863.,5923.,
75998.,5975.,6035.,6130.,6229.,6274.,6280.,6306.,6351.,6379.,
84328.,4428.,4514.,4612.,4702.,4795.,4891.,4985.,5075.,5170.,
95265.,5360.,5458.,5555.,5651.,5746.,5838.,5932.,6021.,6115.
  VECTOR VALUESYOUT( 97)=6206.,6300.,6370.,6443.,6499.,6594.,
16681.,6773.,6817.,6962.,7052.,7090.,7140.,7235.,7285.,7275.,
27346.,7312.,7420.,7512.,7605.,7542.,7512.,7442.,7325.,7230.,
37125.,7227.,7370.,7225.,7100.,7225.,7280.,7377.,7505.,7600.,
47688.,7752.,7770.,7810.,7843.,7890.,7970.,8055.,8150.,8192.,
58180.,8220.,8150.,8080.,8070.,7955.,7900.,7898.,7820.,7760.,
63865.,3860.,3855.,3852.,3851.,3847.,3842.,3839.,3835.,3830.,
73827.,3823.,3819.,3886.,3885.,3884.,3885.,3885.,3890.,3890.,
83890.,3890.,3890.,3895.,3895.,3898.,3898.,3900.,3904.,3906.,
93908.,3912.,3964.,4050.,4144.,4235.,3958., -0., -0., -0.
  INTEGER N,T,TH,Q,ST,O,XY,TX,I ,LINE,A,TAG,ID,CNT
  DIMENSIONDAT(10000,DIM),IMAGE(8000),XOUT(200),YOUT(200),XCNT(
1450),YCNT(540),DUM(5,DIM2),DATA(6),TIT(12)
  VECTOR VALUES DIM2=2,1,2
  VECTOR VALUES DIM=2,1,10
  READ FORMAT CONST,XMAX,XMIN,YMAX,YMIN,SCAL,N,O,LINE,COORSC
  VECTOR VALUES CONST=$4F5.0,S1,F7.0,S1,2I2,I6,S3,F8.2 *$
  FACTOR=3960./SCAL
  WHENEVER COORSC.NE.0.0, FACTOR=(63360.*COORSC)/SCAL
  INCHES=(XMAX-XMIN)*FACTOR
  I=(INCHES/10)+1
  XMAX=((I*10)/FACTOR)+XMIN
  YDIM=(60*I)*((YMAX-YMIN)/(XMAX-XMIN))
  INCMAX=(XMAX-XMIN)/I
  XMAX=XMIN+INCMAX
  EXECUTE PLOT1.(0,1,YDIM,1,100)
  DELTY=((YMAX-YMIN)/YDIM)*1.15
  DELTAY=(YMAX-YMIN)/YDIM
  DELTX=(XMAX-XMIN)/100.
  START
  READ FORMAT FORM,DATA(0)...DATA(6),DIM(2), A,ID
  VECTOR VALUES FORM=$7C6,I6,S4,I3,S5,I2 *$
  READ FORMAT TITLE, TIT(1)...TIT(12)
  VECTOR VALUES TITLE=$12C6 *$
  PRINT FORMAT TYPE,ID,DATA(0)...DATA(6),TIT(1)...TIT(12)

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VECTOR VALUES TYPE=$1H1,S12,30HCODE(TYPE) NUMBER OF DATA CARD
1 /S15,I2,///1H ,S12,14HCURRENT FORMAT ,/S16,7C6,///S20,12C6*$
D=1.
THROUGH INPUT, FOR ST=1,1,D.L. 1.
READ FORMAT DATA, DAT(ST,1)...DAT(ST,DIM(2))
VECTOR VALUES DATA=$
1 *$
INPUT
D=DAT(ST,A)+DAT(ST,A+1)
Q=ST-2
CNT=0
THROUGH TONE, FOR ST=1,1,ST.G.DIM(2)
WHENEVER ST.E.A.OR.ST.E.A+1, TRANSFER TO TONE
THROUGH GONE, FOR TH=0,1,TH.G.(I-1)
INC=TH*INCMAK
EXECUTE PLOT2.(IMAGE,XMAX+INC,XMIN+INC,YMAX,YMIN)
WHENEVER LINE.E. 0, TRANSFER TO NOGRID
LINES=LINE
XY=(XMIN+INC)/LINE
XMIN1=(XY+1)*LINES
TX=YMIN/LINE
YMIN1=(TX+1)*LINES
TAG=-1
THROUGH AE, FOR C=XMIN1,LINES,C.G.XMAX+INC
THROUGH AB, FOR D=YMIN,DELTAY ,D.G.YMAX
AB
EXECUTE PLOT3.($I$,C,D,1)
DUM(1,1)=C
AE
EXECUTE PLTN.(DUM,1,1,C-(2.*DELT),YMIN,DELT,DELT, TAG,XMAX,
1INC,XMIN)
THROUGH AF, FOR C=YMIN1,LINES,C.G.YMAX
THROUGH AC, FOR D=XMIN+INC,DELT,D.G.XMAX+INC
AC
EXECUTE PLOT3.($-$,D,C,1)
DUM(1,1)=C
WHENEVER TH.E.0, EXECUTE PLTN.(DUM,1,1,XMIN-DELT,C,DELT,DELT
1Y,TAG,XMAX,INC,XMIN)
AF
WHENEVER TH.E.1-1, EXECUTE PLTN.(DUM,1,1,(XMAX+INC)-(5.*DELT)
1,C,DELT,DELT, TAG,XMAX,INC,XMIN)
NOGRID
TAG=0
WHENEVER N.NE.0, EXECUTE PLOT3.($O$,XOUT(1),YOUT(1),192)
WHENEVER O.NE.0, EXECUTE PLOT3.($X$,XCNT(1),YCNT(1),444)
THROUGH GRAPH1, FOR T=1,1,T.G.Q
WHENEVER D/T(T,A).L.XMIN+INC .OR.DAT(T,A).GE.XMAX+
1INC ,TRANSFER TO GRAPH1
V=V
W=W
EXECUTE PLTN.(DAT,T,ST,V,W,DELT,DELT,A,XMAX,INC,XMIN)
GRAPH1
CONTINUE
PRINT FORMAT SKIP
VECTOR VALUES SKIP=$1H1 *$
EXECUTE OMIT.(3)
EXECUTE PLOT4.(0.0,ZERO)
PRINT FORMAT SKIP2
VECTOR VALUES SKIP2=$ 1H //// *$
GONE
CONTINUE
CNT=CNT+1
PRINT FORMAT END,CNT
VECTOR VALUES END=$S20,17HEND OF MAP NO. I3*$
TONE
CONTINUE
TRANSFER TO START
END OF PROGRAM

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R
R
R   EXTERNAL FUNCTION--PLTN--
R
EXTERNAL FUNCTION(DAT,T,ST,V,W,DELTX,DELTY,A,XMAX,INC,XMIN)
ENTRY TO PLTN.
INTEGERM,Z,B,U,J,P,BCD,T,ST,A,FLAG
VECTOR VALUES BCD(0)=$0$, $1$, $2$, $3$, $4$, $5$, $6$, $7$, $8$, $9$
VECTOR VALUES P(0)=10000,1000,100,10,1
K=DELTX
FLAG=0
WHENEVER DAT(T,ST).L.0
FLAG=1
DAT(T,ST)=.ABS.(DAT(T,ST))
END OF CONDITIONAL
WHENEVER DAT(T,ST).L.10.
M=4
OR WHENEVER DAT(T,ST).L.100.
M=3
OR WHENEVER DAT(T,ST).L.1000.
M=2
OR WHENEVER DAT(T,ST).L.10000
M=1
OTHERWISE
M=0
END OF CONDITIONAL
Z=6-M
AA=DAT(T,ST)
WHENEVER A.E.-1,TRANSFER TO BEGIN
WHENEVER XMAX+INC-DAT(T,A).LE.DELTX
V=DAT(T,A)-((7.-M+FLAG)*DELTX)
OR WHENEVER DAT(T,A)-XMIN-INC.LE.7.*DELTX
EXECUTE PLOT3.($$,DAT(T,A),DAT(T,A+1),1)
V=DAT(T,A)
OTHERWISE
V=DAT(T,A)-((6.-M+FLAG)*DELTX)
END OF CONDITIONAL
W=DAT(T,A+1)
WHENEVER FLAG.E.1
EXECUTE PLOT3.($$,V+K,W,1)
K=K+ DELTX
END OF CONDITIONAL
BEGIN THROUGH GRAPH,FOR J=P(M),-(9*J)/10,Z.E.1
Z=Z-1
B=AA
U=B/J
EXECUTE PLOT3.(BCD(U),V+K,W,1)
AA=AA-(U*J)
K=K+DELTX
WHENEVER Z.E.1
EXECUTE PLOT3.($$,V+K,W,1)
WHENEVER AA.L. .1, TRANSFER TO GRAPH
K=K+DELTX
AA=AA*10.
B=AA
EXECUTE PLOT3.(BCD(B),V+K,W,1)
GRAPH END OF CONDITIONAL
FUNCTION RETURN
END OF FUNCTION

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