The principal tributary of the South Fork is the Little South Fork. Large meanders which occur in both streams indicate that at one time they had reached maturity. However, a more recent uplift of the plateau has upset the balance of these rivers, so that they are once more cutting downward in their beds. In places this intrenchment is very advanced; neither has reached maturity in the present cycle of erosion.

The smaller tributaries of these streams are all youthful. Draining only local portions of the area, they do not reflect the complex nature of the rivers into which they flow. In the western part of the area, where the Rockcastle Conglomerate has been eroded, exposing the underlying limestone deposits, karst drainage is prevalent. In nearly every instance the tributaries enter the major streams from a higher level, so that small waterfalls are characteristic of the triangle.

The flow of the streams is regular, with only minor seasonal changes in regimen. The maximum rise, known locally as a "tide," occurred in 1917, with a record increase in the level of the Cumberland River of 52.8 feet at Burnside. Fortunately the intrenched character of the major streams confided the floodwaters to the immediate vicinity of the river and, aside from covering the best agricultural land, which is on the river flats, the inundation did little damage.

The drainage of the plateau proper is of a dendritic type. In the larger reentrants into the plateau, however, erosion has advanced enough to permeate the limestone deposits, which are characteristic of the Highland Rim. Here mature karst features have developed. In all instances the karst drainage is close to the Highland Rim.

SURFACE CONFIGURATION

On the peneplain surface of the triangle the South Fork of the Cumberland River and its tributaries have been active agents of erosion, so that the surface is no longer that of a plain. In general, it has been lowered until the area presents the maximum of relief and the rounded interfluves associated with the mature stage of erosion. Several kinds of surface, directly related to the underlying structure, can be observed. The plateau was originally capped by the Rockcastle Conglomerate. This rock, which extends from northeastern Kentucky through Tennessee, has been described as a heavy bed of sandstone or conglomerate. "It is characteristically a pebbly and gravelly conglomerate and varies in thickness from 100 feet to [nearly] zero at the margins of the plateau."[3]

The unevenness of the deposit is caused, in part, by erosion. Near the border of the plateau erosion has advanced to a later stage than within the area. Consequently the cliff-making rock has been stripped from the surface at an uneven rate. The presence or the absence of this deposit makes the greatest difference in the configuration of the surface and divides the triangle into two major districts. In sections where the conglomerate is a capping rock the cycle of erosion has been retarded, so that flat-topped interfluves, more characteristic of youth, are separated from mature valleys by vertical cliffs rising as much as two hundred feet (Pl. I, Fig. 1). Where the Rockcastle deposit has been removed, or reduced to a small remnant, the surface assumes a mature profile, with wider, flatter valleys and rounded interfluves (Pl. I, Fig. 2).

On the surface configuration map (Fig. 3) the extent of the conglomerate may be noted by the predominance of flat-topped interfluves in the area southeast of the South Fork of the Cumberland River. Though it is true that a number of flat-topped areas are represented on other parts of the map, the greatest concentration appears in the southeast. In the vicinity of the river, however, mature rounded tops indicate the lack of conglomerate.

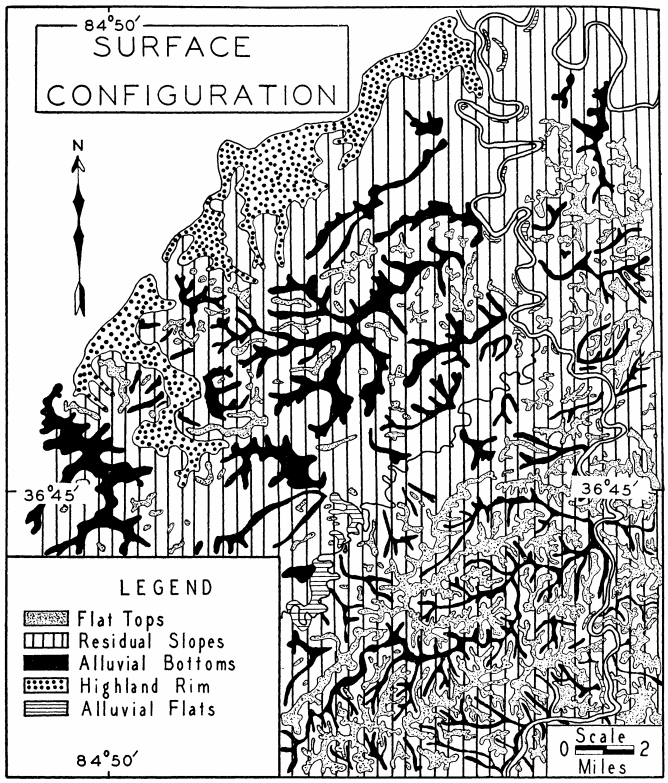

FIG. 3

The Rockcastle Conglomerate is underlain by two kinds of limestone, the St. Genevieve and the St. Louis. In areas where the conglomerate has been removed these form the surface rocks. There is little or no appreciable difference in the surface configuration in the parts of the triangle dominated by either of these deposits. Both have essentially the same resistance to erosion and, as a result, similar profiles. The basic difference between the flat-topped interfluve areas and the districts of residual slope is closely related to these two rocks.

In addition to these two major surface divisions smaller amounts of land have been classified as colluvial slopes. This subdivision is not directly related to surficial rock deposits, but implies that the slopes result from soil wash and are gentler. It breaks the otherwise sharp line that separates the residual slopes from the alluvial lands.

Alluvial flats and alluvial bottom lands constitute the two final subdivisions of surface configuration. The former areas are restricted to the immediate vicinity of the two major streams and, in general, are the best agricultural lands. They are not only highly fertile, but have the added advantage of lying in comparatively large level tracts. The alluvial flats are roughly scroll-shaped, as may be seen on the map (Fig. 3), and are typical of the mature stage of stream erosion. It is possible to divide these deposits into upper and lower flats, depending upon the cycle in which they were laid down. Briefly, the upper flats are older, less fertile areas related to the deposits of the Little South Fork and the South Fork of the Cumberland River and were deposited prior to the last uplifting of the plateau. The lower flats represent recent deposits made since the last uplift; they are separated from the upper flats by a vertical distance of approximately ten feet. These flats are affected by the annual rise of the river, and in this respect differ from the upper flats; they are more fertile but smaller.

In contrast to the alluvial flats the alluvial bottoms are small and are related to the minor tributary streams. Although these areas are also the result of stream deposit, they differ from the flats in that they are narrow and are confined to the valley bottoms. They are composed of a thin veneer covering the underlying rock. Replenished each year by the overflowing of the creeks, they, like the flats, are classed as superior agricultural lands. Where the Rockcastle Conglomerate controls erosion these bottoms are very small, whereas in the round-topped areas indicated by the residual slope classification they are somewhat larger. On these lands and on the alluvial flats and alluvial bottoms is found the only soil capable of supporting continuous agricultural production.

SOILS

Most of the soils of the triangle are residual; the patches of alluvial soils are confined to the vicinity of the streams. The residual soils were formed by the weathering of sedimentary rocks, which inherently are not capable of producing fertile soils.[4]

All soils derived from the Rockcastle Conglomerate are thin and sandy. They tend to dry out rapidly because of their porous nature; this gives the plateau an aspect of moisture deficiency during dry weather. In contrast, during and immediately after precipitation these areas seem to be saturated. Because of a small amount of clay in the soils they are very slick when wet. They range from a thin layer to eight inches. Confined to the plateau top, they are deficient in humus, highly leached, and light yellow. These soils are entirely unsuited to present-day methods of agriculture.

The soils of the residual slope areas, produced by the weathering of limestone, are usually resolved into heavy soils and are underlain by dark red clays. Good drainage is typical of these areas. The soils, which have been classified as sandy loams, rest on tight clay subsoils.[5] Although they cannot be considered first-class agricultural soils, it is possible to produce good crops on them in areas of little slope. Unfortunately, the latter condition does not prevail in the triangle, where, being located on the valley slopes, they wash badly, especially under agricultural use. In many parts the entire A horizon has been removed by sheet erosion and the bright red subsoil exposed.

Erosion is a very serious problem. Both sheet and gully erosion are year-round processes. In spite of attempts by the state to exercise control, little has been accomplished. Sheet erosion may be encountered in all sections of the triangle; gully erosion is characteristic of all but the alluvial soils (Pl. II, Fig. 1). In many parts crop land has been seriously reduced by the removal of the top soil. In these localities the land is promptly abandoned. No attempts are made to prevent such land from eroding further.

From these washing slopes, and from the streams as well, an apron has been built up around the base of each ridge and outlier. The name "colluvial soils" has been given to this combination of local and river deposits. They correspond closely to the classification "colluvial slope" and may be characterized as being light yellow sandy clay. A large percentage of the agricultural production is carried on in these areas.

Alluvial soils are found in the valley bottoms; they are the only ones within the triangle capable of supporting agriculture year after year. Deposited by streams during flood, they receive a fresh supply of soil and organic material which maintains their fertility. Thus they reflect the heterogeneous character of the rocks through which the streams flow. They are a light brown sandy loam.

The inhabitants of the area realize that these soils are superior, and their excellence is reflected in the increased price of alluvial lands, in spite of their being the most isolated. In many parts of the triangle attempts have been made to enlarge the available alluvial deposits. This is done by throwing a rock or log dam across the bed of a creek which drains the hollow. During spring floods these obstructions check the flow of water and cause the transported material to be deposited above the dam (Pl. II, Fig. 2). Over a period of years the creek may build up the deposits to a height of ten or fifteen feet. In one hollow which has been settled well over a hundred years the farmers no longer cultivate the slopes, but prefer to concentrate their efforts on the superior alluvial soils obtained in this manner.

CLIMATE AND VEGETATION

The climagraph presented indicates that the climatic conditions are representative of a Cfa (BB'r) type of climate (Fig. 4). The precipitation is regular, with no pronounced dry season. The mean annual temperature of the triangle is between 55.1° F. and 57.5° F. The warmest weather is in July; the coldest, in February. Usually the temperature is mild, although days of

extreme heat (above 100°F.) and cold (below 0° F.) do occur. Data on frost and length of growing season indicate that the average number of continuous frost-free days is 189.

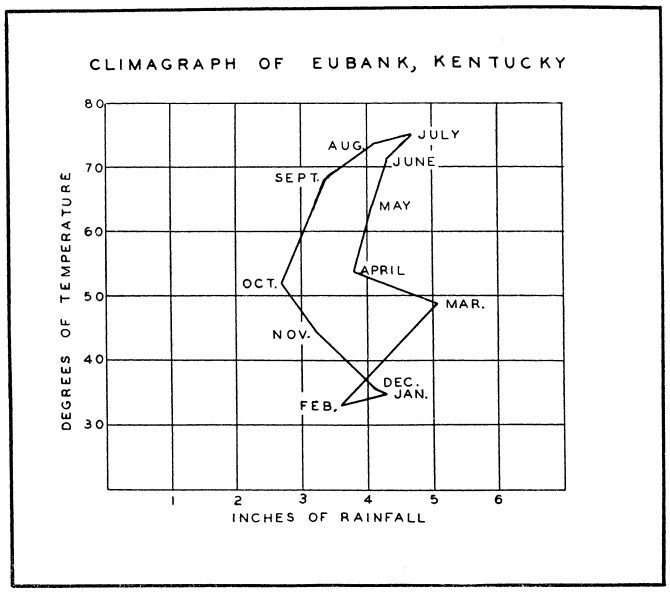

FIG. 4

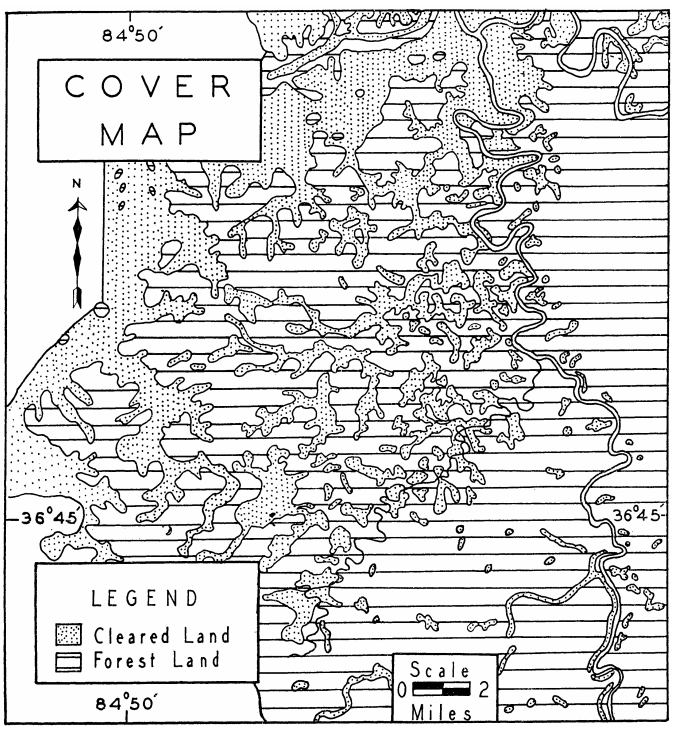

FIG. 5

Although the cover map (Fig. 5) reflects the broader climatic characteristics of the area, the detailed distribution of vegetation is more closely related to the edaphic elements. The outcrop of the Rockcastle Conglomerate is marked by a characteristic growth (Pl. III). On this land may be found the true mountain flora.[6] Conspicuous members of this association include white pine, yellow pine, chestnut, and gumwood. In the valleys spruce, hemlock, and pine are most common. The smaller trees are rhododendron, laurel, sourwood, and mountain magnolia, known locally as "cucumber tree." In addition, huckleberry, blackberry, and trailing arbutus are present. Arbutus clings to the cliffs of the Rockcastle Conglomerate and is not found in adjoining areas.

Parts of the triangle not controlled by the conglomerate support a normal hardwood growth. The dominant trees are as follows:[7]

Tree	*Percentage*
Hickory	18.1
Chestnut-oak	33.9
Basswood	10.0
Yellow poplar	29.0

Other trees present in small numbers are black oak, white oak, black gum and red maple. Hemlock, also, is sparse, and a marked correlation between it and local limestone outcrops was noted. The true chestnut, which was formerly an important member of the association has been almost entirely removed by blight. According to the University of Kentucky, 97 per cent of the few remaining trees are seriously infected.

CARLETON COLLEGE
NORTHFIELD, MINNESOTA

* It is hoped that Part II, "Cultural Geography," will appear in a later volume in this series.

[1] BB'r according to Thornthwaite's classification of climates. See Thornthwaite, C. W., "The Climates of North America," *The Geographical Review*, Vol. 21, No. 4, pl. 3. 1931.

[2] Burnside is in Pulaski County; Monticello is the county seat of Wayne County; and Stearns is the largest town in McCreary County. The last two counties are in the southernmost range of counties in Kentucky; Pulaski is directly north and adjoins them.

[3] *The Geologic Atlas of the United States. London Folio, Kentucky*, U S G S (Library Edition, Washington, D.C., 1889), p. 3.

[4] In the absence of any soil survey for the counties under consideration a generalized distribution of soils may be inferred from the surface configuration map (Fig. 3).

[5] A more detailed description of the chemical components of these soils may be found in S. D. Averitt, *The Soils of Kentucky*, Kentucky Agricultural Experiment Station, State University, Lexington, Kentucky, Bull. 193. Lexington, Kentucky, 1915.

[6] Miller, A. M., *The Geology of Kentucky*, p. 115. Department of Geology and Forestry, University of Kentucky, Lexington, Kentucky, 1919.

[7] Figures taken from *Forestry in the Economic Life of Knott County, Kentucky*, Kentucky Agricultural Experiment Station, University of Kentucky, Bull. 326. Lexington, Kentucky, 1932.

WILSON PLATE I

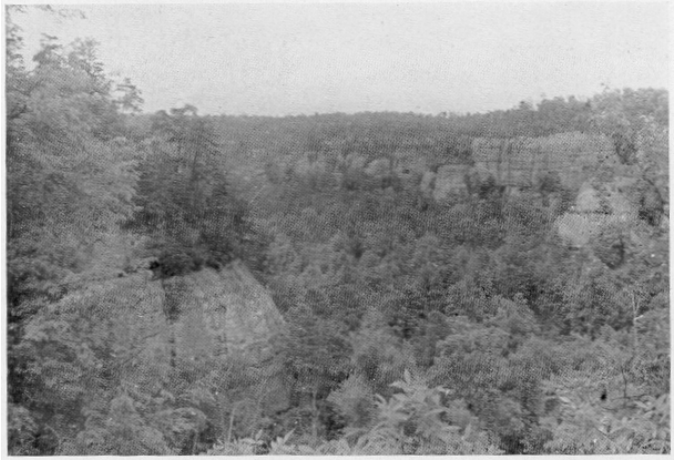

FIG. 1. Outcropping of Rockcastle Conglomerate, with characteristic development of vertical cliffs and flat-topped interfluves

FIG. 2. An outlier of Rockcastle Conglomerate, with the flat-topped area reduced to a remnant surrounded by broad mature valley

WILSON PLATE II

FIG. 1. Gully erosion on residual soils near Parker's Lake

FIG. 2. Soil dam showing the deposition of soil above it

WILSON PLATE III

Vegetation characteristic of the flat-topped interfluve areas

PROTOTRETA, A NEW GENUS OF BRACHIOPOD FROM THE MIDDLE CAMBRIAN OF MONTANA

W. CHARLES BELL

THE genus *Acrotreta* was described in 1848 by Kutorga, who assigned three species to it. Of these, *A. subconica* Kutorga from the Ordovician of Russia was selected by Hall and Clarke in 1892 as the genotype. Kutorga based his description of *A. subconica* on four specimens, which showed only the exterior of the shell; no other examples of the species have since been collected from either the type locality or strata in Russia. Prior to 1912 several species from the Cambrian and lower Ordovician rocks of North America had been assigned to the genus on the basis of external similarity. The internal features of some of these species were known and came to be accepted by American paleontologists as characteristic of *Acrotreta*. As a result, when Walcott prepared the most recent diagnosis of the genus, in 1912, he based his definition almost entirely on North American species.

J. A. Thomson (1927, p. 120) states in a discussion of the genus concept as related to the brachiopods: "The importance of a full knowledge of the genotype . . . becomes evident, for generic classification of a species is not so much a process of ascertaining whether the species possesses the characters which have been claimed to hold good for the genus, as a process of comparing the species with the genotype in order to estimate its probable relationship through descent." The question therefore arises: "What are the characteristics of the genus *Acrotreta* as typified by the genotype?" Unfortunately, our incomplete knowledge of *A. subconica* precludes a satisfactory answer. Upon what basis, then, have there been assigned to the genus *Acrotreta* some fifty-six species and eleven varieties, almost without exception differentiated by means of variations in the external characters of the ventral valve? Walcott, who is entirely responsible for the present constitution of the genus, included within it species to which the following definition could be applied: Ventral valve corneous, more or less highly conical, and penetrated at or near the apex by a minute foramen, below which the posterior surface of the cone is more or less flattened or grooved; dorsal valve fiat or slightly convex. Obviously this definition takes into consideration only external characters and is based on the supposition that superficial external resemblance to one another among a number of species constitutes generic relationship. In the writer's opinion the similar external form common to most species of *Acrotreta* may well have resulted through polyphyletic development.

Among the brachiopods internal characters are admittedly of superior value in indicating relationships. The internal characters of *Acrotreta* have been essentially disregarded, so far as application to classification is concerned. From Walcott's figures it is apparent that not all species of the genus have similar interiors. It is also apparent that the species can be separated into several groups, within each of which the internal characters are fairly constant. The writer is confident that these groups, which probably are of generic rank, will be found to possess greater stratigraphic significance than the genus *Acrotreta* as now defined.

The incompleteness of our present knowledge of the orders Atremata and Neotremata is due primarily to mechanical difficulties in the technique of preparation. The shells are small (2-10 mm. in length), extremely delicate structurally, and calcareophosphatic in composition. Cleaning the shells with an acid or a base is seemingly impossible, and mechanical methods are successful only when the matrix is relatively nonresistant to the needle. In the writer's experience serial sectioning is the only method which will yield a knowledge of internal characters in almost all cases. Apparently this method has not heretofore been used in studying the Atremata and the Neotremata, and it is recommended as a means of increasing our knowledge of these groups.

On the supposition that characters of generic rank are to be found in the dorsal interior of the Neotremata the writer proposes to describe a new genus, *Prototreta*, which is externally a homeomorph of *Acrotreta*. Because not all the known species have been adequately studied, and because the ventral interior is not yet well known, at present it is impossible to give a complete description of the genus. In this preliminary announcement it is planned to outline the principal generic characters and to designate and figure a genotype.

GENERIC DIAGNOSIS: *Ventral valve*. — Calcareophosphatic (collophane), highly conical, and penetrated at the posterior side of the apex by a minute foramen, below which a groove extends to the margin of the valve (Pl. I, Figs. 1-2). Interior unknown. *Dorsal valve*. — Flat or gently convex, with a minute marginal apex (Pl. I, Fig. 3). Interior (Pl. I, Fig. 4) with posterolateral margins thickened into flat triangular areas (for each of which the name *proparea*[1] is proposed), oriented strongly anacline, which border a broad central groove whose margins diverge anteriorly from the apex approximately at right angles; prominent median septum which, in anterior part of valve, expands laterally and vertically into a strong plate, from which extend six or more finger-like projections. Muscle scars diagrammatically represented in Plate I, Figure 5.

Diplotype.— **Prototreta trapeza,** sp. nov. (Pl. I, Fig. 4); catalogue number 1535, Museum of Paleontology, Montana State University, Missoula, Montana.

Occurrence. — Middle Cambrian, *Bathyuriscus* zone in basal part of Meagher limestone, Nixon Gulch, approximately six miles north of Manhattan, in SW. ¼ Sec. 23, T. 2 N., R. 3 E., Three Forks Quadrangle, Montana. Locality 45, zone 3a, Montana Bureau of Mines and Geology (= locality 19z, U. S. Nat. Mus.), which is at the same stratigraphic position as, and 1,500

feet N. 12° W. from, locality 45, zone 3, of Deiss (1936, p. 1314).

The dorsal valve of *Prototreta* is morphologically unique. Its particular type of posterior margin, called *pseudointerarea* by Schuchert and Cooper (1932, p. 20), simulates closely the pseudointerarea found in the ventral valves of *Obolus* and *Lingulella* of the Atremata. It is assumed that in the Atremata the pedicle protruded between the valves through the groove bordered by the propareas; but it is believed that in the Neotremata, to which *Prototreta* apparently belongs, the pedicle protruded through the foramen at the apex of the ventral valve. Both a ventral foramen and a dorsal groove, which is apparently analogous to the ventral pedicle groove of the Atremata, appear in *Prototreta*. At present the writer cannot account for this anomalous condition. More must be known concerning the ventral valve of *Prototreta* before even a tentative explanation can be made.

Many species of *Acrotreta* have a median septum in the dorsal valve. This septum, which is described and figured by Walcott as a simple, straight, low ridge of varying length, has been practically ignored in classification. Nearly all the knowledge concerning it has been derived from internal molds. The development of the septum in *Prototreta* is striking and, to the writer's knowledge, without parallel in any other brachiopod. In life the structure extended into the interior of the ventral valve, but its function is not clear. Muscle impressions apparently are present upon the septum (a condition unknown in *Acrotreta*) at the base of the expanded plate; but no roughened areas, indicating the former attachment of tissue, have been observed upon the finger-like projections.

Scars which unquestionably served as points of muscle attachment in the dorsal valve have been observed only on the visceral face of the thickened pseudointerarea. One pair of vaguely outlined scars adjoin the inner margins of the propareas. Another pair clearly outlined and deeply incised, occur below the lateral visceral margins of the "pedicle" groove. This muscle pattern differs greatly from that regarded by Walcott as typical of *Acrotreta.* He noted the presence of one pair of muscle *tubercles* at the posterolateral margins of the valve and of another pair bordering the median septum near the center of the valve.

Prototreta has the external characters of *Acrotreta* as conceived by Kutorga. It may be claimed that Prototreta should therefore remain included in *Acrotreta* until it can be proved that the interior of *A. subconica* Kutorga is distinct from that of the Montana genus. The writer grants the justice of this claim, but offers the following defense. If he is correct in his belief that generic characters are to be found in the morphology of the dorsal interior, then more than one genus is included among the species now assigned to *Acrotreta*. Certainly the species from Utah, assigned by Walcott to *Acrotreta*, possess dorsal interiors radically different from those of *Prototreta*, and both differ from the species of the Appalachian province. In the writer's opinion it is desirable to separate as soon as possible the *Acrotretae* of North America into more accurately defined generic groups, and thus to make them valuable for stratigraphic correlation. Because of their unreliability in correlation they are at present almost ignored by Cambrian stratigraphers. If, in the future, one of the new genera is found to be identical with *A. subconica* from Russia, the new name may be relegated to the synonymy of *Acrotreta*.

ACKNOWLEDGMENTS

The writer is grateful to Professors G. M. Ehlers and E. C. Case, of the University of Michigan, for kindly advice and criticism during the writing of this paper. The specimens studied were generously loaned by the Montana Bureau of Mines and Geology.

UNIVERSITY OF MICHIGAN

[1] The term "proparea" is proposed as a descriptive name for each half of the pseudointerarea when a pedicle groove divides it into two parts.

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EXPLANATION OF PLATE I

All specimens figured are preserved in the Museum of Paleontology, Montana State University, Missoula, Montana.

Prototreta trapeza, gen. et sp. nov.

FIGS. 1-2. Apical and posterior views of an almost perfect ventral valve. Note foramen on posterior side of apex in Figure 2. X 6 (No. 1534a)
Middle Cambrian, Pentagon shale; locality 26, zone 4 Continental Divide, Lewis and Clark range, above head of South Fork of Lick Creek, in Sec. 18, T 24 N., R. 11 W., Montana

FIG. 3. Apical view of a well-preserved dorsal valve showing the deep sulcus, apparently a specific character. X 8 (No. 1534b)
Locality 26, zone 4

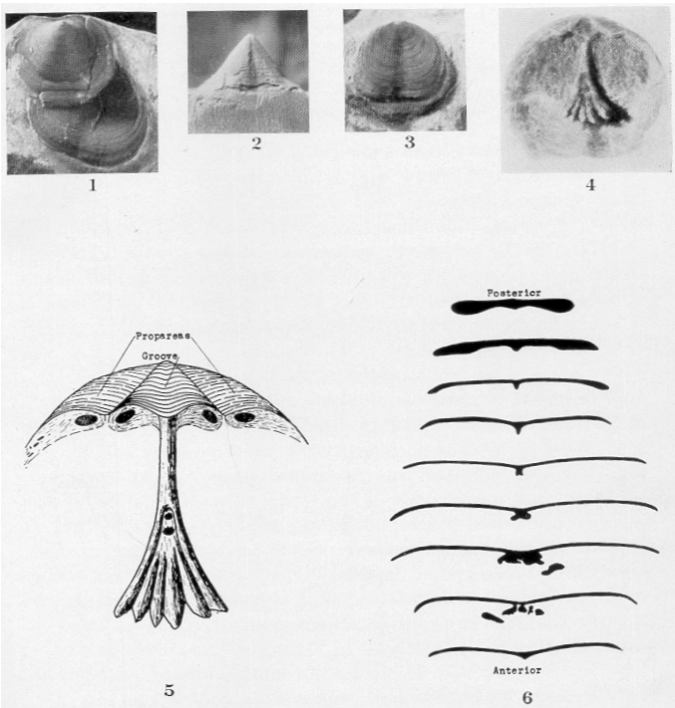
FIG. 4. Interior of a dorsal valve, showing propareas, groove, and expanded median septum. X 9. Diplotype (No. 1535). This valve apparently is identical with, but better

preserved than, dorsal valves from locality 26, zone 4. Locality 45, zone 3a (see page 405)

FIG. 5. Diagramattic representation of the pseudointerarea and expanded median septum characteristic of *Prototreta*. Note muscle scars, which are crosshatched; those on septum are doubtful.

FIG. 6. Drawings of serial sections through a dorsal valve of Prototreta trapeze

BELL PLATE I



Prototreta trapez, genotype of a new brachiopod genus from the Middle Cambrian of Montana

ACIDIZING IN MICHIGAN, 1932-37

LEONARD C. CHAMBERLAIN, JR.,* AND PAUL E. FITZGERALD†

INTRODUCTION

ACIDIZING had its early commercial development in Michigan. The successful treatment of The Pure Oil Company's Fox No. 6 in the Chippewa-Greendale pool began in February, 1932, the industry which is now known as "acidizing." In the five years since this well was treated the process has spread to every oil field in the United States, Canada, and Mexico where production occurs in formations that are susceptible to it. In 1936 there were approximately 5,000 treatments, which used 10,000,000 gallons of acid.

HISTORY

The early history and the results of acidizing in Michigan were described by Newcombe (2), Covell (1), and others. Comments and speculations made in these papers yield an interesting basis for a comparison of equipment, technique, and materials used then and now. Figure 1, Plate I, shows one of the original treating units. Figure 2, Plate I, illustrates one of the present units, into which is built the experience of the last five years. It is faster, more reliable, carries more acid, and is equipped with pumps capable of larger volume and higher pressure. Likewise, stations have changed from the temporary quarters used in 1933, as shown in Figure 3, Plate I, to the permanent type exemplified by the new station at Mt. Pleasant, Michigan, as shown in Figures 1-2, Plate II.

It was agreed then, as it is now, that acidizing made for worthwhile increases in yield in most Michigan wells, except in those producing from the Berea sandstone. It was pointed out, however, that re-treatments were not so successful as first treatments; and speculations were advanced on the possibilities of the presence of "secondary reactions" and on their effect in wells which were shut in for 24 to 36 hours after treatment.

Since then the answer to successful re-treating has been demonstrated to be a matter of directing the acid into tighter, unspent areas and away from the porous section which was opened by the first treatment. The secondary reactions have been found to consist mainly of a re-precipitation of metal hydrates and calcium carbonate. The metal oxides are dissolved from the formation by the fresh acid and are dropped in flocculent form whenever the acid remains too long in contact with the limestone. The calcium carbonate is first dissolved by long contact with the carbon dioxide generated from the primary reaction, and is laid down again when the pressure is finally released at the resumption of production.

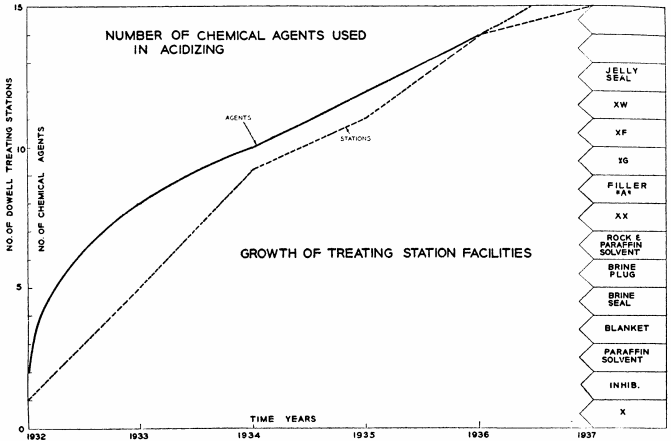


FIG. 1. Yearly growth of stations and chemical agents

The chief differences, then, between acidizing as first used and as now practiced in Michigan are the methods of directing acid into the tighter, more saturated portions of the formation and the combination of newer acids and technique to effect a much shorter treatment, safer from the dangers of re-precipitation. Wells are now put into production in Michigan within less than two hours after acidizing. In 1932 about six chemical agents were applied in acidizing.

Each year since an average of two additional chemicals has been added, which has improved the scope of this service. There are now some fifteen different chemical agents regularly required in acidizing oil and gas wells.

Figure 1 shows the yearly record of the growth of acidizing; one curve indicates the number of chemical agents in use and the other the number of treating stations established. To the inhibited hydrochloric acid[1] and the well-known "Paraffin Solvent" and "Blanket,"[2] with which the start was made, there were soon added the "Brine Seal" for prevention of water increase; "Brine Plug" to prevent action on lead plugs; and a mixture known as "Rock and Paraffin Solvent." Then came the addition of bifluorides[3] to increase the action of acid on siliceous and dolomitic limestones; the Lime Filler "A" as a directing agent in re-treatments; and "XG,"[4] a special acid for "gyp" removal. Finally, there were put into use the "XF"[5] and "XW" acids, containing phenol, cresols, and alcohols, to facilitate penetration and subsequent removal of acid; and the "Jelly Seal,"[6] which has largely replaced Filler "A" and which is the most successful aid yet introduced for acid direction in re-treatments.

Similar strides have been made in testing and research. From reliance on chemical analyses and solubility tests acidizing has gone to controlled flow tests on cores to determine the advisability of the process and, to some degree, the type of agent and the technique to be used. Likewise, research efforts have increased until there are now three fully equipped laboratories, where before there was one such, devoted to the maintenance and improvement of acidizing processes. Figure 3, Plate II, shows one of these laboratories in which may be seen a battery of core-testing apparatus for checking acidizing procedure.

SOME MICHIGAN DATA

Only a few acid tests have been made on cores from Michigan oil-producing formations. Some cores are available which are large enough to provide samples of a size suitable for testing. The interesting results obtained from such samples are exemplified by the following summary of data on two Dundee cores furnished by a major oil company (Fig. 2).

The very great increase in permeability obtained by a doubling of the porosity indicates that the pores, though large, were constricted. Poiseuille's law would indicate a fourfold increase of permeability if the pore volume of uniformly sized pores was uniformly doubled. The vast difference between this theoretical 4 and the 3,750 times actual increase is proof that a small amount of material is almost completely blocking the flow channels, and is a partial explanation of the fact that results from acidizing have been far above expectation.

CORE № 51	WEIGHT OF CORE IN GRAMS	VOLUME OF CORE IN CC	POROSITY	PERMEABILITY (MILLIDARCIES)	INCREASE FROM ACIDIZING
BEFORE ACIDIZING	31 953	13.8	9 43	120	
AFTER ACIDIZING	29 450	13 5	18.5	55,000	458 TIMES
CORE № 53					
BEFORE ACIDIZING	28.858	11.8	4 75	1 2	
AFTER ACIDIZING	27. 804	11.65	10 7	4500	3750 TIMES

COURTESY PURE OIL COMPANY

FIG. 2. Acidation of Dundee cores from Greendale, Michigan

The type of core used is shown in Figure 1, Plate III. It is one inch in diameter and one inch long. The exposed crystals have been only slightly attacked by the acid. X-ray analysis proves these crystals to be pure dolomite, embedded in a matrix of calcite. The acid eats out channels around the blocking crystals. Figure 2, Plate III, is a photomicrograph of the face of an unacidized core; Figure 3, Plate III, that of an acidized one. The fine structure of the calcite is apparent in Figure 2, Plate III, whereas in Figure 3, Plate III, the calcite is dissolved away, a process that exposes the sharp corners of the less soluble dolomitic crystal.[7]

In 1935 the average percentage increase for treatments in Michigan was estimated at 417 (3). Since then some 700 additional acid treatments have been given. Complete records of 12 per cent of these wells were available to the authors in calculating the results that appear in Figure 3, along with other data of interest for the various fields. These results average 964 per cent increase. The Sherman field in Isabella County west of Mt. Pleasant is a new one in which the best treating materials and procedure are still being determined.

Greatest percentage increases are found in the smaller wells. All treated wells that make over 100 barrels a day, except those in the Porter Field, have an average increase of 155 per cent. Porter wells of 100 barrels or more average 765 per cent increase, whereas those wells under 100 barrels a day, in all Michigan, have averaged 1247 per cent since 1935. Quick-penetrating acids which enter and return from the formation more

easily, gel compounds used for directing agents in re-treatments, and abolishment of shut-in periods are largely responsible for the increased returns of the last two years. Phenol, cresylic acid, and various aliphatic alcohols have been used in the HCl to produce these new effects.

	FOR-MATION	GENERAL ANALYSIS	FIELD	AVGE. % INCREASE	TREATING AGENTS & REMARKS
DEVONIAN SYSTEM	TRAVERSE	LIMESTONE AND DOLOMITE 25-90% $CaCO_3$ 78-98 % SOLUBLE	OGEMAW	310	X AND XX EARLY TREATMENT
			EDMORE	400-800	
			HART		
			CHIPPEWA-GENEVA	650-3900	
			MUSKEGON		
	DUNDEE	USUALLY LIMESTONE 70-98% $CaCO_3$ 2-4% $MgCO_3$ 85-99% SOLUBLE SOMETIMES DOLOMITIC	CHIPPEWA GREENDALE	2024	XF ALMOST ANY TYPE ACID IS SUCCESSFUL
			DENVER	1360	
			PORTER	1413	
			OGEMAW	310	X AND XF
			BEAVERTON	400	XF
			ARENAC	620	XXF, XXWF, XF
	U MONROE	DOLOMITE 54 % $CaCO_3$ 44 % $MgCO_3$ 2% SILICEOUS MATERIAL	SHERMAN	132	XF, XXF, XXWF VERY TIGHT XWF BEST AT PRES
			VERNON	4494	XF AND XXWF TIGHT
			CRYSTAL	613	XF AND XXF TIGHT
			MUSKEGON		X

FIG. 3. Data on acidizing in Michigan oil fields

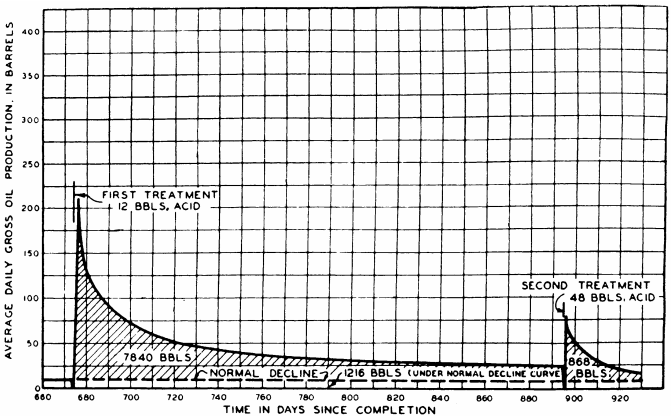


FIG. 4. Decline curves, Covell No. 1

The study of decline curves constitutes the best method of arriving at the real value of acidizing. These curves are made from production figures collected over a long period and give the total increased oil output for that period. In the figures shown the normal decline is designated by the dotted line and the increased oil by the crosshatched portion. Many such curves have already been published (1, 4).

In Figure 4 two acid treatments are demonstrated as having added 8,700 barrels of oil over and above the 1,216 barrels indicated by the normal decline curve. At the normal rate it would have been necessary to operate this well five years to get what it produced in the 260 days following treatment.

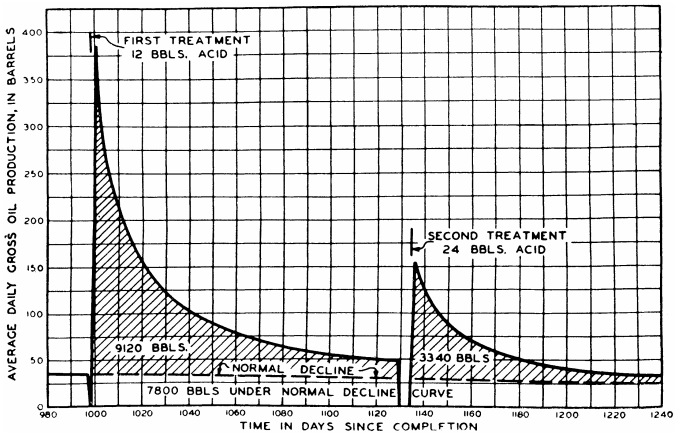


FIG. 5. Decline curves, Covell No. 1

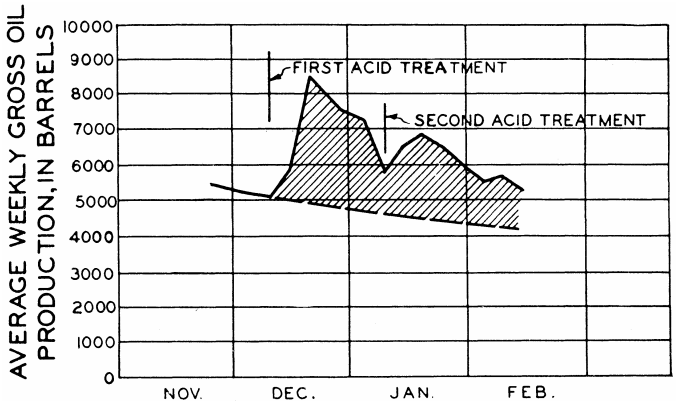


FIG. 6. Decline curves, Arenac field

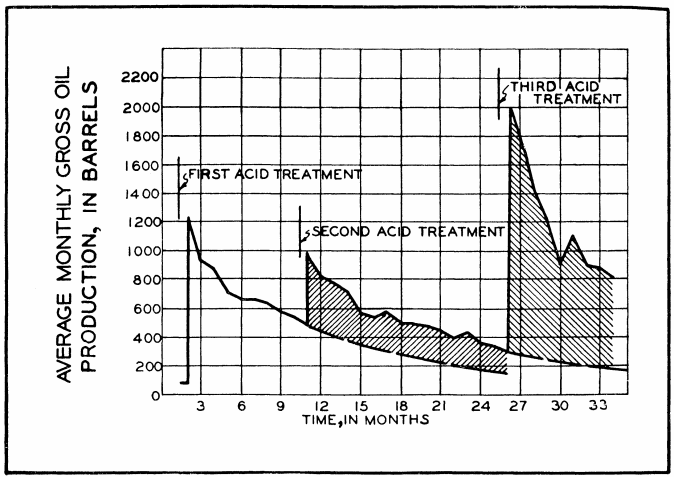


FIG. 7. Decline curves, Porter field

The well from which the data in Figure 5 were derived produced 12,460 barrels over and above the 7,800 barrels indicated for the period of 240 days.

The Arenac Well, from which the data in Figure 6 were derived, recovered during the sixty days following the treatments approximately 17,000 barrels above the normal expected production.

Figure 7 demonstrates what acidizing often does for a new well which comes in making uneconomic amounts of oil. The first acid treatment, given before a decline curve had been established, made the well a commercial producer. The second acidizing added 3,750 barrels in 15 months, and the third gave an even greater return, 6,400 barrels in 8 months.

CONCLUSIONS

Approximately 2,100 acid treatments have been given in Michigan, or an average of 1.5 for each of the 1,400 commercial oil wells that have produced from limestone formations. It is estimated that 80 per cent of all treatments are commercially successful, and that, in proved fields, more than 90 per cent are successful. The general statement holds true today that 75 per cent or greater acid solubility of the producing rock formations is desirable for good results from acidizing and that only a few exceptions have profited from acidizing wells of 25 per cent or less solubility. The rise in the average increase production due to acid treatment is attributed to experience which operators have gained in knowing when a well is a fit subject for acidizing, to new methods of directing acid to unspent production areas, and to new acid solutions and technique which have made it possible to shorten the time of shut-in from thirty-six hours to a matter of minutes.

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† Dowell, Incorporated, Tulsa, Oklahoma.

[1] Grebe, J. J., and Sanford, R. T., "Treatment of Deep Wells." September 13, 1932, U. S. 1,877,504.

[2] Grebe, J. J., "Method of Treating Wells with Acids." June 27, 1933, U. S. 1,916,122.

[3] Heath, Sheldon, and Fry, William, "Acid Treating." August 20, 1935, U. S. 2,011,579.

[4] Grebe, J. J., "Treatment of Wells." January 29, 1935, U. S. 1,989,479.

[5] Chamberlain, L. C., "Treatment of Wells." December 17, 1935, U. S. 2,024,718.

[6] Grebe, J. J., and Stoesser, S. M., "Treatment of Deep Wells." April 23, 1935, U. S. 1,998,756.

[7] These are not photographs of the same spot before and after, but are typical.

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1. COVELL, K. A. Development in Eastern Production Practice and Acid Treatment of Michigan Oil Wells. Oil Weekly, 73 (May 28, 1934): 17-23.

2. NEWCOMBE, R. B. Acid Treatment for Increasing Oil Production Oil Weekly, 69 (May 29, 1933): 19-26.

3. —— Mechanics of and Economical Value of an Acid Treatment of Oil and Gas Bearing Formations, also a Summary of Oil and Gas Developments in Michigan, including Rotary Drilling. Released to Oil and Gas Journal June 6, 1935.

4. ZAVOICO, B. B. Geology and Economic Significance of Central Michigan Field. World Petroleum, 6 (May 1935): 309-324.

CHAMBERLAIN AND FITZGERALD PLATE I

FIG. 1. Original treating unit

FIG. 2. Present treating unit

FIG. 3. Temporary field headquarters

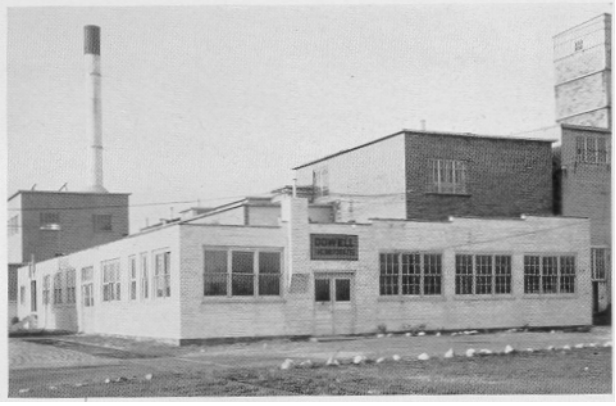

FIG. 1. Mt. Pleasant treating station

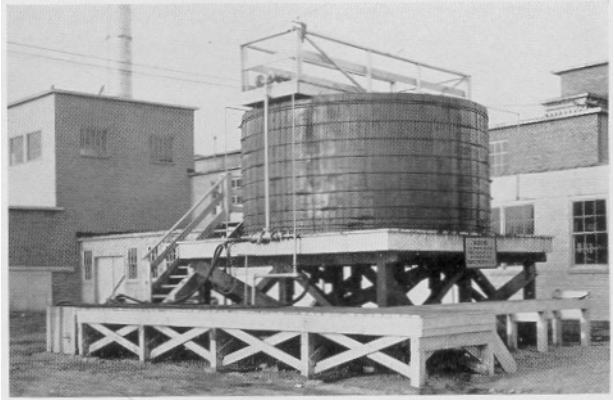

FIG. 2. Mt. Pleasant acid storage

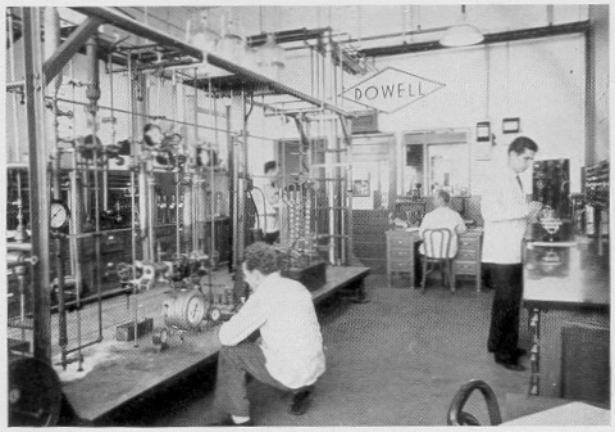

FIG. 3. Dowell laboratory

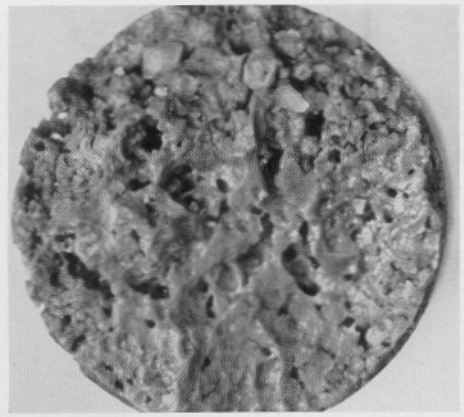

FIG. 1. Michigan Dundee core 51 after acidization

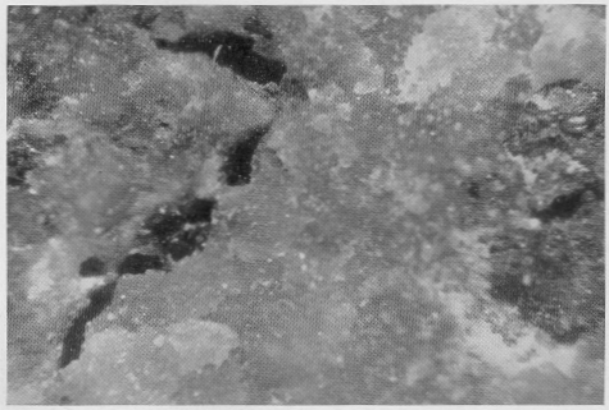

FIG. 2. Photomicrograph of core unacidized

FIG. 3. Photomicrograph of core acidized

PRESENT TRENDS IN STUDIES OF THE MICHIGAN HURONIAN

ROBERT M. DICKEY

THE student of pre-Cambrian geology, somewhat bewildered ordinarily by an intricate mass of detail and a variety of conflicting opinions, occasionally finds value in attempts to summarize his information and to discern the general lines along which researches in the subject are proceeding. This is very true of investigations of the Michigan Huronian rocks, and an effort of this nature is highly appropriate during the centennial of the Michigan Geological Survey, which has participated ably and honorably in furthering the growth of knowledge of the pre-Cambrian geology of the state.

If, following Leith,[1] we regard the Algonkian as "that part of the pre-Cambrian sedimentary column in a particular region to which ordinary stratigraphic methods can be applied," the Huronian rocks of Michigan may be defined as that portion of the Algonkian which is at present stratigraphically delimited at its base by the Eparchean Interval and which has its upper stratigraphic terminus in the marked erosional break that preceded the deposition of the clastic beds of the Lower Keweenawan. The Michigan Huronian proper is, in generally accepted present usage, separated into the Lower, Middle, and Upper divisions by means of two well-marked and widespread unconformities which, although not characterized in many places by highly pronounced structural discordances, are nevertheless to our knowledge omnipresent in the known pre-Cambrian of the Upper Peninsula.

Since the Archean of Michigan, stratigraphically below the Algonkian, is defined by Leith[2] as "the underlying, more or less indivisible, basement complex, containing igneous or sedimentary rocks, or both, in which ordinary stratigraphic methods do not apply," the base of the Algonkian and that of the Huronian coincide in the Eparchean Interval. By definition, however, this boundary is inherently one of temporary location, existing in its present position only until further detailed work and improved field and laboratory methods serve to decipher the riddles of the Archean and to depress the upper limit of the "indivisible" basement complex. Refinements in methods of study and mapping will doubtless clarify stratigraphic relationships which now seem to be almost hopelessly confused.

A deserved criticism of the present definitions of Archean and Algonkian may be based upon their lack of elasticity and upon their potential failure to answer future requirements. For example, a pre-Huronian sequence consisting largely of flows, which, because of lack of detailed study or by reason of its advanced metamorphism, has not been worked out in the past, may some day be unraveled. In such an event it must, if the present terminology is retained, exist as a unit left dangling between the Archean and the Algonkian, unable to enter the former division because no longer a portion of the indivisible basement complex or the latter because not dominantly sedimentary.

The term "Huronian" as employed in its modern sense carries no connotation of age equivalence of similar rocks in separated areas, but refers rather to rock type. Although not lending itself readily to definition in a few words, "Huronian type" includes pre-Cambrian rock sequences which are susceptible of treatment by ordinary stratigraphic methods and which are largely sedimentary, including both elastics and products of chemical precipitation, with subordinate amounts of pyroclastics and volcanics, all of which have been indurated by processes normal to an anamorphic environment.

If, then, "Huronian" is employed as a term descriptive of rock type, doubt may be expressed as to the future utility of the designations Lower, Middle, and Upper Huronian, since these obviously have reference to stratigraphic location. If, for instance, further investigation reveals, as it well may, the existence of a sequence of Huronian type unconformably below the base of our present Lower Huronian, will this sequence be regarded as Lower Huronian, and if so, how then shall we refer to our present Lower and Middle Huronian? Another possible danger attaching to the traditional separation of the Huronian into Lower, Middle, and Upper divisions is that reluctance will doubtless be felt to recognize any additional major stratigraphic sequence which may be found as our knowledge of the Huronian rocks advances. In the present absence of such contingencies the existing nomenclature of the Huronian divisions answers our needs, but the future should witness no hesitancy in casting it aside in favor of a less rigid system of terminology as the occasion warrants.

The increasing acceptance of what may be referred to as the "type" classification of the pre-Cambrian rocks seems desirable and promises to remove many of the difficulties and controversies introduced into the study by premature attempts to set up in various correlations time equivalents based upon evidence which is all too often entirely insufficient.

"Archean" and "Algonkian" are almost universally employed to designate the major divisions of the pre-Cambrian by workers in that field in North America. Paleontologists and students of post-Lipalian stratigraphy are of similar unanimity in referring to these as "Archeozoic" and "Proterozoic." It is generally felt by geologists who deal largely with the pre-Cambrian that the latter terms carry with them implications of the existence of various forms of pre-Cambrian life which, upon the evidence afforded by the pre-Cambrian rocks, cannot be supported by a sound basis of fact. It is understandable that the paleontologist, viewing the abrupt appearance of manifold and varied life at the base of the Cambrian, should logically assume the existence of living forms in the pre-Cambrian. In the Lower Huronian Kona and Randville dolomites of the Upper Peninsula occur peculiar structures which have been regarded as algal in origin, and the writer inclines

toward this view. These structures, because of their uniform condition of alternating broad convexities and sharp concavities upward, have been used for a number of years in determining the tops of complexly deformed beds in which they occur. However, many geologists familiar with the occurrences take issue with any ascription of organic origin to these features. These are perhaps the best direct evidences of the existence of life in the Michigan Huronian which have yet been discovered. Other evidence, of an indirect nature, is to be found in the presence of limestone in the Huronian and in the graphite of certain Huronian slates. In the Archean rocks of Michigan no traces of the existence of life have been discovered. Consequently, the student of the Michigan pre-Cambrian feels, doubtless with justification, that the burden of proof in the form of conclusive field evidence rests with those who advocate a division of the pre-Cambrian upon a basis of the life supposed to have been present. Until such proof is brought forwrard, it is not unreasonable to state that the terms "Archean" and "Algonkian," which imply nothing as to life forms in the pre-Cambrian, are preferable to "Archeozoic" and "Proterozoic."

The broader outlines of the stratigraphy and of the correlation of the various members of the Michigan Huronian have been established, and in a number of instances, notably in the iron formations of the various ore-producing districts of Michigan, the stratigraphy has been covered in detail. Similar careful work has been done on various other divisions of the Huronian. Some of the results have been published, but a large part of the present information is unavailable in printed form. A great deal remains to be done in researches of this nature, and such efforts are of the utmost importance. Detailed studies of the iron formations, because of their obvious economic value, have progressed more rapidly and have received better financial support than projects dealing with other portions of the Huronian, where prospects of immediate monetary returns from an investment in such work are more uncertain.

In the correct deciphering of the stratigraphic minutiae of the Michigan Huronian rest our principal hopes of a proper understanding of the manner in which these rocks have reacted to deforming stresses. The writer ventures the prediction that, as progress is made in such investigations, faulting will be recognized as having played a much more important part in determining the present location and attitude of the Huronian beds than has generally been con-ceded in the past. It is not impossible that further discoveries of iron ore will be made similar to that of the great Plymouth open pit mine on the Gogebic Range, located in a downfaulted block of the Ironwood iron formation in an area where for many years only Archean rocks were believed to exist. Work directed toward this end should, needless to say, include not only the iron formations, but all rocks of the Huronian.

From a more or less academic standpoint relationships within the Huronian, and in particular the relationships of these rocks to the igneous complexes which bound them in many places, once understood, should yield valuable information upon the ultimate nature of deformation of the earth's crust. Perhaps nowhere can the deep-seated conditions involved in mountain building be studied to better advantage than in the truncated, eroded roots of ancient mountain ranges now represented by the Huronian rocks of the Upper Peninsula. Attacks upon such problems are now being made, and although at present there is considerable lack of agreement in many instances upon the relative ages of the igneous rocks and the Huronian involved, a reconciliation of opposing views is doubtless not many years removed.

In stratigraphic studies of the Huronian the investigation of heavy accessory mineral assemblages occurring in the various rocks is attaining increasing prominence as an aid in correlation and in the understanding of the paleogeography and geologic history of the pre-Cambrian of the Upper Peninsula. The groundwork for this important phase of geologic activity is now being established by examination of hundreds of specimens from the Michigan pre-Cambrian, principally by S. A. Tyler and R. W. Marsden of the University of Wisconsin, and their results will soon be forthcoming. The subject is so broad as to provide an extremely interesting and almost inexhaustible field for future work. Not only will the prosecution of such endeavors add to our knowledge of the Huronian, but the study of heavy accessory mineral assemblages itself will undoubtedly benefit thereby, through improvements in technique and increasing standardization in methods.

Measurements of the absolute age of various igneous rocks of the pre-Cambrian by investigation of the products of radioactive disintegration are showing steady advances through the studies of A. C. Lane and W. D. Urry. Although many geologists are not at present disposed to accept their results as indisputable criteria in disagreements concerning correlation, such studies have even now, with the work in what might be termed its infancy, very definite value. To cite only a single case, for a number of years most of the basic dioritic dikes that cut the iron formation of the Gogebic Range have been regarded as Middle Keweenawan, and as having served in the capacity of feeders for the Middle Keweenawan traps. However, although definite evidence has not yet been uncovered, the conviction has been growing for some time that many of these dikes are pre-Keweenawan, and probably late Upper Huronian. This conviction has been supported by the results of age determination on a radioactive basis carried out by Lane and Urry, who used the helium method. Their findings placed a specimen from one of these dikes as late Upper Huronian. Since the dikes bottom a large number of the Gogebic Range iron ore bodies, and have evidently exerted a definite influence upon the development of such ores, the correct determination of their relative age is of no small importance in studying the manner of concentration of the Ironwood iron formation to ore.

Leith[3] has deplored attempts to emphasize the time element in pre-Cambrian correlation, asserting, with reason, that our information is so meager as to render almost valueless correlations which stress this factor. He states, however, that in the future the time element may be validly introduced as researches progress which involve age determinations by studies of the products of radioactive disintegration, the proper correlation of separated batholiths, investigation of the heavy accessory mineral assemblages not only of pre-Cambrian igneous bodies but of pre-Cambrian sediments, the manner of origin of the pre-Cambrian iron formations, more extensive and detailed mapping of pre-Cambrian areas, and a study of metamorphic processes. This list may be amplified by mentioning the possibility of increasing future emphasis upon time planes represented by various deposits of volcanic ash, such as those of Hemlock arid Clarksburg ages. The occurrences and implications of these have been studied for a number of years by W. A. Seaman. It is true that utilization of the various bentonite and metabentonite beds of the Paleozoic in this manner has not as yet met with widespread acceptance, but the potential significance of occurrences of volcanic ash within the Michigan Huronian should doubtless receive more general recognition than has been the case in the past. Further, our attempts to introduce the time factor into pre-Cambrian correlations encounter the same obstacles often met with in similar efforts elsewhere in the geologic column; the present knowledge of conditions of sedimentation is frequently inadequate to enable us to set up proper time relations among lithologically diverse portions of a given bed. In many instances our understanding of the time element in pre-Cambrian correlation will doubtless advance in step with increases in the steadily growing fund of information concerning the facts of sedimentation.

The problem of the origin of the Huronian iron formations of Michigan has been and continues to be a subject of much discussion. The unusual lithology of these rocks and the peculiar circumstance of their confinement in the geologic column to the pre-Cambrian, although they are of widespread geographic occurrence, furnish some basis for the suspicion that they are exceptions to the general validity of uniformitarianism in pre-Cambrian petrogenesis. A number of reasonable objections may be offered to either of the principal hypotheses of origin, i.e. that the iron formations are normal products of advanced weathering, and subaqueous transportation and deposition, or that they have been developed by precipitation of materials contributed to sea waters by submarine basic lavas. Rhythmic chemical precipitation of ferrous carbonate in gelatinous silica may have been a factor in producing their characteristic banded textures, but objections to this postulate can be readily interposed. Without detailed discussion of the various postulates of origin, it will perhaps suffice to mention here that students of the Huronian generally doubt that the final solution to the problem has been reached. No specific, intensive study of the question is being undertaken at present, apparently, but it is confidently expected that before many years elapse this outstanding challenge to geologic thought will be satisfactorily met.

More agreement exists regarding the manner of concentration of the iron formations to ore than the mode of origin of the iron formations proper, but opinion remains divided despite years of diligent effort directed to the subject. The majority of students familiar with the conditions believe that the iron ore concentration has been effected through the agency of oxidizing waters possessing an important downward component of movement, concentrated in their flow downward along favorable avenues of migration such as cross faults, and in the direction of pitch of structural troughs bottomed by impervious rocks of various types. Whether these waters were meteoric, hydrothermal, or hybrid remains a debated subject, and the scope of this paper does not permit full consideration of the several hypotheses. The preponderance of field evidence may be stated to favor meteoric water circulation as the dominant factor, but it is possible that this postulate does not cover the whole story. It is subject to constant critical inspection by all geologists interested in development of the Lake Superior iron ores.

The character of the deep mine waters in the Michigan Huronian has received little concerted attention since the studies of Lane. Although a number of chemical analyses are available, many more should be made, and these should be carefully coordinated with the geology and the ore occurrences in the iron mines. The writer's work, now in progress, on the origin of the manganiferous iron ores of a portion of the Gogebic Range has led to the suspicion that deep mine waters, of the calcium chloride type, have been and are at present a factor in the transportation and deposition of manganese. The general subject of the origin, nature, and flow of these deep saline waters offers a promising field for future research.

It has been the aim of this paper to sketch the directions in which present-day thought on problems of the Michigan Huronian is trending and to point out a few potential fields for study. In the past decade geologists who have concerned themselves with the pre-Cambrian of Michigan have been relatively few, in part because of lack of financial support, and in some measure at least because the attention of Michigan geologists has been directed elsewhere. The opportunities existing in the Upper Peninsula for advancement of geological knowledge are magnificent; we have as yet made only a beginning. The problems of the pre-Cambrian are in general not essentially different from many of those existing throughout the geologic column, and pre-Cambrian work is not unique in its possession of structural and petrologic complexities. If the experience of many geologists who have dealt largely with more recent units of the geologic section could be brought to bear upon the intricacies of the Archean and the Algonkian, it can hardly be doubted that the progress of pre-Cambrian studies would be materially accelerated.

[1] Leith, C. K., "The Pre-Cambrian," *Proc. Geol Soc. Am. for 1933*, p. 171. 1934.

[2] *Ibid*.

[3] *Op. cit*, pp. 169-172.

THE ORIGIN OF PERCHED DUNES ON THE MANISTEE MORAINE, MICHIGAN

KENNETH W. DOW

INTRODUCTION

MANY of the sand dunes of northern Lake Michigan are perched in that they rest upon substrata elevated above the present lake level. The term "perched" includes dune forms resting upon old beaches referable to past glacial and postglacial lake stages, such as the Nipissing and the Algonquin. Dunes of this type on the Beaver Islands and on South Fox Island have been described by Fuller.[1] The present study, however, is concerned only with the perched dunes found along the western edges of the Manistee moraine, where the irregular spurs come out to the shore. This moraine constitutes the major portion of the second or inner ridge of the Port Huron morainic system (Fig. 1). Observations made thus far include Sleeping Bear Point and the shore line from Pointe Betsie south through Arcadia (Fig. 2). The primary purpose has been to determine if possible the chief origin of the sandy materials of which these perched dunes are composed. To this end an arbitrary classification into four main types was made:

Type I, Sand of beach origin — accumulation due to wind action.
Type II, Sand of beach origin — accumulation due to wind action accompanied by shore recession.
Type III, Sand derived from morainic drift.
Type IV, Sand of combined beach and morainic origin.

It should perhaps be mentioned that some geologists[2] believe that, immediately after the retreat of the ice and before vegetation had established itself upon the surface of the drift, the wind was peculiarly effective in forming loess deposits and sand dunes. The observations of Russell[3] on the Malaspina Glacier were contradictory to this view. Here he found vegetation following closely upon the retreat of the ice, and even noted a dense forest growing on a moraine which rested upon the ice of the glacier. Though Russell was dealing in Alaska with a relatively local mountain glacier, whereas the ice which covered the State of Michigan was of continental proportions, it does not seem as if the conditions attendant on the growth of vegetation would be vastly different. In any case, there seems to be little of practical value to be gained by introducing this theory into the solution of the present problem.

FIG. 1. The Manistee moraine (after Leverett). Dark areas indicate principal locations and close correlatives of the moraine

TYPE I: SAND OF BEACH ORIGIN — ACCUMULATION DUE TO WIND ACTION

There are two kinds of perched sand deposits of beach origin. Type I consists of sand which has blown up from the beach to the top of the moraine. In this type the height to which sand particles can be blown must be considered. The opinion of Barrows[4] that "winds can carry sand to any height up gentle slopes, but are unable to carry it up very steep slopes" seems generally to be favored. The truncated bluffs of the Manistee moraine range from a few feet to more than three hundred feet above Lake Michigan, with the angle of the front slope averaging approximately 53°. The angle of repose for sand is from 30° to 35°. The upper surface of the moraine is very irregular, and if the sand should be blown up the face of the bluff one would expect it to collect mainly in the hollows or along the lower portions. This condition is often true, but has not been found to be sufficiently consistent to serve as a determining factor.

Outcroppings of a pinkish clay, varying greatly in thickness, occur throughout the lower portions of the bluffs along this part of the shore. It is often laminated and is practically free from pebbles. The origin of this clay deposit, which was noted by Desor,[5] has been the subject of much speculation. The various theories cannot be treated here except to say that they indicate a widespread deposit, of earlier date than the surface morainal drift, but resting upon older glacial deposits. Leverett[6] believes the clay to have been laid down in a

large body of water either during an ice recession within the Wisconsin stage of glaciation or as a pre-Wisconsin interglacial deposit.

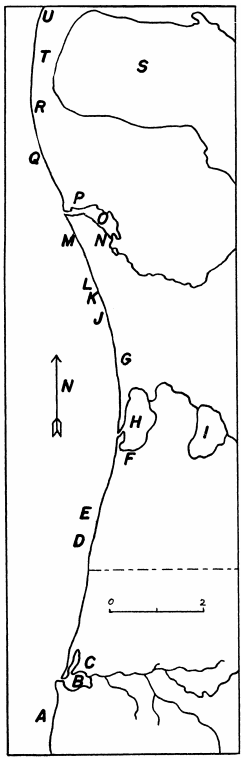

FIG. 2. Sketch map of shore line from Pointe Betsie south through Arcadia

A. First large perched dune south of Arcadia
B. North Bar Lake
C. Arcadia
D. "Baldy"
E. "Razor Back"
F. Watervale
G. "Lookout Hill"
H. Lower Herring Lake
I. Upper Herring Lake
J. Large blowout
K. Low spot in moraine
L. Low morainic hill
M. "Thelma's Cradle"
N. Elberta
O. Lake Betsie
P. Frankfort
Q. "Crater" group
R. Wildewood Resort
S. Crystal Lake
T. Crystal Lake bar
U. Pointe Betsie Light

Vegetation is able to gain a foothold more readily on the lower flanks of the bluffs mainly because the clay has a greater capability for retaining moisture than has the overlying drift material. The result is a zone of denser vegetation giving a distinctly banded appearance to the surface of the slope (Pl. I, Fig. 1). If sand were blown from the beach, up the slope, it would be retarded and trapped by this vegetation. Along the lower portions of the bluffs, however, there seldom seems to be much loose sand on the surface. A possible exception to this observation may exist near "Razor Back" (*E*[7]). Here an inclined coating of fine sand leading from the beach up to a height of about fifty feet seems to indicate transportation up the slope.

On the edge of the bluff at Sleeping Bear Point, Glen Arbor Township, one can almost always feel the sting from rather coarse particles of sand being carried and blown inland by the wind. It is difficult to determine whether or not this sand comes directly up the slope. Along the southern portion of the bluff may be found scattered tufts of grass, behind each of which is a small accumulation of sand, which would seemingly indicate progression of the sand up the face of the bluff in a northeasterly direction. Of course, with a northwest wind, sand could readily blow up the more gentle slope out at the end of the point and continue south along the front face of the bluff until, with a shift of the wind to the west, it would migrate directly inland. This, however, does not seem to occur. It is probable, therefore, that some of the sand does progress directly up the bluff from the beach below, but *slowly*.

To quote from Free,[8] "It has become apparent that much surface material is moved from place to place by aeolian action and that much of this transport is to be ascribed to the slow and unnoticed, but continuous, action of ordinary winds. The winds are so ubiquitous and so incessantly in motion that their aggregate geologic work is by no means negligible, though it may be momentarily inappreciable." This seems to be true of the area under consideration, and in all likelihood some of the sand incorporated in the perched dunes is material that, over a long period of time, has progressed slowly up the steep slopes of the moraine.

TYPE II: SAND OF BEACH ORIGIN — ACCUMULATION DUE TO WIND ACTION ACCOMPANIED BY SHORE RECESSION

Type II consists of sand which has been forced to migrate from the beach inland and up the slopes of the moraine as the shore line has been cut back by the waves. That the dunes are formed by this second method is the most common explanation of perched sand deposits. Solger[9] gives a good illustration of this mode of formation on the adjusted coast of Pomerania. Whether or not this explanation holds true in the Lake Michigan region is somewhat doubtful. For one thing, the lakeward slopes of the moraine are, and must also in the past have been, far steeper than those up which the dunes in Pomerania have traveled. This is true of all the portions of the moraine studied, with the exception of the section extending south from Elberta past "Thelma's Cradle" (*M*) and the area in the vicinity of the extremely low spot in the moraine (*K*), for at these places the height of the moraine is not so great. There seems to be no reason why the sand could not have moved up onto the moraine as the shore was cut back and this may well have occurred at *M*. At *L*, however, there is a slight rise in the surface of the moraine in the form of a gently rolling hill elongated in an east-west direction. The

western extremity of this hill has been only partly truncated, and, if the theory were correct, one would expect to find sand in the process of migrating up the still rather gentle slope. There is, however, only a very slight windblown deposit along the edge, far too small to be classed as a dune. Thus it would seem that, with the possible exception of the example cited above, formation of perched dunes by this method is unimportant in this area, although it must not be neglected as a contributing factor.

TYPE III: SAND DERIVED FROM MORAINIC DRIFT

Sand supplied by this third method could be derived either from the drift exposed by erosion on the face of the bluff or from surface deflation of the sandy till. In the following discussion it will be apparent that surface deflation is of relatively small importance, for the action ceases to be effective as soon as the larger residual particles are sufficiently numerous to protect the surface.

As has been stated, layers of pink clay are common in the lower parts of the moraine. On top of this clay morainic drift has been deposited in varying amounts. There are, furthermore, many local differences in the character of the materials composing the drift. It is common, especially in the upper portions of the moraine, for layers of fine sand to alternate in every possible way with layers of pebbles. In many places this imperfectly stratified material appears to be a water-laid deposit. Some of it probably represents local debris reworked and redeposited by the waters resulting from the melting of the ice. In any event, the upper portions, even when there is a liberal admixture of pebbles, are predominantly sandy.

Leverett's[10] soil studies for the townships in Benzie County which are situated nearest the Lake Michigan shore between Crystal Lake and Manistee County show that of 33 sections, 12 are swamp and lake, 4 are mostly sand, and 17 are sandy till. The same general composition occurs in Leelanau County, Glen Arbor Township, where, of 20 sections, the distribution is 6, 4, and 10, respectively.

Because of the extremely sandy drift in the exposed bluffs many of the early geologists mistakenly considered them wind-blown deposits. This was especially true of Sleeping Bear Point, which Schoolcraft,[11] in 1820, called "a bank of sand 200 feet high and 8 or 9 miles long." The same error appeared repeatedly on maps,[12] and as late as 1851 Desor[13] thought the bluffs nothing but a huge dune, although he rightly recognized the sandy deposits near the Manistee River as being of glacial origin.

In the present study an effort has been made to determine whether or not the perched dunes are better developed opposite local exposures of unusually sandy material than elsewhere. Results obtained have not been conclusive thus far, but a more important factor than such a location appears to be the action of gullying in the normally sandy drift. Frequently this gullying and sliding has been intense, and perched deposits of sand seem to occur in greater quantity at the heads of the gullies. This is especially characteristic of the bluff south from the low spot in the moraine (*K*) and also south of "Baldy" (*D*). There is much loose material and, often, fine sand in the gullies. In all instances noted this appears to be sliding down from the top of the bluff toward the beach below.

Except for a sparse natural growth which obtains a precarious foothold, what vegetation exists on the upper portions of these bluffs is mainly of the "slip slope" type (Pl. I, Fig. 2). Often trees along the edges of the bluffs are undercut and expose a tangled mass of dried roots. Trees, shrubs, and larger plant forms on the slope usually have slipped down from above. These slowly die or continue their gradual descent to the base of the bluff, where they are destroyed by the waves at periods of high water.

As erosion of the bluff progresses the upper portions retreat consistently. Fresh material is constantly exposed, and as it breaks off or slumps down from the edge the larger and coarser fragments .which are too big to be carried readily by the wind begin to slide down the slope. The rapidity of their descent depends upon their size and shape and upon local conditions. One can always find at the base of the bluff near "Razor Back" (*E*) and also at a place south of "Baldy" (*D*) beautifully striated and polished boulders which have been loosened by erosion and have rolled down the slope from above. That these boulders have been exposed recently is indicated by the high lustrous polish found on some of them. This polish could not have been retained if they had been directly subjected to weathering processes for even a relatively short time. Occasionally, however, angular fragments of softer rock remain on the slope sufficiently long to become pitted and blasted. Stone lattice effects are often produced on a minor scale. These corrugations indicate, further, that the wind must be carrying an appreciable quantity of sand, and that a certain amount of finer material must constantly blow up, or blow around, on the slope.

It is thought that, as the coarser pieces begin their descent of the slope, the finer fragments or sandy particles with which they have been associated are picked up or rolled along by the wind and are carried up over the edge of the bluff and deposited on top of the moraine. This is considered to be true mainly of the finer materials exposed in the upper portions of the slope, where they can easily be carried the short distance to the summit.

When sand particles reach the top of the bluff their progress may be checked somewhat by vegetal covering on the upper surface. Such growth usually consists of a dense tangle of wild grape, poison ivy, bittersweet, and associated xerophytic types. Here the sand collects and eventually becomes heaped up in a narrow perched ridge paralleling the edge of the slope. With continued erosion and undermining of the bluff it is not long before

the lakeward part of this perched ridge slumps. The fine sand is picked up by the wind and blown to the top again, and the process is repeated. Examples of this type of narrow perched dune along the edge of the bluff are very common. (See the rough sketch of the "Crater" group, Fig. 3.)

An interesting sand deposit, closely allied to this border type of perched dune, is found at *A*, south of Arcadia. On the summit of the bluff a layer of sand, eight or more feet thick, is being blown inland. Between this capping layer of sand and the edge of the bluff a bench, four or five feet in width, shows the original very sandy and slightly pebbly surface of the moraine. On this bench stands a row of dead pine trees (Pl. II, Fig. 1). From all appearances, the sandy capping layer has advanced not only into, but through, the onetime forest fringe. A few of the dead trees have fallen from their position and have rolled down the slope. The bluff is apparently being cut back rather rapidly. However, as it is eroded, the loose capping sand is moved more easily by the wind than is the material on which the trees were formerly growing. This old surface, though very sandy, is probably almost entirely morainic and is therefore somewhat more consolidated and less readily shifted. Also, the dead tree roots may still exert some binding influence on this old layer. It seems as though the loose sand on top must originally have been derived from the old sandy morainic surface when the bluff extended farther to the west. With the erosion of the slope this sandy material has been blown up and inland, so that at present there are two distinct sandy horizons, the top one consisting mainly of a redeposition farther inland of the particles in the bottom layer.

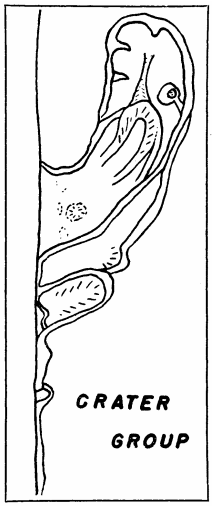

FIG. 3. The “Crater” group, an example of the border type of perched dune in southern Michigan

Where vegetation does not check the sand movement, or where other conditions are favorable, the sand may be blown inland to form larger perched dunes and apices. These eventually become deformed as constant recession of the bluff truncates the lakeward portions, arid the process may result in the formation of large blow-outs or "horseshoes." Inland migration is also facilitated by the addition of fresh sand to the perched dunes. This addition takes place as the fine drift material continues to be exposed in the upper parts of the eroded face of the bluff.

When the sand has been blown inland for some distance, into large horseshoes, there may be a broad opening at the lakeward end, or the entrance may consist of a narrow wind rift between high arms of sand (Pl. II, Fig. 2). In either case the opening is usually practically devoid of vegetation, and deflation has progressed to such an extent that most of the finer material has been removed. The coarser materials originally present in the upper portions of the drift are thus left as an imperfect pavement on the surface. Although this coarse layer is a quite effective preventive of surface erosion by the wind, it affords only temporary protection to the moraine and is not proof against undermining along the edge of the bluff. As has been shown, this latter action is most important.

At various places the surface of the moraine exposed seems to dip down sharply to the east, so that the perched sands rest on the eastern flanks of partly eroded swells in the moraine and may fill basin-like hollows or sags. Eventually, in many locations, the height of the moraine will be somewhat reduced as erosion of the front slope continues back into these hollows (Pl. II, Fig. 2; Pl. III, Fig. 1).

As a result of the constant erosion of the lakeward parts of the Manistee moraine much fine material does exist on the front surfaces of the bluffs. Under favorable conditions this loose sand may be picked up by the wind, and some of it may eventually reach the top of the slope to add to the perched accumulation. On several occasions sand movement along the slopes was noted. In one instance the bluff south of "Razor Back" (*E*) was observed when a high wind was coming from the southwest. A small amount of sand seemed to be blowing up from the beach onto the lower flanks of the moraine. The most apparent movement, however, was on the slopes themselves, where the sand was blowing northward, in a course horizontal to the face of the bluff. In places where the sandy drift jutted out the cliffs were "smoking." Most of the material being moved seemed to come from the sandy patches on the slopes themselves, and the particles were being carried along without much apparent change in elevation.

Needless to say, all the fine material exposed near the top of the bluff is not blown up the slope. Much of it undoubtedly slides down along with the coarser fragments. During heavy storms, slides and flows of finer material often occur. Also, when great sections held together by tree and plant roots break off from the top of the bluff both coarse and fine materials are carried down the slope.

The rate at which this process takes place depends entirely upon the rapidity of erosion of the bluffs, and the erosion, though unceasing, varies in intensity with the location. Minor factors must also be taken into

consideration. If vegetation is able to gain a foothold temporarily, erosion is retarded. Again, during periods when the level of Lake Michigan is unusually high, as it was in the summer of 1929, the waves cut directly into the bases of the bluffs and greatly accelerate the erosive process.

Because of the irregularity of the moraine it is impossible to estimate how much material has been removed, but the amount must have been very great. However, Leverett[14] believes that southward from Frankfort the nearness of deep water to the present shore precludes the supposition that the headlands were as long as those farther north. This factor would also militate against formation of dunes of the second type. The Crystal Lake bar was formed during Algonquin time 15 and is unusual because at present it has a convex curvature toward the Lake Michigan shore. It is thought that it developed originally as a normal bar of concave outline between the limiting morainic ridges, and that subsequent erosion cut back the land and reversed the curvature of the bar. Thus it may be seen that erosion, since Algonquin time, has been intense at this particular point along the shore.

That erosion of the sandy drift material is probably of great significance in the accumulation of sand on top of the moraine is borne out at location *K*, south of Frankfort. This site appears to furnish one of the important keys to the solution of the problem. Here, as compared with the height of the bluffs on either side, there is a relatively low spot in the moraine. The total elevation from the beach to the top of the bluff is about 66 feet, and the reddish sandy clay outcrops up to approximately 49.5 feet. There is a thin recent sand deposit on the upper surface. This leaves only 10 feet of morainic drift overlying the clay, an amount much less than that normally found. Although this low spot is apparently particularly favorable for such action, sand does not seem to be blown up from the beach, nor is there any accumulation due to migration up the slope as the shore has receded. On the other hand, this is the only locality where the overlying sandy drift is noticeably much thinner and where there would be a deficiency in the supply of sand exposed by erosion.

From all evidences, therefore, sandy material derived from the morainic drift would seem to be the most important constituent of the perched dunes in the areas described.

To review briefly, erosion of the drift along the edge of the bluff results in a natural sorting action, and in the removal of the larger particles. The sandy accumulation which remains, bordering as it does the edge of the slope, is in a constant state of simultaneous accretion and destruction. This unstable condition persists until such time as the sand may be picked up by the wind and transported inland, out of immediate danger from undermining.

TYPE IV: SAND OF COMBINED BEACH AND MORAINIC ORIGIN

Studies made thus far indicate that the majority of the perched dunes of the Manistee moraine belong to the fourth, or composite, type.

The amounts of sand derived from the three types included under this composite grouping vary, but, as a rule, the second type is unimportant, the first type is responsible for a moderate percentage of the material, and the third type is the dominant contributing factor.

In conclusion, it is believed that a brief description of Sleeping Bear Point may be of interest, since it presents somewhat different conditions than ordinarily exist in other parts of the area studied. Here splendid examples of *Windkanten* can be found in the rocky capping layer. Because of its exposed location the entire surface of the moraine, bordering the lake, has been swept bare of most of the fine sandy material, with the exception of the perched relic or remnant known as the "Bear" and another small sandy accumulation to the south. The "Bear," which is the most prominent perched feature, is a rather small hill whose front slopes extend down to the top edge of the bluff (Pl. III, Fig. 1). Exhumed trees and old humus layers indicate that it was not all built at one period, but is composed of sand blown up from various directions at different times. The main part of the hill appears to have been at one time slightly more to the south and west. At present the base of the northern slope is covered mainly with arborvitae, and a dense growth of calamovilfa, sand cherry, and dogwood occurs nearer the top. The back, or eastern, slope is thickly wooded in patches, the intervening areas being grassed (Pl. III, Fig. 2). The southern and western slopes are being actively eroded, and it is evident that a large amount of material has recently been removed, for a great difference was noted between the appearance of this portion of the dune in 1934 and in 1936, two years later. Waterman[16] in his article on the ecology of this area also mentions the rapid erosion of the "Bear." Indeed it is surprising that such an exposed and unstable remnant should have persisted over so long a period. It was well known to the Indians who formerly inhabited the area, and was frequently made the subject of their legendary tales.

The vast semiperched accumulation of moving sand steadily advancing eastward toward Glen Lake is composed almost wholly of material swept from the exposed surfaces of the higher portions of the moraine. The edge of the moraine is notched by a series of gullies oriented for the most part northeast-southwest. The larger gullies represent intermittent drainage channels. They branch slightly and cut deeply into the moraine. The northern slope of each is covered with loose stories, but fresh sand covers the stones on the southern slope. Extending northeast on the top of the moraine from the southern flank of each gully is a long, narrow tail of sand, varying in size with the size of the gully. This material

appears to come from sandy outcroppings some distance down the face of the bluff.

CONCLUSIONS

An attempt has been made in the present study to determine what processes have been most effective in the development of the perched sand dunes found on the Manistee moraine along the eastern shore of northern Lake Michigan.

1. It is believed that, over a long period of time, sand blown up from the beach to the top of the moraine has contributed a considerable amount of material to the perched dunes.

2. In this area actual migration of the dunes up the morainic slopes, with continued recession of the shore line, does not seem to have been important.

3. It is thought that the greater part of the material in the dunes has been derived from the sandy drift of the moraine. In this process continual erosion of the front slope of the bluff and effective wind action have played an important part.

4. The perched dunes are termed composite, since their origin can be ascribed to no single factor or process, but seems to include in varying degrees all the types noted above.

Further studies of the perched dunes in other portions of the Manistee moraine will have to be made before these observations can be completely verified.

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[2] See, for example, Sauer, C. O., "Geography of the Upper Illinois Valley and History of Development," *Illinois State Geol. Surv., Bull. 27*, p. 116. 1916.

[3] Russell, Israel C., *Glaciers of North America*, pp. 113-114. 1897.

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[5] Desor, E., "On the Superficial Deposits of the District." In *Report on the Geology of the Lake Superior Land District*, by J. W. Foster and J. D. Whitney, Part II (Washington, 1851), p. 240.

[6] Leverett, Frank, and Taylor, Frank B., "The Pleistocene of Indiana and Michigan and the History of the Great Lakes," *U. S. Geol. Surv., Mon. 53*, pp. 814-315. 1915.

[7] Capital letters refer to locations on the outline map, Figure 2.

[8] Free, E. E., "A Possible Error in the Estimates of the Rate of Geologic Denudation," *Science*, N. S., pp. 423-424. 1909.

[9] Solger, F., *Dünenbuch*, p. 98, fig. 28. 1910.

[10] Leverett, Frank, "Surface Geology and Agricultural Conditions of the Southern Peninsula of Michigan," *Ann. Rep. Mich. Geol. and Biol. Surv.*, Publ. 9, Series 7, pp. 93, 114. 1911.

[11] Schoolcraft, H. R., *Narrative Journal of Travels through the Northwestern Regions of the United States to the Sources of the Mississippi River in 1820*, p. 401. 1821.

[12] Young, J. H., *The Tourist's Pocket Map of Michigan*. Philadelphia: S. A. Mitchell, 1837.

[13] Desor, E., p. 263 of work cited in note 5.

[14] P. 427 of work cited in note 6.

[15] Scott, Irving D., "Inland Lakes of Michigan," *Ann. Rep. Mich. Geol. and Biol Surv. 1920*, Publ. 30, Geol. Series 25, p. 172. 1921.

[16] Waterman, Warren G., "Ecology of Glen Lake and Sleeping Bear Region," *Pap. Mich. Acad. Sci., Arts, and Letters*, 6 (1926): 363. 1927.

DOW PLATE I

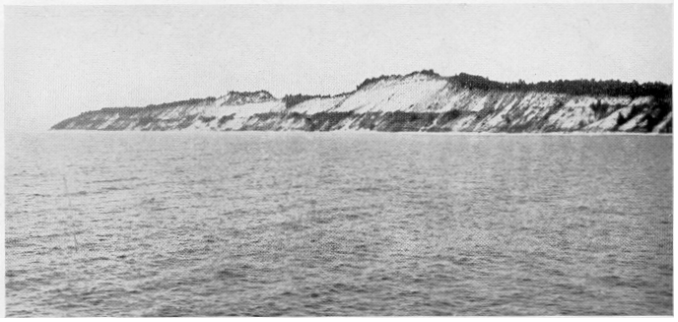

FIG. 1. Shore line north of Frankfort opposite "Crater" group, showing denser vegetation on clay in lower parts of bluff

FIG. 2. Bluff near "Razor Back," showing typical sandy drift and slip-slope vegetation. Note undermining along edge of bluff in upper right-hand corner; also steepness and height of slope

DOW PLATE II

FIG. 1. Bluff south of Arcadia, showing how sandy capping layer has migrated into and through former forest fringe

FIG. 2. Descending from "Baldy." View looking west toward Lake Michigan through wind rift. Note high area of sand on either side and manner in which surface of moraine rises toward edge of bluff

DOW PLATE III

FIG. 1. "Sleeping Bear." View looking north; South Manitou Island in distance. Note particularly character of moraine and steepness of slope toward lake

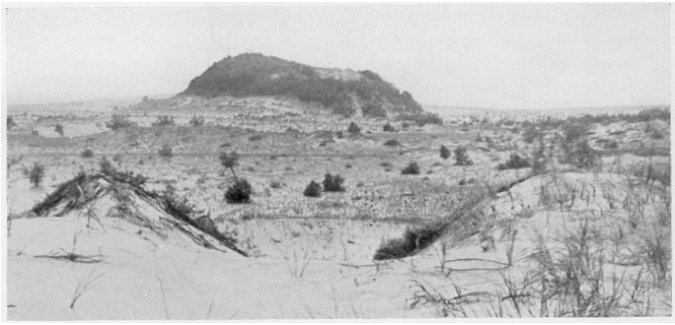

FIG. 2. "Sleeping Bear." View looking west toward Lake Michigan. Note sand hummocks in foreground and higher surface of moraine to the west

THE ROGERS CITY LIMESTONE, A NEW MIDDLE DEVONIAN FORMATION IN MICHIGAN

GEORGE M. EHLERS AND ROBERT E. RADABAUGH

DURING 1922 the senior author of this paper had occasion to examine a few gastropods which were collected from the so-called Dundee limestone of Presque Isle County, Michigan, by the late Mr. H. H. Hindshaw of Alpena, Michigan. As a result of this examination two of the specimens were found to be identical with *Büchelia tyrrelli* (Whiteaves) and *Omphalocirrus manitobensis* Whiteaves, species which occur in the Middle Devonian strata of Manitoba.

The senior author did not have an opportunity to determine the exact stratigraphic occurrence of these gastropods until the summer of 1926, at which time he participated in a preliminary study of the so-called Dundee limestone and the Traverse group of rocks for the Michigan Geological Survey. During the course of the 1926 study he found that the upper half of the "Dundee" limestone contained the two gastropods noted in the previous paragraph and several other fossils which were identical with or closely related to species occurring in the Manitoban limestone and the underlying Winnipegosan dolomite of Manitoba. This information was transmitted to Dr. E. R. Pohl, who noted (1930*a*, p. 31, and 1930*b*, p. 60) the presence of "Manitoba beds" with a northern fauna above the Dundee limestone.

During the summer of 1936 the writers of the present paper spent several days in a study of the "Dundee" limestone of Presque Isle County. As a result of this study they are able to recognize two formations in the "Dundee" limestone, a lower one, with a characteristic Dundee limestone fauna, to which the name "Dundee limestone" should be restricted, and an upper one, with a fauna distinct from that of the Dundee limestone, for which the name "Rogers City limestone" is proposed.

The best exposure of the Rogers City limestone is exhibited in the very large quarry of the Michigan Limestone and Chemical Company at Rogers City, Presque Isle County. The lithologic character and the common fossils of the Rogers City and Dundee limestones of this quarry are noted in the following generalized section.

SECTION OF STRATA EXPOSED IN QUARRY OF MICHIGAN LIMESTONE AND CHEMICAL COMPANY AT ROGERS CITY, MICHIGAN

	THICKNESS Feet	Inches
Traverse group (Bell shale)		
9. Shale, calcareous, bluish gray and abundantly fossiliferous.	1–10	
Disconformity		
Rogers City limestone		
8. Limestone, buff-gray to buff, medium-grained, fairly thick-bedded and porous, containing *Prismatophyllum sp.*, *Favosites sp.*, a costellate *Atrypa*, *Büchelia tyrrelli* (Whiteaves), *Omphalocirrus manitobensis* Whiteaves, and other gastropods	49	
7. Limestone, gray, finely crystalline, dense and thick-bedded, containing numerous specimens of *Gypidula sp.*, a few individuals of a costellate *Atrypa*, and *Omphalocirrus manitobensis* Whiteaves	4–6	
6. Limestone. Lower 2 to 3 feet mottled buff and buff-gray, magnesian and thin-bedded; upper 6 feet less mottled, less magnesian and thicker-bedded than underlying beds. Limestone contains numerous specimens of a costellate *Atrypa*, a few specimens of *Gypidula sp.*, and *Omphalocirrus manitobensis* Whiteaves	8	6
5. Dolomite, with discontinuous, alternating buff and buff-gray bands, fine-grained and thin-bedded, with molds of *Productella sp.*, *Atrypa sp.* and other brachiopods, pelecypods, *Tentaculites sp.*, and *Proetus sp.*	8–9	
Dundee limestone		
4. Limestone, gray, weathering to a buff-gray, composed of numerous shells of brachiopods and a smaller number of other invertebrates. Characteristic fossils are *Prismatophyllum sp.*, *Productella spinulocostata* Hall, *Etheridgina? spinosa* Bassett, *Atrypa costata* Bassett, *A. ehlersi* Bassett, *Spirifer lucasensis* Stauffer, and a species of *Athyris* identical with a species found in Dundee limestone of southeastern Michigan	6	5
3. Limestone, gray, weathering buff-gray, with few chert nodules and remains of *Prismatophyllum sp.*, *Atrypa costata* Bassett, *A. ehlersi* Bassett, and other fossils	2–3	
2. Limestone, buff-gray to buff, weathering to brown, and thick-bedded, with *Diphyphyllum rectiseptatum* Rominger, *Prismatophyllum sp.* with corallites averaging 8 mm. in diameter, *Prismatophyllum sp.* with corallites 4 to 5 mm. in diameter, *Atrypa costata* Bassett, and *A. ehlersi* Bassett	59	
1. Limestone, buff-gray to gray, mottled, dense and somewhat magnesian in lower part, containing *Synaptophyllum? sp.*, *Atrypa elegans* Grabau, *A. costata* Bassett, *Pentamerella sp.* cf. *P. parva* Bassett, and numerous specimens of *Paracyclas sp.*	72	

In the description of this section the Dundee limestone is shown to have a thickness of 139 to 140 feet; the Rogers City limestone, 69½ to 72½ feet; and the Bell shale, 1 to 10 feet. The maximum thicknesses of these three formations in near-by areas are greater, however, than those exhibited in the quarry.

Drilling tests made by the Michigan Limestone and Chemical Company show that dolomites and some limestones are present beneath the lowest Dundee strata exposed in the quarry. Further information may indicate that a part of these dolomites and limestones belong to the Dundee formation and a part to the underlying Mackinac limestone, which appears at the surface in the region bordering the Strait of Mackinac.

The maximum thickness of the Rogers City limestone, as shown by diamond drill cores a few miles south of the quarry, is about 106 feet; that of the Bell shale is about 60 feet.

From the foregoing discussion the Rogers City limestone of the type section exhibited in the Michigan Limestone arid Chemical Company quarry at Rogers City may be defined as the strata occupying a position between the Dundee limestone and the Bell shale of the Traverse group.

The base of the Rogers City limestone apparently is conformable with the Dundee limestone and, where it appears in the Michigan Limestone and Chemical Company quarry, is at the base of a conspicuous 8- to 9-foot bed of dolomite (see Pl. I, Figs. 1-2). More extensive field work may indicate that the contact is not conformable; furthermore, study of large collections of fossils from the dolomite may prove that this bed should be included within the underlying Dundee limestone.

The contact of the Rogers City limestone with the overlying Bell shale is disconformable; the effects of erosion of the Rogers City limestone prior to the deposition of the Bell shale are well illustrated. In the quarry of the Michigan Limestone and Chemical Company, about two miles south of the crusher plant, the Bell shale occupies a broad, shallow depression eroded in the Rogers City limestone. Beneath the bottom of the depression the Rogers City limestone is only about 60 feet in thickness, which, when compared with the maximum thickness of 106 feet, indicates a local removal of 46 feet of strata. The surface of the limestone in this depression shows anastomosing solution channels, one to two inches in width and averaging about one inch in depth, which were formed by weathering prior to the deposition of the Bell shale (see Pl. II, Fig. 1). During the course of quarrying so-called pockets of Bell shale are encountered within the Rogers City limestone. Some of these pockets are small caverns formed by the solution of the limestone prior to the deposition of the shale and subsequently filled with it (see Pl. II, Fig. 2); others are crevices formed by solution along joints and later filled with the shale.

The stratigraphic relationship of the Rogers City limestone to the Devonian section of New York is of considerable interest. The limestone is overlain by the Bell shale, which probably is a correlate of some part of the Hamilton group of New York below the Ludlowville formation. It is underlain by the Dundee limestone, which occupies a stratigraphic position at some unknown distance above limestone breccias with overlying calcareous strata collectively known as the Mackinac limestone and exposed in the region bordering the Strait of Mackinac. On Mackinac Island just east of the strait are cherty limestones which, as noted by Dr. Carl Rominger (1873, pp. 24-26), contain numerous typical Onondaga fossils, some of which are present in the underlying breccias. Since the upper part and possibly all of the Mackinac limestone is of Onondaga age, as shown by the studies of Rorninger and of Grabau (1913, p. 365), the Dundee and the Rogers City limestones are seen to hold a position in the standard New York Devonian section between the Ulsterian and the Erian series, which contain respectively the Onondaga limestone and the Hamilton group, the correlatives of the Mackinac limestone and Traverse group. Whether the Dundee and the Rogers City limestones should be assigned to the Ulsterian or the Erian series or to a distinct series can be determined only by further study.

The Rogers City limestone is related to certain Devonian strata of northwestern Manitoba, which, according to Dr. E. M. Kindle (1914, pp. 248, 251-257), consist of the Elm Point limestone at the base, the Winnipegosan dolomite in the middle, and the Manitoban limestone at the top. A

large number of species of gastropods and a few species of other invertebrates, which were listed by J. B. Tyrrell (1892, pp. 207-208 E) as being confined to the Winnipegosan dolomite, have been found in the Rogers City limestone. *Stringocephalus burtini* Defrance, which is characteristic of the Winnipegosan dolomite and certain Middle Devonian strata of Europe, has not been found in the Rogers City limestone. The apparent absence of *Stringocephalus* in the Rogers City limestone seems unusual, because this limestone contains many gastropod genera which are characteristic of the *Stringocephalus* zone of Manitoba and Europe. Some of the genera and species of gastropods found in the Rogers City limestone have been reported from both the Stringocephalus-bearing Winnipegosan dolomite and the Manitoban limestone. The occurrence of these genera and species in the Winnipegosan dolomite and the Manitoban limestone makes it impossible at this time to state whether one or both of these formations should be correlated with the Rogers City limestone. It is hoped that a further study of these formations and their faunas by the junior author will show the exact stratigraphic relationship of the Rogers City limestone to the Devonian strata of Manitoba.

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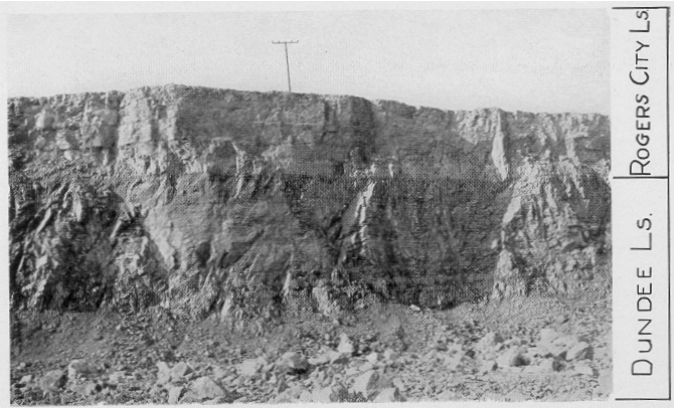

FIG. 1. Part of southern face of Michigan Limestone and Chemical Company quarry at Rogers City, showing contact between Dundee and Rogers City limestones. Light band just above contact represents the conspicuous dolomite described as interval 5 of the quarry section (see p. 442)

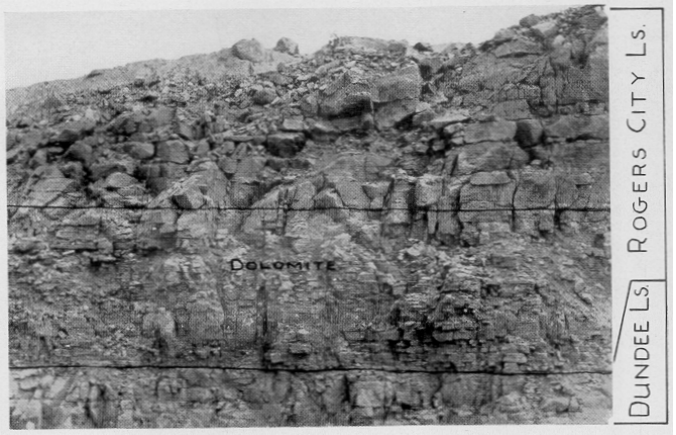

FIG. 2. Northern face of same quarry, showing in detail the contact between the Dundee and Rogers City limestones and the thin bedding of the dolomite just above this contact

FIG. 1. Upper surface of a block of Rogers City limestone, showing anastomosing channels formed by solution prior to deposition of Bell shale. Note presence of Bell shale, shown by lighter color, in many of the channels

FIG. 2. Mass of Bell shale in a small cavern (outlined in ink at center) within the Rogers City limestone of the Michigan Limestone and Chemical Company quarry

LITHOLOGY OF THE TRAVERSE GROUP OF CENTRAL MICHIGAN

BENJAMIN F. HAKE AND JED B. MAEBIUS

SCOPE OF PAPER

IN THIS paper it is the writers' intention to delineate and describe briefly the character and extent of the lithologic units into which they have been able to subdivide the Traverse group in central Michigan, where these rocks are at considerable depths beneath the surface and are known only from samples obtained by drilling. They also wish to suggest possible correlations between the lithologic units of the Traverse group as determined by subsurface methods and the formations into which the group has been divided by those who have studied surface exposures. Because of the impossibility of examining the strata directly, the Traverse group in central Michigan can never be satisfactorily subdivided on a faunal basis.

The divisions of the Traverse group here made are essentially divisions of expediency, but experience has shown that these lithologic units are capable of precise recognition over short distances and of approximate identification for distances of many miles, in some instances almost completely across the state. These divisions are thus formations, at least in the sense of being units capable of identification over large areas, and they may prove to be of greater service than many of the formations to which names have been applied.

NATURE OF PREPARATORY WORK

The data here presented are derived wholly from examination of samples taken from wells drilled for oil. These samples were collected systematically as the drilling progressed, successive samples representing thicknesses of strata ranging between 2 and 20 feet. Before examination the samples were thoroughly washed; on account of the elimination of mud from the cuttings, it is possible that during the examination of samples some thin beds of shale may have been penetrated by the wells without being recognized. The authors do not believe that this possibility represents any great actual loss because it is their observation that, where limestones are inter-bedded with any noticeable amount of shale, the limestones are themselves slightly argillaceous. Furthermore, considerable experience in subsurface geological work has convinced the senior author that, if any important part of a geologic section is composed of shale, some quantities of that material remain in the samples after repeated washings, even where those shales are composed to a large extent of very soft or even absorbent clays.

The samples are subjected to systematic megascopic and microscopic examination, and also to some investigation by treatment with acid and staining fluids to bring into relief the textures and mineralogical

compositions of the rock chips. The collection of data for this report has been carried on over a period of about two and one-half years, during which time samples of the Traverse group from many scores of wells have been examined. The descriptions presented on the cross sections are from wells selected chiefly on account of the completeness and the authenticity of their sample record (see Appendix). All descriptions and statements made in this paper concerning the rocks of this group refer solely to the characteristics of the sediments within the area traversed by the accompanying sections, since the writers have had but little opportunity to visit or to study the surface exposures of these rocks.

ACKNOWLEDGMENTS

For opportunity to make and permission to publish the observations reported here the writers are indebted to the Gulf Refining Company. They also wish to acknowledge the assistance of Mrs. Helen Cannon, who, while working as assistant to the senior author, contributed to this paper by examining many of the sets of samples used. Dr. G. M. Ehlers has been very generous with his time and his intimate knowledge of surface exposures of the group in helping with the formulation of a tentative correlation between the divisions here made and those recognizable in the outcrop. Many oil companies, drilling contractors, and individual operators have rendered valuable aid by preserving samples of these formations where penetrated by their wells. Samples collected by the Department of Conservation have also been of great assistance.

SEDIMENTS UNDERLYING THE TRAVERSE GROUP

The Traverse group is underlain by massive calcareous sediments which are generally spoken of as Dundee, but which in many localities may actually be of greater age. In the eastern part of the state the Traverse rests on a brown dense to fine-grained limestone which is correlated with the Dundee formation. In the central part the lithology of this underlying series is quite variable, being in some places pure limestone like that in eastern Michigan and in others dolomitic limestone. In some localities pure dolomites occur. In Isabella and Gratiot counties and south westward it is doubtful in many places whether the Traverse rests on Dundee or on some older beds. Farther west, in the vicinity of Kent and Muskegon counties, the Traverse rests on buff to brown, dense to fine-grained limestone which is similar to and tentatively correlated with the Dundee formation.

The beds beneath the Traverse are remarkably free from argillaceous material. Recognizable fossil fragments are very rare. The beds are brown to buff, locally almost white. The gray color, which is predominant in the Traverse, is lacking in the sediments below it.

THE TRAVERSE BASIN OF SUBSIDENCE

In its major aspects the depression within which the Traverse formation was deposited is an elongated basin, with its principal axis in a northwest-southeast position and situated approximately beneath the inner portion of Saginaw Bay (Fig. 1). The maximum observed depth of this basin occurs northwest of the north shore of Saginaw Bay, but it cannot be stated that this is the greatest depth of the basin because there has not yet been enough drilling along the apparent northwest prolongation of the axis to define the area of maximum subsidence.

The regional warping by which this basin of deposition was produced was complicated to some extent by localized crustal deformations, as is evidenced by considerable variations in the total thickness of the Traverse group displayed by closely adjacent wells. On account of the fact that so many of the wells have been completed without preserving adequate samples of the Traverse, it has been impossible to formulate any worth-while conclusions concerning the details of diastrophism in Michigan during Traverse time.

GENERAL CHARACTERISTICS OF THE TRAVERSE SEDIMENTS

Though recognizing that such procedure may prove to be incorrect, the writers use the term "Traverse group" in this paper to designate that series of beds which underlies all gray and black shales near the base of the Antrim formation and which overlies the massive, buff to brown, relatively unfossiliferous limestones and dolomites belonging to the Dundee and older formations.

The predominant feature of the lithology of the Traverse group of sediments in central Michigan is its composition of calcareous, argillaceous, and siliceous materials in various degrees of admixture. These rocks range from remarkably pure limestones through cherty, dolomitic, and shaly limestones and limy shales to nearly pure clay shales.

Limestones and dolomites predominate in the west and southwest. In southern Ottawa and northern Allegan counties the Traverse group is composed entirely of massive clean limestone and dolomite. Beds of shale appear in the group a few miles north and east, and these intercalated shales increase in number and thickness eastward across the state, so that in north-central Huron County massive limestone composes only about 20 per cent of the thickness of the group.

Although brown limestones and white limestones occur frequently, the characteristic color of this group is gray. This appearance is due in part to the fact that many of the limestones are made up of comminuted fragments of fossils of different shades and textures and in part to the presence of varying amounts of clay.

The second outstanding characteristic of the rocks of this group is the presence of abundant fossil debris,